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# Atomic Transition Probabilities Scandium through Manganese

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David R. Lide, Jr., Editor

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# Foreword

The *Journal of Physical and Chemical Reference Data* is published jointly by the American Institute of Physics and the American Chemical Society for the National Bureau of Standards. Its objective is to provide critically evaluated physical and chemical property data, fully documented as to the original sources and the criteria used for evaluation. One of the principal sources of material for the journal is the National Standard Reference Data System (NSRDS), a program coordinated by NBS for the purpose of promoting the compilation and critical evaluation of property data.

The regular issues of the *Journal of Physical and Chemical Reference Data* are published quarterly and contain compilations and critical data reviews of moderate length. Longer monographs, volumes of collected tables, and other material unsuited to a periodical format are published separately as *Supplements to the Journal*.

This critical compilation, "Atomic Transition Probabilities—Scandium through Manganese," by G. A. Martin, J. R. Fuhr and W. L. Wiese, is presented as Supplement No. 3 to Volume 17 of the *Journal of Physical and Chemical Reference Data*.

David R. Lide, Jr., Editor
*Journal of Physical and Chemical Reference Data*

# Atomic Transition Probabilities
## Scandium through Manganese

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Atomic transition probabilities for about 8,800 spectral lines of five iron-group elements, Sc ($Z = 21$) to Mn ($Z = 25$), are critically compiled, based on all available literature sources. The data are presented in separate tables for each element and stage of ionization and are further subdivided into allowed (i.e., electric dipole—E1) and forbidden (magnetic dipole—M1, electric quadrupole—E2, and magnetic quadrupole—M2) transitions. Within each data table the spectral lines are grouped into multiplets, which are in turn arranged according to parent configurations, transition arrays, and ascending quantum numbers. For each line the transition probability for spontaneous emission and the line strength are given, along with the spectroscopic designation, the wavelength, the statistical weights, and the energy levels of the upper and lower states. For allowed lines the absorption oscillator strength is listed, while for forbidden transitions the type of transition is identified (M1, E2, etc.). In addition, the estimated accuracy and the source are indicated. In short introductions, which precede the tables for each ion, the main justifications for the choice of the adopted data and for the accuracy rating are discussed. A general introduction contains a discussion of our method of evaluation and the principal criteria for our judgements.

Key words: allowed and forbidden transitions; chromium; line strengths; manganese; oscillator strengths; scandium; titanium; transition probabilities; vanadium.

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## List of Tables

## 1. Introductory Remarks

This is the third major critical compilation by the NBS Data Center on Atomic Transition Probabilities. A first tabulation[1] containing transition probabilities for about 4,000 spectral lines of the elements hydrogen through neon, atomic numbers $Z = 1$ through 10, including the neutral atoms as well as their various ions, was published in 1966. A second data volume[2] was issued in 1969, containing data for about 5,000 lines of the elements sodium ($Z = 11$) through calcium ($Z = 20$), again for all stages of ionization for which data were available. The data compilation work then continued with a series of smaller tables for the atoms and ions of the elements of the iron group, i.e., Sc and Ti[3]; V, Cr, and Mn[4]; Fe, Co, and Ni[5]; and the forbidden lines of all these elements.[6] From the beginning, it has been our intention to integrate these smaller tabulations into a single volume for the iron-group elements, in updated and expanded form. Unexpectedly, a great deal of new data were generated for these elements during the past few years, often with much improved accuracy, so that our revisions and additions became very extensive. Thus it took a much longer time than anticipated to complete these largely new data tables, and the greatly expanded tabulations had to be split into two separate volumes. This volume contains the material on the elements Sc ($Z = 21$) through Mn ($Z = 25$), and a companion volume[7] contains the material on Fe ($Z = 26$) through Ni ($Z = 28$).

In the present compilation, we maintain the scope and format of our earlier tabulations, i.e., we present critically evaluated atomic transition probabilities of allowed and forbidden discrete transitions of all stages of ionization for which we have reliable data. We have aimed at listing data for at least the more prominent lines of each spectrum, even if some of these data are of low accuracy. Furthermore, we have also presented transition-probability data for weaker transitions if the accuracy of these data has been estimated to be better than ± 50%.

The original literature is continually monitored by this NBS Data Center, and a master reference list is maintained from which all literature sources for this compilation have been taken.

## 2. Method of Evaluation

For the compilation of data on a critical basis, the central task is the evaluation of the data accuracy and the subsequent choice of the most accurate material. In order to accomplish this task in a consistent manner, we had established general guideposts for each experimental and theoretical approach in our earlier compilation work, and we have maintained these criteria in this work. Specifically, we judge each original literature source by the following principal criteria:

(1) Our general evaluation of the capabilities and reliability of the applied experimental or theoretical method.
(2) The author's consideration of the major critical factors in his approach that enter into the results.
(3) The degree of agreement and general consistency between the author's results and other reliable data.
(4) The degree of fit of the data into established systematic trends and, if deviations exist, the reasons for such disagreements.
(5) The author's estimate of his uncertainties.

We have discussed our general evaluations of each experimental and theoretical method in considerable detail in the introductions to our previous tabulations.[1–6] Thus, we refer to these publications for further details. However, we should point out that, in this tabulation, we illustrate particularly interesting situations by providing comparison tables or graphs in the introductions to individual spectra. For example, in the introduction to the forbidden lines of Ti XXI, we present a table comparing theoretical and the few available experimental data on M1 and M2 lines of He-like ions.

With respect to error estimates, we should note that the theoretical literature sources, which provide a large part of the data, generally contain no error estimates, since no reliable assessment of the uncertainties introduced by the various approximations is possible. But even for the experimental papers, where error estimates may often readily be made, the statements by some authors are too imprecise and also incomplete, so that they are not particularly useful as presented. Sometimes only statistical measurement errors have been given, without allowance for systematic errors. It therefore became essential to judge each paper by the principal factors 1–4 listed above, in addition to utilizing the author's error estimate (point (5)) whenever appropriate.

## 3. General Arrangement of the Tables

We have continued to use the same general arrangement of the tables as in our earlier volumes,[1,2] i.e., we have included data which serve to identify the spectral lines, as well as the actual transition probabilities (and related quantities), accuracy estimates, and references to the sources of the compiled material. However, for most of the spectra of neutral and singly ionized atoms of the iron-group elements, the transition array column was dropped. Instead, in order to identify the lower and upper levels of a transition, we adopted the level designation scheme of C. E. Moore,[8] who affixed lower-case letters ($a,b,c,...,x,y,z$) to the term designations. This convention is also retained in the very recent tables of "Atomic Energy Levels" by J. Sugar and C. Corliss.[9] In other special cases, we have adapted our notation to the special coupling situations encountered in those spectra, as, for example, the $J_1j$ coupling encountered in Ne-like ions and $J_1j$ and $J_1\ell$ coupling for Ar-like ions.

Material pertaining to spectral-line identifications has been taken from the comprehensive wavelength tabulations of Reader and Corliss,[10] Kelly,[11,12] and Kelly and

Palumbo,[13] the multiplet tables of C. E. Moore,[14,15] and the recent energy-level compilation of Sugar and Corliss[9] (this last reference supersedes earlier compilations by Sugar and others[16,17]). We have supplemented the wavelength and energy-level data from these sources with original literature data when needed in the course of preparing our transition-probability tables. A listing of all data sources other than Refs. 9–17 is given in Table 1.

Wavelengths and energy levels which are the results of theoretical calculations, or which were either calculated from experimentally determined data or interpolated or extrapolated from data on similar (e.g., isoelectronic) species, are placed in square brackets in order to distinguish them from the usually more accurate experimental material.

For each transition-probability table which contains a minimum of twenty distinct wavelength values, we provide a "list of tabulated lines," i.e., a listing, in ascending order of wavelength, of the spectral lines contained therein, along with an index to the multiplet number (or numbers) in which each is to be found. Wavelengths that are printed in italics in the transition-probability tables are not included in these line lists.

TABLE 1. Special source material for wavelength and energy-level data. Complete citations are given below

| Spectrum | References | Spectrum | References | Spectrum | References |
|---|---|---|---|---|---|
| Sc I | 1 | Ti XVI | 32,66 | Cr XII | 14,53,81,82 |
| Sc II | 2 | Ti XVII | 33,34,35,36,67,68 | Cr XIII | 14,54,55,56,57,58,81 |
| Sc III | 3,4 | Ti XVIII | 29,34,35,37,39 | Cr XIV | 20,54,56,83,84,95 |
| Sc IV | 5 | Ti XIX | 29,38,39,69,70 | Cr XV | 23,24,96,97,98 |
| Sc V | 5,6,7,8 | Ti XX | 71,72,73,74 | Cr XVI | 26,65,95 |
| Sc VI | 9 | Ti XXI | 41,45 | Cr XVII | 28,31,64,65,66,95,99 |
| Sc VII | 9,10,11 | V I | 75,76 | Cr XVIII | 95,99 |
| Sc VIII | 9,11,12,13 | V IV | 77 | Cr XIX | 36,95,99 |
| Sc IX | 9,12,14,15 | V V | 78 | Cr XX | 29,95 |
| Sc X | 14,16,17,18,19 | V VI | 79 | Cr XXI | 29,38,69,95,100,101 |
| Sc XI | 14,16,20,21 | V VII | 6,7,8,9 | Cr XXII | 43,71,73,74,95 |
| Sc XII | 22,23,24 | V VIII | 6,7,9,80 | Cr XXIII | 41,45 |
| Sc XIII | 25,26,27 | V IX | 6,9,10,81,82 | Mn I | 102 |
| Sc XIV | 25,27,28,29,30,31 | V X | 9,13,81 | Mn II | 103 |
| Sc XV | 32 | V XI | 6,9,14,15 | Mn VI | 104 |
| Sc XVI | 27,29,33,34,35,36 | V XII | 14,54,55,56 | Mn VII | 105 |
| Sc XVII | 29,37 | V XIII | 20,54,83,84 | Mn VIII | 106,107 |
| Sc XVIII | 29,38,39,40 | V XIV | 22,23,24,60 | Mn IX | 6,7,8,9 |
| Sc XIX | 39,41,42,43,44 | V XV | 25,26,66,85 | Mn X | 6,7,9,82 |
| Sc XX | 41,45 | V XVI | 25,28,31,66,86 | Mn XI | 6,9,10,81,82,93 |
| Ti I | 46 | V XVII | 32 | Mn XII | 9,13,82,94 |
| Ti II | 47 | V XVIII | 33,34,35,36,66,68,86 | Mn XIII | 15,56,81,82,94 |
| Ti III | 48 | V XIX | 29,34,35,39,86 | Mn XIV | 14,54,55,56,81,82,108 |
| Ti IV | 49 | V XX | 29,38,39,40,87 | Mn XV | 20,54,56,83,84,95 |
| Ti V | 50 | V XXI | 39,44,72,73,74 | Mn XVI | 23,97 |
| Ti VI | 8,51,52 | V XXII | 41,45 | Mn XVII | 26,85,95 |
| Ti VII | 9,51 | Cr I | 88 | Mn XVIII | 28,31,95 |
| Ti VIII | 9,10,11 | Cr II | 89 | Mn XIX | 95 |
| Ti IX | 9,11,13 | Cr V | 90 | Mn XX | 29,36,95 |
| Ti X | 9,11,14,53 | Cr VI | 91 | Mn XXI | 29,95 |
| Ti XI | 14,19,54,55,56,57,58 | Cr VII | 92 | Mn XXII | 29,38,69,95,109 |
| Ti XII | 20,59 | Cr VIII | 6,7,8,9 | Mn XXIII | 43,74,95 |
| Ti XIII | 22,24,60,61 | Cr IX | 6,7,9,82 | Mn XXIV | 41,45 |
| Ti XIV | 25,26,62,63 | Cr X | 6,9,10,82,93 | | |
| Ti XV | 25,28,29,30,31,62,64,65,66 | Cr XI | 9,13,82,94 | | |


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We have denoted the uncertainties in the atomic transition-probability data as in our earlier compilations, i.e.,

A . . for uncertainties within 3 percent,
B . . for uncertainties within 10 percent,
C . . for uncertainties within 25 percent,
D . . for uncertainties within 50 percent,
E . . for uncertainties greater than 50 percent.

The word *uncertainty* is used here with the connotation "estimated extent of the deviation from the true value." The estimation procedure is based on our evaluation of random errors *as well as our estimates of the maximum effect of possible systematic errors*. We have often made further distinctions in the uncertainty labels by assigning plus or minus signs to some transitions to indicate that these lines are estimated to be somewhat better or worse than similar lines. These should, therefore, be the first or last choice among similar transitions.

A summary of the abbreviations and special symbols used in the tables is given in Section 4. Included there for convenience are formulas which relate various properties of individual spectral lines to those for entire multiplets. In Table 2, we provide the conversion factors which we have used throughout this compilation to convert from transition probabilities to oscillator strengths and line strengths, and vice versa.

TABLE 2. Conversion factors

The factor in each box converts by multiplication the quantity above it into the one at its left.

| | $A_{ki}$ | $f_{ik}$ | $S$ |
|---|---|---|---|
| $A_{ki}$ | 1 | $\dfrac{6.670_3 \times 10^{15} g_i}{g_k \lambda^2}$ | E1 $\dfrac{2.026_1 \times 10^{18}}{g_k \lambda^3}$<br>E2 $\dfrac{1.679_9 \times 10^{18}}{g_k \lambda^5}$<br>M1 $\dfrac{2.697_4 \times 10^{13}}{g_k \lambda^3}$<br>M2 $\dfrac{6.626_5 \times 10^{12}}{g_k \lambda^5}$ |
| $f_{ik}$ | $\dfrac{1.499_2 \times 10^{-16} \lambda^2 g_k}{g_i}$ | 1 | E1 $\dfrac{303.7_6}{g_i \lambda}$ |
| $S$ | E1 $4.935_5 \times 10^{-19}\, g_k \lambda^3$<br>E2 $5.952_6 \times 10^{-19}\, g_k \lambda^5$<br>M1 $3.707_3 \times 10^{-14}\, g_k \lambda^3$<br>M2 $1.509_1 \times 10^{-13}\, g_k \lambda^5$ | E1 $3.292_1 \times 10^{-3}\, g_i \lambda$ | 1 |

The line strength ($S$) is given in atomic units; formulas and values for these quantities in SI units are as follows:

For E1 transitions, $a_0^2 e^2 = 7.188_3 \times 10^{-59}$ m$^2$ C$^2$.
For E2 transitions, $a_0^4 e^2 = 2.012_9 \times 10^{-79}$ m$^4$ C$^2$.
For M1 transitions, $\mu_B^2 = (eh/4\pi m_e)^2 = 8.600_7 \times 10^{-47}$ J$^2$ T$^{-2}$.
For M2 transitions, $\mu_B^2 a_0^2 = 2.408_5 \times 10^{-67}$ J$^2$ m$^2$ T$^{-2}$,

where $a_0$, $e$, $m_e$, and $h$ are the Bohr radius, electron charge, electron mass, and Planck constant, respectively, and $\mu_B$ is the Bohr magneton.
The transition probability ($A_{ki}$) is in units of s$^{-1}$, and the $f$-value is dimensionless. The wavelength ($\lambda$) is given in Ångström units, and $g_i$ and $g_k$ are the statistical weights of the lower and upper level, respectively.

[Note: the definition of the line strength for E2 transitions which is used by some authors yields an $S$-value that is 50% higher than that employed here and in earlier NBS transition-probability compilations. We have multiplied such line strengths by $\frac{2}{3}$ before tabulating them here, and have indicated this fact in the short introductions to the pertinent data tables.]

For the atomic constants entering into the relations given in this table, we have used the recommendations of the CODATA Task Group on Fundamental Constants (E. R. Cohen and B. N. Taylor, Rev. Mod. Phys. **59**, 1121 (1987)). The 1987 values were not available at the time we compiled most data for this publication; however, differences between these and the earlier (CODATA Task Group, 1973) values of the fundamental constants, which we utilized, amount to only 0.002% or less for the E1 transitions and 0.05% or less for the M1, E2, and M2 (forbidden) transitions and have therefore not affected our tabulated data.

## 4. Key to Abbreviations and Symbols Used in the Tables

1. Symbols for indication of accuracy:

A...... uncertainties within 3 percent,
B...... uncertainties within 10 percent,
C...... uncertainties within 25 percent,
D...... uncertainties within 50 percent,
E...... uncertainties greater than 50 percent.

2. Abbreviations appearing in the source column of allowed transitions:

*ls* = *LS* coupling rules applied
*n* = normalized to a scale different from that of the author (as explained in the introductory remarks to the pertinent spectrum).
*interp.* = derived by an interpolation technique, rather than taken directly from the literature.

3. Special symbols used in the wavelength and energy level columns:

The number in parentheses under the multiplet designation refers to the sequence number of Ref. 14 (Revised Multiplet Table). If letters "uv" are added, we refer to the sequence number of Ref. 15 (Ultraviolet Multiplet Table).

Numbers in italics indicate multiplet values, i.e., weighted averages of *line* values.

Numbers in square brackets indicate approximate calculated or extrapolated values.

*Useful Relations*

(A) Statistical weights:

The statistical weights are related to the inner quantum number $J_L$ (for one-electron spectra: $j_l$) of a level (i.e., initial or final state of a *line*) by

$$g_L = 2J_L + 1,$$

and to the quantum numbers of a term (initial or final state of a *multiplet*) by

$$g_M = (2L+1)(2S+1).$$

(The "multiplet" values $g_M$ may also be obtained by summing over all possible "line" values $g_L$. $S$ is the resultant spin.)

(B) Relations between the strengths of allowed lines and the total multiplet strength:

1. Line strength $S$:

$$S(i,k) = \sum_{J_i,J_k} S(J_i,J_k)$$

or

$$S\,(\text{Multiplet}) = \Sigma\, S\,(\text{line})$$

($k$ denotes the upper and $i$ the lower term).

2. Absorption oscillator strength $f_{ik}$:

$$f_{ik}^{\text{multiplet}} = \frac{1}{\bar{\lambda}_{ik} \sum_{J_i} (2J_i+1)} \sum_{J_i,J_k} (2J_i+1) \times \lambda(J_i,J_k) \times f(J_i,J_k).$$

The mean wavelength for the multiplet, $\bar{\lambda}_{ik}$, may be obtained from the *weighted* energy levels. Often the wavelength differences for the lines within a multiplet are small, in which case the wavelength factors may be neglected.

3. Transition probability $A_{ki}$:

$$A_{ki}^{\text{multiplet}} = \frac{1}{(\bar{\lambda}_{ik})^3 \sum_{J_k} (2J_k+1)} \sum_{J_i,J_k} (2J_k+1) \times \lambda(J_i,J_k)^3 \times A\,(J_i,J_k).$$

Relative strengths $S(J_i,J_k)$ of the components of a multiplet are listed for the case of *LS* coupling in C. W. Allen, *Astrophysical Quantities*, 3rd ed. (The Athlone Press, London, 1973); H. E. White and A. Y. Eliason, Phys. Rev. **44**, 753 (1933); B. W. Shore and D. H. Menzel, *Principles of Atomic Structure*, p. 447 (John Wiley & Sons, Inc., New York, 1968); L. Goldberg, Astrophys. J. **82**, 1 (1935) and **84**, 11 (1936).

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# Scandium

## Sc I

Ground State: $1s^22s^22p^63s^23p^63d4s^2\ ^2D_{3/2}$

Ionization Energy: 6.56154 eV = 52922.0 cm$^{-1}$

### Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2112.8 | 22 | 2439.17 | 8 | 3015.37 | 5 | 4743.82 | 2 |
| 2116.7 | 22 | 2462.66 | 23 | 3019.35 | 5 | 4753.17 | 20 |
| 2120.4 | 22 | 2468.40 | 23 | 3030.76 | 5 | 4779.36 | 20 |
| 2262.3 | 9 | 2472.93 | 23 | 3039.78 | 4 | 4791.52 | 20 |
| 2266.6 | 9 | 2692.78 | 12 | 3061.03 | 3 | 5302.98 | 1 |
| 2270.9 | 9 | 2695.64 | 12 | 3068.19 | 3 | 5342.99 | 1 |
| 2280.8 | 13 | 2699.02 | 11 | 3073.34 | 3 | 5349.73 | 1 |
| 2289.6 | 13 | 2706.74 | 11 | 3255.68 | 18 | 6193.70 | 15 |
| 2311.29 | 26 | 2707.93 | 12 | 3269.90 | 18 | 6210.66 | 19 |
| 2315.69 | 26 | 2711.34 | 11 | 3273.63 | 18 | 6239.44 | 19 |
| 2320.32 | 26 | 2717.05 | 7 | 3907.48 | 17 | 6239.80 | 15 |
| 2324.75 | 26 | 2719.13 | 11 | 3911.81 | 17 | 6258.90 | 15 |
| 2328.19 | 25 | 2724.60 | 7 | 3933.38 | 17 | 6276.28 | 19 |
| 2334.67 | 24 | 2726.48 | 10 | 3996.60 | 16 | 6305.65 | 19 |
| 2335.2 | 25 | 2734.29 | 10 | 4020.39 | 16 | 6305.99 | 15 |
| 2336.81 | 24 | 2739.06 | 10 | 4023.68 | 16 | 6344.83 | 14 |
| 2346.03 | 24 | 2965.88 | 6 | 4047.80 | 16 | 6378.82 | 14 |
| 2428.66 | 8 | 2974.01 | 6 | 4082.39 | 21 | 6413.35 | 14 |
| 2429.19 | 8 | 2980.76 | 6 | 4737.65 | 2 | 6448.09 | 14 |
| 2438.63 | 8 | 2988.97 | 6 | 4741.02 | 2 | | |

For this spectrum, we principally rely on the data of Parkinson *et al.*,[1] who measured relative oscillator strengths by means of the anomalous dispersion (hook) method. Parkinson *et al.* normalized their data to nine absolute $f$-values, which were obtained by Bell and Lyzenga[2] with the atomic beam technique. Refs. 1 and 2 are very consistent for this set of nine lines: except for one line, the relative differences lie within ±15 percent. We followed the authors' error estimates throughout the compilation.

Bell and Lyzenga's absolute scale (as well as the relative scale of Parkinson *et al.*) is closely supported by level-crossing (Hanle effect) lifetime measurements by Birkhahn *et al.*[3] As Table 1 shows, reciprocals of sums of the transition probabilities are in good agreement with the experimental lifetimes.

TABLE 1. Data comparison

| Upper Level | Experimental (Hanle effect) lifetimes [ns] (Ref. 3) | $(\sum_i A_{ki})^{-1}$[ns] (Refs. 2,4) |
|---|---|---|
| $y\ ^2F^\circ_{7/2}$ | 5.3 ± 0.6 | 7.1 |
| $y\ ^2F^\circ_{5/2}$ | 7.4 ± 0.6 | 6.9 |

TABLE 1. Data comparison—Continued

| Upper Level | Experimental (Hanle effect) lifetimes [ns] (Ref. 3) | $(\sum_i A_{ki})^{-1}$[ns] (Refs. 2,4) |
|---|---|---|
| $y\ ^2D^\circ_{5/2}$ | 5.7 ± 0.2 | 6.4 |
| $y\ ^2D^\circ_{3/2}$ | 5.0 ± 0.2 | 5.8 |

The lines which make the predominant contribution to these sums have all been measured by Bell and Lyzenga. Also included are the $A$-values of weak infrared lines, which have been calculated by Kurucz and Peytremann.[4]

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Sc I: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d4s^2$–$4s^24p$ | $^2$D – $^2$P° | *5344.1* | *101.0* | *18808* | 10 | 6 | 0.0053 | 0.0014 | 0.24 | −1.87 | C | 1 |
| | | | 5349.73 | 168.3 | 18856 | 6 | 4 | 0.0040 | 0.0012 | 0.12 | −2.16 | C | 1 |
| | | | 5342.99 | 0.0 | 18711 | 4 | 2 | 0.0051 | 0.0011 | 0.077 | −2.36 | C | 1 |
| | | | 5302.98 | 0.0 | 18856 | 4 | 4 | 0.0013 | 5.6(−4)[a] | 0.039 | −2.65 | C | 1 |
| 2. | $3d^2(^3$F$)4s$–$3d^2(^3$F$)4p$ | $^4$F – $^4$D° | | | | | | | | | | | |
| | | | 4743.82 | 11677 | 32752 | 10 | 8 | 1.8 | 0.48 | 75 | 0.68 | E | 1 |
| | | | 4741.02 | 11610 | 32697 | 8 | 6 | 1.7 | 0.42 | 53 | 0.53 | E | 1 |
| | | | 4737.65 | 11558 | 32659 | 6 | 4 | 2.0 | 0.46 | 43 | 0.44 | E | 1 |
| 3. | $3d4s^2$–$3d^2(^3$F$)4p$ | $^2$D – $^4$D° | | | | | | | | | | | |
| | | | 3068.19 | 168.3 | 32752 | 6 | 8 | 0.0056 | 0.0011 | 0.064 | −2.20 | C | 1 |
| | | | 3073.34 | 168.3 | 32697 | 6 | 6 | 0.0074 | 0.0011 | 0.064 | −2.20 | C | 1 |
| | | | 3061.03 | 0.0 | 32659 | 4 | 4 | 0.0087 | 0.0012 | 0.049 | −2.31 | C | 1 |
| 4. | | $^2$D – $^2$G° | | | | | | | | | | | |
| | | | 3039.78 | 168.3 | 33056 | 6 | 8 | 0.0053 | 9.8(−4) | 0.059 | −2.23 | C | 1 |
| 5. | | $^2$D – $^2$F° | *3018.1* | *101.0* | *33225* | 10 | 14 | 0.79 | 0.15 | 15 | 0.18 | C | 1 |
| | | | 3019.35 | 168.3 | 33278 | 6 | 8 | 0.82 | 0.15 | 8.9 | −0.05 | C | 1 |
| | | | 3015.37 | 0.0 | 33154 | 4 | 6 | 0.66 | 0.13 | 5.3 | −0.27 | C | 1 |
| | | | 3030.76 | 168.3 | 33154 | 6 | 6 | 0.092 | 0.013 | 0.76 | −1.12 | C | 1 |
| 6. | | $^2$D – $^2$D° | *2978.1* | *101.0* | *33670* | 10 | 10 | 0.51 | 0.068 | 6.7 | −0.17 | C | 1 |
| | | | 2980.76 | 168.3 | 33707 | 6 | 6 | 0.44 | 0.059 | 3.5 | −0.45 | C | 1 |
| | | | 2974.01 | 0.0 | 33615 | 4 | 4 | 0.45 | 0.060 | 2.3 | −0.62 | C | 1 |
| | | | 2988.97 | 168.3 | 33615 | 6 | 4 | 0.068 | 0.0061 | 0.36 | −1.44 | C | 1 |
| | | | 2965.88 | 0.0 | 33707 | 4 | 6 | 0.071 | 0.014 | 0.55 | −1.25 | C | 1 |
| 7. | $3d4s^2$–$3d^2(^3$P$)4p$ | $^2$D – $^4$D° | | | | | | | | | | | |
| | | | 2724.60 | 168.3 | 36860 | 6 | 6 | 0.016 | 0.0017 | 0.094 | −1.98 | C | 1 |
| | | | 2717.05 | 0.0 | 36794 | 4 | 4 | 0.036 | 0.0040 | 0.14 | −1.80 | C | 1 |
| 8. | | $^2$D – $^2$D° | *2434.8* | *101.0* | *41159* | 10 | 10 | 0.27 | 0.024 | 1.9 | −0.63 | C | 1 |
| | | | 2438.63 | 168.3 | 41163 | 6 | 6 | 0.21 | 0.019 | 0.90 | −0.95 | C | 1 |
| | | | 2429.19 | 0.0 | 41153 | 4 | 4 | 0.28 | 0.025 | 0.80 | −1.00 | C | 1 |
| | | | 2439.17 | 168.3 | 41153 | 6 | 4 | 0.022 | 0.0013 | 0.062 | −2.11 | C | 1 |
| | | | 2428.66 | 0.0 | 41163 | 4 | 6 | 0.021 | 0.0027 | 0.088 | −1.96 | C | 1 |
| 9. | | $^2$D – $^2$P° | *2268.9* | *101.0* | *44161* | 10 | 6 | 0.52 | 0.024 | 1.8 | −0.62 | C | 1 |
| | | | [2270.9] | 168.3 | 44189 | 6 | 4 | 0.46 | 0.024 | 1.1 | −0.85 | C | 1 |
| | | | [2266.6] | 0.0 | 44105 | 4 | 2 | 0.48 | 0.019 | 0.55 | −1.13 | C | 1 |
| | | | [2262.3] | 0.0 | 44189 | 4 | 4 | 0.058 | 0.0044 | 0.13 | −1.75 | C | 1 |
| 10. | $3d4s^2$–$3d^2(^1$D$)4p$ | $^2$D – $^2$F° | *2731.3* | *101.0* | *36703* | 10 | 14 | 0.013 | 0.0020 | 0.18 | −1.70 | C | 1 |
| | | | 2734.29 | 168.3 | 36730 | 6 | 8 | 0.0091 | 0.0014 | 0.073 | −2.09 | C | 1 |
| | | | 2726.48 | 0.0 | 36666 | 4 | 6 | 0.012 | 0.0020 | 0.073 | −2.09 | C | 1 |
| | | | 2739.06 | 168.3 | 36666 | 6 | 6 | 0.0056 | 6.3(−4) | 0.034 | −2.42 | C | 1 |

Sc I: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11. | | $^2D - ^2D°$ | *2709.4* | *101.0* | *36998* | 10 | 10 | 0.31 | 0.034 | 3.0 | −0.47 | C | 1 |
| | | | 2711.34 | 168.3 | 37040 | 6 | 6 | 0.29 | 0.032 | 1.7 | −0.72 | C | 1 |
| | | | 2706.74 | 0.0 | 36934 | 4 | 4 | 0.26 | 0.029 | 1.0 | −0.94 | C | 1 |
| | | | 2719.13 | 168.3 | 36934 | 6 | 4 | 0.023 | 0.0017 | 0.090 | −2.00 | C | 1 |
| | | | 2699.02 | 0.0 | 37040 | 4 | 6 | 0.030 | 0.0049 | 0.17 | −1.71 | C | 1 |
| 12. | | $^2D - ^2P°$ | *2702.0* | *101.0* | *37099* | 10 | 6 | 0.16 | 0.011 | 0.95 | −0.97 | C | 1 |
| | | | 2707.93 | 168.3 | 37086 | 6 | 4 | 0.15 | 0.011 | 0.59 | −1.18 | C | 1 |
| | | | 2692.78 | 0.0 | 37125 | 4 | 2 | 0.16 | 0.0087 | 0.31 | −1.46 | C | 1 |
| | | | 2695.64 | 0.0 | 37086 | 4 | 4 | 0.014 | 0.0015 | 0.052 | −2.23 | C | 1 |
| 13. | $3d4s^2–3d^2(^1G)4p$ | $^2D - ^2F°$ | | | | | | | | | | | |
| | | | [2280.8] | 0.0 | 43830 | 4 | 6 | 0.28 | 0.033 | 0.99 | −0.88 | C | 1 |
| | | | [2289.6] | 168.3 | 43830 | 6 | 6 | 0.041 | 0.0032 | 0.15 | −1.71 | C | 1 |
| 14. | $3d4s^2–$ $3d4s(^3D)4p$ | $^2D - ^4F°$ | | | | | | | | | | | |
| | | | 6344.83 | 0.0 | 15757 | 4 | 6 | 2.4(−4) | 2.2(−4) | 0.018 | −3.06 | C | 1 |
| | | | 6413.35 | 168.3 | 15757 | 6 | 6 | 0.0013 | 8.2(−4) | 0.10 | −2.31 | C | 1 |
| | | | 6378.82 | 0.0 | 15673 | 4 | 4 | 0.0016 | 9.5(−4) | 0.080 | −2.42 | C | 1 |
| | | | 6448.09 | 168.3 | 15673 | 6 | 4 | 2.6(−4) | 1.1(−4) | 0.014 | −3.18 | C | 1 |
| 15. | | $^2D - ^4D°$ | | | | | | | | | | | |
| | | | 6193.70 | 0.0 | 16141 | 4 | 6 | 5.0(−4) | 4.3(−4) | 0.035 | −2.76 | C | 1 |
| | | | 6258.90 | 168.3 | 16141 | 6 | 6 | 0.0041 | 0.0024 | 0.30 | −1.84 | C | 1 |
| | | | 6239.80 | 0.0 | 16022 | 4 | 4 | 0.0065 | 0.0038 | 0.31 | −1.82 | C | 1 |
| | | | 6305.99 | 168.3 | 16022 | 6 | 4 | 0.0030 | 0.0012 | 0.15 | −2.15 | C | 1 |
| 16. | | $^2D - ^2D°$ | *4022.4* | *101.0* | *24955* | 10 | 10 | 1.66 | 0.403 | 53.4 | 0.606 | C+ | 2 |
| | | | 4023.68 | 168.3 | 25014 | 6 | 6 | 1.44 | 0.350 | 27.8 | 0.322 | C+ | 2 |
| | | | 4020.39 | 0.0 | 24866 | 4 | 4 | 1.65 | 0.400 | 21.2 | 0.204 | C+ | 2 |
| | | | 4047.80 | 168.3 | 24866 | 6 | 4 | 0.116 | 0.0190 | 1.52 | −0.943 | C+ | 2 |
| | | | 3996.60 | 0.0 | 25014 | 4 | 6 | 0.153 | 0.0549 | 2.89 | −0.658 | C+ | 2 |
| 17. | | $^2D - ^2F°$ | *3910.6* | *101.0* | *25665* | 10 | 14 | 1.39 | 0.446 | 57.4 | 0.649 | C+ | 2 |
| | | | 3911.81 | 168.3 | 25725 | 6 | 8 | 1.37 | 0.420 | 32.4 | 0.401 | C+ | 2 |
| | | | 3907.48 | 0.0 | 25585 | 4 | 6 | 1.28 | 0.440 | 22.7 | 0.246 | C+ | 2 |
| | | | 3933.38 | 168.3 | 25585 | 6 | 6 | 0.129 | 0.0300 | 2.33 | −0.745 | C+ | 2 |
| 18. | | $^2D - ^2P°$ | *3271.2* | *101.0* | *30662* | 10 | 6 | 3.1 | 0.30 | 32 | 0.47 | C | 1 |
| | | | 3273.63 | 168.3 | 30707 | 6 | 4 | 2.7 | 0.29 | 19 | 0.24 | C | 1 |
| | | | 3269.90 | 0.0 | 30573 | 4 | 2 | 3.1 | 0.25 | 11 | 0.00 | C | 1 |
| | | | 3255.68 | 0.0 | 30707 | 4 | 4 | 0.31 | 0.050 | 2.1 | −0.70 | C | 1 |
| 19. | $3d4s^2–$ $3d4s(^1D)4p$ | $^2D - ^2D°$ | *6267.1* | *101.0* | *16053* | 10 | 10 | 0.016 | 0.0092 | 1.9 | −1.04 | C | 1 |
| | | | 6305.65 | 168.3 | 16023 | 6 | 6 | 0.015 | 0.0087 | 1.1 | −1.28 | C | 1 |
| | | | 6210.66 | 0.0 | 16097 | 4 | 4 | 0.012 | 0.0067 | 0.55 | −1.57 | C | 1 |
| | | | 6276.28 | 168.3 | 16097 | 6 | 4 | 0.0016 | 6.3(−4) | 0.079 | −2.42 | C | 1 |
| | | | 6239.44 | 0.0 | 16023 | 4 | 6 | 0.0019 | 0.0017 | 0.14 | −2.18 | C | 1 |

Sc I: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20. | | $^2$D - $^2$F° | *4769.2* | *101.0* | *21063* | 10 | 14 | 0.010 | 0.0048 | 0.75 | −1.32 | C | 1 |
| | | | 4779.36 | 168.3 | 21086 | 6 | 8 | 0.0084 | 0.0038 | 0.36 | −1.64 | C | 1 |
| | | | 4753.17 | 0.0 | 21033 | 4 | 6 | 0.010 | 0.0051 | 0.32 | −1.69 | C | 1 |
| | | | 4791.52 | 168.3 | 21033 | 6 | 6 | 0.0023 | 7.8(−4) | 0.074 | −2.33 | C | 1 |
| 21. | | $^2$D - $^2$P° | | | | | | | | | | | |
| | | | 4082.39 | 168.3 | 24657 | 6 | 4 | 0.360 | 0.0600 | 4.83 | −0.444 | C+ | 2 |
| 22. | $3d4s^2$–$3d^2(^3F)5p$ | $^2$D - $^2$D° | | | | | | | | | | | |
| | | | [2120.4] | 168.3 | 47315 | 6 | 6 | 0.20 | 0.014 | 0.57 | −1.09 | C | 1 |
| | | | [2116.7] | 0.0 | 47230 | 4 | 4 | 0.20 | 0.014 | 0.38 | −1.26 | C | 1 |
| | | | [2112.8] | 0.0 | 47315 | 4 | 6 | 0.032 | 0.0032 | 0.090 | −1.89 | C | 1 |
| 23. | $3d4s^2$–$3d4s(^3D)5p$ | $^2$D - $^2$P° | *2470.7* | *101.0* | *40563* | 10 | 6 | 0.049 | 0.0027 | 0.22 | −1.57 | C | 1 |
| | | | 2472.93 | 168.3 | 40594 | 6 | 4 | 0.029 | 0.0018 | 0.087 | −1.97 | C | 1 |
| | | | 2468.40 | 0.0 | 40500 | 4 | 2 | 0.049 | 0.0022 | 0.072 | −2.05 | C | 1 |
| | | | 2462.66 | 0.0 | 40594 | 4 | 4 | 0.021 | 0.0019 | 0.062 | −2.12 | C | 1 |
| 24. | $3d4s^2$–$3d4s(^1D)5p$ | $^2$D - $^2$P° | *2341.6* | *101.0* | *42793* | 10 | 6 | 0.17 | 0.0083 | 0.64 | −1.08 | C | 1 |
| | | | 2346.03 | 168.3 | 42780 | 6 | 4 | 0.13 | 0.0073 | 0.34 | −1.36 | C | 1 |
| | | | 2334.67 | 0.0 | 42819 | 4 | 2 | 0.17 | 0.0069 | 0.21 | −1.56 | C | 1 |
| | | | 2336.81 | 0.0 | 42780 | 4 | 4 | 0.037 | 0.0030 | 0.092 | −1.92 | C | 1 |
| 25. | | $^2$D - $^2$F° | | | | | | | | | | | |
| | | | [2335.2] | 168.3 | 42979 | 6 | 8 | 0.036 | 0.0039 | 0.18 | −1.63 | C | 1 |
| | | | 2328.19 | 0.0 | 42939 | 4 | 6 | 0.046 | 0.0056 | 0.17 | −1.65 | C | 1 |
| 26. | | $^2$D - $^2$D° | *2318.5* | *101.0* | *43220* | 10 | 10 | 0.28 | 0.022 | 1.7 | −0.65 | C | 1 |
| | | | 2320.32 | 168.3 | 43253 | 6 | 6 | 0.24 | 0.019 | 0.88 | −0.94 | C | 1 |
| | | | 2315.69 | 0.0 | 43170 | 4 | 4 | 0.25 | 0.020 | 0.61 | −1.10 | C | 1 |
| | | | 2324.75 | 168.3 | 43170 | 6 | 4 | 0.041 | 0.0022 | 0.10 | −1.88 | C | 1 |
| | | | 2311.29 | 0.0 | 43253 | 4 | 6 | 0.041 | 0.0049 | 0.15 | −1.71 | C | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc II

Ca Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^63d4s\ ^3D_1$

Ionization Energy: 12.79987 eV = 103237.1 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 1880.6 | 13 | 3060.54 | 29 | 3361.26 | 17 | 3645.31 | 15 |
| 2064.3 | 14 | 3065.12 | 29 | 3361.93 | 17 | 3651.80 | 15 |
| 2068.0 | 14 | 3075.36 | 29 | 3368.94 | 17 | 3666.53 | 15 |
| 2232.9 | 11 | 3107.41 | 19 | 3372.15 | 17 | 3678.33 | 40 |
| 2273.1 | 24 | 3107.52 | 42 | 3373.52 | 44 | 3859.59 | 47 |
| 2611.19 | 28 | 3128.27 | 31 | 3378.20 | 44 | 4246.82 | 20 |
| 2667.70 | 25 | 3133.07 | 31 | 3379.16 | 37 | 4314.08 | 2 |
| 2735.57 | 33 | 3139.72 | 31 | 3379.38 | 44 | 4320.75 | 2 |
| 2746.36 | 39 | 3190.98 | 35 | 3535.71 | 21 | 4325.00 | 2 |
| 2782.31 | 30 | 3199.33 | 35 | 3558.53 | 16 | 4374.46 | 1 |
| 2789.15 | 30 | 3244.16 | 18 | 3567.70 | 16 | 4670.41 | 7 |
| 2801.31 | 30 | 3251.32 | 18 | 3572.53 | 16 | 5031.01 | 6 |
| 2819.49 | 32 | 3311.70 | 34 | 3576.34 | 16 | 5239.81 | 23 |
| 2822.12 | 32 | 3312.72 | 34 | 3580.66 | 45 | 5318.37 | 5 |
| 2826.64 | 32 | 3317.02 | 34 | 3580.93 | 16 | 5526.79 | 9 |
| 2870.85 | 36 | 3320.40 | 43 | 3586.78 | 45 | 5657.91 | 8 |
| 2912.98 | 27 | 3331.04 | 43 | 3589.63 | 16 | 5890.03 | 4 |
| 2979.68 | 38 | 3343.23 | 43 | 3590.47 | 16 | 6604.58 | 3 |
| 2988.92 | 26 | 3352.07 | 17 | 3613.83 | 15 | 20566 | 10 |
| 3039.92 | 41 | 3353.72 | 22 | 3630.74 | 15 | | |
| 3045.73 | 29 | 3359.23 | 12 | 3642.78 | 15 | | |
| 3052.92 | 29 | 3359.67 | 17 | 3643.75 | 46 | | |

For this ion, we have used the superposition-of-configurations (SOC) calculations by Weiss,[1] and the semiempirical calculations of Kurucz and Peytremann,[2] who employed scaled Thomas-Fermi-Dirac wavefunctions. These authors have taken configuration interaction effects into account and have calculated the individual line strengths in intermediate coupling. The agreement between the two sources is generally quite good: 67% of log *gf*-values for the 36 common lines agree within ±50%. For strong lines, the agreement is particularly impressive: of all the log *gf*-values in Ref. 2 which are equal to or larger than −0.5, 95% agree with those of Ref. 1 to within ±50%.

However, for weaker lines, numerous discrepancies of a factor of two or more are encountered. For two lines, $\lambda$ = 1880.6 Å and 3244.17 Å, Kurucz and Peytremann's oscillator strengths are lower than Weiss' by factors of 8 and 19, respectively. In the case of the 1880.6 Å line, which is the $3d4s\ ^1D_2 - 4s4p\ ^1P_1^\circ$ transition, the disagreement between Refs. 1 and 2 is probably due to Kurucz and Peytremann's inadequate representation of the wavefuctions of the upper and lower terms; they did not take into account "term-dependent" effects, as described in detail by Hansen[3] and as used by Weiss.[1] In particular, the $4s4p\ ^1P^\circ$ wavefunction is different from that obtained in a center of gravity calculation, but the $^3P$ is not. In this compilation we have, therefore, omitted all lines from Ref. 2 involving the $4s4p\ ^1P_1^\circ$ level, as well as all log *gf*-values less than −0.5. We have tabulated Weiss' data whenever available, but have lowered the accuracy ratings for weak lines and lines originating from highly excited states.

An indication of the reliability of Weiss' absolute scale is obtained by comparing reciprocals of sums of his transition probabilities, $(\Sigma A_{ki})^{-1}$, to lifetimes measured by Arnesen *et al.*[4] and Stoner *et al.*[5] The authors in both Refs. 4 and 5 used state-selective laser excitation, which should produce cascade-free lifetimes, estimated to be accurate to within ±10%. As Table 1 shows, Weiss' data agree fairly reasonably (within 30%) with the experimental lifetimes. It appears, however, that some of the individual *A*-values contributing to the sums may be too large. For this reason, we have assigned his values an accuracy rating of "D".

TABLE 1. Comparison of experimental and theoretical data

| Upper Level | Lifetimes via laser excitation [ns] (Ref. 4) | (Ref. 5) | $(\Sigma A_{ki})^{-1}$ [ns] (Ref. 1) |
|---|---|---|---|
| $3d4p$ $^3F_2^o$ | 6.2 | | 5.2 |
| $3d4p$ $^1P_1^o$ | | 9.2 | 6.6 |

## References


[1]A. W. Weiss, private communication.

[2]R. L. Kurucz and E. Peytremann, Smithsonian Astrophysical Observatory Special Report **362** (1975).

[3]J. E. Hansen, J. Phys. B **6**, 1387 (1973).

[4]A. Arnesen, A. Bengtsson, L. J. Curtis, R. Hallin, C. Nordling, and T. Noreland, Phys. Lett. A **56**, 355 (1976).

[5]J. O. Stoner, Jr., L. Klynning, I. Martinson, B. Engman, and L. Liljeby, "Beam-Foil Spectroscopy," Vol. 2, 873–876 (Eds. I. A. Sellin and D. J. Pegg, Plenum Press, NY, 1976).


Sc II: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^2$–$3d4p$ | $^3$F – $^3$F° | | | | | | | | | | | |
| | | | 4374.46 | 4988 | 27841 | 9 | 9 | 0.14 | 0.040 | 5.2 | −0.44 | D | 2 |
| 2. | | $^3$F – $^3$D° | | | | | | | | | | | |
| | | | 4314.08 | 4988 | 28161 | 9 | 7 | 0.41 | 0.088 | 11 | −0.10 | D | 2 |
| | | | 4320.75 | 4884 | 28021 | 7 | 5 | 0.39 | 0.079 | 7.8 | −0.26 | D | 2 |
| | | | 4325.00 | 4803 | 27918 | 5 | 3 | 0.43 | 0.073 | 5.2 | −0.44 | D | 2 |
| 3. | | $^1$D – $^1$D° | 6604.58 | 10945 | 26081 | 5 | 5 | 0.010 | 0.0066 | 0.72 | −1.48 | D− | 1 |
| 4. | | $^1$D – $^3$D° | | | | | | | | | | | |
| | | | 5890.03 | 10945 | 27918 | 5 | 3 | 7.6(−4)[a] | 2.4(−4) | 0.023 | −2.93 | E | 1 |
| 5. | | $^1$D – $^3$P° | | | | | | | | | | | |
| | | | 5318.37 | 10945 | 29742 | 5 | 3 | 0.0072 | 0.0018 | 0.16 | −2.04 | E | 1 |
| 6. | | $^1$D – $^1$P° | 5031.01 | 10945 | 30816 | 5 | 3 | 0.49 | 0.11 | 9.2 | −0.26 | D | 1 |
| 7. | | $^1$D – $^1$F° | 4670.41 | 10945 | 32350 | 5 | 7 | 0.18 | 0.085 | 6.5 | −0.37 | D | 1 |
| 8. | | $^3$P – $^3$P° | | | | | | | | | | | |
| | | | 5657.91 | 12154 | 29824 | 5 | 5 | 0.13 | 0.063 | 5.9 | −0.50 | D | 2 |
| 9. | | $^1$G – $^1$F° | 5526.79 | 14261 | 32350 | 9 | 7 | 0.42 | 0.15 | 25 | 0.13 | D | 1 |
| 10. | | $^1$S – $^1$P° | [20566] | 25955 | 30816 | 1 | 3 | 7.4(−4) | 0.014 | 0.95 | −1.85 | D− | 1 |
| 11. | $3d^2$–$4s4p$ | $^1$D – $^1$P° | [2232.9] | 10945 | 55715 | 5 | 3 | 0.78 | 0.035 | 1.3 | −0.76 | D | 1 |
| 12. | | $^1$S – $^1$P° | 3359.23 | 25955 | 55715 | 1 | 3 | 0.078 | 0.040 | 0.44 | −1.40 | D− | 1 |
| 13. | $3d4s$–$4s4p$ | $^1$D – $^1$P° | [1880.6] | 2541 | 55715 | 5 | 3 | 5.0 | 0.16 | 5.0 | −0.10 | D | 1 |
| 14. | $3d4p$–$4p^2$ | $^3$D° – $^3$P | | | | | | | | | | | |
| | | | [2064.3] | 28161 | 76589 | 7 | 5 | 2.2 | 0.10 | 4.8 | −0.15 | E | 2 |
| | | | [2068.0] | 28021 | 76361 | 5 | 3 | 2.0 | 0.076 | 2.6 | −0.42 | E | 2 |
| 15. | $3d4s$–$3d4p$ | $^3$D – $^3$F° | *3627.2* | *105.5* | *27667* | 15 | 21 | 1.8 | 0.50 | 89 | 0.87 | D | 1 |
| | | | 3613.83 | 177.8 | 27841 | 7 | 9 | 1.9 | 0.47 | 39 | 0.52 | D | 1 |
| | | | 3630.74 | 67.7 | 27602 | 5 | 7 | 1.6 | 0.44 | 26 | 0.34 | D | 1 |
| | | | 3642.78 | 0.0 | 27444 | 3 | 5 | 1.5 | 0.50 | 18 | 0.18 | D | 1 |
| | | | 3645.31 | 177.8 | 27602 | 7 | 7 | 0.14 | 0.029 | 2.4 | −0.70 | D | 1 |
| | | | 3651.80 | 67.7 | 27444 | 5 | 5 | 0.25 | 0.050 | 3.0 | −0.60 | D | 1 |
| | | | 3666.53 | 177.8 | 27444 | 7 | 5 | 0.0051 | 7.3(−4) | 0.062 | −2.29 | E | 1 |

Sc II: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16. | | $^3$D – $^3$D° | *3575.5* | *105.5* | *28066* | 15 | 15 | 2.1 | 0.40 | 71 | 0.78 | D | 1 |
| | | | 3572.53 | 177.8 | 28161 | 7 | 7 | 1.8 | 0.35 | 29 | 0.39 | D | 1 |
| | | | 3576.34 | 67.7 | 28021 | 5 | 5 | 1.4 | 0.27 | 16 | 0.13 | D | 1 |
| | | | 3580.93 | 0.0 | 27918 | 3 | 3 | 1.5 | 0.28 | 10 | −0.07 | D | 1 |
| | | | 3590.47 | 177.8 | 28021 | 7 | 5 | 0.32 | 0.045 | 3.7 | −0.50 | D | 1 |
| | | | 3589.63 | 67.7 | 27918 | 5 | 3 | 0.51 | 0.059 | 3.5 | −0.53 | D | 1 |
| | | | 3558.53 | 67.7 | 28161 | 5 | 7 | 0.30 | 0.080 | 4.7 | −0.40 | D | 1 |
| | | | 3567.70 | 0.0 | 28021 | 3 | 5 | 0.35 | 0.11 | 3.9 | −0.48 | D | 1 |
| 17. | | $^3$D – $^3$P° | *3368.1* | *105.5* | *29787* | 15 | 9 | 1.4 | 0.14 | 23 | 0.32 | D | 1 |
| | | | 3372.15 | 177.8 | 29824 | 7 | 5 | 1.2 | 0.14 | 11 | −0.00 | D | 1 |
| | | | 3368.94 | 67.7 | 29742 | 5 | 3 | 1.0 | 0.10 | 5.7 | −0.29 | D | 1 |
| | | | 3361.93 | 0.0 | 29736 | 3 | 1 | 1.4 | 0.078 | 2.6 | −0.63 | D | 1 |
| | | | 3359.67 | 67.7 | 29824 | 5 | 5 | 0.20 | 0.034 | 1.9 | −0.77 | D | 1 |
| | | | 3361.26 | 0.0 | 29742 | 3 | 3 | 0.32 | 0.054 | 1.8 | −0.79 | D | 1 |
| | | | 3352.07 | 0.0 | 29824 | 3 | 5 | 0.013 | 0.0036 | 0.12 | −1.96 | E | 1 |
| 18. | | $^3$D – $^1$P° | | | | | | | | | | | |
| | | | 3251.32 | 67.7 | 30816 | 5 | 3 | 0.033 | 0.0032 | 0.17 | −1.80 | E | 1 |
| | | | 3244.16 | 0.0 | 30816 | 3 | 3 | 0.022 | 0.0034 | 0.11 | −1.99 | E | 1 |
| 19. | | $^3$D – $^1$F° | | | | | | | | | | | |
| | | | 3107.41 | 177.8 | 32350 | 7 | 7 | 0.0015 | 2.2(−4) | 0.016 | −2.81 | E | 1 |
| 20. | | $^1$D – $^1$D° | 4246.82 | 2541 | 26081 | 5 | 5 | 1.5 | 0.41 | 29 | 0.32 | D | 1 |
| 21. | | $^1$D – $^1$P° | 3535.71 | 2541 | 30816 | 5 | 3 | 0.83 | 0.093 | 5.4 | −0.33 | D | 1 |
| 22. | | $^1$D – $^1$F° | 3353.72 | 2541 | 32350 | 5 | 7 | 2.0 | 0.47 | 26 | 0.37 | D | 1 |
| 23. | $4s^2$–$3d4p$ | $^1$S – $^1$P$^0$ | 5239.81 | 11736 | 30816 | 1 | 3 | 0.14 | 0.17 | 2.9 | −0.77 | D | 1 |
| 24. | $4s^2$–$4s4p$ | $^1$S – $^1$P° | [2273.1] | 11736 | 55715 | 1 | 3 | 7.7 | 1.8 | 13 | 0.26 | D | 1 |
| 25. | $4s4p$–$4p^2$ | $^3$P° – $^3$P | | | | | | | | | | | |
| | | | 2667.70 | 39115 | 76589 | 3 | 5 | 1.5 | 0.27 | 7.1 | −0.09 | E | 2 |
| 26. | $3d4p$–$3d4d$ | $^1$D° – $^1$F | 2988.92 | 26081 | 59528 | 5 | 7 | 2.9 | 0.55 | 27 | 0.44 | E | 2 |
| 27. | | $^1$D° – $^1$P | 2912.98 | 26081 | 60400 | 5 | 3 | 1.1 | 0.083 | 4.0 | −0.38 | E | 2 |
| 28. | | $^1$D° – $^1$D | 2611.19 | 26081 | 64367 | 5 | 5 | 2.2 | 0.23 | 9.9 | 0.06 | E | 2 |
| 29. | | $^3$F° – $^3$G | | | | | | | | | | | |
| | | | 3065.12 | 27841 | 60457 | 9 | 11 | 4.3 | 0.73 | 67 | 0.82 | E | 2 |
| | | | 3052.92 | 27602 | 60348 | 7 | 9 | 4.0 | 0.72 | 50 | 0.70 | E | 2 |
| | | | 3045.73 | 27444 | 60267 | 5 | 7 | 3.9 | 0.76 | 38 | 0.58 | E | 2 |
| | | | 3075.36 | 27841 | 60348 | 9 | 9 | 0.25 | 0.036 | 3.3 | −0.49 | E | 2 |
| | | | 3060.54 | 27602 | 60267 | 7 | 7 | 0.33 | 0.046 | 3.3 | −0.49 | E | 2 |
| 30. | | $^3$F° – $^3$F | | | | | | | | | | | |
| | | | 2801.31 | 27841 | 63529 | 9 | 9 | 1.3 | 0.16 | 13 | 0.15 | E | 2 |
| | | | 2789.15 | 27602 | 63445 | 7 | 7 | 1.3 | 0.15 | 9.6 | 0.02 | E | 2 |
| | | | 2782.31 | 27444 | 63375 | 5 | 5 | 1.3 | 0.15 | 6.8 | −0.13 | E | 2 |

Sc II: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31. | | $^3D^o - {}^3D$ | | | | | | | | | | | |
| | | | 3139.72 | 28161 | 60002 | 7 | 7 | 2.1 | 0.31 | 22 | 0.33 | E | 2 |
| | | | 3133.07 | 28021 | 59929 | 5 | 5 | 1.8 | 0.26 | 13 | 0.11 | E | 2 |
| | | | 3128.27 | 27918 | 59875 | 3 | 3 | 1.9 | 0.28 | 8.6 | −0.08 | E | 2 |
| 32. | | $^3D^o - {}^3F$ | | | | | | | | | | | |
| | | | 2826.64 | 28161 | 63529 | 7 | 9 | 2.8 | 0.43 | 28 | 0.48 | E | 2 |
| | | | 2822.12 | 28021 | 63445 | 5 | 7 | 2.5 | 0.42 | 19 | 0.32 | E | 2 |
| | | | 2819.49 | 27918 | 63375 | 3 | 5 | 2.3 | 0.46 | 13 | 0.14 | E | 2 |
| 33. | | $^3D^o - {}^3P$ | | | | | | | | | | | |
| | | | 2735.57 | 28161 | 64706 | 7 | 5 | 0.81 | 0.065 | 4.1 | −0.34 | E | 2 |
| 34. | | $^3P^o - {}^3D$ | | | | | | | | | | | |
| | | | 3312.72 | 29824 | 60002 | 5 | 7 | 1.2 | 0.28 | 15 | 0.15 | E | 2 |
| | | | 3311.70 | 29742 | 59929 | 3 | 5 | 0.92 | 0.25 | 8.3 | −0.12 | E | 2 |
| | | | 3317.02 | 29736 | 59875 | 1 | 3 | 0.65 | 0.32 | 3.5 | −0.49 | E | 2 |
| 35. | | $^3P^o - {}^3S$ | | | | | | | | | | | |
| | | | 3199.33 | 29824 | 61071 | 5 | 3 | 1.9 | 0.17 | 9.2 | −0.06 | E | 2 |
| | | | 3190.98 | 29742 | 61071 | 3 | 3 | 1.1 | 0.17 | 5.4 | −0.29 | E | 2 |
| 36. | | $^3P^o - {}^3P$ | | | | | | | | | | | |
| | | | 2870.85 | 29824 | 64647 | 5 | 3 | 1.1 | 0.081 | 3.9 | −0.39 | E | 2 |
| 37. | | $^1P^o - {}^1P$ | 3379.16 | 30816 | 60400 | 3 | 3 | 2.5 | 0.42 | 14 | 0.10 | E | 2 |
| 38. | | $^1P^o - {}^1D$ | 2979.68 | 30816 | 64367 | 3 | 5 | 1.2 | 0.26 | 7.6 | −0.11 | E | 2 |
| 39. | | $^1P^o - {}^1S$ | 2746.36 | 30816 | 67217 | 3 | 1 | 3.9 | 0.15 | 3.9 | −0.36 | E | 2 |
| 40. | | $^1F^o - {}^1F$ | 3678.33 | 32350 | 59528 | 7 | 7 | 1.0 | 0.21 | 18 | 0.16 | E | 2 |
| 41. | | $^1F^o - {}^1G$ | 3039.92 | 32350 | 65236 | 7 | 9 | 3.5 | 0.62 | 44 | 0.64 | E | 2 |
| 42. | $3d4p-3d5s$ | $^1D^o - {}^1D$ | 3107.52 | 26081 | 58252 | 5 | 5 | 0.79 | 0.12 | 5.9 | −0.24 | E | 2 |
| 43. | | $^3F^o - {}^3D$ | | | | | | | | | | | |
| | | | 3343.23 | 27841 | 57744 | 9 | 7 | 1.1 | 0.15 | 15 | 0.12 | E | 2 |
| | | | 3331.04 | 27602 | 57614 | 7 | 5 | 1.0 | 0.12 | 9.1 | −0.08 | E | 2 |
| | | | 3320.40 | 27444 | 57552 | 5 | 3 | 1.2 | 0.12 | 6.3 | −0.24 | E | 2 |
| 44. | | $^3D^o - {}^3D$ | | | | | | | | | | | |
| | | | 3379.38 | 28161 | 57744 | 7 | 7 | 0.73 | 0.12 | 9.7 | −0.06 | E | 2 |
| | | | 3378.20 | 28021 | 57614 | 5 | 5 | 0.55 | 0.094 | 5.2 | −0.33 | E | 2 |
| | | | 3373.52 | 27918 | 57552 | 3 | 3 | 0.65 | 0.11 | 3.7 | −0.48 | E | 2 |
| 45. | | $^3P^o - {}^3D$ | | | | | | | | | | | |
| | | | 3580.66 | 29824 | 57744 | 5 | 7 | 0.46 | 0.12 | 7.3 | −0.21 | E | 2 |
| | | | 3586.78 | 29742 | 57614 | 3 | 5 | 0.34 | 0.11 | 3.9 | −0.48 | E | 2 |

Sc II: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46. | | $^1P^\circ$ - $^1D$ | 3643.75 | 30816 | 58252 | 3 | 5 | 0.47 | 0.16 | 5.6 | −0.33 | E | 2 |
| 47. | | $^1F^\circ$ - $^1D$ | 3859.59 | 32350 | 58252 | 7 | 5 | 1.1 | 0.18 | 16 | 0.10 | E | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc II

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 7043.5 | 7 | 8384.3 | 6 | 13950 | 2 | 21615 | 5 |
| 7098.5 | 7 | 10661 | 3 | 20319 | 5 | 959250 | 1 |
| 8225.2 | 6 | 10780 | 3 | 20471 | 5 | 1240000 | 1 |
| 8261.2 | 6 | 13599 | 2 | 20759 | 5 | 1889000 | 4 |
| 8271.3 | 6 | 13697 | 2 | 20784 | 5 | 3650000 | 4 |
| 8307.7 | 6 | 13749 | 2 | 20815 | 5 | | |
| 8326.6 | 6 | 13750 | 2 | 21113 | 5 | | |
| 8347.3 | 6 | 13851 | 2 | 21245 | 5 | | |

For this ion, we selected the work of Warner and Kirkpatrick,[1] who used a single-configuration approximation and calculated radial integrals with scaled Thomas-Fermi wavefunctions. We have tabulated M1 and E2 transition probabilities for 12 lines within the $3d^2$ configuration and E2 data for 17 lines in the $3d4s$–$3d^2$ transition array. We have omitted lines involving the $3d^2$ $^1D$, $^1S$, and $3d4s$ $^1D$ levels, because of the strong likelihood of configuration interaction.

### Reference

[1]B. Warner and R. C. Kirkpatrick, Mon. Not. R. Astron. Soc. **144**, 397 (1969).

Sc II: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^2$–$3d^2$ | $^3F$ - $^3F$ | | | | | | | | | | |
| | | | [959250] | 4883.6 | 4987.8 | 7 | 9 | M1 | 2.3(−5)[a] | 6.8 | C | 1 |
| | | | [1240000] | 4802.9 | 4883.6 | 5 | 7 | M1 | 1.4(−5) | 6.9 | C | 1 |
| 2. | | $^3F$ - $^3P$ | | | | | | | | | | |
| | | | [13950] | 4987.8 | 12154 | 9 | 5 | E2 | 0.038 | 60 | E | 1 |
| | | | [13851] | 4883.6 | 12102 | 7 | 3 | E2 | 0.034 | 31 | E | 1 |
| | | | [13749] | 4802.9 | 12074 | 5 | 1 | E2 | 0.053 | 16 | E | 1 |
| | | | [13750] | 4883.6 | 12154 | 7 | 5 | E2 | 0.011 | 16 | E | 1 |
| | | | [13697] | 4802.9 | 12102 | 5 | 3 | E2 | 0.018 | 15 | E | 1 |
| | | | [13599] | 4802.9 | 12154 | 5 | 5 | E2 | 0.0016 | 2.2 | E | 1 |

Sc II: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | | $^3$F - $^1$G (7F) | | | | | | | | | | |
| | | | [10780] | 4987.8 | 14261 | 9 | 9 | M1 | 8.5(−4) | 3.6(−4) | E | 1 |
| | | | [10661] | 4883.6 | 14261 | 7 | 9 | M1 | 5.3(−4) | 2.1(−4) | E | 1 |
| 4. | | $^3$P - $^3$P | | | | | | | | | | |
| | | | [1889000] | 12102 | 12154 | 3 | 5 | M1 | 2.0(−6) | 2.5 | C | 1 |
| | | | [3650000] | 12074 | 12102 | 1 | 3 | M1 | 3.7(−7) | 2.0 | C | 1 |
| 5. | $3d4s$-$3d^2$ | $^3$D - $^3$F | | | | | | | | | | |
| | | | [20319] | 67.7 | 4987.8 | 5 | 9 | E2 | 0.0017 | 32 | E | 1 |
| | | | [20471] | 0.0 | 4883.6 | 3 | 7 | E2 | 0.0020 | 30 | E | 1 |
| | | | [20784] | 177.8 | 4987.8 | 7 | 9 | E2 | 0.0026 | 54 | E | 1 |
| | | | [20759] | 67.7 | 4883.6 | 5 | 7 | E2 | 0.0046 | 74 | E | 1 |
| | | | [20815] | 0.0 | 4802.9 | 3 | 5 | E2 | 0.0050 | 58 | E | 1 |
| | | | [21245] | 177.8 | 4883.6 | 7 | 7 | E2 | 0.0025 | 45 | E | 1 |
| | | | [21113] | 67.7 | 4802.9 | 5 | 5 | E2 | 0.0034 | 42 | E | 1 |
| | | | [21615] | 177.8 | 4802.9 | 7 | 5 | E2 | 3.0(−4) | 4.2 | E | 1 |
| 6. | | $^3$D - $^3$P (3F) | | | | | | | | | | |
| | | | [8384.3] | 177.8 | 12102 | 7 | 3 | E2 | 0.40 | 30 | E | 1 |
| | | | [8326.6] | 67.7 | 12074 | 5 | 1 | E2 | 0.88 | 21 | E | 1 |
| | | | [8347.3] | 177.8 | 12154 | 7 | 5 | E2 | 0.49 | 59 | E | 1 |
| | | | [8307.7] | 67.7 | 12102 | 5 | 3 | E2 | 0.074 | 5.2 | E | 1 |
| | | | [8271.3] | 67.7 | 12154 | 5 | 5 | E2 | 0.32 | 37 | E | 1 |
| | | | [8261.2] | 0.0 | 12102 | 3 | 3 | E2 | 0.41 | 28 | E | 1 |
| | | | [8225.2] | 0.0 | 12154 | 3 | 5 | E2 | 0.084 | 9.4 | E | 1 |
| 7. | | $^3$D - $^1$G | | | | | | | | | | |
| | | | [7043.5] | 67.7 | 14261 | 5 | 9 | E2 | 0.0022 | 0.20 | E | 1 |
| | | | [7098.5] | 177.8 | 14261 | 7 | 9 | E2 | 5.1(−5) | 0.0049 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc III

K Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^63d\ ^2D_{3/2}$

Ionization Energy: 24.75704 eV = 199677.37 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 627.069 | 4 | 693.969 | 8 | 769.019 | 7 | 780.729 | 3 |
| 627.847 | 4 | 730.600 | 2 | 769.524 | 7 | 961.052 | 14 |
| 627.85 | 4 | 731.655 | 2 | 779.53 | 3 | 965.448 | 14 |
| 693.724 | 8 | 731.66 | 2 | 780.597 | 3 | 966.293 | 13 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 970.638 | 13 | 2011.07 | 9 | 3481.06 | 21 | 6251.4 | 33 |
| 970.73 | 13 | 2012.91 | 9 | 4061.21 | 15 | 6251.70 | 33 |
| 973.295 | 6 | 2096.94 | 29 | 4068.66 | 15 | 6254.26 | 33 |
| 974.965 | 6 | 2104.71 | 29 | 4068.7 | 15 | 6256.01 | 16 |
| 1148.24 | 12 | 2111.94 | 28 | 4225.78 | 31 | 6307.60 | 16 |
| 1154.52 | 12 | 2119.52 | 28 | 4229.3 | 31 | 7339.03 | 37 |
| 1162.44 | 11 | 2119.83 | 28 | 4229.37 | 31 | 7344.4 | 37 |
| 1168.61 | 11 | 2308.53 | 17 | 4637.8 | 32 | 7344.75 | 37 |
| 1168.88 | 11 | 2310.95 | 17 | 4642.08 | 32 | 7449.16 | 22 |
| 1493.50 | 19 | 2313.09 | 17 | 4648.15 | 32 | 7548.15 | 22 |
| 1494.5 | 19 | 2455.52 | 23 | 4740.95 | 25 | 8814.29 | 30 |
| 1494.51 | 19 | 2460.6 | 23 | 4780.87 | 25 | 8829.79 | 30 |
| 1598.00 | 1 | 2627.33 | 27 | 4923.3 | 36 | 8829.9 | 30 |
| 1603.06 | 1 | 2639.55 | 27 | 4944.07 | 36 | 8865.89 | 20 |
| 1610.19 | 1 | 2666.91 | 26 | 4992.89 | 24 | 8866.0 | 20 |
| 1679.82 | 18 | 2678.73 | 26 | 5006.80 | 35 | 8881.59 | 20 |
| 1681.1 | 18 | 2679.49 | 26 | 5026.67 | 35 | 9371.74 | 34 |
| 1681.11 | 18 | 2699.07 | 5 | 5028.3 | 35 | 9447.4 | 34 |
| 1895.44 | 10 | 2734.05 | 5 | 5032.09 | 24 | | |
| 1912.62 | 10 | 3479.79 | 21 | 5037.18 | 24 | | |
| 1993.89 | 9 | 3479.8 | 21 | 6238.31 | 16 | | |

For this relatively simple alkali-like spectrum, we have used the Hartree-Fock calculations of Weiss[1] and Biemont.[2] We have also included the data of Kurucz and Peytremann,[3] who calculated log *gf*-values by a semiempirical, scaled Thomas-Fermi-Dirac method. Van Deurzen *et al.*[4] have observed a number of Sc III lines not listed in Refs. 1–3. For these additional lines (except for those going down to the 3*d* configuration, where significant interaction with the core electrons is likely), we have calculated oscillator strengths by means of the Coulomb approximation.[5] We also compared the data of Refs. 2 and 3 to our own Coulomb approximation calculations. For transitions in which we found little or no cancellation in the transition integral, our oscillator strengths are in excellent agreement with those of Biemont and those of Kurucz and Peytremann. In fact, for 26 of 27 overlapping transitions, the agreement between our log *gf*-values (obtained via the Coulomb approximation) and those of Biemont is within ±12%. Similarly, for all nine overlapping transitions, the agreement between our data and those of Kurucz and Peytremann is within ±10%. For cases in which severe cancellation effects were evident, our calculations yielded oscillator strengths, on the average, about thirty percent lower than Biemont's. (For these transitions, the data of Kurucz and Peytremann were largely unavailable for comparison purposes.) Therefore, if significant cancellation effects appeared, we retained Biemont's data, but reduced the accuracy ratings accordingly.

As the following table shows, our tabulated theoretical data produce lifetimes (in the form of reciprocals of sums of transition probablities) not too different from the beam-foil lifetimes of Buchta *et al.*[5] and Anderson *et al.*[6] Cascading effects in the beam-foil experiments are probably responsible for the systematic differences between the theoretical data and the experimental lifetimes.

Lifetimes (in ns) of various excited levels of Sc III

| Upper atomic level | $\tau_k$ | | $(\sum_i A_{ki})^{-1}$ |
|---|---|---|---|
| | Buchta *et al.*[6] | Andersen *et al.*[7] | This compilation |
| $4p\ ^2P^\circ$ | 1.9 | 1.7 | 1.3 |
| $4d\ ^2D$ | 1.2 | | 0.90 |
| $5s\ ^2S$ | 1.4 | | 1.1 |
| $5d\ ^2D$ | 2.4 | | 2.3 |

## References


[1]A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **71**, 157 (1967).

[2]E. Biemont, Physica C **81**, 158 (1976).

[3]R. L. Kurucz and E. Peytremann, Smithsonian Astrophysical Observatory Special Report 362 (1975).

[4]C. H. H. Van Deurzen, J. G. Conway, and S. P. Davis, J. Opt. Soc. Am. **63**, 158 (1973).

[5]D. R. Bates and A. Damgaard, Philos. Trans. R. Soc. London, Ser. A **242**, 101 (1949).

[6]R. Buchta, L. J. Curtis, I. Martinson, and J. Brzozowski, Phys. Scr. **4**, 55 (1971).

[7]T. Andersen, P. Petersen, and E. Biemont, J. Quant. Spectrosc. Radiat. Transfer **17**, 389 (1977).

Sc III: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d$–$4p$ | $^2$D – $^2$P° | *1605.1* | *118.6* | *62420* | 10 | 6 | 4.5 | 0.10 | 5.5 | 0.02 | D | 1 |
| | | | 1603.06 | 197.6 | 62578 | 6 | 4 | 4.1 | 0.10 | 3.3 | −0.20 | D | *ls* |
| | | | 1610.19 | 0.0 | 62104 | 4 | 2 | 4.4 | 0.085 | 1.8 | −0.47 | D | *ls* |
| | | | 1598.00 | 0.0 | 62578 | 4 | 4 | 0.46 | 0.018 | 0.37 | −1.15 | D− | *ls* |
| 2. | $3d$–$4f$ | $^2$D – $^2$F° | *731.23* | *118.6* | 136874 | 10 | 14 | 13 | 0.15 | 3.5 | 0.16 | D | 3 |
| | | | 731.655 | 197.6 | 136874 | 6 | 8 | 13 | 0.14 | 2.0 | −0.08 | D | 3 |
| | | | 730.600 | 0.0 | 136874 | 4 | 6 | 12 | 0.14 | 1.4 | −0.24 | D | 3 |
| | | | [731.66] | 197.6 | 136874 | 6 | 6 | 0.87 | 0.0069 | 0.10 | −1.38 | E | 3 |
| 3. | $3d$–$5p$ | $^2$D – $^2$P° | *780.61* | *118.6* | *128224* | 10 | 6 | 1.4 | 0.0078 | 0.20 | −1.11 | E | 3 |
| | | | 780.729 | 197.6 | 128283 | 6 | 4 | 1.3 | 0.0076 | 0.12 | −1.34 | E | 3 |
| | | | 780.597 | 0.0 | 128107 | 4 | 2 | 1.4 | 0.0063 | 0.065 | −1.60 | E | 3 |
| | | | [779.53] | 0.0 | 128283 | 4 | 4 | 0.14 | 0.0013 | 0.013 | −2.29 | E | 3 |
| 4. | $3d$–$5f$ | $^2$D – $^2$F° | *627.54* | *118.6* | 159472 | 10 | 14 | 8.8 | 0.073 | 1.5 | −0.14 | D | 3 |
| | | | 627.847 | 197.6 | 159472 | 6 | 8 | 8.6 | 0.068 | 0.84 | −0.39 | D | 3 |
| | | | 627.069 | 0.0 | 159472 | 4 | 6 | 8.0 | 0.070 | 0.58 | −0.55 | D− | 3 |
| | | | [627.85] | 197.6 | 159472 | 6 | 6 | 0.58 | 0.0034 | 0.042 | −1.69 | E | 3 |
| 5. | $4s$–$4p$ | $^2$S – $^2$P° | *2710.6* | 25539 | *62420* | 2 | 6 | 3.39 | 1.12 | 20.0 | 0.350 | C | 1 |
| | | | 2699.07 | 25539 | 62578 | 2 | 4 | 3.43 | 0.75 | 13.3 | 0.175 | C | *ls* |
| | | | 2734.05 | 25539 | 62104 | 2 | 2 | 3.3 | 0.37 | 6.7 | −0.13 | D | *ls* |
| 6. | $4s$–$5p$ | $^2$S – $^2$P° | *973.85* | 25539 | *128224* | 2 | 6 | 0.17 | 0.0071 | 0.046 | −1.85 | E | 2 |
| | | | 973.295 | 25539 | 128283 | 2 | 4 | 0.17 | 0.0048 | 0.031 | −2.01 | E | *ls* |
| | | | 974.965 | 25539 | 128107 | 2 | 2 | 0.16 | 0.0023 | 0.015 | −2.33 | E | *ls* |
| 7. | $4s$–$6p$ | $^2$S – $^2$P° | *769.18* | 25539 | *155547* | 2 | 6 | 0.16 | 0.0044 | 0.022 | −2.06 | E | 2 |
| | | | 769.019 | 25539 | 155575 | 2 | 4 | 0.16 | 0.0029 | 0.015 | −2.24 | E | *ls* |
| | | | 769.524 | 25539 | 155490 | 2 | 2 | 0.16 | 0.0015 | 0.0074 | −2.53 | E | *ls* |
| 8. | $4s$–$7p$ | $^2$S – $^2$P° | *693.81* | 25539 | *169670* | 2 | 6 | 0.12 | 0.0026 | 0.012 | −2.29 | E | 2 |
| | | | 693.724 | 25539 | 169686 | 2 | 4 | 0.12 | 0.0017 | 0.0077 | −2.47 | E | *ls* |
| | | | 693.969 | 25539 | 169638 | 2 | 2 | 0.12 | 8.5(−4)[a] | 0.0039 | −2.77 | E | *ls* |
| 9. | $4p$–$4d$ | $^2$P° – $^2$D | *2004.8* | *62420* | *112285* | 6 | 10 | 11.1 | 1.11 | 44.0 | 0.82 | C− | 2 |
| | | | 2011.07 | 62578 | 112303 | 4 | 6 | 11.0 | 1.00 | 26.4 | 0.60 | C− | *ls* |
| | | | 1993.89 | 62104 | 112258 | 2 | 4 | 9.4 | 1.12 | 14.7 | 0.350 | C− | *ls* |
| | | | 2012.91 | 62578 | 112258 | 4 | 4 | 1.8 | 0.11 | 2.9 | −0.36 | D | *ls* |
| 10. | $4p$–$5s$ | $^2$P° – $^2$S | *1906.9* | *62420* | 114862 | 6 | 2 | 8.7 | 0.159 | 6.0 | −0.020 | C− | 2 |
| | | | 1912.62 | 62578 | 114862 | 4 | 2 | 5.8 | 0.16 | 4.0 | −0.20 | C− | *ls* |
| | | | 1895.44 | 62104 | 114862 | 2 | 2 | 3.0 | 0.16 | 2.0 | −0.49 | D | *ls* |
| 11. | $4p$–$5d$ | $^2$P° – $^2$D | *1166.6* | *62420* | *148142* | 6 | 10 | 1.9 | 0.064 | 1.5 | −0.42 | D | 2 |
| | | | 1168.61 | 52578 | 148150 | 4 | 6 | 1.9 | 0.058 | 0.90 | −0.63 | D | *ls* |
| | | | 1162.44 | 62104 | 148130 | 2 | 4 | 1.6 | 0.065 | 0.50 | −0.88 | D | *ls* |
| | | | 1168.88 | 62578 | 148130 | 4 | 4 | 0.32 | 0.0065 | 0.10 | −1.59 | D− | *ls* |

Sc III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8\ s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | $4p$–$6s$ | $^{2}\mathrm{P}^{\circ}-{}^{2}\mathrm{S}$ | *1152.4* | *62420* | 149194 | 6 | 2 | 3.4 | 0.023 | 0.52 | −0.86 | D | 2 |
| | | | 1154.52 | 62578 | 149194 | 4 | 2 | 2.3 | 0.023 | 0.35 | −1.04 | D | *ls* |
| | | | 1148.24 | 62104 | 149194 | 2 | 2 | 1.1 | 0.022 | 0.17 | −1.35 | D− | *ls* |
| 13. | $4p$–$6d$ | $^{2}\mathrm{P}^{\circ}-{}^{2}\mathrm{D}$ | *969.19* | *62420* | *165599* | 6 | 10 | 0.67 | 0.016 | 0.30 | −1.03 | D− | 2 |
| | | | 970.638 | 62578 | 165603 | 4 | 6 | 0.67 | 0.014 | 0.18 | −1.25 | D− | *ls* |
| | | | 966.293 | 62104 | 165593 | 2 | 4 | 0.56 | 0.016 | 0.10 | −1.50 | D− | *ls* |
| | | | [970.73] | 62578 | 165593 | 4 | 4 | 0.11 | 0.0016 | 0.020 | −2.20 | E | *ls* |
| 14. | $4p$–$7s$ | $^{2}\mathrm{P}^{\circ}-{}^{2}\mathrm{S}$ | *963.98* | *62420* | 166157 | 6 | 2 | 1.8 | 0.0082 | 0.16 | −1.31 | D− | 2 |
| | | | 965.448 | 62578 | 166157 | 4 | 2 | 1.2 | 0.0087 | 0.11 | −1.46 | D− | *ls* |
| | | | 961.052 | 62104 | 166157 | 2 | 2 | 0.60 | 0.0084 | 0.053 | −1.78 | E | *ls* |
| 15. | $4d$–$4f$ | $^{2}\mathrm{D}-{}^{2}\mathrm{F}^{\circ}$ | *4065.7* | *112285* | 136874 | 10 | 14 | 3.2 | 1.1 | 150 | 1.05 | D | 3 |
| | | | 4068.66 | 112303 | 136874 | 6 | 8 | 3.1 | 1.0 | 83 | 0.79 | D | 3 |
| | | | 4061.21 | 112258 | 136874 | 4 | 6 | 2.9 | 1.1 | 58 | 0.64 | D | 3 |
| | | | [4068.7] | 112303 | 136874 | 6 | 6 | 0.21 | 0.052 | 4.1 | −0.51 | D | 3 |
| 16. | $4d$–$5p$ | $^{2}\mathrm{D}-{}^{2}\mathrm{P}^{\circ}$ | *6272.2* | *112285* | *128224* | 10 | 6 | 0.74 | 0.263 | 54 | 0.420 | C− | 2 |
| | | | 6256.01 | 112303 | 128283 | 6 | 4 | 0.66 | 0.26 | 32 | 0.19 | C− | *ls* |
| | | | 6307.60 | 112258 | 128107 | 4 | 2 | 0.73 | 0.22 | 18 | −0.06 | C− | *ls* |
| | | | 6238.31 | 112258 | 128283 | 4 | 4 | 0.075 | 0.044 | 3.6 | −0.76 | D | *ls* |
| 17. | $4d$–$6p$ | $^{2}\mathrm{D}-{}^{2}\mathrm{P}^{\circ}$ | *2310.8* | *112285* | *155547* | 10 | 6 | 0.17 | 0.0083 | 0.63 | −1.08 | E | 2 |
| | | | 2310.95 | 112303 | 155575 | 6 | 4 | 0.16 | 0.0083 | 0.38 | −1.30 | E | *ls* |
| | | | 2313.09 | 112258 | 155490 | 4 | 2 | 0.17 | 0.0069 | 0.21 | −1.56 | E | *ls* |
| | | | 2308.53 | 112258 | 155575 | 4 | 4 | 0.017 | 0.0014 | 0.042 | −2.26 | E | *ls* |
| 18. | $4d$–$6f$ | $^{2}\mathrm{D}-{}^{2}\mathrm{F}^{\circ}$ | *1680.6* | *112285* | 171788 | 10 | 14 | 0.067 | 0.0040 | 0.22 | −1.40 | E | *ca* |
| | | | 1681.11 | 112303 | 171788 | 6 | 8 | 0.069 | 0.0039 | 0.13 | −1.63 | E | *ls* |
| | | | 1679.82 | 112258 | 171788 | 4 | 6 | 0.063 | 0.0040 | 0.088 | −1.80 | E | *ls* |
| | | | [1681.1] | 112303 | 171788 | 6 | 6 | 0.0045 | 1.9(−4) | 0.0063 | −2.94 | E | *ls* |
| 19. | $4d$–$7f$ | $^{2}\mathrm{D}-{}^{2}\mathrm{F}^{\circ}$ | *1494.1* | *112285* | 179215 | 10 | 14 | 0.098 | 0.0046 | 0.23 | −1.34 | E | *ca* |
| | | | 1494.51 | 112303 | 179215 | 6 | 8 | 0.099 | 0.0044 | 0.13 | −1.58 | E | *ls* |
| | | | 1493.50 | 112258 | 179215 | 4 | 6 | 0.093 | 0.0047 | 0.092 | −1.73 | E | *ls* |
| | | | [1494.5] | 112303 | 179215 | 6 | 6 | 0.0067 | 2.2(−4) | 0.0066 | −2.87 | E | *ls* |
| 20. | $4f$–$5d$ | $^{2}\mathrm{F}^{\circ}-{}^{2}\mathrm{D}$ | *8872.3* | 136874 | *148142* | 14 | 10 | 0.20 | 0.17 | 70 | 0.38 | D | 3 |
| | | | 8865.89 | 136874 | 148150 | 8 | 6 | 0.20 | 0.17 | 40 | 0.14 | D | 3 |
| | | | 8881.59 | 136874 | 148130 | 6 | 4 | 0.20 | 0.16 | 28 | −0.02 | D | 3 |
| | | | [8866.0] | 136874 | 148150 | 6 | 6 | 0.0098 | 0.012 | 2.0 | −1.16 | E | 3 |
| 21. | $4f$–$6d$ | $^{2}\mathrm{F}^{\circ}-{}^{2}\mathrm{D}$ | *3480.3* | 136874 | *165599* | 14 | 10 | 0.055 | 0.0071 | 1.1 | −1.00 | E | *ca* |
| | | | 3479.79 | 136874 | 165603 | 8 | 6 | 0.050 | 0.0069 | 0.63 | −1.26 | E | *ls* |
| | | | 3481.06 | 136874 | 165593 | 6 | 4 | 0.053 | 0.0064 | 0.44 | −1.42 | E | *ls* |
| | | | [3479.8] | 136874 | 165603 | 6 | 6 | 0.0025 | 4.5(−4) | 0.031 | −2.57 | E | *ls* |
| 22. | $5s$–$5p$ | $^{2}\mathrm{S}-{}^{2}\mathrm{P}^{\circ}$ | *7481.8* | 114862 | *128224* | 2 | 6 | 0.57 | 1.43 | 70 | 0.456 | C− | 2 |
| | | | 7449.16 | 114862 | 128283 | 2 | 4 | 0.58 | 0.96 | 47 | 0.28 | C− | *ls* |
| | | | 7548.15 | 114862 | 128107 | 2 | 2 | 0.54 | 0.46 | 23 | −0.03 | D | *ls* |

Sc IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | | $^1$S - $^1$P° | 289.851 | 0 | 345005 | 1 | 3 | 1040 | 3.92 | 3.74 | 0.593 | C+ | 1 |
| 3. | $3p^6$–$3p^54s$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | 299.037 | 0 | 334405 | 1 | 3 | 20 | 0.080 | 0.079 | −1.10 | E | *interp.* |
| 4. | | $^1$S - $^1$P° | 296.311 | 0 | 337484 | 1 | 3 | 86 | 0.34 | 0.33 | −0.47 | E | *interp.* |

# Sc V

Cl Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^5\ ^2P^\circ_{3/2}$

Ionization Energy: 91.9 eV = 741000 cm$^{-1}$

## Allowed Transitions

Line strengths for transitions of the arrays $3s^23p^5$–$3s3p^6$ and $3p^5$–$3p^43d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang *et al.*[1] These relativistic calculations include a perturbative treatment of the Breit interaction and the Lamb shift. Configuration mixing was limited to some configurations within the $n=3$ complex. Those configurations which were assumed to lie far above $3p^5$ or $3p^43d$ in energy were excluded, as were all configurations outside the complex.

According to the semi-empirical HX (Hartree-Fock with statistical allowance for exchange) calculations of Bromage *et al.*[2] for Fe X, some levels of the $3p^43d$ configuration are strongly mixed in the *LS* basis, and in a few cases the *LS* designations given in Ref. 2 differed from those of Huang *et al.* The level designations used in this compilation are in accord with the theoretical results of Refs. 1 and 2 for Fe X. Percentage compositions published by Bromage[3] for the levels of the $3p^43d$ configuration in V VII and Ni XII indicate that the designations for the iron ion are appropriate for the neighboring ions of the chlorine isoelectronic sequence. Transitions involving highly mixed levels have been excluded, as have the very weak transitions.

The calculated wavelengths of Huang *et al.* differ appreciably from the observed ones found in the literature. Thus the available experimentally determined wavelengths were used in making the conversion from line strengths to *f*- and *A*-values. (Otherwise, the calculated wavelengths of Huang *et al.* were used, but they provide only a rough idea of the spectral-line positions.) Bromage *et al.* indicate that it was necessary to scale down some configuration-interaction parameters by a greater amount than usual in order to fit their calculated energy levels for Fe X to the experimental data. This could be an indication that neglecting to take configuration interaction into account on a larger scale yields significant errors in the energy levels and/or *f*-values.

### References

[1]K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables **28**, 355 (1983).
[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Phys. Scr. **15**, 177 (1977).
[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).

Sc V: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^5$–$3s3p^6$ | $^2$P° - $^2$S | *578.13* | *1442* | 174412 | 6 | 2 | 20.5 | 0.0342 | 0.391 | −0.69 | C− | 1 |
| | | | 573.355 | 0 | 174412 | 4 | 2 | 14.0 | 0.0346 | 0.261 | −0.86 | C− | 1 |
| | | | 587.936 | 4325 | 174412 | 2 | 2 | 6.5 | 0.0336 | 0.130 | −1.173 | C− | 1 |

Sc v: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ (10$^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | $3p^5$–$3p^4(^3P)3d$ | $^2P^\circ$ – $^4P$ | | | | | | | | | | | |
| | | | [362] | | | 2 | 4 | 0.77 | 0.0030 | 0.0072 | −2.22 | E | 1 |
| | | | [357] | | | 4 | 4 | 0.45 | 8.5(−4)[a] | 0.0040 | −2.47 | E | 1 |
| | | | [365] | | | 2 | 2 | 0.094 | 1.9(−4) | 4.5(−4) | −3.43 | E | 1 |
| | | | [360] | | | 4 | 2 | 0.11 | 1.1(−4) | 5.0(−4) | −3.37 | E | 1 |
| 3. | | $^2P^\circ$ – $^2D$ | *283.90* | *1442* | *353680* | 6 | 10 | 1020 | 2.05 | 11.5 | 1.090 | C− | 1 |
| | | | 283.91 | 0 | 352220 | 4 | 6 | 1000 | 1.8 | 6.9 | 0.87 | C | 1 |
| | | | 284.45 | 4325 | 355870 | 2 | 4 | 950 | 2.31 | 4.32 | 0.66 | C | 1 |
| | | | 281.00 | 0 | 355870 | 4 | 4 | 62 | 0.073 | 0.27 | −0.53 | D | 1 |
| 4. | $3p^5$–$3p^4(^1D)3d$ | $^2P^\circ$ – $^2F$ | | | | | | | | | | | |
| | | | [321] | | | 4 | 6 | 0.12 | 2.8(−4) | 0.0012 | −2.94 | E | 1 |
| 5. | | $^2P^\circ$ – $^2S$ | *297.44* | *1442* | 337640 | 6 | 2 | 890 | 0.391 | 2.30 | 0.371 | C− | 1 |
| | | | 296.17 | 0 | 337640 | 4 | 2 | 620 | 0.410 | 1.60 | 0.215 | C− | 1 |
| | | | 300.00 | 4325 | 337640 | 2 | 2 | 260 | 0.35 | 0.70 | −0.15 | C− | 1 |
| 6. | $3p^5$–$3p^4(^1S)3d$ | $^2P^\circ$ – $^2D$ | | | | | | | | | | | |
| | | | [297] | | | 4 | 6 | 0.98 | 0.0019 | 0.0076 | −2.11 | E | 1 |
| | | | [301] | | | 2 | 4 | 3.0 | 0.0081 | 0.016 | −1.79 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc v

## Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $3p^5$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for mixing among odd-parity configurations was limited to the set $3s^23p^5$, $3s3p^53d$, $3p^53d^2$, and $3s^23p^33d^2$. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables 28, 355 (1983).

Sc v: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^5$–$3p^5$ | $^2P^\circ$ – $^2P^\circ$ | | | | | | | | | | |
| | | | [23120] | 0 | 4325 | 4 | 2 | M1 | 1.45 | 1.33 | B | 1 |
| | | | " | " | " | 4 | 2 | E2 | 1.2(−4)[a] | 0.94 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc VI

S Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^4\ ^3P_2$

Ionization Energy: 110.68 eV = 892700 cm$^{-1}$

## Forbidden Transitions

Transition probabilities for magnetic dipole and electric quadrupole lines within the $3p^4$ configuration are the results of the scaled Thomas-Fermi calculations of Mendoza and Zeippen.[1] They included a number of correlation configurations in their basis set and introduced Breit-Pauli relativistic corrections as a perturbation to the nonrelativistic Hamiltonian.

### Reference

[1]C. Mendoza and C. J. Zeippen, Mon. Not. R. Astron. Soc. **202**, 981 (1983).

Sc VI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^4$–$3p^4$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | [29880] | 0 | 3346 | 5 | 3 | M1 | 0.833 | 2.47 | C+ | 1 |
| | | | " | " | " | 5 | 3 | E2 | 2.0(−5)[a] | 0.85 | D− | 1 |
| | | | [89980] | 3346 | 4457 | 3 | 1 | M1 | 0.0732 | 1.98 | C+ | 1 |
| | | | [22430] | 0 | 4457 | 5 | 1 | E2 | 1.2(−4) | 0.41 | D− | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [4673.1] | 0 | 21393 | 5 | 5 | M1 | 4.1 | 0.078 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.0093 | 0.062 | E | 1 |
| | | | [5539.5] | 3346 | 21393 | 3 | 5 | M1 | 0.83 | 0.026 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 5.9(−4) | 0.0092 | E | 1 |
| | | | [5902.9] | 4457 | 21393 | 1 | 5 | E2 | 1.5(−4) | 0.0032 | E | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [2030.9] | 0 | 49224 | 5 | 1 | E2 | 0.24 | 0.0049 | E | 1 |
| | | | [2179.0] | 3346 | 49224 | 3 | 1 | M1 | 49 | 0.019 | E | 1 |
| 4. | | $^1$D - $^1$S | [3592.1] | 21393 | 49224 | 5 | 1 | E2 | 4.3 | 1.5 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc VII

P Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^3\ ^4S^\circ_{3/2}$

Ionization Energy: 138.0 eV = 1113000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 275 | 8 | 302.436 | 7 | 317 | 5 | 558.044 | 1 |
| 286.927 | 6 | 307.320 | 10 | 532.585 | 2 | 562.504 | 1 |
| 290.232 | 8 | 308 | 9 | 533.442 | 2 | 571.249 | 1 |
| 298.557 | 4 | 308.180 | 10 | 534.513 | 2 | 596.530 | 3 |
| 301.820 | 7 | 309 | 9 | 535.377 | 2 | 598.707 | 3 |

Line strengths for transitions of the arrays $3s^23p^3$–$3s3p^4$ and $3p^3$–$3p^23d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to configurations within the $n=3$ complex having no more than two electrons in the $3d$ subshell.

Huang published diagrams of energy levels (designated in *LS* coupling) in the $3s^23p^3$, $3s3p^4$, and $3s^23p^23d$ configurations of Cl III, Ti VIII, and Fe XII, but he has not provided percentage compositions. We have used the percentages given by Bromage *et al.*[2] for Fe XII, and by Bromage[3] for V IX and Ni XIV, as a guide to naming the levels; their values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to a few configurations within the $n=3$ complex. Whenever a term designation of a level in Fe XII, as given in Ref. 1, is different from that indicated in Ref. 2, all transitions involving the corresponding level in Sc VII are omitted from this compilation. Furthermore, any level indicated by Huang to have changed its energyat indicated in Ref. 2, all transitions involving the corresponding level in Sc VII are omitted from this compilation. Furthermore, any level indicated by Huang to have changed its energy ranking relative to other levels of the same $J$-value and parity, in proceeding along the isoelectronic sequence from Cl III to Ti VIII, is omitted here, since, unlike the case of V IX through Ni XIV, there are no data available on percentage compositions of these levels in Sc VII.

Transitions involving levels which are indicated to be of low purity in *LS* coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **30**, 313 (1984).
[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).
[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).

Sc VII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^3$–$3s3p^4$ | $^4S^\circ - {}^4P$ | *566.08* | 0 | *176653* | 4 | 12 | 6.7 | 0.097 | 0.72 | −0.41 | D | 1 |
| | | | 571.249 | 0 | 175055 | 4 | 6 | 6.5 | 0.048 | 0.36 | −0.72 | D | 1 |
| | | | 562.504 | 0 | 177777 | 4 | 4 | 6.8 | 0.032 | 0.24 | −0.89 | D | 1 |
| | | | 558.044 | 0 | 179197 | 4 | 2 | 7.0 | 0.016 | 0.12 | −1.18 | D | 1 |

Sc VII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | | $^2D^\circ - ^2D$ | *534.08* | | | 10 | 10 | 13 | 0.055 | 0.97 | −0.26 | D | 1 |
| | | | 534.513 | | | 6 | 6 | 12 | 0.051 | 0.54 | −0.51 | D | 1 |
| | | | 533.442 | | | 4 | 4 | 13 | 0.056 | 0.39 | −0.65 | D | 1 |
| | | | 535.377 | | | 6 | 4 | 0.69 | 0.0020 | 0.021 | −1.92 | E | 1 |
| | | | 532.585 | | | 4 | 6 | 0.38 | 0.0024 | 0.017 | −2.01 | E | 1 |
| 3. | | $^2P^\circ - ^2D$ | | | | | | | | | | | |
| | | | 598.707 | | | 4 | 6 | 2.0 | 0.016 | 0.13 | −1.18 | D | 1 |
| | | | 596.530 | | | 2 | 4 | 1.4 | 0.015 | 0.057 | −1.54 | D | 1 |
| 4. | $3p^3$–$3p^2(^3P)3d$ | $^4S^\circ - ^4P$ | | | | | | | | | | | |
| | | | 298.557 | 0 | 334944 | 4 | 6 | 530 | 1.1 | 4.2 | 0.63 | D | 1 |
| 5. | | $^2D^\circ - ^4P$ | | | | | | | | | | | |
| | | | [317] | | | 6 | 6 | 2.2 | 0.0034 | 0.021 | −1.70 | E | 1 |
| 6. | | $^2D^\circ - ^2F$ | | | | | | | | | | | |
| | | | 286.927 | | | 6 | 8 | 660 | 1.1 | 6.2 | 0.82 | E | 1 |
| 7. | $3p^3$–$3p^2(^1D)3d$ | $^2D^\circ - ^2D$ | | | | | | | | | | | |
| | | | 301.820 | | | 4 | 4 | 390 | 0.53 | 2.1 | 0.33 | D | 1 |
| | | | 302.436 | | | 6 | 4 | 53 | 0.049 | 0.29 | −0.54 | D | 1 |
| 8. | | $^2D^\circ - ^2P$ | | | | | | | | | | | |
| | | | 290.232 | | | 6 | 4 | 7.7 | 0.0065 | 0.037 | −1.41 | E | 1 |
| | | | [275] | | | 4 | 4 | 1.6 | 0.0018 | 0.0065 | −2.14 | E | 1 |
| 9. | | $^2P^\circ - ^2D$ | | | | | | | | | | | |
| | | | [308] | | | 2 | 4 | 31 | 0.089 | 0.18 | −0.75 | D | 1 |
| | | | [309] | | | 4 | 4 | 0.10 | 1.4(−4)[a] | 5.8(−4) | −3.24 | E | 1 |
| 10. | | $^2P^\circ - ^2P$ | | | | | | | | | | | |
| | | | 308.180 | | | 4 | 4 | 350 | 0.49 | 2.0 | 0.29 | E | 1 |
| | | | 307.320 | | | 2 | 4 | 80 | 0.23 | 0.46 | −0.34 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Sc VII

### Forbidden Transitions

Line strengths for magnetic dipole and electric quadrupole transitions within the $3p^3$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to configurations within the $n=3$ complex having no more than two electrons in the $3d$ subshell. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. We have excluded from this compilation the electric quadrupole contributions to the $^4S^\circ_{3/2} - ^2P^\circ_{3/2}$ and $^4S^\circ_{3/2} - ^2P^\circ_{1/2}$ transitions, since their strengths are very small and thus subject to considerable uncertainty.

Data for these same transitions calculated by Mendoza and Zeippen[2] with the scaled Thomas-Fermi approach with allowance for correlation are generally in very good agreement with the results of Ref. 1. These latter calculations treated relativistic effects by introducing Breit-Pauli corrections as a perturbation to the nonrelativistic Hamiltonian.

## References

[1]K.-N. Huang, At. Data Nucl. Data Tables **30**, 313 (1984).
[2]C. Mendoza and C. J. Zeippen, Mon. Not. R. Astron. Soc. **198**, 127 (1982).

Sc VII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^3$–$3p^3$ | $^4S°$ - $^2D°$ | | | | | | | | | | |
| | | | [3306] | | | 4 | 6 | M1 | 0.015 | 1.2(−4)[a] | E | 1 |
| | | | " | | | 4 | 6 | E2 | 0.0085 | 0.012 | E | 1 |
| | | | [3382] | | | 4 | 4 | M1 | 0.73 | 0.0042 | E | 1 |
| | | | " | | | 4 | 4 | E2 | 0.0050 | 0.0053 | E | 1 |
| 2. | | $^4S°$ - $^2P°$ | | | | | | | | | | |
| | | | [1988] | | | 4 | 4 | M1 | 21 | 0.024 | D | 1 |
| | | | [2024] | | | 4 | 2 | M1 | 8.9 | 0.0055 | E | 1 |
| 3. | | $^2D°$ - $^2D°$ | | | | | | | | | | |
| | | | [148000] | | | 4 | 6 | M1 | 0.00322 | 2.32 | C+ | 1 |
| | | | " | | | 4 | 6 | E2 | 3.8(−10) | 0.096 | E | 1 |
| 4. | | $^2D°$ - $^2P°$ | | | | | | | | | | |
| | | | [5221.0] | | | 6 | 2 | E2 | 0.18 | 0.85 | D− | 1 |
| | | | [4983.9] | | | 6 | 4 | M1 | 4.3 | 0.079 | D | 1 |
| | | | " | | | 6 | 4 | E2 | 0.38 | 2.8 | D− | 1 |
| | | | [5042.5] | | | 4 | 2 | M1 | 4.6 | 0.044 | D | 1 |
| | | | " | | | 4 | 2 | E2 | 0.31 | 1.2 | D− | 1 |
| | | | [4821.2] | | | 4 | 4 | M1 | 8.4 | 0.14 | C | 1 |
| | | | " | | | 4 | 4 | E2 | 0.18 | 1.1 | D− | 1 |
| 5. | | $^2P°$ - $^2P°$ | | | | | | | | | | |
| | | | [109000] | | | 2 | 4 | M1 | 0.0067 | 1.28 | C+ | 1 |
| | | | " | | | 2 | 4 | E2 | 8.5(−10) | 0.031 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc VIII

Si Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^2\ ^3P_0$

Ionization Energy: 158.1 eV = 1275000 cm$^{-1}$

## Allowed Transitions

Line strengths for transitions of the arrays $3s^23p^2$–$3s3p^3$ and $3p^2$–$3p3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published diagrams of energy levels (designated in *LS* coupling) in the $3s^23p^2$, $3s3p^3$, and $3s^23p3d$ configurations of siliconlike S, Ar, Ti, Fe, and Zn, but he has not provided percentage compositions. We have used the percentages given by Bromage *et al.*[2] for Fe XIII, and by Bromage[3] for V X and Ni XV, as a guide to naming the levels; their values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to a partial set of configurations within the $n=3$ complex. Whenever the term designation of a level in Fe XIII, as given in Ref. 1, is different from that indicated in Ref. 2, all transitions involving the corresponding level in Sc VIII are omitted from this compilation. Furthermore, any level indicated by Huang to have changed its energy ranking relative to other levels of the same $J$-value and parity, in proceeding along the isoelectronic sequence from S III to Ti IX, is omitted here, since, unlike the case of V X through Ni XV, there are no data available on percentage compositions of these levels in Sc VIII.

Transitions involving levels which are indicated to be of low purity in $LS$ coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded.

## References


[1]K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985).

[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).

[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).


Sc VIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^2$–$3s3p^3$ | $^3$P - $^3$D° | *566.83* | *3816* | *180236* | 9 | 15 | 5.8 | 0.046 | 0.78 | −0.38 | D− | 1 |
| | | | 571.442 | 5505 | 180501 | 5 | 7 | 5.6 | 0.038 | 0.36 | −0.72 | D | 1 |
| | | | 562.547 | 2272 | 180029 | 3 | 5 | 5.2 | 0.041 | 0.23 | −0.91 | D | 1 |
| | | | 555.672 | 0 | 179962 | 1 | 3 | 3.9 | 0.055 | 0.10 | −1.26 | D | 1 |
| | | | 572.987 | 5505 | 180029 | 5 | 5 | 0.73 | 0.0036 | 0.034 | −1.74 | D− | 1 |
| | | | 562.777 | 2272 | 179962 | 3 | 3 | 2.0 | 0.0094 | 0.052 | −1.55 | D− | 1 |
| | | | 573.206 | 5505 | 179962 | 5 | 3 | 0.068 | 2.0(−4)[a] | 0.0019 | −3.00 | E | 1 |
| 2. | | $^3$P - $^3$P° | *490.28* | *3816* | *207782* | 9 | 9 | 17 | 0.060 | 0.87 | −0.27 | D | 1 |
| | | | 494.295 | 5505 | 207813 | 5 | 5 | 13 | 0.048 | 0.39 | −0.62 | D | 1 |
| | | | 486.645 | 2272 | 207762 | 3 | 3 | 5.8 | 0.021 | 0.099 | −1.21 | D | 1 |
| | | | 494.430 | 5505 | 207762 | 5 | 3 | 5.6 | 0.012 | 0.10 | −1.21 | D | 1 |
| | | | 486.810 | 2272 | 207691 | 3 | 1 | 17 | 0.021 | 0.099 | −1.21 | C− | 1 |
| | | | 486.525 | 2272 | 207813 | 3 | 5 | 3.1 | 0.019 | 0.089 | −1.26 | D | 1 |
| | | | 481.321 | 0 | 207762 | 1 | 3 | 5.7 | 0.059 | 0.094 | −1.23 | D | 1 |
| 3. | $3p^2$–$3p3d$ | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 311.138 | 2272 | 323673 | 3 | 1 | 280 | 0.13 | 0.41 | −0.40 | D | 1 |
| 4. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 307.083 | 5505 | 331150 | 5 | 7 | 420 | 0.83 | 4.2 | 0.62 | D | 1 |
| 5. | | $^3$P - $^1$F° | | | | | | | | | | | |
| | | | [279.37] | 5505 | 363459 | 5 | 7 | 3.1 | 0.0050 | 0.023 | −1.60 | E | 1 |
| 6. | | $^3$P - $^1$P° | | | | | | | | | | | |
| | | | [268.25] | 0 | 372790 | 1 | 3 | 0.94 | 0.0031 | 0.0027 | −2.51 | E | 1 |
| 7. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [326.66] | 25024 | 331150 | 5 | 7 | 2.5 | 0.0056 | 0.030 | −1.55 | E | 1 |
| 8. | | $^1$D - $^1$F° | 295.478 | 25024 | 363459 | 5 | 7 | 458 | 0.84 | 4.08 | 0.62 | C | 1 |
| 9. | | $^1$S - $^1$P° | 314.53 | 54861 | 372790 | 1 | 3 | 350 | 1.5 | 1.6 | 0.19 | D | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc VIII

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 663.79 | 11 | 2025.4 | 3 | 3614.0 | 8 | 44000 | 1 |
| 696.17 | 10 | 3350.6 | 4 | 3660.4 | 8 | 185000 | 7 |
| 930 | 9 | 3589.5 | 8 | 3667.2 | 8 | 212000 | 7 |
| 950 | 9 | 3596.1 | 8 | 4394.0 | 2 | 1500000 | 7 |
| 1200 | 6 | 3598.2 | 8 | 5121.8 | 2 | | |
| 1800 | 5 | 3604.8 | 8 | 18160 | 1 | | |
| 1901.5 | 3 | 3605.3 | 8 | 30920 | 1 | | |

Line strengths for magnetic dipole and electric quadrupole transitions are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration interaction encompassed all configurations within the $n=3$ complex. Huang calculated line strengths for transitions within the $3p^2$ configuration, as well as for transitions between pairs of odd-parity levels whose lower level is one of the four lowest-lying odd-parity levels in the $n=3$ complex. Transitions involving odd-parity levels which are indicated by Bromage *et al.*[2] (for Fe XIII) or Bromage[3] (for V X and Ni XV) to be of low purity in *LS* coupling in Fe-group species are omitted here, as are lines whose strengths are very small. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor $^2/_3$ which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985) and private communication.

[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).

[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).

Sc VIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^2$–$3p^2$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | [30920] | 2272 | 5505 | 3 | 5 | M1 | 0.451 | 2.47 | C+ | 1 |
| | | | " | " | " | 3 | 5 | E2 | 8.0(−6)[a] | 0.67 | D− | 1 |
| | | | [44000] | 0 | 2272 | 1 | 3 | M1 | 0.209 | 1.98 | C+ | 1 |
| | | | [18160] | 0 | 5505 | 1 | 5 | E2 | 5.3(−5) | 0.31 | D− | 1 |

Sc VIII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [5121.8] | 5505 | 25024 | 5 | 5 | M1 | 4.4 | 0.11 | E | 1 |
| | | | 〃 | 〃 | 〃 | 5 | 5 | E2 | 0.0061 | 0.064 | E | 1 |
| | | | [4394.0] | 2272 | 25024 | 3 | 5 | M1 | 2.2 | 0.034 | E | 1 |
| | | | 〃 | 〃 | 〃 | 3 | 5 | E2 | 0.0018 | 0.0090 | E | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [2025.4] | 5505 | 54861 | 5 | 1 | E2 | 0.31 | 0.0062 | E | 1 |
| | | | [1901.5] | 2272 | 54861 | 3 | 1 | M1 | 63 | 0.016 | E | 1 |
| 4. | | $^1$D - $^1$S | [3350.6] | 25024 | 54861 | 5 | 1 | E2 | 5.2 | 1.3 | D− | 1 |
| 5. | $3s3p^3$–$3s3p^3$ | $^5$S° - $^3$D° | | | | | | | | | | |
| | | | [1800] | | | 5 | 7 | E2 | 0.057 | 0.0045 | E | 1 |
| | | | [1800] | | | 5 | 5 | E2 | 0.053 | 0.0030 | E | 1 |
| 6. | | $^5$S° - $^3$P° | | | | | | | | | | |
| | | | [1200] | | | 5 | 5 | M1 | 44 | 0.014 | E | 1 |
| | | | [1200] | | | 5 | 3 | M1 | 22 | 0.0043 | E | 1 |
| 7. | | $^3$D° - $^3$D° | | | | | | | | | | |
| | | | [212000] | 180029 | 180501 | 5 | 7 | M1 | 0.0019 | 4.6 | D+ | 1 |
| | | | 〃 | 〃 | 〃 | 5 | 7 | E2 | 2.8(−11) | 0.050 | E | 1 |
| | | | [1500000] | 179962 | 180029 | 3 | 5 | M1 | 7.2(−6) | 4.5 | E | 1 |
| | | | [185000] | 179962 | 180501 | 3 | 7 | E2 | 1.1(−11) | 0.010 | E | 1 |
| 8. | | $^3$D° - $^3$P° | | | | | | | | | | |
| | | | [3667.2] | 180501 | 207762 | 7 | 3 | E2 | 1.1 | 1.3 | D− | 1 |
| | | | [3614.0] | 180029 | 207691 | 5 | 1 | E2 | 2.5 | 0.91 | D− | 1 |
| | | | [3660.4] | 180501 | 207813 | 7 | 5 | M1 | 5.7 | 0.052 | E | 1 |
| | | | 〃 | 〃 | 〃 | 7 | 5 | E2 | 1.3 | 2.5 | D− | 1 |
| | | | [3604.8] | 180029 | 207762 | 5 | 3 | E2 | 0.19 | 0.21 | D− | 1 |
| | | | [3605.3] | 179962 | 207691 | 3 | 1 | M1 | 6.3 | 0.011 | E | 1 |
| | | | [3598.2] | 180029 | 207813 | 5 | 5 | M1 | 3.6 | 0.031 | E | 1 |
| | | | 〃 | 〃 | 〃 | 5 | 5 | E2 | 0.89 | 1.6 | D− | 1 |
| | | | [3596.1] | 179962 | 207762 | 3 | 3 | M1 | 6.2 | 0.032 | E | 1 |
| | | | 〃 | 〃 | 〃 | 3 | 3 | E2 | 1.1 | 1.2 | D− | 1 |
| | | | [3589.5] | 179962 | 207813 | 3 | 5 | M1 | 1.4 | 0.012 | E | 1 |
| | | | 〃 | 〃 | 〃 | 3 | 5 | E2 | 0.25 | 0.44 | D− | 1 |
| 9. | $3s3p^3$–$3s^23p3d$ | $^3$D° - $^3$F° | | | | | | | | | | |
| | | | [930] | | | 5 | 9 | E2 | 1.9 | 0.0071 | E | 1 |
| | | | [950] | | | 3 | 7 | E2 | 0.93 | 0.0030 | E | 1 |
| | | | [930] | | | 7 | 9 | M1 | 260 | 0.069 | E | 1 |
| | | | 〃 | 〃 | 〃 | 7 | 9 | E2 | 0.46 | 0.0017 | E | 1 |
| 10. | | $^3$D° - $^3$P° | | | | | | | | | | |
| | | | [696.17] | 180029 | 323673 | 5 | 1 | E2 | 120 | 0.012 | E | 1 |
| 11. | | $^3$D° - $^3$D° | | | | | | | | | | |
| | | | [663.79] | 180501 | 331150 | 7 | 7 | M1 | 29 | 0.0022 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc IX

Al Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p\ ^2P^\circ_{1/2}$

Ionization Energy: 180.03 eV = 1452000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 263 | 24 | 326 | 21 | 400 | 14 | 542 | 10 |
| 274 | 23 | 328 | 21 | 416.041 | 2 | 549 | 6 |
| 275 | 23 | 344 | 22 | 417.46 | 4 | 550 | 6 |
| 306 | 25 | 346 | 22 | 421.18 | 4 | 551 | 6 |
| 314 | 17 | 348 | 22 | 426 | 12 | 552 | 6 |
| 317 | 17 | 350 | 22 | 426.256 | 2 | 555 | 10 |
| 318 | 20 | 359 | 5 | 426.86 | 4 | 556 | 10 |
| 318.615 | 15 | 369 | 19 | 427 | 12 | 560 | 8 |
| 320 | 16 | 378 | 18 | 429 | 12 | 561 | 8 |
| 321 | 26,27 | 385.869 | 3 | 432 | 7 | 616 | 9 |
| 322 | 20 | 390.888 | 3 | 433 | 7 | 617 | 9 |
| 323 | 16,20 | 394 | 13 | 440 | 11 | 628 | 9 |
| 324.199 | 15 | 394.647 | 3 | 521.894 | 1 | 630 | 9 |
| 324.570 | 15 | 395 | 13 | 536.982 | 1 | | |
| 325 | 27 | 399.888 | 3 | 538.075 | 1 | | |

Line strengths for transitions of the arrays $3s^23p$–$3s3p^2$, $3s3p^2$–$3p^3$, $3s^23d$–$3s3p3d$, $3s^23p$–$3s^23d$, and $3s3p^2$–$3s3p3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published neither an energy-level diagram nor percentage compositions for levels of the $3s^23p$, $3s3p^2$, $3s^23d$, $3p^3$, and $3s3p3d$ configurations in Sc IX. We have used the percentages given by Fawcett[2] for the adjacent Al-like ions as a guide to naming the levels; the latter's values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to all configurations within the $n=3$ complex.

Transitions involving levels which are indicated to be of low purity in *LS* coupling in one or both adjacent Al-like ions are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded. A few wavelengths computed by Huang for transitions in Ar VIII differ significantly from those which resulted from the fitting and scaling procedure applied by Fawcett[2]; lines for which the wavelengths are in serious disagreement have been omitted in our tabulation for Sc IX.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986) and private communication.

[2]B. C. Fawcett, At. Data Nucl. Data Tables **28**, 557 (1983).

Sc IX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p$–$3s3p^2$ | $^2P^\circ$ – $^2D$ | *531.93* | *3841* | *191837* | 6 | 10 | 9.3 | 0.066 | 0.69 | −0.40 | E | 1 |
| | | | 536.982 | 5762 | 191988 | 4 | 6 | 8.9 | 0.058 | 0.41 | −0.63 | D | 1 |
| | | | 521.894 | 0 | 191610 | 2 | 4 | 8.9 | 0.073 | 0.25 | −0.84 | D | 1 |
| | | | 538.075 | 5762 | 191610 | 4 | 4 | 0.88 | 0.0038 | 0.027 | −1.82 | E | 1 |

Sc IX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | | $^2P^\circ - ^2S$ | *422.80* | *3841* | 240361 | 6 | 2 | 78 | 0.069 | 0.58 | −0.38 | D | 1 |
| | | | 426.256 | 5762 | 240361 | 4 | 2 | 27 | 0.037 | 0.21 | −0.82 | D | 1 |
| | | | 416.041 | 0 | 240361 | 2 | 2 | 52 | 0.14 | 0.37 | −0.57 | D | 1 |
| 3. | | $^2P^\circ - ^2P$ | *393.38* | *3841* | *258046* | 6 | 6 | 230 | 0.54 | 4.2 | 0.51 | D | 1 |
| | | | 394.647 | 5762 | 259155 | 4 | 4 | 192 | 0.448 | 2.33 | 0.254 | C− | 1 |
| | | | 390.888 | 0 | 255828 | 2 | 2 | 130 | 0.29 | 0.74 | −0.24 | D | 1 |
| | | | 399.888 | 5762 | 255828 | 4 | 2 | 98 | 0.12 | 0.62 | −0.33 | D | 1 |
| | | | 385.869 | 0 | 259155 | 2 | 4 | 40.7 | 0.182 | 0.462 | −0.439 | C− | 1 |
| 4. | $3s3p^2–3p^3$ | $^4P - ^4S^\circ$ | *423.37* | | | 12 | 4 | 200 | 0.18 | 3.0 | 0.33 | D | 1 |
| | | | 426.86 | | | 6 | 4 | 98 | 0.18 | 1.5 | 0.03 | D | 1 |
| | | | 421.18 | | | 4 | 4 | 68 | 0.18 | 1.0 | −0.14 | D | 1 |
| | | | 417.46 | | | 2 | 4 | 36 | 0.19 | 0.51 | −0.43 | D | 1 |
| 5. | | $^4P - ^2P^\circ$ | | | | | | | | | | | |
| | | | [359] | | | 4 | 4 | 0.65 | 0.0012 | 0.0059 | −2.30 | E | 1 |
| 6. | | $^2D - ^2D^\circ$ | *550* | | | 10 | 10 | 16 | 0.072 | 1.3 | −0.14 | E | 1 |
| | | | [550] | | | 6 | 6 | 14 | 0.065 | 0.71 | −0.41 | E | 1 |
| | | | [551] | | | 4 | 4 | 12 | 0.057 | 0.41 | −0.65 | E | 1 |
| | | | [552] | | | 6 | 4 | 2.8 | 0.0084 | 0.092 | −1.30 | E | 1 |
| | | | [549] | | | 4 | 6 | 1.2 | 0.0082 | 0.059 | −1.49 | E | 1 |
| 7. | | $^2D - ^2P^\circ$ | *433* | | | 10 | 6 | 67 | 0.11 | 1.6 | 0.05 | D | 1 |
| | | | [433] | | | 6 | 4 | 59 | 0.11 | 0.95 | −0.18 | D | 1 |
| | | | [433] | | | 4 | 2 | 70 | 0.098 | 0.56 | −0.41 | D | 1 |
| | | | [432] | | | 4 | 4 | 6.9 | 0.019 | 0.11 | −1.11 | D | 1 |
| 8. | | $^2S - ^2P^\circ$ | *560* | | | 2 | 6 | 7.3 | 0.10 | 0.38 | −0.69 | D | 1 |
| | | | [560] | | | 2 | 4 | 8.9 | 0.084 | 0.31 | −0.77 | D | 1 |
| | | | [561] | | | 2 | 2 | 4.0 | 0.019 | 0.069 | −1.43 | D | 1 |
| 9. | | $^2P - ^2P^\circ$ | *624* | | | 6 | 6 | 14 | 0.081 | 1.0 | −0.31 | E | 1 |
| | | | [628] | | | 4 | 4 | 12 | 0.071 | 0.59 | −0.54 | D | 1 |
| | | | [617] | | | 2 | 2 | 13 | 0.071 | 0.29 | −0.85 | D | 1 |
| | | | [630] | | | 4 | 2 | 4.0 | 0.012 | 0.098 | −1.33 | D | 1 |
| | | | [616] | | | 2 | 4 | 0.76 | 0.0086 | 0.035 | −1.76 | E | 1 |
| 10. | $3s^23d–$ $3s3p(^3P^\circ)3d$ | $^2D - ^2F^\circ$ | *548* | | | 10 | 14 | 11 | 0.067 | 1.2 | −0.18 | E | 1 |
| | | | [542] | | | 6 | 8 | 11 | 0.067 | 0.72 | −0.39 | E | 1 |
| | | | [555] | | | 4 | 6 | 8.9 | 0.062 | 0.45 | −0.61 | E | 1 |
| | | | [556] | | | 6 | 6 | 1.1 | 0.0053 | 0.058 | −1.50 | E | 1 |
| 11. | | $^2D - ^2P^\circ$ | | | | | | | | | | | |
| | | | [440] | | | 4 | 4 | 0.65 | 0.0019 | 0.011 | −2.12 | E | 1 |

Sc IX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ (10$^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | $3s^23d$– $3s3p(^1P^\circ)3d$ | $^2D$ – $^2F^\circ$ | *428* | | | 10 | 14 | 160 | 0.60 | 8.4 | 0.78 | E | 1 |
| | | | [429] | | | 6 | 8 | 150 | 0.57 | 4.8 | 0.53 | E | 1 |
| | | | [426] | | | 4 | 6 | 150 | 0.61 | 3.4 | 0.38 | E | 1 |
| | | | [427] | | | 6 | 6 | 8.7 | 0.024 | 0.20 | −0.85 | E | 1 |
| 13. | | $^2D$ – $^2D^\circ$ | | | | | | | | | | | |
| | | | [395] | | | 6 | 6 | 120 | 0.27 | 2.1 | 0.21 | E | 1 |
| | | | [394] | | | 4 | 6 | 5.5 | 0.019 | 0.10 | −1.11 | E | 1 |
| 14. | | $^2D$ – $^2P^\circ$ | | | | | | | | | | | |
| | | | [400] | | | 4 | 2 | 190 | 0.23 | 1.2 | −0.04 | D | 1 |
| 15. | $3p$–$3d$ | $^2P^\circ$ – $^2D$ | *322.34* | *3841* | *314072* | 6 | 10 | 260 | 0.68 | 4.3 | 0.61 | D | 1 |
| | | | 324.199 | 5762 | 314215 | 4 | 6 | 260 | 0.61 | 2.6 | 0.39 | D | 1 |
| | | | 318.615 | 0 | 313858 | 2 | 4 | 220 | 0.67 | 1.4 | 0.13 | D | 1 |
| | | | 324.570 | 5762 | 313858 | 4 | 4 | 46 | 0.073 | 0.31 | −0.54 | D | 1 |
| 16. | $3s3p^2$– $3s3p(^3P^\circ)3d$ | $^4P$ – $^4P^\circ$ | | | | | | | | | | | |
| | | | [323] | | | 6 | 6 | 47 | 0.074 | 0.47 | −0.35 | D | 1 |
| | | | [320] | | | 4 | 6 | 120 | 0.28 | 1.2 | 0.06 | D | 1 |
| 17. | | $^4P$ – $^4D^\circ$ | | | | | | | | | | | |
| | | | [317] | | | 6 | 8 | 281 | 0.57 | 3.54 | 0.53 | C− | 1 |
| | | | [314] | | | 4 | 6 | 120 | 0.27 | 1.1 | 0.03 | D | 1 |
| | | | [317] | | | 6 | 6 | 150 | 0.22 | 1.4 | 0.13 | D | 1 |
| 18. | | $^2D$ – $^4P^\circ$ | | | | | | | | | | | |
| | | | [378] | | | 6 | 6 | 1.3 | 0.0027 | 0.020 | −1.79 | E | 1 |
| 19. | | $^2D$ – $^4D^\circ$ | | | | | | | | | | | |
| | | | [369] | | | 6 | 8 | 0.41 | 0.0011 | 0.0081 | −2.18 | E | 1 |
| 20. | | $^2D$ – $^2F^\circ$ | *320* | | | 10 | 14 | 100 | 0.22 | 2.3 | 0.34 | E | 1 |
| | | | [318] | | | 6 | 8 | 100 | 0.21 | 1.3 | 0.09 | E | 1 |
| | | | [322] | | | 4 | 6 | 93 | 0.22 | 0.92 | −0.06 | E | 1 |
| | | | [323] | | | 6 | 6 | 10 | 0.016 | 0.10 | −1.03 | E | 1 |
| 21. | | $^2S$ – $^2P^\circ$ | *327* | | | 2 | 6 | 220 | 1.1 | 2.3 | 0.33 | D | 1 |
| | | | [328] | | | 2 | 4 | 240 | 0.79 | 1.7 | 0.20 | D | 1 |
| | | | [326] | | | 2 | 2 | 170 | 0.27 | 0.57 | −0.27 | D | 1 |
| 22. | | $^2P$ – $^2P^\circ$ | *348* | | | 6 | 6 | 110 | 0.20 | 1.4 | 0.09 | D | 1 |
| | | | [350] | | | 4 | 4 | 84 | 0.15 | 0.71 | −0.21 | D | 1 |
| | | | [344] | | | 2 | 2 | 120 | 0.22 | 0.50 | −0.36 | D | 1 |
| | | | [348] | | | 4 | 2 | 34 | 0.031 | 0.14 | −0.91 | D | 1 |
| | | | [346] | | | 2 | 4 | 11 | 0.041 | 0.094 | −1.08 | D | 1 |

Sc IX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23. | $3s3p^2$–$3s3p(^1P^\circ)3d$ | $^2D - ^2F^\circ$ | *275* | | | 10 | 14 | 210 | 0.33 | 3.0 | 0.52 | E | 1 |
| | | | [275] | | | 6 | 8 | 210 | 0.31 | 1.7 | 0.27 | E | 1 |
| | | | [274] | | | 4 | 6 | 200 | 0.33 | 1.2 | 0.12 | E | 1 |
| | | | [274] | | | 6 | 6 | 13 | 0.014 | 0.078 | −1.06 | E | 1 |
| 24. | | $^2D - ^2P^\circ$ | | | | | | | | | | | |
| | | | [263] | | | 4 | 2 | 2.0 | 0.0010 | 0.0036 | −2.38 | E | 1 |
| 25. | | $^2S - ^2P^\circ$ | | | | | | | | | | | |
| | | | [306] | | | 2 | 2 | 95 | 0.13 | 0.27 | −0.57 | D | 1 |
| 26. | | $^2P - ^2D^\circ$ | | | | | | | | | | | |
| | | | [321] | | | 4 | 6 | 410 | 0.95 | 4.0 | 0.58 | E | 1 |
| 27. | | $^2P - ^2P^\circ$ | | | | | | | | | | | |
| | | | [321] | | | 2 | 2 | 70 | 0.11 | 0.23 | −0.66 | D | 1 |
| | | | [325] | | | 4 | 2 | 53 | 0.0423 | 0.181 | −0.77 | C− | 1 |

## Sc IX

### Forbidden Transitions

Line strengths for magnetic dipole and electric quadrupole transitions within the $3s^23p$ $^2P^\circ$ and $3s3p^2$ $^4P$ terms are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986).

Sc IX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p$–$3p$ | $^2P^\circ - ^2P^\circ$ | | | | | | | | | | |
| | | | [17350] | 0 | 5762 | 2 | 4 | M1 | 1.72 | 1.33 | C+ | 1 |
| | | | " | " | " | 2 | 4 | E2 | 1.5(−4)[a] | 0.56 | D− | 1 |
| 2. | $3s3p^2$–$3s3p^2$ | $^4P - ^4P$ | | | | | | | | | | |
| | | | [31600] | | | 4 | 6 | M1 | 0.51 | 3.59 | C | 1 |
| | | | " | | | 4 | 6 | E2 | 7.8(−6) | 0.88 | D− | 1 |
| | | | [47400] | | | 2 | 4 | M1 | 0.210 | 3.32 | C | 1 |
| | | | " | | | 2 | 4 | E2 | 1.2(−7) | 0.071 | E | 1 |
| | | | [19000] | | | 2 | 6 | E2 | 7.1(−5) | 0.63 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc x

Mg Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s^2\ {}^1S_0$

Ionization Energy: 225.18 eV = 1816200 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 76.343 | 12 | 352.55 | 19 | 465.01 | 2 | 595.98 | 5 |
| 101.978 | 11 | 357.490 | 14 | 468.74 | 2 | 596.3 | 5 |
| 335.815 | 13 | 383.58 | 15 | 475.3 | 7 | 597.7 | 5 |
| 337.888 | 13 | 422.850 | 1 | 476.19 | 7 | 735.79 | 3 |
| 338.115 | 13 | 449.28 | 2 | 490.23 | 4 | 855.58 | 8 |
| 342.509 | 13 | 455.32 | 2 | 576.79 | 5 | | |
| 342.877 | 13 | 458.132 | 2 | 586.96 | 5 | | |
| 343.100 | 13 | 459.38 | 2 | 588.2 | 5 | | |

Oscillator strengths were interpolated from the results of theoretical calculations reported by various researchers for the neighboring magnesium-like ions Ca IX and Ti XI. Data for the three transitions $3s^2\ {}^1S_0 - 3snp\ {}^1P^\circ_1$ ($n = 3$–5) were reported by Shorer *et al.*,[1] who applied the relativistic random phase approximation (RRPA) with allowance for correlation within the context of a frozen core. The source of $f$-values for transitions of the arrays $3s3p$–$3p^2$, $3s3d$–$3p3d$, $3s3p$–$3s3d$, and $3p^2$–$3p3d$ is the work of Fawcett,[2] who performed Hartree-Fock calculations which included relativistic effects and statistical allowance for exchange (HXR); he incorporated correlation effects due to all configurations within the $n = 3$ complex. The oscillator strength for the $3p3d\ {}^1F^\circ$ – $3d^2\ {}^1G$ transition was interpolated from results of the nonrelativistic multiconfiguration Hartree-Fock (MCHF) calculations of Froese Fischer and Godefroid[3]; their atomic model incorporated large-scale allowance for configuration interaction.

Transitions involving levels which are indicated in Ref. 2 to be of low purity in *LS* coupling in neighboring Mg-like ions are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings.

### References


[1] P. Shorer, C. D. Lin, and W. R. Johnson, Phys. Rev. A **16**, 1109 (1977).

[2] B. C. Fawcett, At. Data Nucl. Data Tables **28**, 579 (1983).

[3] C. Froese Fischer and M. Godefroid, Nucl. Instrum. Methods **202**, 307 (1982).


Sc x: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8\ s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^2$–$3s3p$ | $^1S$ - $^1P^\circ$ | 422.850 | 0 | 236490 | 1 | 3 | 131 | 1.05 | 1.46 | 0.021 | C+ | *interp.* |
| 2. | $3s3p$–$3p^2$ | $^3P^\circ$ - $^3P$ | *458.7* | *162300* | *380300* | 9 | 9 | 100 | 0.33 | 4.5 | 0.47 | D | *interp.* |
| | | | 458.132 | 164500 | 382800 | 5 | 5 | 76 | 0.24 | 1.8 | 0.08 | D | *interp.* |
| | | | 459.38 | 160100 | 377800 | 3 | 3 | 28 | 0.088 | 0.40 | −0.58 | C− | *interp.* |
| | | | 468.74 | 164500 | 377800 | 5 | 3 | 44 | 0.087 | 0.67 | −0.36 | C− | *interp.* |
| | | | 465.01 | 160100 | 375100 | 3 | 1 | 110 | 0.12 | 0.55 | −0.44 | C− | *interp.* |
| | | | 449.28 | 160100 | 382800 | 3 | 5 | 26 | 0.13 | 0.58 | −0.41 | D | *interp.* |
| | | | 455.32 | 158200 | 377800 | 1 | 3 | 39 | 0.36 | 0.54 | −0.44 | C− | *interp.* |
| 3. | | $^1P^\circ$ - $^1D$ | [735.79] | 236490 | 372398 | 3 | 5 | 8.9 | 0.12 | 0.87 | −0.44 | D | *interp.* |

Sc X: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^1P^\circ - {}^1S$ | 490.23 | 236490 | 440480 | 3 | 1 | 110 | 0.13 | 0.63 | −0.41 | C− | *interp.* |
| 5. | $3s3d-3p3d$ | $^3D - {}^3F^\circ$ | *584.8* | *456300* | *627300* | 15 | 21 | 28 | 0.20 | 5.9 | 0.49 | D | *interp.* |
| | | | 576.79 | 456500 | 629900 | 7 | 9 | 30.4 | 0.195 | 2.59 | 0.135 | C | *interp.* |
| | | | 586.96 | 456100 | 626500 | 5 | 7 | 25 | 0.18 | 1.7 | −0.05 | C− | *interp.* |
| | | | 595.98 | 456000 | 623800 | 3 | 5 | 21 | 0.19 | 1.1 | −0.24 | D− | *interp.* |
| | | | [588.2] | 456500 | 626500 | 7 | 7 | 4.0 | 0.021 | 0.28 | −0.83 | C− | *interp.* |
| | | | [596.3] | 456100 | 623800 | 5 | 5 | 4.7 | 0.025 | 0.25 | −0.90 | D | *interp.* |
| | | | [597.7] | 456500 | 623800 | 7 | 5 | 0.12 | 4.4(−4)[a] | 0.0061 | −2.51 | E | *interp.* |
| 6. | | $^3D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | | | | 3 | 1 | | 0.070 | | −0.68 | C | *interp.* |
| 7. | | $^3D - {}^3D^\circ$ | | | | | | | | | | | |
| | | | 476.19 | 456500 | 666500 | 7 | 7 | 45.6 | 0.155 | 1.70 | 0.035 | C | *interp.* |
| | | | [475.3] | 456100 | 666500 | 5 | 7 | 7.8 | 0.037 | 0.29 | −0.73 | C− | *interp.* |
| 8. | | $^1D - {}^1D^\circ$ | [855.58] | 516218 | 633100 | 5 | 5 | 3.8 | 0.042 | 0.59 | −0.68 | D | *interp.* |
| 9. | | $^1D - {}^1F^\circ$ | | | | 5 | 7 | | 0.58 | | 0.46 | D− | *interp.* |
| 10. | | $^1D - {}^1P^\circ$ | | | | 5 | 3 | | 0.16 | | −0.10 | D− | *interp.* |
| 11. | $3s^2-3s4p$ | $^1S - {}^1P^\circ$ | 101.978 | 0 | 980604 | 1 | 3 | 580 | 0.27 | 0.091 | −0.57 | D+ | *interp.* |
| 12. | $3s^2-3s5p$ | $^1S - {}^1P^\circ$ | 76.343 | 0 | 1309900 | 1 | 3 | 350 | 0.092 | 0.023 | −1.04 | C− | *interp.* |
| 13. | $3s3p-3s3d$ | $^3P^\circ - {}^3D$ | *340.1* | *162300* | *456300* | 9 | 15 | 150 | 0.44 | 4.4 | 0.59 | C− | *interp.* |
| | | | 342.509 | 164500 | 456500 | 5 | 7 | 146 | 0.359 | 2.02 | 0.254 | C− | *interp.* |
| | | | 337.888 | 160100 | 456100 | 3 | 5 | 120 | 0.33 | 1.1 | −0.00 | C− | *interp.* |
| | | | 335.815 | 158200 | 456000 | 1 | 3 | 85 | 0.43 | 0.48 | −0.37 | C− | *interp.* |
| | | | 342.877 | 164500 | 456100 | 5 | 5 | 36 | 0.064 | 0.36 | −0.49 | C− | *interp.* |
| | | | 338.115 | 160100 | 456000 | 3 | 3 | 64 | 0.11 | 0.37 | −0.48 | C− | *interp.* |
| | | | 343.100 | 164500 | 456000 | 5 | 3 | 4.1 | 0.0043 | 0.024 | −1.67 | D− | *interp.* |
| 14. | | $^1P^\circ - {}^1D$ | 357.490 | 236490 | 516218 | 3 | 5 | 260 | 0.84 | 3.0 | 0.40 | D− | *interp.* |
| 15. | $3p^2-3p3d$ | $^1D - {}^1D^\circ$ | 383.58 | 372398 | 633100 | 5 | 5 | 100 | 0.23 | 1.5 | 0.06 | E | *interp.* |
| 16. | | $^1D - {}^1F^\circ$ | | | | 5 | 7 | | 0.29 | | 0.16 | E | *interp.* |
| 17. | | $^1D - {}^1P^\circ$ | | | | 5 | 3 | | 0.0017 | | −2.07 | E | *interp.* |
| 18. | | $^3P - {}^3P^\circ$ | | | | | | | | | | | |
| | | | | | | 3 | 1 | | 0.076 | | −0.64 | C− | *interp.* |
| 19. | | $^3P - {}^3D^\circ$ | | | | | | | | | | | |
| | | | 352.55 | 382800 | 666500 | 5 | 7 | 190 | 0.49 | 2.8 | 0.39 | D | *interp.* |
| 20. | | $^1S - {}^1P^\circ$ | | | | 1 | 3 | | 0.92 | | −0.04 | C− | *interp.* |
| 21. | $3p3d-3d^2$ | $^1F^\circ - {}^1G$ | | | | 7 | 9 | | 0.458 | | 0.51 | C− | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XI

Na Isoelectronic Sequence

Ground State: $1s^22s^22p^63s\ ^2S_{1/2}$

Ionization Energy: 249.837 eV = 2015060 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 58.082 | 5 | 97.777 | 21 | 186.8 | 36 | 371.1 | 43 |
| 64.70 | 15 | 97.830 | 21 | 201.6 | 46 | 372.95 | 7 |
| 64.98 | 15 | 97.838 | 21 | 201.7 | 46 | 381.60 | 7 |
| 69.252 | 13 | 104.2 | 20 | 220.9 | 52 | 382.49 | 7 |
| 69.575 | 13 | 104.219 | 20 | 226.3 | 29 | 389.7 | 69 |
| 70.445 | 3 | 104.3 | 20 | 227.0 | 29 | 392 | 74 |
| 70.509 | 3 | 104.435 | 9 | 241.7 | 35 | 460.8 | 61 |
| 71.527 | 12 | 105.140 | 9 | 243.1 | 35 | 463.4 | 61 |
| 71.887 | 12 | 105.170 | 9 | 243.2 | 35 | 505.117 | 1 |
| 77.87 | 25 | 134.4 | 31 | 294.7 | 57 | 522.810 | 1 |
| 77.917 | 25 | 138.283 | 19 | 300.0 | 44 | 555.9 | 68 |
| 77.94 | 25 | 138.380 | 19 | 300.2 | 44 | 556.5 | 68 |
| 78.509 | 11 | 138.40 | 19 | 300.3 | 44 | 585.5 | 60 |
| 78.917 | 11 | 146 | 39 | 302.0 | 34 | 589.6 | 60 |
| 78.927 | 11 | 168 | 48 | 304.4 | 34 | 652.7 | 73 |
| 79.220 | 24 | 168.22 | 18 | 313 | 63 | 653.2 | 73 |
| 79.258 | 24 | 168.3 | 48 | 315 | 63 | 1026 | 33 |
| 83.958 | 10 | 168.396 | 18 | 353.9 | 51 | 1050 | 33 |
| 84.351 | 23 | 168.942 | 18 | 354.0 | 51 | 1053 | 33 |
| 84.393 | 23 | 171.2 | 37 | 354.1 | 51 | 1313 | 28 |
| 84.395 | 23 | 172.0 | 37 | 359.4 | 70 | 1359 | 28 |
| 84.433 | 10 | 174.6 | 47 | 360 | 70 | 2964 | 42 |
| 94.888 | 2 | 181 | 53 | 369.4 | 43 | 2978 | 42 |
| 95.117 | 2 | 185.9 | 36 | 369.8 | 43 | 2989 | 42 |

Strengths of the lines of the $3s$–$3p$ and $3p$–$3d$ transitions were taken from Edlen's interpolation formulae.[1] These were based on the results of Weiss' Hartree-Fock calculations,[2] in which ratios of relativistic Dirac to nonrelativistic line strengths in hydrogenic ions were applied as scaling factors to the nonrelativistic Hartree-Fock line strengths in the corresponding sodiumlike species. Oscillator strengths for the $4p$–$4d$ transitions were derived by Gruzdev and Sherstyuk[3] using the relativistic variant of their effective orbital quantum number method, which utilizes a Coulomb potential in conjunction with a semiempirical orbital quantum number which is determined from experimental energy levels.

Multiplet $f$-values calculated by Biemont[4] using a fully variational Hartree-Fock approach are quoted for numerous transitions $nl$–$n'l'$ ($3 \leqslant n \leqslant 5$; $4 \leqslant n' \leqslant 8$; $l,l' = s,p,d,f$). Data for additional transitions (namely, those for which $n > 5$, where $n$ is the principal quantum number of the lower state) can be found in Ref. 4. Whenever wavelengths of individual lines within a multiplet either were available directly or could be determined from the energy levels, the multiplet strength was distributed among the lines according to $LS$-coupling rules, except in cases where the wavelengths of all the lines in the multiplet are identical. The strength of the $3p\ ^2P^\circ - 4s\ ^2S$ multiplet was not distributed between the two lines in the multiplet, however, since the relativistic single-configuration Hartree-Fock calculations of Kim and Cheng[5] indicate that in the corresponding transition in sodiumlike iron the ratio of the two line strengths deviates somewhat from the value that would be obtained in the case of pure $LS$ coupling.

Transitions with small $f$-values were generally assigned lower accuracy ratings.

## References


[1] B. Edlen, Phys. Scr. **17**, 565 (1978).
[2] A. W. Weiss, J. Quant. Spectrosc. Radiat. Transfer **18**, 481 (1977).
[3] P. F. Gruzdev and A. I. Sherstyuk, Opt. Spectrosc. (USSR) **46**, 353 (1979).
[4] E. Biemont, Astron. Astrophys., Suppl. Ser. **31**, 285 (1978).
[5] Y.-K. Kim and K.-T. Cheng, J. Opt. Soc. Am. **68**, 836 (1978).

Sc XI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 3*s*–3*p* | $^2S - ^2P°$ | *510.88* | 0 | *195741* | 2 | 6 | 42.3 | 0.496 | 1.67 | −0.003 | B | 1 |
| | | | 505.117 | 0 | 197974 | 2 | 4 | 44.0 | 0.337 | 1.12 | −0.172 | B | 1 |
| | | | 522.810 | 0 | 191274 | 2 | 2 | 39.3 | 0.161 | 0.554 | −0.492 | B | 1 |
| 2. | 3*s*–4*p* | $^2S - ^2P°$ | *94.966* | 0 | *1053010* | 2 | 6 | 409 | 0.166 | 0.104 | −0.479 | C | 4 |
| | | | 94.888 | 0 | 1053860 | 2 | 4 | 410 | 0.11 | 0.069 | −0.66 | C | *ls* |
| | | | 95.117 | 0 | 1051320 | 2 | 2 | 408 | 0.055 | 0.0347 | −0.96 | C | *ls* |
| 3. | 3*s*–5*p* | $^2S - ^2P°$ | *70.467* | 0 | *1419100* | 2 | 6 | 240 | 0.054 | 0.025 | −0.97 | C | 4 |
| | | | 70.445 | 0 | 1419500 | 2 | 4 | 250 | 0.037 | 0.017 | −1.13 | C | *ls* |
| | | | 70.509 | 0 | 1418300 | 2 | 2 | 240 | 0.018 | 0.0083 | −1.45 | C | *ls* |
| 4. | 3*s*–6*p* | $^2S - ^2P°$ | | | | 2 | 6 | | 0.0251 | | −1.299 | C | 4 |
| 5. | 3*s*–7*p* | $^2S - ^2P°$ | 58.082 | 0 | 1721700 | 2 | 6 | 92 | 0.0139 | 0.0053 | −1.56 | C | 4 |
| 6. | 3*s*–8*p* | $^2S - ^2P°$ | | | | 2 | 6 | | 0.0086 | | −1.76 | D | 4 |
| 7. | 3*p*–3*d* | $^2P° - ^2D$ | *378.74* | *195741* | *459770* | 6 | 10 | 111 | 0.398 | 2.98 | 0.378 | B | 1 |
| | | | 381.60 | 197974 | 460020 | 4 | 6 | 109 | 0.356 | 1.79 | 0.154 | B | 1 |
| | | | 372.95 | 191274 | 459400 | 2 | 4 | 97.3 | 0.406 | 0.996 | −0.091 | B | 1 |
| | | | 382.49 | 197974 | 459400 | 4 | 4 | 17.9 | 0.0393 | 0.198 | −0.803 | B | 1 |
| 8. | 3*p*–4*s* | $^2P° - ^2S$ | *127.88* | *195741* | 977719 | 6 | 2 | 910 | 0.074 | 0.19 | −0.35 | C | 4 |
| 9. | 3*p*–4*d* | $^2P° - ^2D$ | *104.91* | *195741* | *1148975* | 6 | 10 | 780 | 0.214 | 0.443 | 0.109 | C | 4 |
| | | | 105.140 | 197974 | 1149087 | 4 | 6 | 770 | 0.192 | 0.266 | −0.114 | C | *ls* |
| | | | 104.435 | 191274 | 1148807 | 2 | 4 | 660 | 0.215 | 0.148 | −0.366 | C | *ls* |
| | | | 105.170 | 197974 | 1148807 | 4 | 4 | 130 | 0.022 | 0.030 | −1.06 | D | *ls* |
| 10. | 3*p*–5*s* | $^2P° - ^2S$ | *84.267* | *195741* | 1382400 | 6 | 2 | 392 | 0.0139 | 0.0231 | −1.079 | C | 4 |
| | | | 84.433 | 197974 | 1382400 | 4 | 2 | 259 | 0.0139 | 0.0154 | −1.256 | C | *ls* |
| | | | 83.958 | 191274 | 1382400 | 2 | 2 | 130 | 0.014 | 0.0077 | −1.56 | C | *ls* |
| 11. | 3*p*–5*d* | $^2P° - ^2D$ | *78.777* | *195741* | *1465100* | 6 | 10 | 500 | 0.077 | 0.12 | −0.34 | C | 4 |
| | | | 78.917 | 197974 | 1465200 | 4 | 6 | 490 | 0.069 | 0.072 | −0.56 | C | *ls* |
| | | | 78.509 | 191274 | 1465000 | 2 | 4 | 420 | 0.077 | 0.040 | −0.81 | C | *ls* |
| | | | [78.927] | 197974 | 1465000 | 4 | 4 | 82 | 0.0077 | 0.0080 | −1.51 | D | *ls* |
| 12. | 3*p*–6*s* | $^2P° - ^2S$ | *71.767* | *195741* | 1589100 | 6 | 2 | 210 | 0.0053 | 0.0075 | −1.50 | D | 4 |
| | | | 71.887 | 197974 | 1589100 | 4 | 2 | 140 | 0.0053 | 0.0050 | −1.68 | D | *ls* |
| | | | 71.527 | 191274 | 1589100 | 2 | 2 | 69 | 0.0053 | 0.0025 | −1.97 | D | *ls* |
| 13. | 3*p*–6*d* | $^2P° - ^2D$ | *69.464* | *195741* | 1635300 | 6 | 10 | 305 | 0.0368 | 0.050 | −0.66 | C | 4 |
| | | | 69.575 | 197974 | 1635300 | 4 | 6 | 300 | 0.033 | 0.030 | −0.88 | C | *ls* |
| | | | 69.252 | 191274 | 1635300 | 2 | 4 | 260 | 0.037 | 0.017 | −1.13 | C | *ls* |
| | | | [69.575] | 197974 | 1635300 | 4 | 4 | 50 | 0.0036 | 0.0033 | −1.84 | D | *ls* |
| 14. | 3*p*–7*s* | $^2P° - ^2S$ | | | | 6 | 2 | | 0.0027 | | −1.79 | D | 4 |

Sc XI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | $3p$–$7d$ | $^2P^o - {}^2D$ | *64.89* | *195741* | 1737000 | 6 | 10 | 197 | 0.0207 | 0.0265 | −0.91 | C | 4 |
| | | | 64.98 | 197974 | 1737000 | 4 | 6 | 196 | 0.0186 | 0.0159 | −1.129 | C | *ls* |
| | | | 64.70 | 191274 | 1737000 | 2 | 4 | 160 | 0.021 | 0.0088 | −1.38 | C | *ls* |
| | | | [64.98] | 197974 | 1737000 | 4 | 4 | 33 | 0.0021 | 0.0018 | −2.07 | D | *ls* |
| 16. | $3p$–$8s$ | $^2P^o - {}^2S$ | | | | 6 | 2 | | 0.0016 | | −2.02 | D | 4 |
| 17. | $3p$–$8d$ | $^2P^o - {}^2D$ | | | | 6 | 10 | | 0.0129 | | −1.111 | C | 4 |
| 18. | $3d$–$4p$ | $^2D - {}^2P^o$ | *168.57* | *459770* | *1053010* | 10 | 6 | 220 | 0.057 | 0.32 | −0.24 | C | 4 |
| | | | 168.396 | 460020 | 1053860 | 6 | 4 | 200 | 0.057 | 0.19 | −0.47 | C | *ls* |
| | | | 168.942 | 459400 | 1051320 | 4 | 2 | 230 | 0.049 | 0.11 | −0.70 | C | *ls* |
| | | | [168.22] | 459400 | 1053860 | 4 | 4 | 22 | 0.0095 | 0.021 | −1.42 | D | *ls* |
| 19. | $3d$–$4f$ | $^2D - {}^2F^o$ | *138.34* | *459770* | *1182620* | 10 | 14 | 2300 | 0.91 | 4.1 | 0.96 | C | 4 |
| | | | 138.380 | 460020 | 1182670 | 6 | 8 | 2200 | 0.84 | 2.3 | 0.70 | C | *ls* |
| | | | 138.283 | 459400 | 1182550 | 4 | 6 | 2000 | 0.88 | 1.6 | 0.55 | C | *ls* |
| | | | [138.40] | 460020 | 1182550 | 6 | 6 | 150 | 0.044 | 0.12 | −0.58 | D | *ls* |
| 20. | $3d$–$5p$ | $^2D - {}^2P^o$ | *104.2* | *459770* | *1419100* | 10 | 6 | 85 | 0.0083 | 0.028 | −1.08 | D | 4 |
| | | | 104.219 | 460020 | 1419500 | 6 | 4 | 76 | 0.0083 | 0.017 | −1.30 | D | *ls* |
| | | | [104.3] | 459400 | 1418300 | 4 | 2 | 83 | 0.0068 | 0.0093 | −1.57 | D | *ls* |
| | | | [104.2] | 459400 | 1419500 | 4 | 4 | 8.5 | 0.0014 | 0.0019 | −2.26 | E | *ls* |
| 21. | $3d$–$5f$ | $^2D - {}^2F^o$ | *97.809* | *459770* | *1482200* | 10 | 14 | 850 | 0.171 | 0.55 | 0.233 | C | 4 |
| | | | 97.830 | 460020 | 1482200 | 6 | 8 | 840 | 0.16 | 0.31 | −0.02 | C | *ls* |
| | | | 97.777 | 459400 | 1482100 | 4 | 6 | 790 | 0.17 | 0.22 | −0.17 | C | *ls* |
| | | | [97.838] | 460020 | 1482100 | 6 | 6 | 58 | 0.0083 | 0.016 | −1.30 | D | *ls* |
| 22. | $3d$–$6p$ | $^2D - {}^2P^o$ | | | | 10 | 6 | | 0.0029 | | −1.54 | D | 4 |
| 23. | $3d$–$6f$ | $^2D - {}^2F^o$ | *84.381* | *459770* | 1644900 | 10 | 14 | 430 | 0.064 | 0.18 | −0.19 | C | 4 |
| | | | 84.393 | 460020 | 1644900 | 6 | 8 | 420 | 0.060 | 0.10 | −0.44 | C | *ls* |
| | | | 84.351 | 459400 | 1644900 | 4 | 6 | 410 | 0.065 | 0.072 | −0.59 | C | *ls* |
| | | | [84.395] | 460020 | 1644900 | 6 | 6 | 29 | 0.0031 | 0.0051 | −1.74 | D | *ls* |
| 24. | $3d$–$7p$ | $^2D - {}^2P^o$ | *79.246* | *459770* | 1721700 | 10 | 6 | 25 | 0.0014 | 0.0037 | −1.85 | D | 4 |
| | | | [79.258] | 460020 | 1721700 | 6 | 4 | 22 | 0.0014 | 0.0022 | −2.07 | D | *ls* |
| | | | [79.220] | 459400 | 1721700 | 4 | 2 | 24 | 0.0012 | 0.0012 | −2.34 | D | *ls* |
| | | | [79.220] | 459400 | 1721700 | 4 | 4 | 2.5 | 2.4(−4)[a] | 2.5(−4) | −3.02 | E | *ls* |
| 25. | $3d$–$7f$ | $^2D - {}^2F^o$ | *77.94* | *459770* | *1743000* | 10 | 14 | 247 | 0.0315 | 0.081 | −0.50 | C | 4 |
| | | | 77.917 | 460020 | 1743400 | 6 | 8 | 250 | 0.030 | 0.046 | −0.75 | C | *ls* |
| | | | 77.87 | 459400 | 1743000 | 4 | 6 | 230 | 0.031 | 0.032 | −0.90 | C | *ls* |
| | | | [77.94] | 460020 | 1743000 | 6 | 6 | 16 | 0.0015 | 0.0023 | −2.05 | D | *ls* |
| 26. | $3d$–$8p$ | $^2D - {}^2P^o$ | | | | 10 | 6 | | 8.0(−4) | | −2.10 | E | 4 |
| 27. | $3d$–$8f$ | $^2D - {}^2F^o$ | | | | 10 | 14 | | 0.0183 | | −0.74 | C | 4 |
| 28. | $4s$–$4p$ | $^2S - {}^2P^o$ | *1328* | 977719 | *1053010* | 2 | 6 | 9.0 | 0.71 | 6.2 | 0.15 | C | 4 |
| | | | [1313] | 977719 | 1053860 | 2 | 4 | 9.2 | 0.47 | 4.1 | −0.02 | C | *ls* |
| | | | [1359] | 977719 | 1051320 | 2 | 2 | 8.5 | 0.23 | 2.1 | −0.33 | C | *ls* |

Sc XI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | 4s–5p | $^2S - ^2P°$ | *226.6* | 977719 | *1419100* | 2 | 6 | 74 | 0.172 | 0.257 | −0.463 | C | 4 |
| | | | [226.3] | 977719 | 1419500 | 2 | 4 | 75 | 0.115 | 0.171 | −0.64 | C | ls |
| | | | [227.0] | 977719 | 1418300 | 2 | 2 | 74 | 0.058 | 0.086 | −0.94 | C | ls |
| 30. | 4s–6p | $^2S - ^2P°$ | | | | 2 | 6 | | 0.058 | | −0.94 | C | 4 |
| 31. | 4s–7p | $^2S - ^2P°$ | [134.4] | 977719 | 1721700 | 2 | 6 | 34.2 | 0.0278 | 0.0246 | −1.255 | C | 4 |
| 32. | 4s–8p | $^2S - ^2P°$ | | | | 2 | 6 | | 0.0158 | | −1.50 | C | 4 |
| 33. | 4p–4d | $^2P° - ^2D$ | *1042* | *1053010* | *1148975* | 6 | 10 | 21.1 | 0.57 | 11.8 | 0.54 | C | 3 |
| | | | [1050] | 1053860 | 1149087 | 4 | 6 | 21 | 0.51 | 7.1 | 0.31 | C | 3 |
| | | | [1026] | 1051320 | 1148807 | 2 | 4 | 18 | 0.57 | 3.9 | 0.06 | C | 3 |
| | | | [1053] | 1053860 | 1148807 | 4 | 4 | 3.4 | 0.056 | 0.78 | −0.65 | C | 3 |
| 34. | 4p–5s | $^2P° - ^2S$ | *303.6* | *1053010* | 1382400 | 6 | 2 | 276 | 0.127 | 0.76 | −0.118 | C | 4 |
| | | | [304.4] | 1053860 | 1382400 | 4 | 2 | 180 | 0.13 | 0.51 | −0.29 | C | ls |
| | | | [302.0] | 1051320 | 1382400 | 2 | 2 | 92 | 0.13 | 0.25 | −0.60 | C | ls |
| 35. | 4p–5d | $^2P° - ^2D$ | *242.7* | *1053010* | *1465100* | 6 | 10 | 116 | 0.171 | 0.82 | 0.011 | C | 4 |
| | | | [243.1] | 1053860 | 1465200 | 4 | 6 | 120 | 0.15 | 0.49 | −0.21 | C | ls |
| | | | [241.7] | 1051320 | 1465000 | 2 | 4 | 97 | 0.17 | 0.27 | −0.47 | C | ls |
| | | | [243.2] | 1053860 | 1465000 | 4 | 4 | 19 | 0.017 | 0.055 | −1.16 | D | ls |
| 36. | 4p–6s | $^2P° - ^2S$ | *186.5* | *1053010* | 1589100 | 6 | 2 | 137 | 0.0238 | 0.088 | −0.85 | C | 4 |
| | | | [186.8] | 1053860 | 1589100 | 4 | 2 | 92 | 0.024 | 0.059 | −1.02 | C | ls |
| | | | [185.9] | 1051320 | 1589100 | 2 | 2 | 46 | 0.024 | 0.029 | −1.32 | C | ls |
| 37. | 4p–6d | $^2P° - ^2D$ | *171.7* | *1053010* | 1635300 | 6 | 10 | 91 | 0.067 | 0.23 | −0.40 | C | 4 |
| | | | [172.0] | 1053860 | 1635300 | 4 | 6 | 93 | 0.062 | 0.14 | −0.61 | C | ls |
| | | | [171.2] | 1051320 | 1635300 | 2 | 4 | 78 | 0.068 | 0.077 | −0.86 | C | ls |
| | | | [172.0] | 1053860 | 1635300 | 4 | 4 | 15 | 0.0066 | 0.015 | −1.58 | D | ls |
| 38. | 4p–7s | $^2P° - ^2S$ | | | | 6 | 2 | | 0.0092 | | −1.26 | D | 4 |
| 39. | 4p–7d | $^2P° - ^2D$ | [146] | *1053000* | 1737000 | 6 | 10 | 63 | 0.0335 | 0.097 | −0.70 | C | 4 |
| 40. | 4p–8s | $^2P° - ^2S$ | | | | 6 | 2 | | 0.0047 | | −1.55 | D | 4 |
| 41. | 4p–8d | $^2P° - ^2D$ | | | | 6 | 10 | | 0.0196 | | −0.93 | C | 4 |
| 42. | 4d–4f | $^2D - ^2F°$ | *2973* | *1148975* | *1182620* | 10 | 14 | 0.73 | 0.135 | 13.2 | 0.130 | C | 4 |
| | | | [2978] | 1149087 | 1182670 | 6 | 8 | 0.72 | 0.13 | 7.5 | −0.12 | C | ls |
| | | | [2964] | 1148807 | 1182550 | 4 | 6 | 0.69 | 0.14 | 5.3 | −0.27 | C | ls |
| | | | [2989] | 1149087 | 1182550 | 6 | 6 | 0.048 | 0.0064 | 0.38 | −1.41 | D | ls |
| 43. | 4d–5p | $^2D - ^2P°$ | *370.2* | *1148975* | *1419100* | 10 | 6 | 99 | 0.122 | 1.49 | 0.086 | C | 4 |
| | | | [369.8] | 1149087 | 1419500 | 6 | 4 | 89 | 0.12 | 0.89 | −0.14 | C | ls |
| | | | [371.1] | 1148807 | 1418300 | 4 | 2 | 99 | 0.102 | 0.497 | −0.391 | C | ls |
| | | | [369.4] | 1148807 | 1419500 | 4 | 4 | 9.9 | 0.020 | 0.099 | −1.09 | D | ls |

Sc XI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 44. | 4d–5f | $^2$D – $^2$F° | *300.1* | *1148975* | *1482200* | 10 | 14 | 370 | 0.69 | 6.8 | 0.84 | C | 4 |
| | | | [300.2] | 1149087 | 1482200 | 6 | 8 | 370 | 0.66 | 3.9 | 0.60 | C | ls |
| | | | [300.0] | 1148807 | 1482100 | 4 | 6 | 340 | 0.68 | 2.7 | 0.44 | C | ls |
| | | | [300.3] | 1149087 | 1482100 | 6 | 6 | 24 | 0.032 | 0.19 | −0.72 | D | ls |
| 45. | 4d–6p | $^2$D – $^2$P° | | | | 10 | 6 | | 0.0192 | | −0.72 | C | 4 |
| 46. | 4d–6f | $^2$D – $^2$F° | *201.7* | *1148975* | 1644900 | 10 | 14 | 206 | 0.176 | 1.17 | 0.246 | C | 4 |
| | | | [201.7] | 1149087 | 1644900 | 6 | 8 | 210 | 0.17 | 0.67 | 0.00 | C | ls |
| | | | [201.6] | 1148807 | 1644900 | 4 | 6 | 193 | 0.176 | 0.468 | −0.152 | C | ls |
| | | | [201.7] | 1149087 | 1644900 | 6 | 6 | 14 | 0.0083 | 0.033 | −1.30 | D | ls |
| 47. | 4d–7p | $^2$D – $^2$P° | [174.6] | *1148975* | 1721700 | 10 | 6 | 25 | 0.0069 | 0.040 | −1.16 | D | 4 |
| 48. | 4d–7f | $^2$D – $^2$F° | *168* | *1148975* | *1743000* | 10 | 14 | 120 | 0.074 | 0.41 | −0.13 | C | 4 |
| | | | [168.3] | 1149087 | 1743400 | 6 | 8 | 120 | 0.069 | 0.23 | −0.38 | C | ls |
| | | | [168] | 1148807 | 1743000 | 4 | 6 | 110 | 0.072 | 0.16 | −0.54 | C | ls |
| | | | [168] | 1149087 | 1743000 | 6 | 6 | 8.5 | 0.0036 | 0.012 | −1.66 | D | ls |
| 49. | 4d–8p | $^2$D – $^2$P° | | | | 10 | 6 | | 0.0034 | | −1.47 | D | 4 |
| 50. | 4d–8f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.0390 | | −0.409 | C | 4 |
| 51. | 4f–5d | $^2$F° – $^2$D | *354.0* | *1182620* | *1465100* | 14 | 10 | 16.1 | 0.0216 | 0.352 | −0.52 | C | 4 |
| | | | [354.0] | 1182670 | 1465200 | 8 | 6 | 15.3 | 0.0216 | 0.201 | −0.76 | C | ls |
| | | | [354.1] | 1182550 | 1465000 | 6 | 4 | 16.1 | 0.0202 | 0.141 | −0.92 | C | ls |
| | | | [353.9] | 1182550 | 1465200 | 6 | 6 | 0.76 | 0.0014 | 0.010 | −2.07 | D | ls |
| 52. | 4f–6d | $^2$F° – $^2$D | [220.9] | *1182620* | 1635300 | 14 | 10 | 6.9 | 0.0036 | 0.037 | −1.30 | D | 4 |
| 53. | 4f–7d | $^2$F° – $^2$D | [181] | *1182620* | 1737000 | 14 | 10 | 3.7 | 0.0013 | 0.011 | −1.74 | D | 4 |
| 54. | 4f–8d | $^2$F° – $^2$D | | | | 14 | 10 | | 6.1(−4) | | −2.07 | E | 4 |
| 55. | 5s–5p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.92 | | 0.26 | C | 4 |
| 56. | 5s–6p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.181 | | −0.441 | C | 4 |
| 57. | 5s–7p | $^2$S – $^2$P° | [294.7] | 1382400 | 1721700 | 2 | 6 | 16 | 0.062 | 0.12 | −0.91 | C | 4 |
| 58. | 5s–8p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.0302 | | −1.219 | C | 4 |
| 59. | 5p–5d | $^2$P° – $^2$D | | | | 6 | 10 | | 0.82 | | 0.69 | C | 4 |
| 60. | 5p–6s | $^2$P° – $^2$S | *588.2* | *1419100* | 1589100 | 6 | 2 | 105 | 0.181 | 2.10 | 0.036 | C | 4 |
| | | | [589.6] | 1419500 | 1589100 | 4 | 2 | 69 | 0.180 | 1.40 | −0.142 | C | ls |
| | | | [585.5] | 1418300 | 1589100 | 2 | 2 | 35 | 0.18 | 0.70 | −0.44 | C | ls |
| 61. | 5p–6d | $^2$P° – $^2$D | *462.5* | *1419100* | 1635300 | 6 | 10 | 28.4 | 0.152 | 1.39 | −0.040 | C | 4 |
| | | | [463.4] | 1419500 | 1635300 | 4 | 6 | 28 | 0.14 | 0.83 | −0.26 | C | ls |
| | | | [460.8] | 1418300 | 1635300 | 2 | 4 | 24.0 | 0.153 | 0.463 | −0.52 | C | ls |
| | | | [463.4] | 1419500 | 1635300 | 4 | 4 | 4.7 | 0.015 | 0.093 | −1.21 | D | ls |
| 62. | 5p–7s | $^2$P° – $^2$S | | | | 6 | 2 | | 0.0338 | | −0.69 | C | 4 |

Sc XI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 63. | $5p$–$7d$ | $^2P^o$ - $^2D$ | *314* | *1419100* | 1737000 | 6 | 10 | 25 | 0.061 | 0.38 | −0.44 | C | 4 |
| | | | [315] | 1419500 | 1737000 | 4 | 6 | 25 | 0.055 | 0.23 | −0.65 | C | *ls* |
| | | | [313] | 1418300 | 1737000 | 2 | 4 | 21 | 0.063 | 0.13 | −0.90 | C | *ls* |
| | | | [315] | 1419500 | 1737000 | 4 | 4 | 4.1 | 0.0060 | 0.025 | −1.62 | D | *ls* |
| 64. | $5p$–$8s$ | $^2P^o$ - $^2S$ | | | | 6 | 2 | | 0.0131 | | −1.105 | C | 4 |
| 65. | $5p$–$8d$ | $^2P^o$ - $^2D$ | | | | 6 | 10 | | 0.0316 | | −0.72 | C | 4 |
| 66. | $5d$–$5f$ | $^2D$ - $^2F^o$ | | | | 10 | 14 | | 0.239 | | 0.378 | C | 4 |
| 67. | $5d$–$6p$ | $^2D$ - $^2P^o$ | | | | 10 | 6 | | 0.193 | | 0.286 | C | 4 |
| 68. | $5d$–$6f$ | $^2D$ - $^2F^o$ | *556.2* | *1465100* | 1644900 | 10 | 14 | 94 | 0.61 | 11 | 0.79 | C | 4 |
| | | | [556.5] | 1465200 | 1644900 | 6 | 8 | 93 | 0.57 | 6.3 | 0.54 | C | *ls* |
| | | | [555.9] | 1465000 | 1644900 | 4 | 6 | 86 | 0.60 | 4.4 | 0.38 | C | *ls* |
| | | | [556.5] | 1465200 | 1644900 | 6 | 6 | 6.1 | 0.028 | 0.31 | −0.77 | D | *ls* |
| 69. | $5d$–$7p$ | $^2D$ - $^2P^o$ | [389.7] | *1465100* | 1721700 | 10 | 6 | 22.7 | 0.0310 | 0.398 | −0.51 | C | 4 |
| 70. | $5d$–$7f$ | $^2D$ - $^2F^o$ | *360* | *1465100* | *1743000* | 10 | 14 | 63 | 0.171 | 2.03 | 0.233 | C | 4 |
| | | | [359.4] | 1465200 | 1743400 | 6 | 8 | 63 | 0.163 | 1.16 | −0.009 | C | *ls* |
| | | | [360] | 1465000 | 1743000 | 4 | 6 | 59 | 0.17 | 0.81 | −0.17 | C | *ls* |
| | | | [360] | 1465200 | 1743000 | 6 | 6 | 4.2 | 0.0082 | 0.058 | −1.31 | D | *ls* |
| 71. | $5d$–$8p$ | $^2D$ - $^2P^o$ | | | | 10 | 6 | | 0.0113 | | −0.95 | C | 4 |
| 72. | $5d$–$8f$ | $^2D$ - $^2F^o$ | | | | 10 | 14 | | 0.076 | | −0.12 | C | 4 |
| 73. | $5f$–$6d$ | $^2F^o$ - $^2D$ | *653.2* | *1482200* | 1635300 | 14 | 10 | 12 | 0.053 | 1.6 | −0.13 | C | 4 |
| | | | [653.2] | 1482200 | 1635300 | 8 | 6 | 11 | 0.053 | 0.91 | −0.37 | C | *ls* |
| | | | [652.7] | 1482100 | 1635300 | 6 | 4 | 12 | 0.050 | 0.64 | −0.53 | C | *ls* |
| | | | [652.7] | 1482100 | 1635300 | 6 | 6 | 0.56 | 0.0036 | 0.046 | −1.67 | D | *ls* |
| 74. | $5f$–$7d$ | $^2F^o$ - $^2D$ | [392] | *1482200* | 1737000 | 14 | 10 | 5.6 | 0.0092 | 0.17 | −0.89 | D | 4 |
| 75. | $5f$–$8d$ | $^2F^o$ - $^2D$ | | | | 14 | 10 | | 0.0033 | | −1.34 | D | 4 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XI

## Forbidden Transitions

The electric quadrupole *gf*-value for the $3s$–$3d$ multiplet in this sodiumlike ion was reported by Godefroid *et al.*[1]; it was calculated earlier by Biemont and Godefroid[2] using a fully variational Hartree-Fock approach. This $f$-value was converted to a multiplet strength, which was then distributed between the two lines of the multiplet according to *LS*-coupling rules.

### References


[1]M. Godefroid, C. E. Magnusson, P. O. Zetterberg, and I. Joelsson, Phys. Scr. **32**, 125 (1985).

[2]E. Biemont and M. Godefroid, Phys. Scr. **18**, 323 (1978).

Sc XI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm⁻¹) | $E_k$ (cm⁻¹) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s⁻¹) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s$–$3d$ | $^2$S – $^2$D | | | | | | | | | | |
| | | | [217.38] | 0 | 460020 | 2 | 6 | E2 | 3.7(+5)[a] | 0.65 | C | 1,*ls* |
| | | | [217.68] | 0 | 459400 | 2 | 4 | E2 | 3.75(+5) | 0.436 | C | 1,*ls* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XII

Ne Isoelectronic Sequence

Ground State: $1s^22s^22p^6\ ^1S_0$

Ionization Energy: 687.36 eV = 5543900 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 26.544 | 9 | 126 | 3 | 380 | 13 | 411 | 14 |
| 26.920 | 8 | 129 | 4 | 385 | 13 | 502 | 16 |
| 27.260 | 7 | 133 | 1 | 399.550 | 15 | 517.171 | 11 |
| 30.480 | 6 | 142 | 2 | 401 | 15 | 599 | 10 |
| 30.816 | 5 | 370 | 13 | 404 | 17 | 777 | 12 |

For resonance transitions to $J = 1$ levels of the $2p^53s$ and $2p^53d$ configurations, we quote $A$-values which were calculated by Vainshtein and Safronova[1] using a charge-expansion perturbation theory approach with allowance for mixing of the $2p^53s$, $2p^53d$, and $2s2p^63p$ configurations. Their results for the $2p^6$–$2p^53d$ transitions in the isoelectronic ions Ar IX and Fe XVII are in rather good agreement with those of Shorer,[2] who used the relativistic random phase approximation (RRPA) with allowance for mixing between configurations of type $2p^5ns$ and $2p^5nd$, as well as correlation effects due to configurations having a vacancy in the $1s$ or $2s$ subshell. But the data of Ref. 1 for the two $2p^6$–$2p^53s$ transitions are approximately a factor of two smaller than those of Shorer for the abovementioned neonlike species, so we have increased the transition probabilities of Ref. 1 for these two lines by a factor of two.

$A$-values quoted here for a number of transitions involving an electron jump of the type $2s$–$2p$, $3s$–$3p$, or $3p$–$3d$ were taken from the work of Pokleba and Safronova,[3] who used wavefunctions calculated by a charge-expansion perturbation theory approach with allowance for mixing of configurations in which a single $2s$ or $2p$ electron is excited to an $n=3$ orbital but with no inclusion of configurations in which an electron occupies the $n=4$ shell. In cases where better wavelength data were available, these transition probabilities were first converted to line strengths, which were then reconverted to $f$- and $A$-values by using the more accurate wavelengths. Transitions involving levels of the $2p^53p$ and $2p^53d$ configurations which are indicated by Jupen and Litzen[4] or by Fawcett[5] to be of low to moderate purity in $LS$ coupling in Ti XIII are excluded here, as are very weak lines. The pattern of levels within the $2s2p^63d$ configuration in the isoelectronic ions Fe XVII and Ni XIX resulting from the scaled Thomas-Fermi calculations of Loulergue and Nussbaumer[6] with extensive allowance for correlation is entirely different from that determined by Vainshtein and Safronova, whose energy levels were apparently used by Pokleba and Safronova in their transition probability calculations. We have thus excluded transitions out of these levels from our tabulation.

### References

[1]L. A. Vainshtein and U. I. Safronova, *Spektroskopicheskie Konstanty Atomov*, 5–122 (Ed. V. B. Belyanin, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Nauch. Sov. Spektrosk., Moscow, 1977).
[2]P. Shorer, Phys. Rev. A **20**, 642 (1979).
[3]A. K. Pokleba and U. I. Safronova, Preprint No. 11, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Inst. Spektrosk. (Moscow, 1981).
[4]C. Jupen and U. Litzen, Phys. Scr. **30**, 112 (1984).
[5]B. C. Fawcett, private communication, as quoted in E. Träbert, Z. Phys. A **319**, 25 (1984).
[6]M. Loulergue and H. Nussbaumer, Astron. Astrophys. **45**, 125 (1975).

Sc XII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5(^2P^\circ_{3/2})3s-2s2p^63s$ | $(^3/_2,^1/_2)^\circ-{}^3S$ | | | | | | | | | | | |
| | | | [133] | | | 5 | 3 | 440 | 0.070 | 0.15 | −0.46 | D− | 3 |
| 2. | $2s^22p^5(^2P^\circ_{1/2})3s-2s2p^63s$ | $(^1/_2,^1/_2)^\circ-{}^3S$ | | | | | | | | | | | |
| | | | [142] | | | 3 | 3 | 87 | 0.026 | 0.037 | −1.10 | D− | 3 |
| 3. | $2s^22p^53p-2s2p^63p$ | $^3S-{}^3P^\circ$ | | | | | | | | | | | |
| | | | [126] | | | 3 | 3 | 120 | 0.029 | 0.036 | −1.07 | E | 3 |
| | | | [126] | | | 3 | 1 | 230 | 0.018 | 0.023 | −1.26 | D | 3 |
| 4. | | $^3D-{}^3P^\circ$ | | | | | | | | | | | |
| | | | [129] | | | 7 | 5 | 390 | 0.069 | 0.21 | −0.31 | D | 3 |
| 5. | $2p^6-2p^5(^2P^\circ_{3/2})3s$ | $^1S-(^3/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 30.816 | 0 | 3245100 | 1 | 3 | 2160 | 0.092 | 0.0094 | −1.035 | C− | 1*n* |
| 6. | $2p^6-2p^5(^2P^\circ_{1/2})3s$ | $^1S-(^1/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 30.480 | 0 | 3280800 | 1 | 3 | 3280 | 0.137 | 0.0138 | −0.86 | C− | 1*n* |
| 7. | $2p^6-2p^53d$ | $^1S-{}^3P^\circ$ | | | | | | | | | | | |
| | | | 27.260 | 0 | 3668400 | 1 | 3 | 240 | 0.0080 | 7.2(−4)[a] | −2.10 | E | 1 |
| 8. | | $^1S-{}^3D^\circ$ | | | | | | | | | | | |
| | | | 26.920 | 0 | 3714700 | 1 | 3 | 7800 | 0.25 | 0.023 | −0.59 | D | 1 |
| 9. | | $^1S-{}^1P^\circ$ | 26.544 | 0 | 3767300 | 1 | 3 | 7.9(+4) | 2.5 | 0.22 | 0.40 | C− | 1 |
| 10. | $2p^5(^2P^\circ_{3/2})3s-2p^53p$ | $(^3/_2,^1/_2)^\circ-{}^3S$ | | | | | | | | | | | |
| | | | [599] | | | 5 | 3 | 15 | 0.048 | 0.48 | −0.62 | D | 3 |
| 11. | | $(^3/_2,^1/_2)^\circ-{}^3D$ | | | | | | | | | | | |
| | | | 517.171 | | | 5 | 7 | 29 | 0.16 | 1.4 | −0.08 | D | 3 |
| 12. | $2p^5(^2P^\circ_{1/2})3s-2p^53p$ | $(^1/_2,^1/_2)^\circ-{}^3S$ | | | | | | | | | | | |
| | | | [777] | | | 1 | 3 | 0.30 | 0.0081 | 0.021 | −2.09 | E | 3 |
| 13. | $2p^53p-2p^53d$ | $^3S-{}^3P^\circ$ | *375* | | | 3 | 9 | 39 | 0.25 | 0.92 | −0.13 | E | 3 |
| | | | [370] | | | 3 | 5 | 32 | 0.11 | 0.40 | −0.48 | E | 3 |
| | | | [380] | | | 3 | 3 | 46 | 0.10 | 0.37 | −0.52 | D | 3 |
| | | | [385] | | | 3 | 1 | 53 | 0.039 | 0.15 | −0.93 | D | 3 |
| 14. | | $^3D-{}^3P^\circ$ | | | | | | | | | | | |
| | | | [411] | | | 7 | 5 | 2.2 | 0.0040 | 0.038 | −1.56 | E | 3 |

Sc XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | | $^3$D - $^3$F° | | | | | | | | | | | |
| | | | 399.550 | | | 7 | 9 | 60 | 0.18 | 1.7 | 0.11 | D | 3 |
| | | | [401] | | | 7 | 7 | 8.5 | 0.020 | 0.19 | −0.84 | E | 3 |
| 16. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | [502] | | | 1 | 3 | 1.8 | 0.020 | 0.034 | −1.69 | D− | 3 |
| 17. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | [404] | | | 1 | 3 | 28 | 0.21 | 0.27 | −0.69 | D | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XIII

F Isoelectronic Sequence

Ground State: $1s^22s^22p^5\ ^2P^\circ_{3/2}$

Ionization Energy: 756.7 eV = 6103000 cm$^{-1}$

## Allowed Transitions

Oscillator strengths for lines of the multiplet $2s^22p^5\ ^2P^\circ - 2s2p^6\ ^2S$ are the results of the Dirac-Fock calculations of Cheng *et al.*,[1] which included a perturbative treatment of the Breit interaction and the Lamb shift.

For lines of the arrays $2p^5$–$2p^43s$ and $2p^5$–$2p^43d$, we quote the $f$-values calculated by Fawcett[2] using Cowan's Hartree-Fock-Relativistic (HFR) method and incorporating scaling of energy parameters on the basis of a least-squares fit to observed energies. Fawcett's calculations included fairly extensive allowance for configuration mixing in both odd- and even-parity states. Transitions involving levels which are indicated by Fawcett to be of low to moderate purity in $LS$ coupling in neighboring fluorinelike ions are excluded from this compilation, as are lines characterized by very small $f$-values.

## References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]B. C. Fawcett, At. Data Nucl. Data Tables **31**, 495 (1984).

Sc XIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5$–$2s2p^6$ | $^2$P° - $^2$S | *133.16* | *12636* | 763638 | 6 | 2 | 807 | 0.0715 | 0.188 | −0.368 | C+ | 1 |
| | | | 130.952 | 0 | 763638 | 4 | 2 | 569 | 0.0732 | 0.126 | −0.533 | C+ | 1 |
| | | | 137.799 | 37908 | 763638 | 2 | 2 | 242 | 0.0688 | 0.0624 | −0.861 | C+ | 1 |
| 2. | $2p^5$–$2p^4(^3P)3s$ | $^2$P° - $^2$P | | | | | | | | | | | |
| | | | 28.280 | 37908 | 3574100 | 2 | 2 | 6100 | 0.073 | 0.014 | −0.84 | C− | 2 |
| | | | 27.979 | 0 | 3574100 | 4 | 2 | 4650 | 0.0273 | 0.0101 | −0.96 | C− | 2 |

Sc XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | $2p^5$–$2p^4(^1D)3s$ | $^2P^\circ$ – $^2D$ | | | | | | | | | | | |
| | | | 27.628 | 0 | 3619500 | 4 | 6 | 4000 | 0.068 | 0.025 | −0.57 | D | 2 |
| | | | 27.911 | 37908 | 3620700 | 2 | 4 | 4200 | 0.099 | 0.018 | −0.70 | D | 2 |
| 4. | $2p^5$–$2p^4(^1S)3s$ | $^2P^\circ$ – $^2S$ | *26.985* | *12636* | 3718400 | 6 | 2 | 4600 | 0.017 | 0.0089 | −1.00 | D | 2 |
| | | | 26.893 | 0 | 3718400 | 4 | 2 | 1800 | 0.010 | 0.0035 | −1.40 | D | 2 |
| | | | 27.170 | 37908 | 3718400 | 2 | 2 | 2700 | 0.030 | 0.0054 | −1.22 | D | 2 |
| 5. | $2p^5$–$2p^4(^3P)3d$ | $^2P^\circ$ – $^4P$ | | | | | | | | | | | |
| | | | 25.242 | 0 | 3961700 | 4 | 2 | 3300 | 0.016 | 0.0053 | −1.19 | E | 2 |
| 6. | $2p^5$–$2p^4(^1D)3d$ | $^2P^\circ$ – $^2S$ | *24.743* | *12636* | 4054200 | 6 | 2 | 6.2(+4)[a] | 0.19 | 0.093 | 0.06 | D | 2 |
| | | | 24.666 | 0 | 4054200 | 4 | 2 | 5.0(+4) | 0.23 | 0.075 | −0.04 | D | 2 |
| | | | 24.899 | 37908 | 4054200 | 2 | 2 | 1.2(+4) | 0.11 | 0.018 | −0.66 | D | 2 |
| 7. | | $^2P^\circ$ – $^2F$ | | | | | | | | | | | |
| | | | 24.648 | 0 | 4057100 | 4 | 6 | 3200 | 0.044 | 0.014 | −0.75 | E | 2 |
| 8. | | $^2P^\circ$ – $^2P$ | | | | | | | | | | | |
| | | | [24.560] | 0 | 4071600 | 4 | 4 | 6.9(+4) | 0.62 | 0.20 | 0.39 | D | 2 |
| | | | 24.791 | 37908 | 4071600 | 2 | 4 | 9200 | 0.17 | 0.028 | −0.47 | D | 2 |
| 9. | | $^2P^\circ$ – $^2D$ | | | | | | | | | | | |
| | | | 24.715 | 37908 | 4084300 | 2 | 4 | 5.5(+4) | 1.0 | 0.16 | 0.30 | D | 2 |
| | | | 24.484 | 0 | 4084300 | 4 | 4 | 9000 | 0.081 | 0.026 | −0.49 | D | 2 |
| 10. | $2p^5$–$2p^4(^1S)3d$ | $^2P^\circ$ – $^2D$ | *24.156* | *12636* | *4152400* | 6 | 10 | 1.7(+4) | 0.25 | 0.12 | 0.118 | E | 2 |
| | | | 24.097 | 0 | 4149900 | 4 | 6 | 8400 | 0.11 | 0.035 | −0.36 | D | 2 |
| | | | 24.284 | 37908 | 4156100 | 2 | 4 | 3.1(+4) | 0.54 | 0.086 | 0.03 | D | 2 |
| | | | 24.061 | 0 | 4156100 | 4 | 4 | 900 | 0.0078 | 0.0025 | −1.51 | E | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Sc XIII

### Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $2p^5$ configuration are the results of the Dirac-Fock calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor $^2/_3$ which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

Sc XIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^5$–$2p^5$ | $^2P^\circ$ - $^2P^\circ$ | | | | | | | | | | |
| | | | 2637.2 | 0 | 37908 | 4 | 2 | M1 | 978 | 1.33 | B | 1 |
| | | | " | " | " | 4 | 2 | E2 | 0.039 | 0.0059 | D | 1 |

# Sc XIV

O Isoelectronic Sequence

Ground State: $1s^22s^22p^4\ ^3P_2$

Ionization Energy: 830.8 eV = 6701000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 22.57 | 30 | 23.161 | 32 | 24.97 | 13 | 26.197 | 9 |
| 22.70 | 28 | 23.17 | 18 | 25.08 | 13 | 26.224 | 9 |
| 22.72 | 30 | 23.21 | 18 | 25.16 | 13 | 109.528 | 2 |
| 22.74 | 30 | 23.23 | 31 | 25.18 | 13 | 113.40 | 2 |
| 22.751 | 33 | 23.271 | 27,36 | 25.19 | 13 | 113.928 | 2 |
| 22.753 | 23 | 23.363 | 26 | 25.280 | 11 | 116.66 | 7 |
| 22.809 | 29 | 23.37 | 18 | 25.392 | 10 | 122.671 | 4 |
| 22.82 | 29 | 23.496 | 25 | 25.403 | 15 | 139.469 | 6 |
| 22.831 | 29 | 23.536 | 17 | 25.439 | 10 | 145.047 | 1 |
| 22.841 | 22 | 23.55 | 17 | 25.481 | 11 | 148.498 | 1 |
| 22.87 | 28 | 23.561 | 17 | 25.50 | 14 | 150.490 | 1 |
| 22.892 | 21 | 23.61 | 35 | 25.59 | 14 | 151.910 | 1 |
| 22.968 | 20 | 23.65 | 24 | 25.644 | 10 | 152.880 | 1 |
| 23.005 | 22 | 23.700 | 34 | 25.652 | 10 | 157.820 | 8 |
| 23.057 | 21 | 23.72 | 17 | 25.680 | 10 | 157.904 | 1 |
| 23.079 | 21 | 23.732 | 17 | 25.921 | 12 | 176.455 | 3 |
| 23.08 | 21 | 23.74 | 17 | 25.985 | 9 | 202.65 | 5 |
| 23.12 | 19 | 24.89 | 13 | 26.056 | 16 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^4$–$2s2p^5$ and $2s2p^5$–$2p^6$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. The results should be quite accurate, except in the case of weak lines. (The $2s^22p^4\ ^1D_2$ - $2s2p^5\ ^3P^\circ_1$ transition has been omitted from this tabulation, because its $f$-value as reported in Ref. 1 is extremely small, and thus very uncertain.)

Transition probabilities for lines of the $2s^22p^4$–$2s2p^5$ array were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis set included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these two sources are in reasonably good agreement, particularly for the stronger transitions.

For lines of the arrays $2p^4$–$2p^33s$ and $2p^4$–$2p^33d$, we quote the $f$-values calculated by Fawcett[3] using Cowan's Hartree-Fock-Relativistic (HFR) method and incorporating scaling of energy parameters on the basis of a least-squares fit to observed energies. Fawcett's calculations included fairly extensive allowance for configuration mixing in both odd- and even-parity states. The weakest lines were not reported, and thus are not tabulated here. Transitions involving levels which are indicated by Fawcett to be of low to moderate purity in *LS* coupling in neighboring oxygenlike ions are excluded from this compilation.

## References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]C. Froese Fischer and H. P. Saha, J. Phys. B **17**, 943 (1984).
[3]B. C. Fawcett, At. Data Nucl. Data Tables **34**, 215 (1986).

Sc XIV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^4$–$2s2p^5$ | $^3P - {}^3P^\circ$ | *150.84* | *14319* | *677259* | 9 | 9 | 350 | 0.12 | 0.53 | 0.03 | C | 1 |
| | | | 150.490 | 0 | 664483 | 5 | 5 | 260 | 0.087 | 0.22 | −0.36 | C | 1 |
| | | | 151.910 | 31174 | 689445 | 3 | 3 | 86 | 0.0297 | 0.0446 | −1.050 | C | 1 |
| | | | 145.047 | 0 | 689445 | 5 | 3 | 170 | 0.0321 | 0.077 | −0.79 | C | 1 |
| | | | 148.498 | 31174 | 704584 | 3 | 1 | 371 | 0.0409 | 0.060 | −0.91 | C | 1 |
| | | | 157.904 | 31174 | 664483 | 3 | 5 | 77 | 0.0477 | 0.074 | −0.84 | C | 1 |
| | | | 152.880 | 35351 | 689445 | 1 | 3 | 108 | 0.114 | 0.057 | −0.94 | C | 1 |
| 2. | | $^3P - {}^1P^\circ$ | | | | | | | | | | | |
| | | | 109.528 | 0 | 912990 | 5 | 3 | 38 | 0.0041 | 0.0074 | −1.69 | E | 1 |
| | | | [113.40] | 31174 | 912990 | 3 | 3 | 1.5 | 2.9(−4)[a] | 3.2(−4) | −3.06 | E | 1 |
| | | | 113.928 | 35351 | 912990 | 1 | 3 | 3.4 | 0.0020 | 7.5(−4) | −2.70 | E | 1 |
| 3. | | $^1D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | 176.455 | 97793 | 664483 | 5 | 5 | 6.2 | 0.0029 | 0.0084 | −1.84 | E | 1 |
| 4. | | $^1D - {}^1P^\circ$ | 122.671 | 97793 | 912990 | 5 | 3 | 1070 | 0.145 | 0.293 | −0.140 | C | 1 |
| 5. | | $^1S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [202.65] | 195985 | 689445 | 1 | 3 | 1.8 | 0.0034 | 0.0023 | −2.47 | E | 1 |
| 6. | | $^1S - {}^1P^\circ$ | 139.469 | 195985 | 912990 | 1 | 3 | 78 | 0.068 | 0.031 | −1.17 | C | 1 |
| 7. | $2s2p^5$–$2p^6$ | $^3P^\circ - {}^1S$ | | | | | | | | | | | |
| | | | [116.66] | 689445 | 1546620 | 3 | 1 | 18 | 0.0012 | 0.0014 | −2.44 | E | 1 |
| 8. | | $^1P^\circ - {}^1S$ | 157.820 | 912990 | 1546620 | 3 | 1 | 1100 | 0.137 | 0.214 | −0.386 | C | 1 |
| 9. | $2p^4$–$2p^3(^4S^\circ)3s$ | $^3P - {}^3S^\circ$ | *26.082* | *14319* | 3848400 | 9 | 3 | 1.4(+4) | 0.049 | 0.038 | −0.35 | C− | 3 |
| | | | 25.985 | 0 | 3848400 | 5 | 3 | 8900 | 0.054 | 0.023 | −0.57 | C− | 3 |
| | | | 26.197 | 31174 | 3848400 | 3 | 3 | 3980 | 0.0410 | 0.0106 | −0.91 | C− | 3 |
| | | | 26.224 | 35351 | 3848400 | 1 | 3 | 1600 | 0.049 | 0.0042 | −1.31 | C− | 3 |
| 10. | $2p^4$–$2p^3(^2D^\circ)3s$ | $^3P - {}^3D^\circ$ | | | | | | | | | | | |
| | | | 25.392 | 0 | 3938200 | 5 | 7 | 4200 | 0.057 | 0.024 | −0.55 | C | 3 |
| | | | 25.644 | 31174 | 3931000 | 3 | 5 | 1600 | 0.026 | 0.0066 | −1.11 | D | 3 |
| | | | 25.680 | 35351 | 3929500 | 1 | 3 | 1300 | 0.038 | 0.0032 | −1.42 | C− | 3 |
| | | | 25.439 | 0 | 3931000 | 5 | 5 | 2700 | 0.026 | 0.011 | −0.89 | D | 3 |
| | | | [25.652] | 31174 | 3929500 | 3 | 3 | 2800 | 0.028 | 0.0071 | −1.08 | C− | 3 |
| 11. | | $^3P - {}^1D^\circ$ | | | | | | | | | | | |
| | | | [25.280] | 0 | 3955700 | 5 | 5 | 500 | 0.0048 | 0.0020 | −1.62 | E | 3 |
| | | | [25.481] | 31174 | 3955700 | 3 | 5 | 570 | 0.0093 | 0.0023 | −1.55 | E | 3 |
| 12. | | $^1D - {}^1D^\circ$ | 25.921 | 97793 | 3955700 | 5 | 5 | 9400 | 0.095 | 0.041 | −0.32 | C− | 3 |

Sc XIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13. | $2p^4$–$2p^3(^2P^\circ)3s$ | $^3P$ – $^3P^\circ$ | *25.02* | | | 9 | 9 | 3600 | 0.034 | 0.025 | −0.52 | D | 3 |
| | | | [24.89] | | | 5 | 5 | 1200 | 0.011 | 0.0045 | −1.26 | D | 3 |
| | | | [25.16] | | | 3 | 3 | 810 | 0.0077 | 0.0019 | −1.64 | D | 3 |
| | | | [24.97] | | | 5 | 3 | 750 | 0.0042 | 0.0017 | −1.68 | D | 3 |
| | | | [25.18] | | | 3 | 1 | 4100 | 0.013 | 0.0032 | −1.41 | C | 3 |
| | | | [25.08] | | | 3 | 5 | 2100 | 0.0033 | 0.0082 | −1.00 | D | 3 |
| | | | [25.19] | | | 1 | 3 | 2400 | 0.069 | 0.0057 | −1.16 | C | 3 |
| 14. | | $^1D$ – $^3P^\circ$ | | | | | | | | | | | |
| | | | [25.50] | | | 5 | 5 | 1700 | 0.017 | 0.0071 | −1.07 | E | 3 |
| | | | [25.59] | | | 5 | 3 | 780 | 0.0046 | 0.0019 | −1.64 | E | 3 |
| 15. | | $^1D$ – $^1P^\circ$ | 25.403 | 97793 | 4033900 | 5 | 3 | 5300 | 0.031 | 0.013 | −0.81 | D | 3 |
| 16. | | $^1S$ – $^1P^\circ$ | 26.056 | 195985 | 4033900 | 1 | 3 | 5200 | 0.16 | 0.014 | −0.80 | D | 3 |
| 17. | $2p^4$–$2p^3(^4S^\circ)3d$ | $^3P$ – $^3D^\circ$ | *23.63* | | | 9 | 15 | 2.1(+4) | 0.30 | 0.21 | 0.43 | D | 3 |
| | | | 23.536 | 0 | 4248800 | 5 | 7 | 2.27(+4) | 0.264 | 0.102 | 0.121 | C− | 3 |
| | | | 23.732 | 31174 | 4244300 | 3 | 5 | 1.2(+4) | 0.17 | 0.040 | −0.29 | D | 3 |
| | | | [23.74] | | | 1 | 3 | 1.23(+4) | 0.312 | 0.0244 | −0.51 | C− | 3 |
| | | | 23.561 | 0 | 4244300 | 5 | 5 | 6600 | 0.055 | 0.021 | −0.56 | D | 3 |
| | | | [23.72] | | | 3 | 3 | 8900 | 0.075 | 0.018 | −0.65 | C− | 3 |
| | | | [23.55] | | | 5 | 3 | 840 | 0.0042 | 0.0016 | −1.68 | D | 3 |
| 18. | $2p^4$–$2p^3(^2D^\circ)3d$ | $^3P$ – $^3F^\circ$ | | | | | | | | | | | |
| | | | [23.17] | | | 5 | 7 | 2600 | 0.029 | 0.011 | −0.84 | E | 3 |
| | | | [23.37] | | | 3 | 5 | 1200 | 0.016 | 0.0037 | −1.32 | E | 3 |
| | | | [23.21] | | | 5 | 5 | 1000 | 0.0082 | 0.0031 | −1.39 | E | 3 |
| 19. | | $^3P$ – $^3G^\circ$ | | | | | | | | | | | |
| | | | [23.12] | | | 5 | 7 | 980 | 0.011 | 0.0042 | −1.26 | E | 3 |
| 20. | | $^3P$ – $^3D^\circ$ | | | | | | | | | | | |
| | | | 22.968 | 0 | 4353900 | 5 | 7 | 6.1(+4) | 0.67 | 0.25 | 0.53 | C− | 3 |
| 21. | | $^3P$ – $^3P^\circ$ | | | | | | | | | | | |
| | | | 23.057 | 31174 | 4368300 | 3 | 3 | 2.8(+4) | 0.22 | 0.050 | −0.18 | D | 3 |
| | | | [22.892] | 0 | 4368300 | 5 | 3 | 3600 | 0.017 | 0.0064 | −1.07 | D | 3 |
| | | | [23.08] | | | 3 | 1 | 3.5(+4) | 0.092 | 0.021 | −0.56 | C− | 3 |
| | | | [23.079] | 35351 | 4368300 | 1 | 3 | 1.2(+4) | 0.28 | 0.021 | −0.55 | D | 3 |
| 22. | | $^3P$ – $^3S^\circ$ | | | | | | | | | | | |
| | | | 22.841 | 0 | 4378100 | 5 | 3 | 6.0(+4) | 0.28 | 0.11 | 0.15 | D | 3 |
| | | | [23.005] | 31174 | 4378100 | 3 | 3 | 3700 | 0.029 | 0.0066 | −1.06 | D | 3 |
| 23. | | $^3P$ – $^1F^\circ$ | | | | | | | | | | | |
| | | | [22.753] | 0 | 4395000 | 5 | 7 | 1.3(+4) | 0.14 | 0.052 | −0.15 | E | 3 |
| 24. | | $^1D$ – $^3G^\circ$ | | | | | | | | | | | |
| | | | [23.65] | | | 5 | 7 | 580 | 0.0068 | 0.0026 | −1.47 | E | 3 |

Sc XIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [23.496] | 97793 | 4353900 | 5 | 7 | 600 | 0.0070 | 0.0027 | −1.46 | E | 3 |
| 26. | | $^1$D - $^3$S° | [23.363] | 97793 | 4378100 | 5 | 3 | 6300 | 0.031 | 0.012 | −0.81 | E | 3 |
| 27. | | $^1$D - $^1$F° | 23.271 | 97793 | 4395000 | 5 | 7 | 3.4(+4) | 0.39 | 0.15 | 0.29 | D | 3 |
| 28. | $2p^4$–$2p^3(^2P°)3d$ | $^3$P - $^3$F° | | | | | | | | | | | |
| | | | [22.70] | | | 5 | 7 | 6600 | 0.071 | 0.027 | −0.45 | E | 3 |
| | | | [22.87] | | | 3 | 5 | 1800 | 0.024 | 0.0054 | −1.14 | E | 3 |
| 29. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 22.809 | 31174 | 4415400 | 3 | 3 | 1.1(+4) | 0.086 | 0.019 | −0.59 | D | 3 |
| | | | [22.82] | | | 3 | 1 | 4.27(+4) | 0.111 | 0.0250 | −0.478 | C− | 3 |
| | | | [22.831] | 35351 | 4415400 | 1 | 3 | 2.1(+4) | 0.49 | 0.037 | −0.31 | D | 3 |
| 30. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | [22.74] | | | 1 | 3 | 3.6(+4) | 0.84 | 0.063 | −0.08 | C− | 3 |
| | | | [22.72] | | | 3 | 3 | 3.45(+4) | 0.267 | 0.060 | −0.096 | C− | 3 |
| | | | [22.57] | | | 5 | 3 | 960 | 0.0044 | 0.0016 | −1.66 | D | 3 |
| 31. | | $^1$D - $^3$F° | | | | | | | | | | | |
| | | | [23.23] | | | 5 | 5 | 3100 | 0.025 | 0.0096 | −0.90 | E | 3 |
| 32. | | $^1$D - $^3$P° | | | | | | | | | | | |
| | | | [23.161] | 97793 | 4415400 | 5 | 3 | 1900 | 0.0092 | 0.0035 | −1.34 | E | 3 |
| 33. | | $^1$D - $^1$P° | [22.751] | 97793 | 4493200 | 5 | 3 | 5200 | 0.024 | 0.0090 | −0.92 | D | 3 |
| 34. | | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [23.700] | 195985 | 4415400 | 1 | 3 | 990 | 0.025 | 0.0020 | −1.60 | E | 3 |
| 35. | | $^1$S - $^3$D° | | | | | | | | | | | |
| | | | [23.61] | | | 1 | 3 | 880 | 0.022 | 0.0017 | −1.66 | E | 3 |
| 36. | | $^1$S - $^1$P° | 23.271 | 195985 | 4493200 | 1 | 3 | 9.0(+4) | 2.2 | 0.17 | 0.34 | D | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Sc XIV

### Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^4$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

Transition probabilities for these same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1.

Line strengths derived from these data are in quite good agreement with the data of Cheng *et al*. For this ion of the oxygen isoelectronic sequence, correlation effects due to mixing with configurations outside the complex were found by Froese Fischer and Saha to be rather small, as shown by a comparison of the results of their calculations employing an extensive basis to those derived by the same technique but limited to configurations within the $n=2$ complex.

The weakest lines are excluded from this compilation, as their transition probabilities are considered to be very uncertain.

### References


[1]K. T. Cheng, Y.-K Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).


Sc XIV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^4$-$2p^4$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | 3206.1 | 0 | 31174 | 5 | 3 | M1 | 655 | 2.40 | C+ | 1 |
| | | | " | " | " | 5 | 3 | E2 | 0.0096 | 0.0058 | E | 1 |
| | | | [23930] | 31174 | 35351 | 3 | 1 | M1 | 3.68 | 1.87 | C+ | 1 |
| | | | [2827.9] | 0 | 35351 | 5 | 1 | E2 | 0.028 | 0.0030 | E | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [1022.6] | 0 | 97793 | 5 | 5 | M1 | 1400 | 0.28 | D | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.48 | 0.0016 | E | 1 |
| | | | [1501.1] | 31174 | 97793 | 3 | 5 | M1 | 160 | 0.098 | D | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [606.76] | 31174 | 195985 | 3 | 1 | M1 | 1.6(+4)[a] | 0.13 | D | 1 |
| 4. | | $^1$D - $^1$S | [1018.4] | 97793 | 195985 | 5 | 1 | E2 | 15 | 0.0099 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Sc XV

N Isoelectronic Sequence

Ground State: $1s^22s^22p^3\,{}^4S^\circ_{3/2}$

Ionization Energy: 927.5 eV = 7481000 cm$^{-1}$

### Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 105.08 | 4 | 130.409 | 12 | 153.843 | 6 | 181.165 | 1 |
| 109.084 | 4 | 131.36 | 2 | 155.765 | 6 | 188.476 | 16 |
| 111.88 | 13 | 133.118 | 12 | 156.436 | 6 | 190.479 | 16 |
| 112.39 | 13 | 136.638 | 12 | 166.58 | 15 | 204.038 | 16 |
| 113.39 | 3 | 138.715 | 14 | 169.964 | 1 | 226.87 | 5 |
| 115.68 | 13 | 139.615 | 12 | 173.245 | 1 | 232.55 | 5 |
| 117.19 | 13 | 143.465 | 11 | 173.481 | 10 | 247.82 | 9 |
| 118.980 | 8 | 146.754 | 11 | 176.834 | 16 | 265.41 | 9 |
| 124.140 | 8 | 146.966 | 14 | 177.436 | 10 | 284.47 | 9 |
| 125.817 | 8 | 147.558 | 14 | 178.32 | 10 | | |
| 129.751 | 7 | 153.197 | 6 | 178.631 | 15 | | |

Sc XV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^3$–$2p^3$ | $^4$S° – $^2$D° | | | | | | | | | | |
| | | | [899.28] | 0 | 111200 | 4 | 4 | M1 | 1100 | 0.12 | D | 1 |
| 2. | | $^4$S° – $^2$P° | | | | | | | | | | |
| | | | [498.88] | 0 | 200450 | 4 | 4 | M1 | 5100 | 0.094 | D | 1 |
| | | | [541.01] | 0 | 184840 | 4 | 2 | M1 | 3000 | 0.035 | D− | 1 |
| 3. | | $^2$D° – $^2$D° | | | | | | | | | | |
| | | | [9291] | 111200 | 121960 | 4 | 6 | M1 | 11.3 | 2.02 | C | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 6 | E2 | 1.2(−5)[a] | 0.0029 | E | 1 |
| 4. | | $^2$D° – $^2$P° | | | | | | | | | | |
| | | | [1590] | 121960 | 184840 | 6 | 2 | E2 | 0.48 | 0.0058 | E | 1 |
| | | | [1274] | 121960 | 200450 | 6 | 4 | M1 | 1200 | 0.37 | D | 1 |
| | | | 〃 | 〃 | 〃 | 6 | 4 | E2 | 2.0 | 0.016 | E | 1 |
| | | | [1358] | 111200 | 184840 | 4 | 2 | M1 | 1000 | 0.19 | D | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 2 | E2 | 1.3 | 0.0073 | E | 1 |
| | | | [1120] | 111200 | 200450 | 4 | 4 | M1 | 2900 | 0.61 | D | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 4 | E2 | 0.95 | 0.0040 | E | 1 |
| 5. | | $^2$P° – $^2$P° | | | | | | | | | | |
| | | | [6404] | 184840 | 200450 | 2 | 4 | M1 | 28.2 | 1.10 | C | 1 |
| | | | 〃 | 〃 | 〃 | 2 | 4 | E2 | 4.7(−5) | 0.0012 | E | 1 |
| 6. | $2p^5$–$2p^5$ | $^2$P° – $^2$P° | | | | | | | | | | |
| | | | [2470] | 1441710 | 1482190 | 4 | 2 | M1 | 1240 | 1.39 | C | 3 |
| | | | 〃 | 〃 | 〃 | 4 | 2 | E2 | 0.048 | 0.0053 | E | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XVI

C Isoelectronic Sequence

Ground State: $1s^22s^22p^2\ ^3P_0$

Ionization Energy: 1009 eV = 8140000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 20.149 | 29 | 131.09 | 5 | 146.052 | 16 | 153.82 | 16 |
| 20.202 | 28 | 131.684 | 4 | 146.286 | 16 | 154.849 | 16 |
| 20.239 | 29 | 132.688 | 10 | 149.47 | 22 | 158.671 | 3 |
| 20.284 | 28 | 133.53 | 17 | 150.973 | 9 | 163.541 | 3 |
| 113 | 15 | 134.503 | 17 | 151.910 | 14 | 164.665 | 3 |
| 117.090 | 6 | 135.004 | 5 | 152.62 | 19 | 165.113 | 3 |
| 121.78 | 20 | 135.631 | 4 | 153.564 | 16 | 167.369 | 18 |
| 127.813 | 4 | 144.913 | 16 | 153.59 | 19 | 168.72 | 18 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 169.19 | 18 | 185.972 | 2 | 203.447 | 2 | 244.82 | 26 |
| 169.664 | 3 | 194.263 | 2 | 224.51 | 21 | 246.63 | 21 |
| 170.400 | 18 | 194.685 | 2 | 227.82 | 21 | 248.73 | 23 |
| 170.867 | 3 | 195.69 | 8 | 229.61 | 23 | 290.47 | 25 |
| 174.111 | 27 | 197.30 | 8 | 238.87 | 7 | 313.50 | 11 |
| 177.43 | 13 | 200.115 | 24 | 241.36 | 7 | 321.75 | 25 |
| 179.343 | 18 | 201.205 | 2 | 242.01 | 7 | 356 | 1 |
| 180.687 | 18 | 202.97 | 2 | 243.01 | 12 | 386 | 1 |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^2$–$2s2p^3$ and $2s2p^3$–$2p^4$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

Transition probabilities for lines of the $2s^22p^2$–$2s2p^3$ array were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these two sources are in reasonably good agreement, particularly for the stronger transitions.

Data for a few lines of the $2p^2$–$2p3d$ array were interpolated from the HX (Hartree-Fock with statistical allowance for exchange) $f$-values of Bromage and Fawcett[3] for the isoelectronic ions Ca XV and Fe XXI.

## References


[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2] C. Froese Fischer and H. P. Saha, Phys. Scr. **32**, 181 (1985).

[3] G. E. Bromage and B. C. Fawcett, Mon. Not. R. Astron. Soc. **178**, 605 (1977).


Sc XVI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^2$–$2s2p^3$ | $^3$P - $^5$S° | | | | | | | | | | | |
| | | | [386] | | | 5 | 5 | 0.054 | 1.2(−4)[a] | 7.6(−4) | −3.22 | E | 1 |
| | | | [356] | | | 3 | 5 | 0.035 | 1.1(−4) | 3.9(−4) | −3.48 | E | 1 |
| 2. | | $^3$P - $^3$D° | *197.36* | *32673* | *539366* | 9 | 15 | 56 | 0.055 | 0.32 | −0.31 | D | 1 |
| | | | 201.205 | 45033 | 542038 | 5 | 7 | 49.1 | 0.0417 | 0.138 | −0.68 | C | 1 |
| | | | 194.685 | 22963 | 536613 | 3 | 5 | 59 | 0.056 | 0.11 | −0.77 | C | 1 |
| | | | 185.972 | 0 | 537722 | 1 | 3 | 55 | 0.085 | 0.052 | −1.07 | C | 1 |
| | | | 203.447 | 45033 | 536613 | 5 | 5 | 1.5 | 9.2(−4) | 0.0031 | −2.34 | E | 1 |
| | | | 194.263 | 22963 | 537722 | 3 | 3 | 13 | 0.0075 | 0.014 | −1.65 | D | 1 |
| | | | [202.97] | 45033 | 537722 | 5 | 3 | 0.15 | 5.6(−5) | 1.9(−4) | −3.55 | E | 1 |
| 3. | | $^3$P - $^3$P° | *166.74* | *32673* | *632393* | 9 | 9 | 140 | 0.059 | 0.29 | −0.28 | C− | 1 |
| | | | 169.664 | 45033 | 634431 | 5 | 5 | 120 | 0.053 | 0.15 | −0.58 | C | 1 |
| | | | 164.665 | 22963 | 630259 | 3 | 3 | 71 | 0.0290 | 0.0472 | −1.060 | C | 1 |
| | | | 170.867 | 45033 | 630259 | 5 | 3 | 37 | 0.0098 | 0.028 | −1.31 | D | 1 |
| | | | 165.113 | 22963 | 628609 | 3 | 1 | 149 | 0.0203 | 0.0331 | −1.215 | C | 1 |
| | | | 163.541 | 22963 | 634431 | 3 | 5 | 12 | 0.0080 | 0.013 | −1.62 | D | 1 |
| | | | 158.671 | 0 | 630259 | 1 | 3 | 36.4 | 0.0412 | 0.0215 | −1.385 | C | 1 |

Sc XVI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^3$P - $^3$S° | *133.39* | *32673* | 782360 | 9 | 3 | 740 | 0.066 | 0.26 | −0.23 | C | 1 |
| | | | 135.631 | 45033 | 782360 | 5 | 3 | 420 | 0.070 | 0.16 | −0.46 | C | 1 |
| | | | 131.684 | 22963 | 782360 | 3 | 3 | 220 | 0.056 | 0.073 | −0.77 | C | 1 |
| | | | 127.813 | 0 | 782360 | 1 | 3 | 75 | 0.055 | 0.023 | −1.26 | C | 1 |
| 5. | | $^3$P - $^1$D° | | | | | | | | | | | |
| | | | 135.004 | 45033 | 785778 | 5 | 5 | 21 | 0.0057 | 0.013 | −1.55 | E | 1 |
| | | | [131.09] | 22963 | 785778 | 3 | 5 | 0.93 | 4.0(−4) | 5.2(−4) | −2.92 | E | 1 |
| 6. | | $^3$P - $^1$P° | | | | | | | | | | | |
| | | | 117.090 | 22963 | 877032 | 3 | 3 | 17 | 0.0034 | 0.0039 | −1.99 | E | 1 |
| 7. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [238.87] | 123408 | 542038 | 5 | 7 | 2.3 | 0.0027 | 0.011 | −1.87 | E | 1 |
| | | | [242.01] | 123408 | 536613 | 5 | 5 | 0.22 | 1.9(−4) | 7.6(−4) | −3.02 | E | 1 |
| | | | [241.36] | 123408 | 537722 | 5 | 3 | 0.40 | 2.1(−4) | 8.3(−4) | −2.98 | E | 1 |
| 8. | | $^1$D - $^3$P° | | | | | | | | | | | |
| | | | [195.69] | 123408 | 634431 | 5 | 5 | 0.77 | 4.4(−4) | 0.0014 | −2.66 | E | 1 |
| | | | [197.30] | 123408 | 630259 | 5 | 3 | 1.5 | 5.3(−4) | 0.0017 | −2.58 | E | 1 |
| 9. | | $^1$D - $^1$D° | 150.973 | 123408 | 785778 | 5 | 5 | 366 | 0.125 | 0.311 | −0.204 | C | 1 |
| 10. | | $^1$D - $^1$P° | 132.688 | 123408 | 877032 | 5 | 3 | 480 | 0.076 | 0.17 | −0.42 | C | 1 |
| 11. | | $^1$S - $^3$D° | | | | | | | | | | | |
| | | | [313.50] | 218747 | 537722 | 1 | 3 | 0.17 | 7.3(−4) | 7.5(−4) | −3.14 | E | 1 |
| 12. | | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [243.01] | 218747 | 630259 | 1 | 3 | 0.53 | 0.0014 | 0.0011 | −2.85 | E | 1 |
| 13. | | $^1$S - $^3$S° | [177.43] | 218747 | 782360 | 1 | 3 | 1.6 | 0.0022 | 0.0013 | −2.66 | E | 1 |
| 14. | | $^1$S - $^1$P° | 151.910 | 218747 | 877032 | 1 | 3 | 124 | 0.129 | 0.065 | −0.89 | C | 1 |
| 15. | $2s2p^3$–$2p^4$ | $^5$S° - $^3$P | | | | | | | | | | | |
| | | | [113] | | | 5 | 5 | 2.2 | 4.3(−4) | 8.0(−4) | −2.67 | E | 1 |
| 16. | | $^3$D° - $^3$P | *150.59* | *539366* | *1203420* | 15 | 9 | 320 | 0.065 | 0.48 | −0.01 | C− | 1 |
| | | | 154.849 | 542038 | 1187830 | 7 | 5 | 250 | 0.063 | 0.22 | −0.36 | C | 1 |
| | | | 146.052 | 536613 | 1221300 | 5 | 3 | 189 | 0.0362 | 0.087 | −0.74 | C | 1 |
| | | | 144.913 | 537722 | 1227770 | 3 | 1 | 278 | 0.0292 | 0.0418 | −1.057 | C | 1 |
| | | | 153.564 | 536613 | 1187830 | 5 | 5 | 83 | 0.0294 | 0.074 | −0.83 | C | 1 |
| | | | 146.286 | 537722 | 1221300 | 3 | 3 | 103 | 0.0332 | 0.0480 | −1.002 | C | 1 |
| | | | [153.82] | 537722 | 1187830 | 3 | 5 | 11 | 0.0067 | 0.010 | −1.70 | D | 1 |
| 17. | | $^3$D° - $^1$D | | | | | | | | | | | |
| | | | 134.503 | 542038 | 1285500 | 7 | 5 | 15 | 0.0030 | 0.0093 | −1.68 | E | 1 |
| | | | [133.53] | 536613 | 1285500 | 5 | 5 | 2.7 | 7.1(−4) | 0.0016 | −2.45 | E | 1 |

Sc XVI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18. | | $^3P^\circ - {}^3P$ | *175.12* | *632393* | *1203420* | 9 | 9 | 86 | 0.0393 | 0.204 | −0.451 | C | 1 |
| | | | 180.687 | 634431 | 1187830 | 5 | 5 | 34.9 | 0.0171 | 0.051 | −1.068 | C | 1 |
| | | | [169.19] | 630259 | 1221300 | 3 | 3 | 2.6 | 0.0011 | 0.0018 | −2.48 | D | 1 |
| | | | 170.400 | 634431 | 1221300 | 5 | 3 | 88 | 0.0229 | 0.064 | −0.94 | C | 1 |
| | | | 167.369 | 630259 | 1227770 | 3 | 1 | 128 | 0.0179 | 0.0296 | −1.270 | C | 1 |
| | | | 179.343 | 630259 | 1187830 | 3 | 5 | 25.0 | 0.0201 | 0.0356 | −1.220 | C | 1 |
| | | | [168.72] | 628609 | 1221300 | 1 | 3 | 30.6 | 0.0392 | 0.0218 | −1.407 | C | 1 |
| 19. | | $^3P^\circ - {}^1D$ | | | | | | | | | | | |
| | | | [153.59] | 634431 | 1285500 | 5 | 5 | 2.1 | 7.5(−4) | 0.0019 | −2.43 | E | 1 |
| | | | [152.62] | 630259 | 1285500 | 3 | 5 | 2.2 | 0.0013 | 0.0020 | −2.41 | E | 1 |
| 20. | | $^3P^\circ - {}^1S$ | | | | | | | | | | | |
| | | | [121.78] | 630259 | 1451380 | 3 | 1 | 8.2 | 6.1(−4) | 7.3(−4) | −2.74 | E | 1 |
| 21. | | $^3S^\circ - {}^3P$ | *237.50* | 782360 | *1203420* | 3 | 9 | 66 | 0.17 | 0.39 | −0.30 | C | 1 |
| | | | [246.63] | 782360 | 1187830 | 3 | 5 | 53 | 0.081 | 0.20 | −0.61 | C | 1 |
| | | | [227.82] | 782360 | 1221300 | 3 | 3 | 77 | 0.060 | 0.14 | −0.74 | C | 1 |
| | | | [224.51] | 782360 | 1227770 | 3 | 1 | 92 | 0.0232 | 0.051 | −1.157 | C | 1 |
| 22. | | $^3S^\circ - {}^1S$ | [149.47] | 782360 | 1451380 | 3 | 1 | 23 | 0.0026 | 0.0038 | −2.11 | E | 1 |
| 23. | | $^1D^\circ - {}^3P$ | | | | | | | | | | | |
| | | | [248.73] | 785778 | 1187830 | 5 | 5 | 3.1 | 0.0029 | 0.012 | −1.84 | E | 1 |
| | | | [229.61] | 785778 | 1221300 | 5 | 3 | 0.34 | 1.6(−4) | 6.0(−4) | −3.10 | E | 1 |
| 24. | | $^1D^\circ - {}^1D$ | 200.115 | 785778 | 1285500 | 5 | 5 | 245 | 0.147 | 0.484 | −0.134 | C | 1 |
| 25. | | $^1P^\circ - {}^3P$ | | | | | | | | | | | |
| | | | [321.75] | 877032 | 1187830 | 3 | 5 | 0.46 | 0.0012 | 0.0038 | −2.44 | E | 1 |
| | | | [290.47] | 877032 | 1221300 | 3 | 3 | 1.9 | 0.0024 | 0.0069 | −2.14 | E | 1 |
| 26. | | $^1P^\circ - {}^1D$ | [244.82] | 877032 | 1285500 | 3 | 5 | 31.0 | 0.0464 | 0.112 | −0.86 | C | 1 |
| 27. | | $^1P^\circ - {}^1S$ | 174.111 | 877032 | 1451380 | 3 | 1 | 570 | 0.087 | 0.15 | −0.58 | C | 1 |
| 28. | $2p^2$–$2p3d$ | $^3P - {}^3D^\circ$ | | | | | | | | | | | |
| | | | 20.284 | 45033 | 4975000 | 5 | 7 | 7.5(+4) | 0.65 | 0.22 | 0.51 | E | *interp.* |
| | | | 20.202 | 0 | 4950000 | 1 | 3 | 6.5(+4) | 1.2 | 0.080 | 0.08 | D | *interp.* |
| 29. | | $^3P - {}^3P^\circ$ | | | | | | | | | | | |
| | | | 20.149 | 22963 | 4986000 | 3 | 3 | 3.5(+4) | 0.21 | 0.042 | −0.20 | E | *interp.* |
| | | | [20.239] | 45033 | 4986000 | 5 | 3 | 2.0(+4) | 0.074 | 0.025 | −0.43 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XVI

## Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^2$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. The weakest lines are excluded from this compilation, as their strengths are considered to be very uncertain.

Transition probabilities for these same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these data are in good agreement with the data of Cheng *et al.*

### References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Scr. **32**, 181 (1985).

Sc XVI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^2$–$2p^2$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | 4530.3 | 22963 | 45033 | 3 | 5 | M1 | 134 | 2.31 | C+ | 1 |
| | | | " | " | " | 3 | 5 | E2 | 7.6(−4)[a] | 0.0043 | E | 1 |
| | | | 4354.3 | 0 | 22963 | 1 | 3 | M1 | 208 | 1.91 | C+ | 1 |
| | | | [2219.9] | 0 | 45033 | 1 | 5 | E2 | 0.014 | 0.0023 | E | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [1275.9] | 45033 | 123408 | 5 | 5 | M1 | 1400 | 0.53 | D | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.23 | 0.0023 | E | 1 |
| | | | [995.57] | 22963 | 123408 | 3 | 5 | M1 | 1000 | 0.19 | D | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [510.77] | 22963 | 218747 | 3 | 1 | M1 | 1.7(+4) | 0.083 | D | 1 |
| 4. | | $^1$D - $^1$S | [1048.9] | 123408 | 218747 | 5 | 1 | E2 | 11 | 0.0083 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XVII

B Isoelectronic Sequence

Ground State: $1s^22s^22p\ ^2P^\circ_{1/2}$

Ionization Energy: 1094 eV = 8820000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 19.16 | 17 | 158.136 | 3 | 201.33 | 12 | 306.89 | 14 |
| 19.311 | 17 | 159.768 | 9 | 202.172 | 8 | 312.23 | 14 |
| 19.33 | 17 | 160.777 | 9 | 203.467 | 8 | 319.37 | 14 |
| 118.96 | 7 | 163.288 | 9 | 205.154 | 8 | 346.69 | 1 |
| 119.67 | 7 | 164.293 | 5 | 210.531 | 2 | 352.29 | 1 |
| 142.617 | 6 | 169.451 | 5 | 212.34 | 2 | 377.70 | 10 |
| 143.888 | 4 | 170.45 | 3 | 217.24 | 15 | 465.38 | 13 |
| 145.836 | 6 | 176.181 | 5 | 223.424 | 15 | 494.68 | 13 |
| 146.574 | 4 | 193.558 | 2 | 223.821 | 15 | | |
| 154.018 | 4 | 196.010 | 12 | 230.357 | 15 | | |
| 157.095 | 4 | 200.559 | 8 | 266.15 | 11 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p$–$2s2p^2$ and $2s2p^2$–$2p^3$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

The Hartree-Fock results of Shamey[2] for the isoelectronic ions Ar XIV and Fe XXII, which allowed for limited configuration interaction, were interpolated to provide $f$-values for the $2p$–$3s$, $2p$–$3d$, and $2p$–$4d$ transitions.

### References


[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2] L. J. Shamey, J. Opt. Soc. Am. **61**, 942 (1971).


Sc XVII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p$–$2s2p^2$ | $^2P^\circ$ - $^4P$ | | | | | | | | | | | |
| | | | [352.29] | 45700 | 329560 | 4 | 6 | 0.093 | 2.6(−4)[a] | 0.0012 | −2.98 | E | 1 |
| | | | [346.69] | 0 | 288440 | 2 | 2 | 0.13 | 2.3(−4) | 5.3(−4) | −3.34 | E | 1 |
| 2. | | $^2P^\circ$ - $^2D$ | *204.68* | *30470* | *519040* | 6 | 10 | 47.0 | 0.0492 | 0.199 | −0.53 | C− | 1 |
| | | | 210.531 | 45700 | 520640 | 4 | 6 | 42.1 | 0.0420 | 0.116 | −0.77 | C | 1 |
| | | | 193.558 | 0 | 516640 | 2 | 4 | 54 | 0.061 | 0.078 | −0.91 | C | 1 |
| | | | [212.34] | 45700 | 516640 | 4 | 4 | 2.4 | 0.0016 | 0.0045 | −2.19 | D | 1 |
| 3. | | $^2P^\circ$ - $^2S$ | *166.14* | *30470* | 632370 | 6 | 2 | 200 | 0.028 | 0.092 | −0.77 | C− | 1 |
| | | | [170.45] | 45700 | 632370 | 4 | 2 | 11 | 0.0025 | 0.0056 | −2.00 | D | 1 |
| | | | 158.136 | 0 | 632370 | 2 | 2 | 220 | 0.083 | 0.086 | −0.78 | C | 1 |

Sc XVII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^2$P° - $^2$P | *151.45* | *30470* | *690740* | 6 | 6 | 332 | 0.114 | 0.342 | −0.164 | C | 1 |
| | | | 154.018 | 45700 | 694980 | 4 | 4 | 290 | 0.103 | 0.209 | −0.385 | C | 1 |
| | | | 146.574 | 0 | 682250 | 2 | 2 | 60 | 0.0193 | 0.0186 | −1.413 | C | 1 |
| | | | 157.095 | 45700 | 682250 | 4 | 2 | 224 | 0.0415 | 0.086 | −0.78 | C | 1 |
| | | | 143.888 | 0 | 694980 | 2 | 4 | 48.8 | 0.0303 | 0.0287 | −1.218 | C | 1 |
| 5. | $2s2p^2$–$2p^3$ | $^4$P - $^4$S° | *171.84* | *315180* | 897130 | 12 | 4 | 311 | 0.0460 | 0.312 | −0.258 | C | 1 |
| | | | 176.181 | 329560 | 897130 | 6 | 4 | 144 | 0.0447 | 0.156 | −0.57 | C | 1 |
| | | | 169.451 | 306970 | 897130 | 4 | 4 | 108 | 0.0463 | 0.103 | −0.73 | C | 1 |
| | | | 164.293 | 288440 | 897130 | 2 | 4 | 60 | 0.0486 | 0.053 | −1.012 | C | 1 |
| 6. | | $^4$P - $^2$D° | | | | | | | | | | | |
| | | | 145.836 | 329560 | 1015260 | 6 | 6 | 3.1 | 0.0010 | 0.0029 | −2.22 | E | 1 |
| | | | 142.617 | 306970 | 1008100 | 4 | 4 | 2.4 | 7.2(−4) | 0.0014 | −2.54 | E | 1 |
| 7. | | $^4$P - $^2$P° | | | | | | | | | | | |
| | | | [119.67] | 306970 | 1142570 | 4 | 4 | 0.88 | 1.9(−4) | 3.0(−4) | −3.12 | E | 1 |
| | | | [118.96] | 288440 | 1129060 | 2 | 2 | 0.61 | 1.3(−4) | 1.0(−4) | −3.59 | E | 1 |
| 8. | | $^2$D - $^2$D° | *202.69* | *519040* | *1012400* | 10 | 10 | 97 | 0.060 | 0.40 | −0.22 | C | 1 |
| | | | 202.172 | 520640 | 1015260 | 6 | 6 | 90 | 0.055 | 0.22 | −0.48 | C | 1 |
| | | | 203.467 | 516640 | 1008100 | 4 | 4 | 64 | 0.0395 | 0.106 | −0.80 | C | 1 |
| | | | 205.154 | 520640 | 1008100 | 6 | 4 | 26.1 | 0.0110 | 0.0446 | −1.180 | C | 1 |
| | | | 200.559 | 516640 | 1015260 | 4 | 6 | 13.7 | 0.0124 | 0.0327 | −1.305 | C | 1 |
| 9. | | $^2$D - $^2$P° | *161.54* | *519040* | *1138070* | 10 | 6 | 153 | 0.0359 | 0.191 | −0.445 | C | 1 |
| | | | 160.777 | 520640 | 1142570 | 6 | 4 | 110 | 0.0283 | 0.090 | −0.77 | C | 1 |
| | | | 163.288 | 516640 | 1129060 | 4 | 2 | 178 | 0.0356 | 0.077 | −0.85 | C | 1 |
| | | | 159.768 | 516640 | 1142570 | 4 | 4 | 30.1 | 0.0115 | 0.0242 | −1.337 | C | 1 |
| 10. | | $^2$S - $^4$S° | [377.70] | 632370 | 897130 | 2 | 4 | 0.049 | 2.1(−4) | 5.2(−4) | −3.38 | E | 1 |
| 11. | | $^2$S - $^2$D° | | | | | | | | | | | |
| | | | [266.15] | 632370 | 1008100 | 2 | 4 | 20.8 | 0.0441 | 0.077 | −1.055 | C | 1 |
| 12. | | $^2$S - $^2$P° | *197.75* | 632370 | *1138070* | 2 | 6 | 25 | 0.044 | 0.057 | −1.06 | E | 1 |
| | | | 196.010 | 632370 | 1142570 | 2 | 4 | 37.6 | 0.0433 | 0.056 | −1.062 | C | 1 |
| | | | [201.33] | 632370 | 1129060 | 2 | 2 | 0.97 | 5.9(−4) | 7.8(−4) | −2.93 | E | 1 |
| 13. | | $^2$P - $^4$S° | | | | | | | | | | | |
| | | | [494.68] | 694980 | 897130 | 4 | 4 | 0.076 | 2.8(−4) | 0.0018 | −2.95 | E | 1 |
| | | | [465.38] | 682250 | 897130 | 2 | 4 | 0.026 | 1.7(−4) | 5.2(−4) | −3.47 | E | 1 |
| 14. | | $^2$P - $^2$D° | *310.89* | *690740* | *1012400* | 6 | 10 | 21 | 0.050 | 0.31 | −0.52 | C− | 1 |
| | | | [312.23] | 694980 | 1015260 | 4 | 6 | 24 | 0.053 | 0.22 | −0.67 | C | 1 |
| | | | [306.89] | 682250 | 1008100 | 2 | 4 | 14.8 | 0.0419 | 0.085 | −1.077 | C | 1 |
| | | | [319.37] | 694980 | 1008100 | 4 | 4 | 0.92 | 0.0014 | 0.0059 | −2.25 | D | 1 |

Sc XVII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | | $^2$P - $^2$P° | *223.55* | *690740* | *1138070* | 6 | 6 | 110 | 0.084 | 0.37 | −0.30 | C− | 1 |
| | | | 223.424 | 694980 | 1142570 | 4 | 4 | 110 | 0.081 | 0.24 | −0.49 | C | 1 |
| | | | 223.821 | 682250 | 1129060 | 2 | 2 | 93 | 0.070 | 0.10 | −0.85 | C | 1 |
| | | | 230.357 | 694980 | 1129060 | 4 | 2 | 23 | 0.0092 | 0.028 | −1.43 | D | 1 |
| | | | [217.24] | 682250 | 1142570 | 2 | 4 | 1.3 | 0.0019 | 0.0027 | −2.42 | D | 1 |
| 16. | $2p$–$3s$ | $^2$P° - $^2$S | | | | | | | | | | | |
| | | | | | | 4 | 2 | | 0.020 | | −1.10 | E | *interp.* |
| | | | | | | 2 | 2 | | 0.021 | | −1.38 | E | *interp.* |
| 17. | $2p$–$3d$ | $^2$P° - $^2$D | *19.26* | *30470* | *5222000* | 6 | 10 | 7.1(+4) | 0.66 | 0.25 | 0.60 | D | *interp.* |
| | | | 19.311 | 45700 | 5224100 | 4 | 6 | 6.9(+4) | 0.58 | 0.15 | 0.37 | D | *interp.* |
| | | | 19.16 | 0 | 5219000 | 2 | 4 | 5.9(+4) | 0.65 | 0.082 | 0.11 | D | *interp.* |
| | | | [19.33] | 45700 | 5219000 | 4 | 4 | 1.1(+4) | 0.064 | 0.016 | −0.59 | D | *interp.* |
| 18. | $2p$–$4d$ | $^2$P° - $^2$D | | | | | | | | | | | |
| | | | | | | 4 | 6 | | 0.11 | | −0.36 | D | *interp.* |
| | | | | | | 2 | 4 | | 0.12 | | −0.62 | E | *interp.* |
| | | | | | | 4 | 4 | | 0.012 | | −1.32 | D | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Sc XVII

### Forbidden Transitions

The line strengths tabulated for the single magnetic dipole and single electric quadrupole transition within the $2s^22p$ ground state configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing is limited to the $n=2$ complex. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 in order to bring this value into conformance with the definition of the quadrupole strength used in the NBS tables.

Transition probabilities for the same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their orbital basis includes many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. The line strengths for both the M1 and E2 transitions, derived from these data by interpolation between appropriately spaced ions of the B sequence, are in very good agreement with the data of Cheng *et al.*[1]

### References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).


Sc XVII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p$–$2p$ | $^2$P° – $^2$P° | | | | | | | | | | |
| | | | 2190.5 | 0 | 45637 | 2 | 4 | M1 | 853 | 1.33 | B | 1 |
| | | | ″ | ″ | ″ | 2 | 4 | E2 | 0.031 | 0.0037 | C | 1 |

# Sc XVIII

Be Isoelectronic Sequence

Ground State: $1s^2 2s^2\ ^1S_0$

Ionization Energy: 1213 eV = 9780000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 17.25 | 11 | 18.38 | 29 | 18.85 | 28 | 186.94 | 4 |
| 17.35 | 11 | 18.39 | 12 | 18.92 | 19 | 203.44 | 3 |
| 17.40 | 10 | 18.45 | 29 | 18.97 | 19,25 | 207.62 | 3 |
| 17.44 | 10 | 18.46 | 29 | 19.03 | 30 | 207.98 | 7 |
| 17.53 | 8 | 18.53 | 27,29 | 19.10 | 19 | 213.68 | 3 |
| 17.55 | 10 | 18.54 | 29 | 19.13 | 31 | 218.74 | 3 |
| 17.57 | 9 | 18.55 | 27 | 19.22 | 21 | 224.61 | 3 |
| 17.77 | 16 | 18.58 | 27 | 19.28 | 21,35 | 230.62 | 3 |
| 17.96 | 15 | 18.61 | 27 | 19.31 | 21 | 330.34 | 6 |
| 18.08 | 14 | 18.63 | 27 | 19.36 | 21 | 348.60 | 1 |
| 18.18 | 24 | 18.64 | 33 | 19.40 | 21 | 444.52 | 5 |
| 18.21 | 24 | 18.65 | 34 | 19.45 | 21,22 | 496.48 | 5 |
| 18.23 | 24 | 18.69 | 27 | 19.78 | 20 | 559.82 | 5 |
| 18.29 | 13 | 18.77 | 28 | 20.15 | 23 | | |
| 18.33 | 24 | 18.78 | 26 | 175.65 | 4 | | |
| 18.34 | 24 | 18.82 | 32 | 180.69 | 2 | | |

Oscillator strengths for transitions of the arrays $2s^2$–$2s2p$ and $2s2p$–$2p^2$ are taken from the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include the configuration interaction most relevant for the states of these configurations, as well as a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except for the weakest intercombination lines. (The $^3P_1^\circ$ – $^1S_0$ transition of the $2s2p$–$2p^2$ array has been omitted here, since the $f$-value is considerably smaller than those of the other lines of this array.)

A number of sources of reliable data, from other relativistic calculations, are available for the $2s$–$2p$ transitions. However, with the exception of some of the weaker lines, they all agree well with the results of Cheng *et al.*[1] The latter are quoted exclusively here since they provide data from a single set of comprehensive calculations, all done at a uniform and reasonably accurate level of approximation, for the valence shell $2s$–$2p$ transitions for all ions of the isoelectronic sequence.

The $f$-values for the $2s^2$–$2s3p$, $2s2p$–$2p3p$, $2s2p$–$2s3s$, $2p^2$–$2p3s$, $2s2p$–$2s3d$, and $2p^2$–$2p3d$ arrays of transitions are taken from the work of Fawcett,[2] who used Cowan's version of the relativistic Hartree-Fock method with intermediate coupling and configuration interaction. This work provides a comprehensive set of data for the entire isoelectronic sequence, calculated at a uniform level of approximation. Some of these transitions, for some ions of this sequence, have also been calculated by Bhatia *et al.*[3] using the program SUPERSTRUCTURE, which includes configuration interaction and intermediate coupling. Where they overlap, these two sets of calculations agree to within the uncertainties assigned here. Transitions involving the $J=1$ levels of $2p3p\ ^3S$ and $^3P$ have been omitted because of erratic behavior of the $f$-values along the sequence.

Oscillator strengths for the transition array $2s^2$–$2s4p$ have been interpolated from the relativistic random phase approximation (RRPA) calculations along the isoelectronic sequence by Lin and Johnson.[4]

A few multiplet $f$-values for transitions involving the outer electron alone, $2s3s$–$2s3p$ and $2s3p$–$2s3d$, have been interpolated along the isoelectronic sequence and assigned a low accuracy.

## References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]B. C. Fawcett, At. Data Nucl. Data Tables **30**, 1 (1984); **33**, 479 (1985).
[3]A. K. Bhatia, U. Feldman, and J. F. Seely, At. Data Nucl. Data Tables **35**, 449 (1986).
[4]C. D. Lin and W. R. Johnson, Phys. Rev. A **15**, 1046 (1977).

Sc XVIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^2$–$2s2p$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [348.60] | 0 | 286860 | 1 | 3 | 0.093 | 5.1(−4)[a] | 5.9(−4) | −3.29 | D | 1 |
| 2. | | $^1$S - $^1$P° | [180.69] | 0 | 553440 | 1 | 3 | 124 | 0.182 | 0.108 | −0.740 | B | 1 |
| 3. | $2s2p$–$2p^2$ | $^3$P° - $^3$P | *216.93* | *304440* | *765410* | 9 | 9 | 95.7 | 0.0675 | 0.434 | −0.216 | B | 1 |
| | | | [218.74] | 321240 | 778400 | 5 | 5 | 66.4 | 0.0476 | 0.171 | −0.623 | B | 1 |
| | | | [213.68] | 286860 | 754860 | 3 | 3 | 25.7 | 0.0176 | 0.0371 | −1.277 | B | 1 |
| | | | [230.62] | 321240 | 754860 | 5 | 3 | 34.3 | 0.0164 | 0.0623 | −1.086 | B | 1 |
| | | | [224.61] | 286860 | 732070 | 3 | 1 | 89.6 | 0.0226 | 0.0501 | −1.169 | B | 1 |
| | | | [203.44] | 286860 | 778400 | 3 | 5 | 30.5 | 0.0315 | 0.0633 | −1.025 | B | 1 |
| | | | [207.62] | 273200 | 754860 | 1 | 3 | 37.8 | 0.0733 | 0.0501 | −1.135 | B | 1 |
| 4. | | $^3$P° - $^1$D | | | | | | | | | | | |
| | | | [186.94] | 321240 | 856160 | 5 | 5 | 10 | 0.0053 | 0.016 | −1.58 | C | 1 |
| | | | [175.65] | 286860 | 856160 | 3 | 5 | 0.75 | 5.8(−4) | 0.0010 | −2.76 | D | 1 |
| 5. | | $^1$P° - $^3$P | | | | | | | | | | | |
| | | | [444.52] | 553440 | 778400 | 3 | 5 | 0.67 | 0.0033 | 0.014 | −2.00 | D | 1 |
| | | | [496.48] | 553440 | 754860 | 3 | 3 | 0.014 | 5.2(−5) | 2.5(−4) | −3.81 | E | 1 |
| | | | [559.82] | 553440 | 732070 | 3 | 1 | 0.10 | 1.6(−4) | 8.8(−4) | −3.32 | E | 1 |
| 6. | | $^1$P° - $^1$D | [330.34] | 553440 | 856160 | 3 | 5 | 26.1 | 0.0711 | 0.232 | −0.671 | B | 1 |
| 7. | | $^1$P° - $^1$S | [207.98] | 553440 | 1034250 | 3 | 1 | 208 | 0.0449 | 0.0922 | −0.871 | B | 1 |
| 8. | $2s^2$–$2s3p$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [17.53] | 0 | [5703000] | 1 | 3 | 2.3(+4) | 0.32 | 0.018 | −0.49 | C− | 2 |
| 9. | | $^1$S - $^1$P° | [17.57] | 0 | 5692000 | 1 | 3 | 2.6(+4) | 0.36 | 0.021 | −0.44 | C− | 2 |
| 10. | $2s2p$–$2p3p$ | $^3$P° - $^3$D | | | | | | | | | | | |
| | | | [17.44] | 321240 | 6054000 | 5 | 7 | 2.2(+4) | 0.14 | 0.040 | −0.15 | C− | 2 |
| | | | [17.44] | 286860 | [6020000] | 3 | 5 | 1.8(+4) | 0.14 | 0.024 | −0.38 | C− | 2 |
| | | | [17.40] | 273200 | [6021000] | 1 | 3 | 5500 | 0.075 | 0.0043 | −1.13 | D | 2 |
| | | | [17.55] | 321240 | [6020000] | 5 | 5 | 1900 | 0.0086 | 0.0025 | −1.37 | D | 2 |
| | | | [17.44] | 286860 | [6021000] | 3 | 3 | 8800 | 0.040 | 0.0069 | −0.92 | D | 2 |
| 11. | | $^3$P° - $^3$P | | | | | | | | | | | |
| | | | [17.35] | 321240 | [6084000] | 5 | 5 | 2.2(+4) | 0.10 | 0.029 | −0.30 | C− | 2 |
| | | | [17.35] | 286860 | [6050000] | 3 | 1 | 2.7(+4) | 0.040 | 0.0069 | −0.92 | D | 2 |
| | | | [17.25] | 286860 | [6084000] | 3 | 5 | 2700 | 0.020 | 0.0034 | −1.22 | D | 2 |
| 12. | | $^1$P° - $^1$P | [18.39] | 553440 | [5990000] | 3 | 3 | 1.2(+4) | 0.063 | 0.011 | −0.72 | D | 2 |
| 13. | | $^1$P° - $^3$D | | | | | | | | | | | |
| | | | [18.29] | 553440 | [6021000] | 3 | 3 | 9400 | 0.047 | 0.0085 | −0.85 | D | 2 |
| 14. | | $^1$P° - $^3$P | | | | | | | | | | | |
| | | | [18.08] | 553440 | [6084000] | 3 | 5 | 3800 | 0.031 | 0.0055 | −1.03 | D | 2 |
| 15. | | $^1$P° - $^1$D | [17.96] | 553440 | [6120000] | 3 | 5 | 3.2(+4) | 0.26 | 0.046 | −0.11 | C− | 2 |

Sc XVIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16. | | $^1P^o - {}^1S$ | [17.77] | 553440 | [6181000] | 3 | 1 | 2.5(+4) | 0.040 | 0.0070 | −0.92 | D | 2 |
| 17. | $2s^2$–$2s4p$ | $^1S - {}^3P^o$ | | | | | | | | | | | |
| | | | | | | 1 | 3 | | 0.014 | | −1.85 | D | *interp.* |
| 18. | | $^1S - {}^1P^o$ | | | | 1 | 3 | | 0.16 | | −0.80 | D | *interp.* |
| 19. | $2s2p$–$2s3s$ | $^3P^o - {}^3S$ | *19.03* | *304440* | [5558000] | 9 | 3 | 1.6(+4) | 0.028 | 0.016 | −0.59 | D | 2 |
| | | | [19.10] | 321240 | [5558000] | 5 | 3 | 8500 | 0.028 | 0.0088 | −0.85 | D | 2 |
| | | | [18.97] | 286860 | [5558000] | 3 | 3 | 5200 | 0.028 | 0.0052 | −1.08 | D | 2 |
| | | | [18.92] | 273200 | [5558000] | 1 | 3 | 1800 | 0.029 | 0.0018 | −1.54 | D | 2 |
| 20. | | $^1P^o - {}^1S$ | [19.78] | 553440 | [5609000] | 3 | 1 | 5600 | 0.011 | 0.0021 | −1.48 | D | 2 |
| 21. | $2p^2$–$2p3s$ | $^3P - {}^3P^o$ | *19.33* | *765410* | *[5939000]* | 9 | 9 | 1.0(+4) | 0.058 | 0.033 | −0.29 | D | 2 |
| | | | [19.31] | 778400 | [5957000] | 5 | 5 | 7500 | 0.042 | 0.013 | −0.68 | D | 2 |
| | | | [19.36] | 754860 | [5919000] | 3 | 3 | 2300 | 0.013 | 0.0025 | −1.41 | D | 2 |
| | | | [19.45] | 778400 | [5919000] | 5 | 3 | 4400 | 0.015 | 0.0048 | −1.12 | D | 2 |
| | | | [19.40] | 754860 | [5910000] | 3 | 1 | 9600 | 0.018 | 0.0034 | −1.27 | D | 2 |
| | | | [19.22] | 754860 | [5957000] | 3 | 5 | 3100 | 0.029 | 0.0055 | −1.06 | D | 2 |
| | | | [19.28] | 732070 | [5919000] | 1 | 3 | 3500 | 0.058 | 0.0037 | −1.24 | D | 2 |
| 22. | | $^1D - {}^1P^o$ | [19.45] | 856160 | [5997000] | 5 | 3 | 8800 | 0.030 | 0.0096 | −0.82 | D | 2 |
| 23. | | $^1S - {}^1P^o$ | [20.15] | 1034250 | [5997000] | 1 | 3 | 3300 | 0.060 | 0.0040 | −1.22 | D | 2 |
| 24. | $2s2p$–$2s3d$ | $^3P^o - {}^3D$ | *18.28* | *304440* | *[5775000]* | 9 | 15 | 8.6(+4) | 0.72 | 0.388 | 0.81 | C− | 2 |
| | | | [18.34] | 321240 | 5775000 | 5 | 7 | 8.5(+4) | 0.60 | 0.18 | 0.48 | C− | 2 |
| | | | [18.21] | 286860 | 5777000 | 3 | 5 | 6.5(+4) | 0.54 | 0.097 | 0.21 | C− | 2 |
| | | | [18.18] | 273200 | [5773000] | 1 | 3 | 4.9(+4) | 0.73 | 0.044 | −0.14 | C− | 2 |
| | | | [18.33] | 321240 | 5777000 | 5 | 5 | 2.2(+4) | 0.11 | 0.033 | −0.26 | C− | 2 |
| | | | [18.23] | 286860 | [5773000] | 3 | 3 | 3.6(+4) | 0.18 | 0.032 | −0.27 | C− | 2 |
| | | | [18.34] | 321240 | [5773000] | 5 | 3 | 2400 | 0.0072 | 0.0022 | −1.44 | C− | 2 |
| 25. | | $^1P^o - {}^1D$ | [18.97] | 553440 | [5824000] | 3 | 5 | 6.8(+4) | 0.61 | 0.11 | 0.26 | C− | 2 |
| 26. | $2p^2$–$2p3d$ | $^3P - {}^3F^o$ | | | | | | | | | | | |
| | | | [18.78] | 778400 | [6103000] | 5 | 7 | 1.3(+4) | 0.098 | 0.030 | −0.31 | C− | 2 |
| 27. | | $^3P - {}^3D^o$ | *18.57* | *765410* | *[6149000]* | 9 | 15 | 9.2(+4) | 0.79 | 0.435 | 0.85 | C− | 2 |
| | | | [18.58] | 778400 | 6160000 | 5 | 7 | 1.0(+5) | 0.74 | 0.23 | 0.57 | C− | 2 |
| | | | [18.55] | 754860 | [6145000] | 3 | 5 | 6.6(+4) | 0.57 | 0.10 | 0.23 | C− | 2 |
| | | | [18.53] | 732070 | [6128000] | 1 | 3 | 8.2(+4) | 1.27 | 0.077 | 0.104 | C− | 2 |
| | | | [18.63] | 778400 | [6145000] | 5 | 5 | 3500 | 0.018 | 0.0055 | −1.05 | D | 2 |
| | | | [18.61] | 754860 | [6128000] | 3 | 3 | 2.3(+4) | 0.12 | 0.022 | −0.44 | C− | 2 |
| | | | [18.69] | 778400 | [6128000] | 5 | 3 | 170 | 5.2(−4) | 1.6(−4) | −2.59 | D | 2 |
| 28. | | $^3P - {}^1D^o$ | | | | | | | | | | | |
| | | | [18.85] | 778400 | [6083000] | 5 | 5 | 2800 | 0.015 | 0.0047 | −1.12 | C− | 2 |
| | | | [18.77] | 754860 | [6083000] | 3 | 5 | 3.0(+4) | 0.26 | 0.048 | −0.11 | D | 2 |

Sc XVIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | | $^3$P - $^3$P° | *18.49* | *765410* | *[6173000]* | 9 | 9 | 6.8(+4) | 0.347 | 0.190 | 0.494 | C− | 2 |
| | | | [18.54] | 778400 | [6171000] | 5 | 5 | 6.2(+4) | 0.320 | 0.098 | 0.204 | C− | 2 |
| | | | [18.45] | 754860 | [6174000] | 3 | 3 | 4.1(+4) | 0.21 | 0.038 | −0.20 | C− | 2 |
| | | | [18.53] | 778400 | [6174000] | 5 | 3 | 2.7(+4) | 0.084 | 0.026 | −0.38 | C− | 2 |
| | | | [18.45] | 754860 | [6176000] | 3 | 1 | 6.5(+4) | 0.11 | 0.020 | −0.48 | C− | 1 |
| | | | [18.46] | 754860 | [6171000] | 3 | 5 | 4300 | 0.037 | 0.0067 | −0.95 | D | 2 |
| | | | [18.38] | 732070 | [6174000] | 1 | 3 | 1100 | 0.017 | 0.0010 | −1.77 | D | 2 |
| 30. | | $^1$D - $^3$F° | | | | | | | | | | | |
| | | | [19.03] | 856160 | [6110000] | 5 | 5 | 5900 | 0.032 | 0.010 | −0.80 | D | 2 |
| 31. | | $^1$D - $^1$D° | [19.13] | 856160 | [6083000] | 5 | 5 | 1.6(+4) | 0.088 | 0.028 | −0.36 | C− | 2 |
| 32. | | $^1$D - $^3$P° | | | | | | | | | | | |
| | | | [18.82] | 856160 | [6171000] | 5 | 5 | 1.1(+4) | 0.058 | 0.018 | −0.54 | C− | 2 |
| 33. | | $^1$D - $^1$P° | [18.64] | 856160 | [6222000] | 5 | 3 | 5100 | 0.016 | 0.0049 | −1.10 | D | 2 |
| 34. | | $^1$D - $^1$F° | [18.65] | 856160 | 6218000 | 5 | 7 | 1.48(+5) | 1.08 | 0.332 | 0.73 | C− | 2 |
| 35. | | $^1$S - $^1$P° | [19.28] | 1034250 | [6222000] | 1 | 3 | 7.8(+4) | 1.30 | 0.083 | 0.114 | C− | 2 |
| 36. | $2s3s$-$2s3p$ | $^3$S - $^3$P° | | | | 3 | 9 | | 0.16 | | −0.32 | D | *interp.* |
| 37. | | $^1$S - $^1$P° | | | | 1 | 3 | | 0.065 | | −1.19 | E | *interp.* |
| 38. | $2s3p$-$2s3d$ | $^3$P° - $^3$D | | | | 9 | 15 | | 0.034 | | −0.51 | E | *interp.* |
| 39. | | $^1$P° - $^1$D | | | | 3 | 5 | | 0.062 | | −0.73 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Sc XVIII

### Forbidden Transitions

Transition probabilities for magnetic dipole and electric quadrupole transitions within the $2s2p$ and $2p^2$ configurations were calculated by Oboladze and Safronova[1] and by Anderson and Anderson,[2] using a nuclear charge expansion method and a multiconfiguration relativistic Hartree-Fock method, respectively. We have given preference to the calculations of the Andersons, which we consider more advanced. However, they have treated only four of the listed transitions. In these cases, Oboladze and Safronova agree with them within 20%. For other ions of the Be sequence, the work of Oboladze and Safronova could be compared with that of various other authors, and the agreements were found to be similarly good.

#### References

[1]N. S. Oboladze and U. I. Safronova, Opt. Spectrosc. (USSR) **48**, 469 (1980).

[2]E. K. Anderson and E. M. Anderson, Opt. Spectrosc. (USSR) **52**, 478 (1982).

Sc XVIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s2p-2s2p$ | $^3P^o - {}^3P^o$ | | | | | | | | | | |
| | | | 2907.9 | 286860 | 321240 | 3 | 5 | M1 | 542 | 2.47 | C+ | 2 |
| | | | [7318.6] | 273200 | 286860 | 1 | 3 | M1 | 45 | 2.0 | C+ | 1 |
| 2. | | $^3P^o - {}^1P^o$ | | | | | | | | | | |
| | | | [430.66] | 321240 | 553440 | 5 | 3 | M1 | 2100 | 0.019 | D− | 1 |
| | | | [375.12] | 286860 | 553440 | 3 | 3 | M1 | 1900 | 0.011 | D− | 2 |
| | | | " | " | " | 3 | 3 | E2 | 6.7 | 8.9(−5)[a] | D− | 2 |
| | | | [356.84] | 273200 | 553440 | 1 | 3 | M1 | 2900 | 0.015 | D− | 1 |
| 3. | $2p^2-2p^2$ | $^3P - {}^3P$ | | | | | | | | | | |
| | | | [4246.9] | 754860 | 778400 | 3 | 5 | M1 | 155 | 2.20 | C | 1 |
| | | | [4386.7] | 732070 | 754860 | 1 | 3 | M1 | 300 | 2.82 | C | 1 |
| 4. | | $^3P - {}^1D$ | | | | | | | | | | |
| | | | [1286.0] | 778400 | 856160 | 5 | 5 | M1 | 1900 | 0.75 | D+ | 2 |
| | | | [987.2] | 754860 | 856160 | 3 | 5 | M1 | 1300 | 0.23 | D | 1 |
| 5. | | $^3P - {}^1S$ | | | | | | | | | | |
| | | | [357.92] | 754860 | 1034250 | 3 | 1 | M1 | 2.6(+4) | 0.044 | D | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XIX

Li Isoelectronic Sequence

Ground State: $1s^22s\ {}^2S_{1/2}$

Ionization Energy: 1287.98 eV = 10388200 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2.892 | 1 | 13.250 | 13 | 29.965 | 32 | 58.072 | 49 |
| 2.895 | 1,3 | 13.340 | 13 | 29.968 | 32 | 59.221 | 56 |
| 2.896 | 3 | 16.819 | 5 | 30.354 | 41 | 59.266 | 56 |
| 2.897 | 2 | 16.861 | 5 | 30.395 | 41 | 59.995 | 63 |
| 10.24 | 10 | 17.634 | 12 | 33.979 | 24 | 60.024 | 63 |
| 10.443 | 9 | 17.779 | 12 | 34.880 | 30 | 70.507 | 48 |
| 10.576 | 22 | 17.793 | 12 | 35.036 | 30 | 71.803 | 54 |
| 10.628 | 22 | 26.101 | 36 | 35.062 | 30 | 71.818 | 54 |
| 10.785 | 8,20 | 26.172 | 36 | 35.561 | 39 | 73.362 | 61 |
| 10.846 | 20 | 26.203 | 36 | 35.618 | 39 | 73.405 | 61 |
| 11.141 | 18 | 26.816 | 26 | 48.936 | 23 | 106.8 | 47 |
| 11.204 | 18 | 27.412 | 34 | 50.551 | 28 | 109.9 | 52 |
| 11.377 | 7 | 27.525 | 34 | 50.914 | 28 | 110.2 | 52 |
| 11.777 | 16 | 27.535 | 34 | 50.935 | 28 | 113.5 | 59 |
| 11.845 | 16 | 27.792 | 43 | 52.285 | 37 | 113.6 | 59 |
| 12.674 | 6 | 27.826 | 43 | 52.408 | 37 | 279.75 | 4 |
| 13.154 | 14 | 29.194 | 25 | 53.294 | 58 | 326.1 | 4 |
| 13.241 | 14 | 29.835 | 32 | 53.422 | 58 | | |

Transition probabilities for the strongest inner-shell transitions to doubly excited $n=2$ states are taken from results of the $Z$-expansion perturbation calculations of Vainshtein and Safronova.[1] Their results are in good agreement with the multiplet oscillator strengths for the $^2P^\circ - {}^2P$ and $^2P^\circ - {}^2D$ transitions of the $1s^22p-1s2p^2$ array which were calculated by Fox and Dalgarno[2] in a $Z$-expansion approximation that included large-scale configuration interaction.

Oscillator strengths for lines of the principal ($2s$–$2p$) resonance multiplet are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*,[3] which include a perturbative treatment of the Breit interaction and the Lamb shift. The results of the MCDF calculations of Armstrong *et al.*[4] were interpolated to provide $f$-values for the $2p$–$3d$ transitions.

The $f$-value for the $3d$–$4f$ transition was taken from a study of systematic trends along isoelectronic sequences by Smith and Wiese.[5] The tabulated data for many additional transitions were taken from the theoretical analysis of Martin and Wiese,[6] which was based on a generalized study of systematic trends for several spectral series of the lithium isoelectronic sequence.

Results of the relativistic Hartree-Fock calculations of Kim and Desclaux[7] for several ions of the Li sequence were incorporated into the data of Ref. 6 for the $2s$–$3p$ transitions. For all other transitions for which the results of Ref. 6 are quoted here, no relativistic calculations were available. However, the relativistic calculations of Younger and Weiss[8] for the hydrogen isoelectronic sequence provide a means of assessing the magnitude of relativistic corrections since the Li sequence is very similar in structure to the H sequence. For those transitions for which relativistic effects were estimated to be significant (specifically, whenever the ratio of the weighted relativistic hydrogenic $f$-values $g_if_{ik}$ of any two lines within a multiplet was found to deviate from the corresponding $LS$-coupling line-strength ratio by more than 5% for the appropriate value of the nuclear charge $Z$), the $f$-values were excluded from the compilation. A more detailed discussion of this comparison is given in Ref. 6.

Although the $2p$–$3s$ multiplet did not satisfy the criterion described in the paragraph above, we have nevertheless quoted the multiplet $f$-value obtained by Onello[9] using a $Z$-expansion technique based on a variational calculation for O VI that allowed for large-scale configuration interaction. The resulting multiplet oscillator strengths for Fe XXIV and Ni XXVI are in very good agreement with data derived from the results of calculations that included relativistic effects.[10,11] We thus felt that the results of Ref. 9 should be sufficiently accurate for inclusion in this compilation.

Biemont[12] has calculated $f$-values in the single-configuration Hartree-Fock approximation for numerous multiplets. His results have been used here to supplement the data taken from the abovementioned sources. Only transitions in which the principal quantum number of the lower state is less than 5 have been tabulated here.

Transition probability data are available for numerous transitions involving doubly excited states with the spectator electron occupying the $n=3$ shell.[13] These have not been tabulated, however, since they belong to, or are very close to belonging to, the unresolved satellites of the helium-like ion.

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Sc XIX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^22s$ – $1s(^2S)2s2p(^3P^\circ)$ | $^2S - {}^2P^\circ$ | *2.893* | | | 2 | 6 | 1.8(+6)[a] | 0.68 | 0.013 | 0.14 | D | 1 |
| | | | [2.892] | | | 2 | 4 | 2.0(+6) | 0.50 | 0.0096 | 0.00 | D | 1 |
| | | | [2.895] | | | 2 | 2 | 1.6(+6) | 0.20 | 0.0038 | −0.40 | D | 1 |

Sc XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | $1s^22p-1s2p^2$ | $^2P^\circ-{}^2D$ | | | | | | | | | | | |
| | | | [2.897] | | | 2 | 4 | 1.2(+6) | 0.30 | 0.0058 | −0.22 | D | 1 |
| 3. | | $^2P^\circ-{}^2P$ | | | | | | | | | | | |
| | | | [2.895] | | | 4 | 4 | 2.7(+6) | 0.34 | 0.013 | 0.13 | D | 1 |
| | | | [2.896] | | | 2 | 2 | 2.2(+6) | 0.28 | 0.0053 | −0.26 | D | 1 |
| 4. | $2s-2p$ | $^2S-{}^2P^\circ$ | *293.6* | 0 | [*340600*] | 2 | 6 | 19.2 | 0.0745 | 0.144 | −0.827 | B+ | 3 |
| | | | 279.75 | 0 | 357460 | 2 | 4 | 22.3 | 0.0523 | 0.0963 | −0.980 | B+ | 3 |
| | | | [326.1] | 0 | [306700] | 2 | 2 | 13.9 | 0.0222 | 0.0477 | −1.353 | B+ | 3 |
| 5. | $2s-3p$ | $^2S-{}^2P^\circ$ | *16.833* | 0 | *5940700* | 2 | 6 | 2.87(+4) | 0.366 | 0.0406 | −0.135 | B | 6 |
| | | | 16.819 | 0 | 5945700 | 2 | 4 | 2.85(+4) | 0.242 | 0.0268 | −0.315 | B | 6 |
| | | | 16.861 | 0 | 5930800 | 2 | 2 | 2.91(+4) | 0.124 | 0.0138 | −0.606 | B | 6 |
| 6. | $2s-4p$ | $^2S-{}^2P^\circ$ | 12.674 | 0 | 7890200 | 2 | 6 | 1.4(+4) | 0.098 | 0.0082 | −0.71 | C+ | 6 |
| 7. | $2s-5p$ | $^2S-{}^2P^\circ$ | 11.377 | 0 | 8789700 | 2 | 6 | 6900 | 0.040 | 0.0030 | −1.10 | C+ | 6 |
| 8. | $2s-6p$ | $^2S-{}^2P^\circ$ | 10.785 | 0 | 9272100 | 2 | 6 | 4030 | 0.0211 | 0.00150 | −1.375 | C+ | 6 |
| 9. | $2s-7p$ | $^2S-{}^2P^\circ$ | 10.443 | 0 | 9575800 | 2 | 6 | 2530 | 0.0124 | 8.53(−4) | −1.606 | C+ | 6 |
| 10. | $2s-8p$ | $^2S-{}^2P^\circ$ | [10.24] | | | 2 | 6 | 1600 | 0.0077 | 5.2(−4) | −1.81 | D | 12 |
| 11. | $2p-3s$ | $^2P^\circ-{}^2S$ | *18.162* | [*340600*] | [5846700] | 6 | 2 | 1.1(+4) | 0.018 | 0.0065 | −0.97 | D | 9 |
| 12. | $2p-3d$ | $^2P^\circ-{}^2D$ | *17.731* | [*340600*] | [*5980300*] | 6 | 10 | 8.61(+4) | 0.677 | 0.237 | 0.609 | B | *interp.* |
| | | | 17.779 | 357460 | 5982100 | 4 | 6 | 8.58(+4) | 0.610 | 0.143 | 0.387 | B | *interp.* |
| | | | 17.634 | [306700] | [5977600] | 2 | 4 | 7.21(+4) | 0.672 | 0.0780 | 0.128 | B | *interp.* |
| | | | [17.793] | 357460 | [5977600] | 4 | 4 | 1.4(+4) | 0.068 | 0.016 | −0.57 | B | *interp.* |
| 13. | $2p-4s$ | $^2P^\circ-{}^2S$ | *13.310* | [*340600*] | [7853800] | 6 | 2 | 4200 | 0.0037 | 9.7(−4) | −1.65 | D+ | 6 |
| | | | [13.340] | 357460 | [7853800] | 4 | 2 | 2800 | 0.0037 | 6.5(−4) | −1.83 | D+ | *ls* |
| | | | [13.250] | [306700] | [7853800] | 2 | 2 | 1400 | 0.0037 | 3.2(−4) | −2.13 | D+ | *ls* |
| 14. | $2p-4d$ | $^2P^\circ-{}^2D$ | *13.212* | [*340600*] | [*7909500*] | 6 | 10 | 2.8(+4) | 0.12 | 0.031 | −0.14 | B | 6 |
| | | | 13.241 | 357460 | 7909800 | 4 | 6 | 2.8(+4) | 0.11 | 0.019 | −0.36 | B | *ls* |
| | | | 13.154 | [306700] | [7909000] | 2 | 4 | 2.2(+4) | 0.12 | 0.010 | −0.64 | B | *ls* |
| | | | 13.241 | 357460 | [7909000] | 4 | 4 | 4600 | 0.012 | 0.0021 | −1.32 | C+ | *ls* |
| 15. | $2p-5s$ | $^2P^\circ-{}^2S$ | | | | 6 | 2 | | 0.0017 | | −1.99 | D+ | 6 |
| 16. | $2p-5d$ | $^2P^\circ-{}^2D$ | *11.822* | [*340600*] | [*8799100*] | 6 | 10 | 1.29(+4) | 0.0452 | 0.0106 | −0.567 | C+ | 6 |
| | | | 11.845 | 357460 | 8799900 | 4 | 6 | 1.29(+4) | 0.0408 | 0.00636 | −0.788 | C+ | *ls* |
| | | | 11.777 | [306700] | [8797800] | 2 | 4 | 1.09(+4) | 0.0455 | 0.00353 | −1.041 | C+ | *ls* |
| | | | 11.845 | 357460 | [8797800] | 4 | 4 | 2200 | 0.0046 | 7.1(−4) | −1.74 | D | *ls* |
| 17. | $2p-6s$ | $^2P^\circ-{}^2S$ | | | | 6 | 2 | | 8.7(−4) | | −2.28 | D | 6 |
| 18. | $2p-6d$ | $^2P^\circ-{}^2D$ | *11.183* | [*340600*] | [*9282800*] | 6 | 10 | 7040 | 0.0220 | 0.00486 | −0.879 | C+ | 6 |
| | | | 11.204 | 357460 | 9282900 | 4 | 6 | 7010 | 0.0198 | 0.00292 | −1.101 | C+ | *ls* |
| | | | 11.141 | [306700] | [9282600] | 2 | 4 | 5930 | 0.0221 | 0.00162 | −1.355 | C+ | *ls* |
| | | | 11.204 | 357460 | [9282600] | 4 | 4 | 1200 | 0.0022 | 3.2(−4) | −2.06 | D | *ls* |

Sc XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19. | 2p–7s | $^2P^\circ$ – $^2S$ | | | | 6 | 2 | | 4.9(–4) | | –2.53 | D | 6 |
| 20. | 2p–7d | $^2P^\circ$ – $^2D$ | *10.826* | *[340600]* | *[9578000]* | 6 | 10 | 4340 | 0.0127 | 0.00272 | –1.118 | C+ | 6 |
| | | | 10.846 | 357460 | 9577500 | 4 | 6 | 4310 | 0.0114 | 0.00163 | –1.341 | C+ | ls |
| | | | 10.785 | [306700] | [9578800] | 2 | 4 | 3660 | 0.0128 | 9.07(–4) | –1.593 | C+ | ls |
| | | | 10.846 | 357460 | [9578800] | 4 | 4 | 710 | 0.0013 | 1.8(–4) | –2.30 | D | ls |
| 21. | 2p–8s | $^2P^\circ$ – $^2S$ | | | | 6 | 2 | | 2.8(–4) | | –2.77 | D | 12 |
| 22. | 2p–8d | $^2P^\circ$ – $^2D$ | *10.611* | *[340600]* | *[9764800]* | 6 | 10 | 2800 | 0.0080 | 0.0017 | –1.32 | D | 12 |
| | | | 10.628 | 357460 | 9766600 | 4 | 6 | 2800 | 0.0071 | 0.0010 | –1.54 | D | ls |
| | | | 10.576 | [306700] | [9762100] | 2 | 4 | 2400 | 0.0082 | 5.7(–4) | –1.79 | D | ls |
| | | | 10.628 | 357460 | [9762100] | 4 | 4 | 460 | 7.9(–4) | 1.1(–4) | –2.50 | E | ls |
| 23. | 3s–4p | $^2S$ – $^2P^\circ$ | [48.936] | [5846700] | 7890200 | 2 | 6 | 3900 | 0.42 | 0.14 | –0.08 | C | 6 |
| 24. | 3s–5p | $^2S$ – $^2P^\circ$ | [33.979] | [5846700] | 8789700 | 2 | 6 | 2040 | 0.106 | 0.0237 | –0.67 | C | 6 |
| 25. | 3s–6p | $^2S$ – $^2P^\circ$ | [29.194] | [5846700] | 9272100 | 2 | 6 | 1200 | 0.047 | 0.0090 | –1.03 | C | 6 |
| 26. | 3s–7p | $^2S$ – $^2P^\circ$ | [26.816] | [5846700] | 9575800 | 2 | 6 | 770 | 0.0248 | 0.00438 | –1.305 | C | 6 |
| 27. | 3s–8p | $^2S$ – $^2P^\circ$ | | | | 2 | 6 | | 0.0153 | | –1.51 | C | 12 |
| 28. | 3p–4d | $^2P^\circ$ – $^2D$ | *50.792* | *5940700* | *[7909500]* | 6 | 10 | 9200 | 0.59 | 0.59 | 0.55 | B | 6 |
| | | | [50.914] | 5945700 | 7909800 | 4 | 6 | 9000 | 0.52 | 0.35 | 0.32 | B | ls |
| | | | [50.551] | 5930800 | [7909000] | 2 | 4 | 7800 | 0.60 | 0.20 | 0.08 | B | ls |
| | | | [50.935] | 5945700 | [7909000] | 4 | 4 | 1500 | 0.058 | 0.039 | –0.63 | C+ | ls |
| 29. | 3p–5s | $^2P^\circ$ – $^2S$ | | | | 6 | 2 | | 0.0091 | | –1.26 | D+ | 6 |
| 30. | 3p–5d | $^2P^\circ$ – $^2D$ | *34.985* | *5940700* | *[8799100]* | 6 | 10 | 4480 | 0.137 | 0.0947 | –0.085 | C+ | 6 |
| | | | [35.036] | 5945700 | 8799900 | 4 | 6 | 4460 | 0.123 | 0.0568 | –0.308 | C+ | ls |
| | | | [34.880] | 5930800 | [8797800] | 2 | 4 | 3770 | 0.138 | 0.0316 | –0.560 | C+ | ls |
| | | | [35.062] | 5945700 | [8797800] | 4 | 4 | 740 | 0.014 | 0.0063 | –1.26 | D | ls |
| 31. | 3p–6s | $^2P^\circ$ – $^2S$ | | | | 6 | 2 | | 0.0039 | | –1.63 | C– | 6 |
| 32. | 3p–6d | $^2P^\circ$ – $^2D$ | *29.921* | *5940700* | *[9282800]* | 6 | 10 | 2490 | 0.0557 | 0.0329 | –0.476 | C+ | 6 |
| | | | [29.965] | 5945700 | 9282900 | 4 | 6 | 2470 | 0.0499 | 0.0197 | –0.700 | C+ | ls |
| | | | [29.835] | 5930800 | [9282600] | 2 | 4 | 2100 | 0.0560 | 0.0110 | –0.951 | C+ | ls |
| | | | [29.968] | 5945700 | [9282600] | 4 | 4 | 410 | 0.0056 | 0.0022 | –1.65 | D | ls |
| 33. | 3p–7s | $^2P^\circ$ – $^2S$ | | | | 6 | 2 | | 0.0019 | | –1.94 | C– | 6 |
| 34. | 3p–7d | $^2P$ – $^2D$ | *27.493* | *5940700* | *[9578000]* | 6 | 10 | 1530 | 0.0289 | 0.0157 | –0.761 | C+ | 6 |
| | | | [27.535] | 5945700 | 9577500 | 4 | 6 | 1520 | 0.0260 | 0.00942 | –0.983 | C+ | ls |
| | | | [27.412] | 5930800 | [9578800] | 2 | 4 | 1290 | 0.0290 | 0.00523 | –1.237 | C+ | ls |
| | | | [27.525] | 5945700 | [9578800] | 4 | 4 | 240 | 0.0028 | 0.0010 | –1.96 | D | ls |
| 35. | 3p–8s | $^2P^\circ$ – $^2S$ | | | | 6 | 2 | | 0.0011 | | –2.18 | D | 12 |

Sc XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36. | 3p-8d | $^2$P° - $^2$D | *26.150* | *5940700* | *[9764800]* | 6 | 10 | 1010 | 0.0173 | 0.0089 | −0.98 | C | 12 |
| | | | [26.172] | 5945700 | 9766600 | 4 | 6 | 1000 | 0.015 | 0.0053 | −1.21 | C | *ls* |
| | | | [26.101] | 5930800 | [9762100] | 2 | 4 | 850 | 0.017 | 0.0030 | −1.46 | C | *ls* |
| | | | [26.203] | 5945700 | [9762100] | 4 | 4 | 170 | 0.0017 | 5.9(−4) | −2.16 | D | *ls* |
| 37. | 3d-4p | $^2$D - $^2$P° | *52.359* | *[5980300]* | 7890200 | 10 | 6 | 510 | 0.0126 | 0.0217 | −0.90 | C | 12 |
| | | | [52.408] | 5982100 | 7890200 | 6 | 4 | 457 | 0.0126 | 0.0130 | −1.123 | C | *ls* |
| | | | [52.285] | [5977600] | 7890200 | 4 | 2 | 510 | 0.010 | 0.0072 | −1.38 | C | *ls* |
| | | | [52.285] | [5977600] | 7890200 | 4 | 4 | 50 | 0.0020 | 0.0014 | −2.09 | D | *ls* |
| 38. | 3d-4f | $^2$D - $^2$F° | | | | 10 | 14 | | 1.00 | | 1.000 | B | 5 |
| 39. | 3d-5p | $^2$D - $^2$P° | *35.595* | *[5980300]* | 8789700 | 10 | 6 | 220 | 0.0025 | 0.0029 | −1.60 | D | 12 |
| | | | [35.618] | 5982100 | 8789700 | 6 | 4 | 190 | 0.0024 | 0.0017 | −1.84 | D | *ls* |
| | | | [35.561] | [5977600] | 8789700 | 4 | 2 | 220 | 0.0021 | 9.7(−4) | −2.08 | D | *ls* |
| | | | [35.561] | [5977600] | 8789700 | 4 | 4 | 21 | 4.1(−4) | 1.9(−4) | −2.79 | E | *ls* |
| 40. | 3d-5f | $^2$D - $^2$F° | | | | 10 | 14 | | 0.157 | | 0.196 | C | 12 |
| 41. | 3d-6p | $^2$D - $^2$P° | *30.379* | *[5980300]* | 9272100 | 10 | 6 | 110 | 9.5(−4) | 9.5(−4) | −2.02 | D | 12 |
| | | | [30.395] | 5982100 | 9272100 | 6 | 4 | 100 | 9.5(−4) | 5.7(−4) | −2.24 | D | *ls* |
| | | | [30.354] | [5977600] | 9272100 | 4 | 2 | 120 | 8.0(−4) | 3.2(−4) | −2.49 | D | *ls* |
| | | | [30.354] | [5977600] | 9272100 | 4 | 4 | 11 | 1.6(−4) | 6.3(−5) | −3.20 | E | *ls* |
| 42. | 3d-6f | $^2$D - $^2$F° | | | | 10 | 14 | | 0.054 | | −0.27 | C | 12 |
| 43. | 3d-7p | $^2$D - $^2$P° | *27.813* | *[5980300]* | 9575800 | 10 | 6 | 68 | 4.7(−4) | 4.3(−4) | −2.33 | D | 12 |
| | | | [27.826] | 5982100 | 9575800 | 6 | 4 | 61 | 4.7(−4) | 2.6(−4) | −2.55 | D | *ls* |
| | | | [27.792] | [5977600] | 9575800 | 4 | 2 | 66 | 3.8(−4) | 1.4(−4) | −2.82 | D | *ls* |
| | | | [27.792] | [5977600] | 9575800 | 4 | 4 | 6.8 | 7.9(−5) | 2.9(−5) | −3.50 | E | *ls* |
| 44. | 3d-7f | $^2$D - $^2$F° | | | | 10 | 14 | | 0.0256 | | −0.59 | C | 12 |
| 45. | 3d-8p | $^2$D - $^2$P° | | | | 10 | 6 | | 2.8(−4) | | −2.55 | D | 12 |
| 46. | 3d-8f | $^2$D - $^2$F° | | | | 10 | 14 | | 0.0145 | | −0.84 | C | 12 |
| 47. | 4s-5p | $^2$S - $^2$P° | [106.8] | [7853800] | 8789700 | 2 | 6 | 900 | 0.464 | 0.326 | −0.032 | C | 6 |
| 48. | 4s-6p | $^2$S - $^2$P° | [70.507] | [7853800] | 9272100 | 2 | 6 | 570 | 0.127 | 0.059 | −0.60 | C | 6 |
| 49. | 4s-7p | $^2$S - $^2$P° | [58.072] | [7853800] | 9575800 | 2 | 6 | 360 | 0.055 | 0.021 | −0.96 | C | 6 |
| 50. | 4s-8p | $^2$S - $^2$P° | | | | 2 | 6 | | 0.0294 | | −1.231 | C | 12 |
| 51. | 4p-5s | $^2$P° - $^2$S | | | | 6 | 2 | | 0.066 | | −0.40 | C | 6 |
| 52. | 4p-5d | $^2$P° - $^2$D | *110.0* | 7890200 | *[8799100]* | 6 | 10 | 1920 | 0.579 | 1.26 | 0.541 | C+ | 6 |
| | | | [109.9] | 7890200 | 8799900 | 4 | 6 | 1920 | 0.522 | 0.756 | 0.320 | C+ | *ls* |
| | | | [110.2] | 7890200 | [8797800] | 2 | 4 | 1590 | 0.579 | 0.420 | 0.064 | C+ | *ls* |
| | | | [110.2] | 7890200 | [8797800] | 4 | 4 | 320 | 0.058 | 0.084 | −0.64 | D | *ls* |
| 53. | 4p-6s | $^2$P° - $^2$S | | | | 6 | 2 | | 0.0149 | | −1.049 | C− | 6 |

Sc XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 54. | 4p–6d | $^2P^\circ - ^2D$ | *71.808* | 7890200 | *[9282800]* | 6 | 10 | 1090 | 0.141 | 0.200 | −0.073 | C+ | 6 |
| | | | [71.803] | 7890200 | 9282900 | 4 | 6 | 1090 | 0.127 | 0.120 | −0.294 | C+ | *ls* |
| | | | [71.818] | 7890200 | [9282600] | 2 | 4 | 912 | 0.141 | 0.0667 | −0.550 | C+ | *ls* |
| | | | [71.818] | 7890200 | [9282600] | 4 | 4 | 170 | 0.014 | 0.013 | −1.27 | D | *ls* |
| 55. | 4p–7s | $^2P^\circ - ^2S$ | | | | 6 | 2 | | 0.0061 | | −1.44 | C− | 6 |
| 56. | 4p–7d | $^2P^\circ - ^2D$ | *59.249* | 7890200 | *[9578000]* | 6 | 10 | 701 | 0.0615 | 0.0720 | −0.433 | C+ | 6 |
| | | | [59.266] | 7890200 | 9577500 | 4 | 6 | 701 | 0.0554 | 0.0432 | −0.655 | C+ | *ls* |
| | | | [59.221] | 7890200 | [9578800] | 2 | 4 | 585 | 0.0616 | 0.0240 | −0.910 | C+ | *ls* |
| | | | [59.221] | 7890200 | [9578800] | 4 | 4 | 120 | 0.0062 | 0.0048 | −1.61 | D | *ls* |
| 57. | 4p–8s | $^2P^\circ - ^2S$ | | | | 6 | 2 | | 0.0032 | | −1.72 | D | 12 |
| 58. | 4p–8d | $^2P^\circ - ^2D$ | *53.345* | 7890200 | *[9764800]* | 6 | 10 | 463 | 0.0329 | 0.0347 | −0.70 | C | 12 |
| | | | [53.294] | 7890200 | 9766600 | 4 | 6 | 464 | 0.0296 | 0.0208 | −0.93 | C | *ls* |
| | | | [53.422] | 7890200 | [9762100] | 2 | 4 | 385 | 0.0330 | 0.0116 | −1.181 | C | *ls* |
| | | | [53.422] | 7890200 | [9762100] | 4 | 4 | 76 | 0.0033 | 0.0023 | −1.88 | D | *ls* |
| 59. | 4d–5p | $^2D - ^2P^\circ$ | *113.6* | *[7909500]* | 8789700 | 10 | 6 | 270 | 0.0314 | 0.117 | −0.50 | C | 12 |
| | | | [113.6] | 7909800 | 8789700 | 6 | 4 | 240 | 0.031 | 0.070 | −0.73 | C | *ls* |
| | | | [113.5] | [7909000] | 8789700 | 4 | 2 | 270 | 0.0261 | 0.0390 | −0.98 | C | *ls* |
| | | | [113.5] | [7909000] | 8789700 | 4 | 4 | 27 | 0.0052 | 0.0078 | −1.68 | D | *ls* |
| 60. | 4d–5f | $^2D - ^2F^\circ$ | | | | 10 | 14 | | 0.889 | | 0.949 | B | 12 |
| 61. | 4d–6p | $^2D - ^2P^\circ$ | *73.389* | *[7909500]* | 9272100 | 10 | 6 | 130 | 0.0065 | 0.016 | −1.19 | D | 12 |
| | | | [73.405] | 7909800 | 9272100 | 6 | 4 | 120 | 0.0066 | 0.0096 | −1.40 | D | *ls* |
| | | | [73.362] | [7909000] | 9272100 | 4 | 2 | 140 | 0.0055 | 0.0053 | −1.66 | D | *ls* |
| | | | [73.362] | [7909000] | 9272100 | 4 | 4 | 14 | 0.0011 | 0.0011 | −2.34 | E | *ls* |
| 62. | 4d–6f | $^2D - ^2F^\circ$ | | | | 10 | 14 | | 0.186 | | 0.270 | C | 12 |
| 63. | 4d–7p | $^2D - ^2P^\circ$ | *60.013* | *[7909500]* | 9575800 | 10 | 6 | 77 | 0.0025 | 0.0049 | −1.60 | D | 12 |
| | | | [60.024] | 7909800 | 9575800 | 6 | 4 | 68 | 0.0024 | 0.0029 | −1.83 | D | *ls* |
| | | | [59.995] | [7909000] | 9575800 | 4 | 2 | 75 | 0.0020 | 0.0016 | −2.09 | D | *ls* |
| | | | [59.995] | [7909000] | 9575800 | 4 | 4 | 7.7 | 4.2(−4) | 3.3(−4) | −2.78 | E | *ls* |
| 64. | 4d–7f | $^2D - ^2F^\circ$ | | | | 10 | 14 | | 0.072 | | −0.14 | C | 12 |
| 65. | 4d–8p | $^2D - ^2P^\circ$ | | | | 10 | 6 | | 0.0013 | | −1.89 | D | 12 |
| 66. | 4d–8f | $^2D - ^2F^\circ$ | | | | 10 | 14 | | 0.0366 | | −0.437 | C | 12 |
| 67. | 4f–5d | $^2F^\circ - ^2D$ | | | | 14 | 10 | | 0.0090 | | −0.90 | D | 12 |
| 68. | 4f–6d | $^2F^\circ - ^2D$ | | | | 14 | 10 | | 0.0016 | | −1.65 | D | 12 |
| 69. | 4f–7d | $^2F^\circ - ^2D$ | | | | 14 | 10 | | 5.7(−4) | | −2.10 | D | 12 |
| 70. | 4f–8d | $^2F^\circ - ^2D$ | | | | 14 | 10 | | 2.7(−4) | | −2.42 | D | 12 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XIX

## Forbidden Transitions

The single magnetic dipole transition within the $1s^22p$ configuration has the line strength of 1.33 in the absence of relativistic effects in the wavefunctions.[1] It is estimated that these effects are negligible, since comprehensive relativistic calculations by Cheng *et al.*[2] for the analogous transition in the $1s^22s^22p$ configuration of the boron sequence show that such relativistic corrections are negligible until much more highly charged ions.

The listed transition probability datum is also expected to be quite accurate since the energy levels are derived from experimental data.

An electric quadrupole transition at the same wavelength is estimated to be of negligible strength, as calculated by Bhatia[3] for this transition in the case of Mn XXIII.

### References

[1]W. L. Wiese, M. W. Smith, and B. M. Miles, "Atomic Transition Probabilities", Vol. II, NSRDS-NBS 22, U.S. Govt. Print. Office, Washington, DC 1969.
[2]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[3]A. K. Bhatia, private communication (1986).

Sc XIX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p-2p$ | $^2P^\circ - {}^2P^\circ$ | | | | | | | | | | |
| | | | [1972.4] | 306700 | 357400 | 2 | 4 | M1 | 1170 | 1.33 | B | *interp.* |

# Sc XX

He Isoelectronic Sequence

Ground State: $1s^2\ {}^1S_0$

Ionization Energy: 5674.8 eV = 45770000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2.2719 | 16 | 2.759 | 3,6 | 11.983 | 30 | 47.288 | 44 |
| 2.2724 | 15 | 2.760 | 6 | 12.197 | 31 | 98.049 | 54 |
| 2.3241 | 14 | 2.761 | 6,9 | 15.638 | 20 | 99.147 | 55 |
| 2.3251 | 13 | 2.768 | 8 | 16.014 | 21 | 101.3 | 57 |
| 2.4454 | 12 | 2.789 | 5 | 16.255 | 26 | 102.2 | 58 |
| 2.4482 | 11 | 2.8728 | 2 | 16.565 | 27 | 280.0 | 18 |
| 2.743 | 10 | 2.8867 | 1 | 31.126 | 40 | 427.4 | 17 |
| 2.751 | 4 | 10.466 | 24 | 31.541 | 41 | 526.6 | 17 |
| 2.752 | 7 | 10.675 | 25 | 31.754 | 47 | 552.8 | 17 |
| 2.754 | 3 | 10.691 | 34 | 32.122 | 48 | 622.7 | 19 |
| 2.756 | 6 | 10.873 | 35 | 45.155 | 38 | | |
| 2.757 | 6 | 11.687 | 22 | 45.832 | 39 | | |
| 2.758 | 3,6 | 11.934 | 23 | 46.722 | 43 | | |

Oscillator strengths for transitions of the $1s^2$–$1s2p$ array are taken from the results of Drake,[1] who incorporated accurate nonrelativistic matrix elements and Dirac hydrogenic matrix elements into a $Z$-expansion technique in order to provide $f$-values which would accurately reflect correlation effects for low-$Z$ ions and relativistic effects for high-$Z$ ions of the helium isoelectronic sequence. The $f$-values for the $1s^2\ {}^1S$ - $1snp\ {}^3P°$ ($n=3$–5) transitions were interpolated from results of the relativistic random phase approximation (RRPA) calculations of Johnson and Lin.[2] Data for other $s$–$p$ and $p$–$s$ transitions were interpolated from the RRPA results of Lin *et al.*,[3] with the exception of the $2s$–$2p$ transitions, where we tabulate the actual published RRPA $A$-values of these same authors.[4]

The charge expansion results of Laughlin[5] are given for various $p$–$d$ and $d$–$p$ transitions, as well as transitions between $4d$ and $4f$ levels. For those multiplets involving no change in principal quantum number ($3p$–$3d$, $4p$–$4d$, $4d$–$4f$) the $f$-values should be considered rather uncertain, since they are sensitive to energy differences. Oscillator strengths for the $2p$–$3d$ transitions and for $1s3p\ {}^3P°$ - $1s3d\ {}^3D$, were interpolated from the variational calculations of Weiss.[6] Both of these calculations indicate that, unlike the triplets, the $nd\ {}^1D$ energy levels ($n=3,4$) lie below the $np\ {}^1P°$ levels, and the $4f\ {}^1F°$ lies below the $4d\ {}^1D$.

Brown and Cortez[7] have provided $f$-values for numerous $d$–$f$ and $f$–$d$ transitions for the isoelectronic sequence by fitting $Z$-expansion formulas to the results of variational calculations for the low-$Z$ ions. Their results for transitions between the lower-lying D and F° terms are tabulated here.

Transition probabilities for the stronger transitions involving the doubly excited $n=2$ states are taken from the comprehensive, charge expansion perturbation theory calculations of Vainshtein and Safronova.[8] Numerous data are also available for transitions involving doubly excited states where the spectator electron has principal quantum number $n=3$.[9] However, these data are not tabulated here since most of the transitions are very close to belonging to the unresolved satellites of the H-like ions, if they do not in fact do so.

## References


[1]G. W. F. Drake, Phys. Rev. A **19**, 1387 (1979).
[2]W. R. Johnson and C. D. Lin, Phys. Rev. A **14**, 565 (1976).
[3]C. D. Lin, W. R. Johnson, and A. Dalgarno, Astrophys. J. **217**, 1011 (1977).
[4]C. D. Lin, W. R. Johnson, and A. Dalgarno, Phys. Rev. A **15**, 154 (1977).
[5]C. J. Laughlin, J. Phys. B **6**, 1942 (1973).
[6]A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **71**, 163 (1967).
[7]R. T. Brown and J.-L. M. Cortez, Astrophys. J. **176**, 267 (1972).
[8]L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **21**, 49 (1978).
[9]L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **25**, 311 (1980).


Sc XX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2$–$1s2p$ | $^1S$ - $^3P°$ | | | | | | | | | | | |
| | | | [2.8867] | 0 | [34641600] | 1 | 3 | 7.42(+4)[a] | 0.0278 | 2.64(−4) | −1.556 | B | 1 |
| 2. | | $^1S$ - $^1P°$ | [2.8728] | 0 | [34808800] | 1 | 3 | 2.00(+6) | 0.741 | 0.00701 | −0.130 | B | 1 |
| 3. | $1s2s$–$2s2p$ | $^3S$ - $^3P°$ | *2.756* | [34451700] | [*70740000*] | 3 | 9 | 1.19(+6) | 0.408 | 0.0111 | 0.088 | C | 8 |
| | | | [2.754] | [34451700] | [70760000] | 3 | 5 | 1.2(+6) | 0.23 | 0.0062 | −0.17 | C | 8 |
| | | | [2.758] | [34451700] | [71710000] | 3 | 3 | 1.2(+6) | 0.14 | 0.0037 | −0.39 | C | 8 |
| | | | [2.759] | [34451700] | [70700000] | 3 | 1 | 1.2(+6) | 0.046 | 0.0012 | −0.86 | C | 8 |
| 4. | | $^1S$ - $^1P°$ | [2.751] | [34648200] | [71000000] | 1 | 3 | 1.2(+6) | 0.41 | 0.0037 | −0.39 | C | 8 |
| 5. | $1s2p$ - $2s^2$ | $^1P°$ - $^1S$ | [2.789] | [34808800] | [70670000] | 3 | 1 | 3.6(+5) | 0.014 | 3.9(−4) | −1.38 | D | 8 |
| 6. | $1s2p$–$2p^2$ | $^3P°$ - $^3P$ | *2.759* | [*34665100*] | [*70920000*] | 9 | 9 | 2.3(+6) | 0.26 | 0.021 | 0.36 | D+ | 8 |
| | | | [2.759] | [34685700] | [70940000] | 5 | 5 | 1.5(+6) | 0.17 | 0.0078 | −0.07 | C | 8 |
| | | | [2.758] | [34641600] | [70900000] | 3 | 3 | 5.8(+5) | 0.066 | 0.0018 | −0.70 | D | 8 |
| | | | [2.761] | [34685700] | [70900000] | 5 | 3 | 9.9(+5) | 0.068 | 0.0031 | −0.47 | D | 8 |
| | | | [2.760] | [34641600] | [70870000] | 3 | 1 | 2.3(+6) | 0.088 | 0.0024 | −0.58 | C | 8 |
| | | | [2.756] | [34641600] | [70940000] | 3 | 5 | 6.6(+5) | 0.13 | 0.0034 | −0.43 | D | 8 |
| | | | [2.757] | [34632600] | [70900000] | 1 | 3 | 8.0(+5) | 0.27 | 0.0025 | −0.56 | D | 8 |
| 7. | | $^3P°$ - $^1D$ | | | | | | | | | | | |
| | | | [2.752] | [34685700] | [71030000] | 5 | 5 | 2.6(+5) | 0.030 | 0.0013 | −0.83 | D | 8 |

Sc xx: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^1$P° – $^3$P | | | | | | | | | | | |
| | | | [2.768] | [34808800] | [70940000] | 3 | 5 | 2.0(+5) | 0.038 | 0.0010 | −0.94 | D | 8 |
| 9. | | $^1$P° – $^1$D | [2.761] | [34808800] | [71030000] | 3 | 5 | 2.1(+6) | 0.40 | 0.011 | 0.08 | C | 8 |
| 10. | | $^1$P° – $^1$S | [2.743] | [34808800] | [71270000] | 3 | 1 | 2.0(+6) | 0.075 | 0.0020 | −0.65 | C | 8 |
| 11. | $1s^2$–$1s3p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [2.4482] | 0 | [40846200] | 1 | 3 | 2.4(+4) | 0.0064 | 5.2(−5) | −2.19 | E | *interp.* |
| 12. | | $^1$S – $^1$P° | [2.4454] | 0 | [40892800] | 1 | 3 | 5.32(+5) | 0.143 | 0.00115 | −0.845 | C+ | *interp.* |
| 13. | $1s^2$–$1s4p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [2.3251] | 0 | [43008300] | 1 | 3 | 1.0(+4) | 0.0025 | 1.9(−5) | −2.60 | E | *interp.* |
| 14. | | $^1$S – $^1$P° | [2.3241] | 0 | [43027500] | 1 | 3 | 2.17(+5) | 0.0527 | 4.03(−4) | −1.278 | C+ | *interp.* |
| 15. | $1s^2$–$1s5p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [2.2724] | 0 | [44006400] | 1 | 3 | 5200 | 0.0012 | 9.0(−6) | −2.92 | E | *interp.* |
| 16. | | $^1$S – $^1$P° | [2.2719] | 0 | [44016100] | 1 | 3 | 1.09(+5) | 0.0254 | 1.90(−4) | −1.595 | C+ | *interp.* |
| 17. | $1s2s$–$1s2p$ | $^3$S – $^3$P° | *468.6* | [34451700] | [*34665100*] | 3 | 9 | 4.44 | 0.0439 | 0.203 | −0.881 | B | 4 |
| | | | [427.4] | [34451700] | [34685700] | 3 | 5 | 5.90 | 0.0269 | 0.114 | −1.093 | B | 4 |
| | | | [526.6] | [34451700] | [34641600] | 3 | 3 | 3.07 | 0.0128 | 0.0664 | −1.417 | B | 4 |
| | | | [552.8] | [34451700] | [34632600] | 3 | 1 | 2.74 | 0.00418 | 0.0228 | −1.901 | B | 4 |
| 18. | | $^3$S – $^1$P° | | | | | | | | | | | |
| | | | [280.0] | [34451700] | [34808800] | 3 | 3 | 0.728 | 8.56(−4) | 0.00237 | −2.591 | B | 4 |
| 19. | | $^1$S – $^1$P° | [622.7] | [34648200] | [34808800] | 1 | 3 | 1.91 | 0.0333 | 0.0683 | −1.477 | B | 4 |
| 20. | $1s2s$–$1s3p$ | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [15.638] | [34451700] | [40846200] | 3 | 3 | 3.41(+4) | 0.125 | 0.0193 | −0.426 | C | *interp.* |
| 21. | | $^1$S – $^1$P° | [16.014] | [34648200] | [40892800] | 1 | 3 | 3.26(+4) | 0.376 | 0.0198 | −0.425 | C | *interp.* |
| 22. | $1s2s$–$1s4p$ | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [11.687] | [34451700] | [43008300] | 3 | 3 | 1.5(+4) | 0.030 | 0.0035 | −1.05 | C+ | *interp.* |
| 23. | | $^1$S – $^1$P° | [11.934] | [34648200] | [43027500] | 1 | 3 | 1.4(+4) | 0.091 | 0.0036 | −1.04 | C+ | *interp.* |
| 24. | $1s2s$–$1s5p$ | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [10.466] | [34451700] | [44006400] | 3 | 3 | 7300 | 0.012 | 0.0012 | −1.44 | C+ | *interp.* |
| 25. | | $^1$S – $^1$P° | [10.675] | [34648200] | [44016100] | 1 | 3 | 7400 | 0.038 | 0.0013 | −1.42 | C+ | *interp.* |
| 26. | $1s2p$–$1s3s$ | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [16.255] | [34641600] | [40793700] | 3 | 3 | 3800 | 0.015 | 0.0024 | −1.35 | C− | *interp.* |
| 27. | | $^1$P° – $^1$S | [16.565] | [34808800] | [40845600] | 3 | 1 | 1.1(+4) | 0.015 | 0.0025 | −1.35 | C+ | *interp.* |

Sc XX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28. | 1s2p–1s3d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.68 | | 0.79 | C+ | *interp.* |
| 29. | | $^1$P° – $^1$D | | | | 3 | 5 | | 0.70 | | 0.32 | C+ | *interp.* |
| 30. | 1s2p–1s4s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [11.983] | [34641600] | [42986500] | 3 | 3 | 1500 | 0.0033 | 3.9(−4) | −2.00 | D | *interp.* |
| 31. | | $^1$P° – $^1$S | [12.197] | [34808800] | [43007500] | 3 | 1 | 4300 | 0.0032 | 3.9(−4) | −2.02 | C | *interp.* |
| 32. | 1s2p–1s4d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.12 | | 0.03 | C | 5 |
| 33. | | $^1$P° – $^1$D | | | | 3 | 5 | | 0.12 | | −0.44 | C | 5 |
| 34. | 1s2p–1s5s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [10.691] | [34641600] | [43995400] | 3 | 3 | 760 | 0.0013 | 1.4(−4) | −2.41 | D | *interp.* |
| 35. | | $^1$P° – $^1$S | [10.873] | [34808800] | [44005900] | 3 | 1 | 2220 | 0.0013 | 1.4(−4) | −2.41 | C | *interp.* |
| 36. | 1s3s–1s3p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.020 | | −1.22 | E | *interp.* |
| 37. | | $^1$S – $^1$P° | | | | 1 | 3 | | 0.059 | | −1.23 | D | *interp.* |
| 38. | 1s3s–1s4p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [45.155] | [40793700] | [43008300] | 3 | 3 | 4480 | 0.137 | 0.061 | −0.386 | C | *interp.* |
| 39. | | $^1$S – $^1$P° | [45.832] | [40845600] | [43027500] | 1 | 3 | 4380 | 0.414 | 0.062 | −0.383 | C | *interp.* |
| 40. | 1s3s–1s5p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [31.126] | [40793700] | [44006400] | 3 | 3 | 2400 | 0.035 | 0.011 | −0.98 | C | *interp.* |
| 41. | | $^1$S – $^1$P° | [31.541] | [40845600] | [44016100] | 1 | 3 | 2370 | 0.106 | 0.0110 | −0.975 | C+ | *interp.* |
| 42. | 1s3p–1s3d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.014 | | −0.90 | D | *interp.* |
| 43. | 1s3p–1s4s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [46.722] | [40846200] | [42986500] | 3 | 3 | 1100 | 0.035 | 0.016 | −0.98 | C− | *interp.* |
| 44. | | $^1$P° – $^1$S | [47.288] | [40892800] | [43007500] | 3 | 1 | 3100 | 0.035 | 0.016 | −0.98 | C | *interp.* |
| 45. | 1s3p–1s4d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.60 | | 0.73 | C | 5 |
| 46. | | $^1$P° – $^1$D | | | | 3 | 5 | | 0.62 | | 0.27 | C | 5 |
| 47. | 1s3p–1s5s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [31.754] | [40846200] | [43995400] | 3 | 3 | 530 | 0.0080 | 0.0025 | −1.62 | D | *interp.* |
| 48. | | $^1$P° – $^1$S | [32.122] | [40892800] | [44005900] | 3 | 1 | 1500 | 0.0077 | 0.0024 | −1.64 | C | *interp.* |
| 49. | 1s3d–1s3p | $^1$D – $^1$P° | | | | 5 | 3 | | 0.0025 | | −1.90 | E | 5 |
| 50. | 1s3d–1s4p | $^3$D – $^3$P° | | | | 15 | 9 | | 0.012 | | −0.74 | C | 5 |
| 51. | | $^1$D – $^1$P° | | | | 5 | 3 | | 0.011 | | −1.26 | C | 5 |

Sc XX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 52. | 1s4s–1s4p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.028 | | −1.08 | E | *interp.* |
| 53. | | $^1$S – $^1$P° | | | | 1 | 3 | | 0.083 | | −1.08 | E | *interp.* |
| 54. | 1s4s–1s5p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [98.049] | [42986500] | [44006400] | 3 | 3 | 1060 | 0.153 | 0.148 | −0.338 | C | *interp.* |
| 55. | | $^1$S – $^1$P° | [99.147] | [43007500] | [44016100] | 1 | 3 | 1000 | 0.46 | 0.15 | −0.34 | D | *interp.* |
| 56. | 1s4p–1s4d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.024 | | −0.67 | D | 5 |
| 57. | 1s4p–1s5s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [101.3] | [43008300] | [43995400] | 3 | 3 | 370 | 0.057 | 0.057 | −0.77 | D | *interp.* |
| 58. | | $^1$P° – $^1$S | [102.2] | [43027500] | [44005900] | 3 | 1 | 1100 | 0.057 | 0.058 | −0.77 | C | *interp.* |
| 59. | 1s4d–1s4p | $^1$D – $^1$P° | | | | 5 | 3 | | 0.0039 | | −1.71 | E | 5 |
| 60. | 1s4d–1s4f | $^3$D – $^3$F° | | | | 15 | 21 | | 9.7(−4) | | −1.84 | E | 5 |
| 61. | 1s4d–1s5f | $^3$D – $^3$F° | | | | 15 | 21 | | 0.89 | | 1.13 | B | 7 |
| 62. | | $^1$D – $^1$F° | | | | 5 | 7 | | 0.89 | | 0.65 | B | 7 |
| 63. | 1s4f–1s4d | $^1$F° – $^1$D | | | | 7 | 5 | | 5.2(−4) | | −2.44 | E | 5 |
| 64. | 1s4f–1s5d | $^3$F° – $^3$D | | | | 21 | 15 | | 0.0089 | | −0.73 | C | 7 |
| 65. | | $^1$F° – $^1$D | | | | 7 | 5 | | 0.0089 | | −1.21 | C | 7 |
| 66. | 1s5s–1s5p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.036 | | −0.97 | E | *interp.* |
| 67. | | $^1$S – $^1$P° | | | | 1 | 3 | | 0.11 | | −0.96 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Sc XX

### Forbidden Transitions

The tabulated values are interpolated from the theoretical results of Hata and Grant[1] for adjacent lower and higher ions. Their multi-configuration Dirac-Fock calculations include both a very detailed consideration of configuration interaction—with configurational wavefunction sets containing as many as 51 interacting states—as well as a fully relativistic treatment based on the Dirac Hamiltonian. Their calculated wavelengths are in excellent agreement with experimental data. For the ions Ti XXI, V XXII and Fe XXV, where very accurate experimental lifetimes are available, the agreement between these and the theoretical data by Hata and Grant is excellent, the differences being only a few percent (see the comparison table in the introduction to the forbidden lines of Ti XXI).

### Reference

[1]J. Hata and I. P. Grant, Mon. Not. R. Astr. Soc. **211**, 549 (1984).

Sc XX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2$–$1s2s$ | $^1$S - $^3$S | [2.9029] | 0 | [34448120] | 1 | 3 | M1 | 2.40(+7)[a] | 6.53(−5) | B | *interp.* |
| 2. | $1s^2$–$1s2p$ | $^1$S - $^3$P° | | | | | | | | | | |
| | | | [2.8833] | 0 | [34682810] | 1 | 5 | M2 | 1.14(+9) | 0.171 | B | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Sc XXI

H Isoelectronic Sequence

Ground State: $1s\ ^2S_{1/2}$

Ionization Energy: 6033.804 eV = 48665520 cm$^{-1}$

## Allowed Transitions

Electric dipole transition probability data for this hydrogen-like ion can be obtained directly, in a non-relativistic approximation, from the data for neutral hydrogen.[1] The oscillator strength is independent of $Z$ along the entire isoelectronic sequence and is therefore identical to the value for the hydrogen atom. Line strengths scale as $Z^{-2}$ and transition probabilities scale as $Z^4$, i.e.,

$$S_Z = Z^{-2} S_H, \qquad A_Z = Z^4 A_H.$$

For higher nuclear charges in this sequence, relativistic corrections will cause these values to deviate increasingly from the non-relativistic ones. The first effect of relativity will be to alter the transition energies, or wavelengths, from the non-relativistic, even though the line strength itself is still well approximated by the non-relativistic value. In this case, experimental energies should be used in the standard conversion formulas, given in the general introduction to this volume, to calculate the most accurate values of $f$ and $A$. It should be noted that the relativistic removal of the $j$-degeneracy introduces dipole transitions which do not occur in the non-relativistic theory, e.g., $2s_{1/2} - 2p_{3/2}$.

For very high $Z$, it is necessary to use the four-component Dirac spinors rather than two-component Schroedinger functions in theoretical calculations, and this introduces relativistic corrections to the line strengths themselves. Several recent systematic studies of the problem[2,3] indicate that these corrections are not large for stages of ionization in the range 20–30. Corrections for $Z = 30$ are usually no larger than 5–10% and generally substantially less than 5%. If an accuracy greater than this is required, the reader is referred to these papers[2,3] for a more detailed error analysis.

### References

[1]W. L. Wiese, M. W. Smith, and B. M. Glennon, Atomic Transition Probabilities - Hydrogen through Neon (A Critical Data Compilation), Vol. I, 157 pp., Nat. Stand. Ref. Data Ser., Nat. Bur. Stand. (U.S.), 4 (May 1966).

[2]S. M. Younger and A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **79**, 629 (1975).

[3]S. J. Rose, Rutherford Appleton Laboratory Report RL–82–114 (December 1982).

# Titanium

## Ti I

Ground State: $1s^22s^22p^63s^23p^63d^24s^2\ ^3F_2$

Ionization Energy: 6.820 eV = 55010 $cm^{-1}$

### Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2276.75 | 37 | 3214.24 | 24 | 3956.34 | 11 | 4562.64 | 5 |
| 2280.00 | 37 | 3341.88 | 22 | 3958.21 | 14 | 4563.43 | 122 |
| 2299.86 | 36 | 3348.54 | 21 | 3962.85 | 9 | 4617.27 | 95 |
| 2302.75 | 36 | 3352.94 | 21 | 3964.27 | 9 | 4623.10 | 95 |
| 2305.69 | 36 | 3354.63 | 22 | 3981.76 | 9 | 4639.94 | 95 |
| 2384.52 | 35 | 3358.27 | 20 | 3982.48 | 8 | 4640.43 | 121 |
| 2418.37 | 34 | 3370.44 | 20 | 3989.76 | 9 | 4645.19 | 95 |
| 2421.31 | 34 | 3371.45 | 22 | 3998.64 | 9 | 4650.02 | 95 |
| 2424.26 | 34 | 3377.58 | 20 | 4008.93 | 9 | 4656.05 | 95 |
| 2428.24 | 33 | 3379.22 | 22 | 4009.65 | 8 | 4656.47 | 4 |
| 2440.98 | 33 | 3385.66 | 22 | 4013.24 | 107 | 4667.59 | 4 |
| 2519.01 | 32 | 3385.94 | 23 | 4024.57 | 9 | 4675.12 | 67 |
| 2520.54 | 32 | 3493.28 | 19 | 4055.01 | 68 | 4681.91 | 4 |
| 2527.99 | 32 | 3506.64 | 19 | 4060.26 | 68 | 4690.83 | 66 |
| 2529.87 | 32 | 3511.63 | 19 | 4064.20 | 68 | 4693.67 | 4 |
| 2541.92 | 32 | 3635.46 | 18 | 4065.09 | 68 | 4715.30 | 4 |
| 2590.27 | 31 | 3637.97 | 17 | 4112.71 | 7 | 4722.60 | 65 |
| 2593.65 | 30 | 3642.68 | 18 | 4186.12 | 92 | 4742.32 | 86 |
| 2596.60 | 30 | 3646.20 | 17 | 4266.23 | 119 | 4742.79 | 114 |
| 2599.91 | 30 | 3653.50 | 18 | 4281.37 | 48 | 4758.12 | 114 |
| 2605.16 | 30 | 3654.59 | 17 | 4284.99 | 97 | 4758.91 | 46 |
| 2611.29 | 30 | 3658.10 | 18 | 4287.41 | 48 | 4759.27 | 114 |
| 2611.47 | 30 | 3660.63 | 17 | 4289.07 | 48 | 4771.10 | 46 |
| 2619.94 | 30 | 3668.97 | 17 | 4290.93 | 48 | 4778.26 | 113 |
| 2631.55 | 29 | 3671.67 | 18 | 4295.75 | 48 | 4781.72 | 46 |
| 2632.42 | 29 | 3687.35 | 18 | 4393.93 | 117 | 4783.31 | 46 |
| 2641.12 | 29 | 3689.92 | 17 | 4417.27 | 104 | 4789.80 | 46 |
| 2644.28 | 29 | 3717.39 | 16 | 4441.27 | 103 | 4805.42 | 120 |
| 2646.65 | 29 | 3722.57 | 16 | 4449.14 | 103 | 4812.91 | 46 |
| 2657.19 | 28 | 3724.57 | 93 | 4450.90 | 103 | 4820.41 | 91 |
| 2661.97 | 27 | 3725.16 | 69 | 4453.31 | 88 | 4840.87 | 54 |
| 2669.61 | 27 | 3729.81 | 16 | 4453.71 | 103 | 4856.01 | 112 |
| 2679.95 | 27 | 3741.06 | 16 | 4455.32 | 88 | 4885.08 | 102 |
| 2733.27 | 70 | 3752.86 | 16 | 4457.43 | 88 | 4913.62 | 102 |
| 2735.30 | 70 | 3753.62 | 16 | 4462.10 | 6 | 4915.24 | 102 |
| 2912.07 | 56 | 3771.65 | 16 | 4465.81 | 96 | 4926.15 | 45 |
| 2933.53 | 26 | 3774.33 | 15 | 4481.26 | 96 | 4928.34 | 109 |
| 2937.30 | 26 | 3786.04 | 55 | 4496.15 | 96 | 4941.56 | 109 |
| 2942.00 | 26 | 3788.80 | 15 | 4496.25 | 6 | 4964.71 | 105 |
| 2948.26 | 26 | 3881.40 | 13 | 4512.73 | 47 | 4981.73 | 44 |
| 2956.13 | 26 | 3889.95 | 13 | 4518.02 | 47 | 4989.14 | 105 |
| 2956.80 | 26 | 3898.49 | 14 | 4518.70 | 87 | 4991.07 | 44 |
| 2967.22 | 26 | 3900.96 | 13 | 4522.80 | 47 | 4997.10 | 3 |
| 2970.38 | 25 | 3914.33 | 13 | 4527.31 | 47 | 4999.50 | 44 |
| 2981.45 | 25 | 3914.75 | 12 | 4533.24 | 47 | 5000.99 | 105 |
| 2983.31 | 25 | 3921.42 | 12 | 4534.78 | 47 | 5007.21 | 44 |
| 3000.87 | 25 | 3924.53 | 14 | 4544.69 | 47 | 5009.65 | 3 |
| 3186.45 | 24 | 3929.88 | 11 | 4548.09 | 124 | 5014.19 | 3 |
| 3191.99 | 24 | 3934.23 | 13 | 4548.76 | 47 | 5014.28 | 44 |
| 3199.92 | 24 | 3947.77 | 12 | 4552.45 | 47 | 5016.16 | 44 |
| 3203.83 | 24 | 3948.67 | 10 | 4555.49 | 47 | 5020.03 | 44 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 5022.87 | 44 | 5328.72 | 40 | 5880.31 | 60 | 7084.25 | 75 |
| 5024.84 | 44 | 5338.33 | 39 | 5899.30 | 62 | 7138.91 | 75 |
| 5036.47 | 85 | 5340.68 | 40 | 5903.32 | 60 | 7188.55 | 74 |
| 5038.40 | 85 | 5351.07 | 129 | 5906.50 | 80 | 7209.44 | 75 |
| 5039.96 | 3 | 5361.72 | 39 | 5918.55 | 60 | 7216.20 | 72 |
| 5040.64 | 44 | 5366.65 | 39 | 5922.11 | 61 | 7244.86 | 74 |
| 5043.58 | 44 | 5384.63 | 39 | 5937.81 | 62 | 7251.74 | 73 |
| 5045.40 | 44 | 5389.18 | 39 | 5941.76 | 61 | 7266.29 | 94 |
| 5062.11 | 108 | 5401.32 | 39 | 5953.16 | 101 | 7271.41 | 71 |
| 5064.07 | 127 | 5408.94 | 1 | 5965.83 | 101 | 7299.67 | 71 |
| 5064.65 | 3 | 5426.26 | 1 | 5978.54 | 101 | 7344.72 | 71 |
| 5071.48 | 85 | 5436.70 | 53 | 6013.42 | 59 | 7357.74 | 71 |
| 5087.06 | 84 | 5446.59 | 1 | 6017.00 | 59 | 7364.11 | 71 |
| 5113.45 | 84 | 5453.65 | 83 | 6064.63 | 58 | 7423.17 | 71 |
| 5145.47 | 84 | 5460.50 | 1 | 6091.18 | 116 | 7432.69 | 71 |
| 5147.48 | 2 | 5471.20 | 81 | 6092.81 | 100 | 7440.60 | 110 |
| 5152.19 | 2 | 5474.23 | 83 | 6098.66 | 130 | 7938.53 | 99 |
| 5173.74 | 2 | 5490.15 | 82 | 6126.22 | 58 | 7949.17 | 89 |
| 5192.97 | 2 | 5490.84 | 1 | 6220.46 | 126 | 8024.84 | 99 |
| 5194.04 | 106 | 5497.92 | 52 | 6258.10 | 79 | 8066.05 | 99 |
| 5201.10 | 106 | 5503.90 | 125 | 6258.71 | 79 | 8068.24 | 99 |
| 5210.39 | 2 | 5562.74 | 51 | 6261.10 | 79 | 8100.10 | 99 |
| 5211.22 | 42 | 5600.05 | 51 | 6303.75 | 79 | 8353.15 | 38 |
| 5219.70 | 2 | 5648.57 | 123 | 6312.24 | 79 | 8412.36 | 38 |
| 5222.69 | 106 | 5662.15 | 118 | 6336.10 | 78 | 8426.50 | 38 |
| 5223.62 | 106 | 5679.91 | 123 | 6358.66 | 79 | 8435.68 | 38 |
| 5224.30 | 106 | 5689.47 | 118 | 6395.47 | 90 | 8675.38 | 57 |
| 5247.29 | 106 | 5702.67 | 118 | 6499.92 | 90 | 8682.99 | 57 |
| 5252.11 | 2 | 5716.45 | 118 | 6554.23 | 77 | 8692.34 | 57 |
| 5259.98 | 128 | 5720.45 | 118 | 6556.07 | 77 | 8734.70 | 57 |
| 5266.49 | 43 | 5739.46 | 111 | 6599.11 | 50 | 9832.15 | 98 |
| 5282.38 | 64 | 5739.98 | 111 | 6650.38 | 76 | 9927.35 | 98 |
| 5289.28 | 43 | 5774.04 | 131 | 6657.03 | 76 | 9997.94 | 98 |
| 5295.78 | 64 | 5785.98 | 131 | 6666.55 | 76 | | |
| 5300.01 | 64 | 5804.27 | 131 | 6743.12 | 49 | | |
| 5323.96 | 41 | 5866.45 | 63 | 6861.47 | 115 | | |

A number of experiments have recently been performed which feature a variety of techniques and provide reliable oscillator strengths for Ti I. These data sources, utilized for this compilation, include experiments by Smith and Kühne[1] and Bachor and Kock,[14] who employed the anomalous dispersion (hook) method in a furnace; Blackwell *et al.*,[2,3,16,17] who measured very accurate relative oscillator strengths by using the absorption technique; Kühne *et al.*,[4] who used the hook method plus emission measurements with a wall-stabilized arc; Whaling *et al.*,[6] who measured branching ratios in a hollow cathode discharge; Holys and Fuhr,[7] Lotrian *et al.*,[8] and Roberts *et al.*,[9] who measured relative oscillator strengths in emission with stabilized arcs; Kostyk,[18] who derived log *gf*-values from solar spectra; and Bell *et al.*,[10] who determined absolute oscillator strengths by the atomic beam method. We have also included a paper by Cardon *et al.*,[5] who applied the "bowtie" method to interrelate the data of Refs. 1 and 6, in order to generate a set of *f*-values with high internal consistency.

This compilation significantly revises some of our previously published critically evaluated data (tabulated in Ref. 11). These earlier compiled oscillator strengths were based largely on those measured by Klemt,[12] who used a wall-stabilized arc and recorded the intensities photographically. His data apparently suffer from an intensity-dependent systematic error.[1–4,6,7] In particular, comparisons between Klemt and the more recent experiments indicate that Klemt's *f*-values for weak lines are probably too high by factors ranging from two to four. Strong support for this revised compilation is indicated by good agreement—generally within 25 percent—among Refs. 1–7 and 10.

The most reliable source of absolute oscillator strengths for this spectrum is probably the work of Bell *et al.*[10] These authors conducted an advanced absorption experiment in which a diffuse titanium atomic beam emanates from a specially constructed oven, and a number of titanium atoms are measured by weighings and chemical analysis of the titanium deposits. These measurements have yielded especially accurate $f$-values for the two lines at 3998.64 Å and 3653.50 Å, with claimed uncertainties of ±10 percent. The uncertainties of the remaining $f$-values measured by Bell *et al.* are estimated to be approximately ±15 percent, primarily since fewer runs were made.

Another reference providing a reliable absolute scale is that of Roberts *et al.*,[13] who measured lifetimes by using the beam-foil technique. These lifetimes are generally accurate to within ±15 percent. The authors of all data sources that we selected for the compilation (excluding Refs. 8 and 18) normalized their own relative oscillator strengths to either Ref. 10 or Ref. 13, or to a combination of the two.

The most reliable sources of relative data for this spectrum are those by Blackwell *et al.*[2,3,16,17] and by Cardon *et al.*[5] The consistency between these two sets of data is quite impressive: on the same absolute scale (which both authors have adopted), the agreement is within ±12 percent for all sixteen overlapping lines (for 12 of 16 lines, the agreement is within ±5 percent). In this compilation, we have averaged the data of Refs. 2, 3, 16, 17, and 5 whenever possible, assigning "B" accuracies to lines having the best agreement (i.e., the twelve lines mentioned above). For lines not tabulated in Refs. 2, 3, 16, 17, and 5, we have chosen the renormalized data of Ref. 1.

In evaluating data for this spectrum, we made numerous graphical comparisons between various data sources. These graphs entailed comparing an individual data source to the accurate log $gf$-values of Blackwell *et al.*[2,3,16,17] After plotting these graphs, we were able to detect intensity-dependent or energy-level-dependent trends in the references in question. Subsequently, we were able to correct for differences in absolute scale by normalizing (whenever necessary) the data of a particular reference to the data of Blackwell *et al.* These comparisons indicated good agreement (no renormalization required) among Refs. 2–7 and 10. Nevertheless, when compared to Blackwell *et al.*, the data of Refs. 1, 4, 7, and 10 exhibit very similar intensity-dependent trends, indicating weak lines to be too strong. Lacking detailed information, one may only speculate on some of the reasons for this dependency: the $f$-values for strong lines measured by Bell *et al.* may be more uncertain than claimed, because of corrections for some of these lines which are on the "knee" of the curve of growth.[15] Also, there may be a small amount of self-absorption present in the Holys-Fuhr experiment; and short distances become increasingly difficult to measure in "hook" experiments.

To obtain better agreement with the above-cited reference data, the log $gf$-values of Ref. 8 were lowered by 0.04 dex and those of Ref. 9 by 0.07 dex. Because of larger scatter in these data, we have lowered the accuracy ratings for the $f$-values of Ref. 8 and have omitted all lines of Ref. 9 having log $gf$-values less than −0.5.

The two most comprehensive sources of oscillator strengths are those by Smith and Kühne[1] and by Whaling *et al.*[6] Each of these references contains data for more than one hundred lines, of which there are eighteen lines in common. Whaling *et al.* normalized their branching ratios to the lifetimes of Roberts *et al.*[13] Smith and Kühne, however, normalized their relative scale to that of Bell *et al.*[10] Although Refs. 1 and 6 generally agree within 20 percent, a comparison of these two references indicates a small difference in scale. On the average, the log $gf$-values of Smith and Kühne are about 0.03 dex smaller than those of Bell *et al.* The reason for this discrepancy is that Smith and Kühne omitted the 3956.34 Å line (the case of largest disagreement between Refs. 1 and 10) in normalizing their data. However, for this same line, the data of Refs. 2, 5, 6, and 10 are in good agreement with each other, but all disagree similarly with the $f$-value tabulated in Ref. 1. Consequently, we have increased all log $gf$-values of Smith and Kühne by 0.03 dex.

When comparing some of their data to those of Whaling *et al.*, Kühne *et al.* noticed that for lines originating from the $y\ ^3F°$ level, the log $gf$-values of Whaling *et al.* are about 0.10 dex lower than their own. There appears to be no obvious reason for this discrepancy; therefore, in these cases we have lowered the accuracies and averaged the two sources whenever the data overlapped.

Another reference providing reliable $f$-values is the work of Kostyk.[18] His oscillator strengths are derived from solar data of Ti I lines, taken from the Liege solar atlas.[19] The data of Kostyk[18] and Blackwell *et al.*[2,3,16,17] overlap for 70 lines. For these common lines, the $f$-values for 48 lines agreed within 25 percent. For each spectral line, Kostyk provided two log $gf$-values, one derived from line depth and the other from equivalent widths of Ti I lines. In this compilation, we have tabulated the *average* of these two values, since we could not establish which method was better.

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Ti I: Allowed transitions

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $a\ ^3F - z\ ^5D°$ (3) | | | | | | | | | | | |
| | | 5460.50 | 386.9 | 18695 | 9 | 9 | 3.90(−4)[a] | 1.74(−4) | 0.0282 | −2.804 | C+ | 16 |
| | | 5426.26 | 170.1 | 18594 | 7 | 7 | 3.19(−4) | 1.41(−4) | 0.0176 | −3.006 | C+ | 2 |
| | | 5490.84 | 386.9 | 18594 | 9 | 7 | 1.4(−4) | 5.0(−5) | 0.0081 | −3.35 | C | 1*n* |
| | | 5446.59 | 170.1 | 18525 | 7 | 5 | 2.5(−4) | 7.9(−5) | 0.0099 | −3.26 | C | 1*n* |
| | | 5408.94 | 0.0 | 18483 | 5 | 3 | 1.11(−4) | 2.92(−5) | 0.00260 | −3.836 | C+ | 2 |
| 2. | $a\ ^3F - z\ ^3F°$ (4) | *5195.7* | *222.5* | *19464* | 21 | 21 | 0.0392 | 0.0159 | 5.70 | −0.477 | C+ | 2 |
| | | 5210.39 | 386.9 | 19574 | 9 | 9 | 0.0357 | 0.0145 | 2.24 | −0.884 | C+ | 2 |
| | | 5192.97 | 170.1 | 19422 | 7 | 7 | 0.0349 | 0.0141 | 1.69 | −1.006 | C+ | 2 |
| | | 5173.74 | 0.0 | 19323 | 5 | 5 | 0.0380 | 0.0152 | 1.30 | −1.118 | C+ | 2 |
| | | 5252.11 | 386.9 | 19422 | 9 | 7 | 0.00123 | 3.96(−4) | 0.0616 | −2.448 | C+ | 2 |
| | | 5219.70 | 170.1 | 19323 | 7 | 5 | 0.00250 | 7.29(−4) | 0.0877 | −2.292 | C+ | 2 |
| | | 5152.19 | 170.1 | 19574 | 7 | 9 | 0.00264 | 0.00135 | 0.160 | −2.024 | C+ | 2 |
| | | 5147.48 | 0.0 | 19422 | 5 | 7 | 0.00350 | 0.00195 | 0.165 | −2.012 | C+ | 2 |
| 3. | $a\ ^3F - z\ ^3D°$ (5) | | | | | | | | | | | |
| | | 5064.65 | 386.9 | 20126 | 9 | 7 | 0.0379 | 0.0113 | 1.70 | −0.991 | C+ | 2 |
| | | 5039.96 | 170.1 | 20006 | 7 | 5 | 0.0389 | 0.0106 | 1.23 | −1.130 | C+ | 16 |
| | | 5014.19 | 0.0 | 19938 | 5 | 3 | 0.053 | 0.012 | 0.99 | −1.22 | C | 1*n* |
| | | 5009.65 | 170.1 | 20126 | 7 | 7 | 0.00209 | 7.87(−4) | 0.0908 | −2.259 | C+ | 2 |
| | | 4997.10 | 0.0 | 20006 | 5 | 5 | 0.00407 | 0.00152 | 0.125 | −2.118 | C+ | 2 |
| 4. | $a\ ^3F - z\ ^3G°$ (6) | | | | | | | | | | | |
| | | 4681.91 | 386.9 | 21740 | 9 | 11 | 0.0235 | 0.00944 | 1.31 | −1.071 | C+ | 2 |
| | | 4667.59 | 170.1 | 21588 | 7 | 9 | 0.0218 | 0.00914 | 0.983 | −1.194 | C+ | 2 |
| | | 4656.47 | 0.0 | 21469 | 5 | 7 | 0.0199 | 0.00904 | 0.693 | −1.345 | C+ | 2 |
| | | 4715.30 | 386.9 | 21588 | 9 | 9 | 6.9(−4) | 2.3(−4) | 0.032 | −2.68 | C | 1*n*,4 |
| | | 4693.67 | 170.1 | 21469 | 7 | 7 | 8.5(−4) | 2.8(−4) | 0.030 | −2.71 | C | 1*n*,4 |
| 5. | $a\ ^3F - z\ ^1D°$ (7) | | | | | | | | | | | |
| | | 4562.64 | 170.1 | 22081 | 7 | 5 | 0.00141 | 3.15(−4) | 0.0332 | −2.656 | C+ | 2 |
| 6. | $a\ ^3F - z\ ^1F°$ (8) | | | | | | | | | | | |
| | | 4496.25 | 170.1 | 22405 | 7 | 7 | 0.0011 | 3.4(−4) | 0.036 | −2.62 | C | 1*n* |
| | | 4462.10 | 0.0 | 22405 | 5 | 7 | 3.72(−4) | 1.55(−4) | 0.0114 | −3.110 | C+ | 2 |
| 7. | $a\ ^3F - z\ ^1G°$ (9) | | | | | | | | | | | |
| | | 4112.71 | 386.9 | 24695 | 9 | 9 | 0.00765 | 0.00194 | 0.236 | −1.758 | C+ | 2 |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | $a\,^3F - z\,^5S°$ (11) | | | | | | | | | | | |
| | | 4009.65 | 170.1 | 25103 | 7 | 5 | 0.0121 | 0.00208 | 0.192 | −1.837 | C+ | 2 |
| | | 3982.48 | 0.0 | 25103 | 5 | 5 | 0.045 | 0.011 | 0.70 | −1.27 | C | 1*n* |
| 9. | $a\,^3F - y\,^3F°$ (12) | *3991.8* | *222.5* | *25267* | 21 | 21 | 0.455 | 0.109 | 30.0 | 0.358 | B | 2,5 |
| | | 3998.64 | 386.9 | 25388 | 9 | 9 | 0.408 | 0.0977 | 11.6 | −0.056 | B | 2,5 |
| | | 3989.76 | 170.1 | 25227 | 7 | 7 | 0.379 | 0.0905 | 8.32 | −0.198 | B | 2,5 |
| | | 3981.76 | 0.0 | 25107 | 5 | 5 | 0.376 | 0.0893 | 5.85 | −0.350 | B | 2,5 |
| | | 4024.57 | 386.9 | 25227 | 9 | 7 | 0.0614 | 0.0116 | 1.38 | −0.981 | B | 2,5 |
| | | 4008.93 | 170.1 | 25107 | 7 | 5 | 0.0703 | 0.0121 | 1.12 | −1.072 | B | 2,5 |
| | | 3964.27 | 170.1 | 25388 | 7 | 9 | 0.0309 | 0.00935 | 0.854 | −1.184 | B | 2,5 |
| | | 3962.85 | 0.0 | 25227 | 5 | 7 | 0.0413 | 0.0136 | 0.887 | −1.167 | B | 2,5 |
| 10. | $a\,^3F - y\,^3D°$ (13) | | | | | | | | | | | |
| | | 3948.67 | 0.0 | 25318 | 5 | 3 | 0.485 | 0.0681 | 4.43 | −0.468 | C+ | 2 |
| 11. | $a\,^3F - (\,°)^b$ | | | | | | | | | | | |
| | | 3956.34 | 170.1 | 25439 | 7 | 5 | 0.300 | 0.0503 | 4.59 | −0.453 | B | 2,5 |
| | | 3929.88 | 0.0 | 25439 | 5 | 5 | 0.0752 | 0.0174 | 1.13 | −1.060 | B | 2,5 |
| 12. | $a\,^3F - z\,^3P°$ (14) | | | | | | | | | | | |
| | | 3947.77 | 170.1 | 25494 | 7 | 5 | 0.096 | 0.016 | 1.5 | −0.95 | C | 1*n*,4 |
| | | 3914.75 | 0.0 | 25537 | 5 | 3 | 0.0083 | 0.0012 | 0.074 | −2.24 | C | 1*n* |
| | | 3921.42 | 0.0 | 25494 | 5 | 5 | 0.0215 | 0.00497 | 0.321 | −1.605 | C+ | 2 |
| 13. | $a\,^3F - y\,^5D°$ (15) | | | | | | | | | | | |
| | | 3914.33 | 386.9 | 25927 | 9 | 9 | 0.023 | 0.0052 | 0.60 | −1.33 | C | 1*n* |
| | | 3900.96 | 170.1 | 25798 | 7 | 7 | 0.0128 | 0.00291 | 0.262 | −1.691 | C+ | 2 |
| | | 3889.95 | 0.0 | 25700 | 5 | 5 | 0.0051 | 0.0012 | 0.074 | −2.24 | C | 1*n* |
| | | 3934.23 | 386.9 | 25798 | 9 | 7 | 0.0045 | 8.0(−4) | 0.094 | −2.14 | C | 1*n* |
| | | 3881.40 | 170.1 | 25927 | 7 | 9 | 0.0030 | 8.6(−4) | 0.077 | −2.22 | C | 1*n* |
| 14. | $a\,^3F - (\,°)^b$ | | | | | | | | | | | |
| | | 3958.21 | 386.9 | 25644 | 9 | 7 | 0.405 | 0.0739 | 8.67 | −0.177 | C+ | 2,5 |
| | | 3924.53 | 170.1 | 25644 | 7 | 7 | 0.0715 | 0.0165 | 1.49 | −0.937 | B | 2,5 |
| | | 3898.49 | 0.0 | 25644 | 5 | 7 | 0.00348 | 0.00111 | 0.0712 | −2.256 | C+ | 2,5 |
| 15. | $a\,^3F - y\,^5G°$ (16) | | | | | | | | | | | |
| | | 3788.80 | 386.9 | 26773 | 9 | 11 | 2.7(−4) | 7.2(−5) | 0.0081 | −3.19 | C | 6 |
| | | 3774.33 | 170.1 | 26657 | 7 | 9 | 3.22(−4) | 8.85(−5) | 0.00770 | −3.208 | C+ | 2 |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16. | $a\ ^3F - x\ ^3F^\circ$ (17) | *3743.3* | *222.5* | *26929* | 21 | 21 | 0.526 | 0.111 | 28.6 | 0.366 | C+ | 1*n*,2 |
| | | 3752.86 | 386.9 | 27026 | 9 | 9 | 0.504 | 0.106 | 11.8 | −0.019 | C+ | 2 |
| | | 3741.06 | 170.1 | 26893 | 7 | 7 | 0.417 | 0.0875 | 7.54 | −0.213 | C+ | 2 |
| | | 3729.81 | 0.0 | 26803 | 5 | 5 | 0.427 | 0.0891 | 5.47 | −0.351 | C+ | 2 |
| | | 3771.65 | 386.9 | 26893 | 9 | 7 | 0.0603 | 0.00999 | 1.12 | −1.046 | C+ | 2 |
| | | 3753.62 | 170.1 | 26803 | 7 | 5 | 0.082 | 0.012 | 1.1 | −1.06 | C | 1*n* |
| | | 3722.57 | 170.1 | 27026 | 7 | 9 | 0.034 | 0.0090 | 0.77 | −1.20 | C | 1*n* |
| | | 3717.39 | 0.0 | 26893 | 5 | 7 | 0.043 | 0.012 | 0.75 | −1.21 | C | 1*n* |
| 17. | $a\ ^3F - x\ ^3D^\circ$ (18) | *3673.9* | *222.5* | *27434* | 21 | 15 | 0.078 | 0.0113 | 2.88 | −0.62 | C | 1*n*,2 |
| | | 3689.92 | 386.9 | 27480 | 9 | 7 | 0.0353 | 0.00561 | 0.613 | −1.297 | C+ | 2 |
| | | 3668.97 | 170.1 | 27418 | 7 | 5 | 0.054 | 0.0079 | 0.66 | −1.26 | C | 1*n* |
| | | 3654.59 | 0.0 | 27355 | 5 | 3 | 0.087 | 0.010 | 0.63 | −1.28 | C | 1*n* |
| | | 3660.63 | 170.1 | 27480 | 7 | 7 | 0.030 | 0.0061 | 0.51 | −1.37 | C | 1*n* |
| | | 3646.20 | 0.0 | 27418 | 5 | 5 | 0.026 | 0.0053 | 0.32 | −1.58 | C | 1*n* |
| | | 3637.97 | 0.0 | 27480 | 5 | 7 | 0.0093 | 0.0026 | 0.15 | −1.89 | C | 1*n* |
| 18. | $a\ ^3F - y\ ^3G^\circ$ (19) | *3646.3* | *222.5* | *27640* | 21 | 27 | 0.805 | 0.206 | 52.0 | 0.637 | C+ | 2,5,6 |
| | | 3653.50 | 386.9 | 27750 | 9 | 11 | 0.754 | 0.184 | 20.0 | 0.220 | C+ | 2 |
| | | 3642.68 | 170.1 | 27615 | 7 | 9 | 0.774 | 0.198 | 16.6 | 0.142 | B | 2,5 |
| | | 3635.46 | 0.0 | 27499 | 5 | 7 | 0.804 | 0.223 | 13.3 | 0.047 | B | 2,5 |
| | | 3671.67 | 386.9 | 27615 | 9 | 9 | 0.0459 | 0.00928 | 1.01 | −1.078 | C+ | 2,5 |
| | | 3658.10 | 170.1 | 27499 | 7 | 7 | 0.0583 | 0.0117 | 0.986 | −1.087 | C+ | 2,5 |
| | | 3687.35 | 386.9 | 27499 | 9 | 7 | 0.0035 | 5.6(−4) | 0.061 | −2.30 | C | 6 |
| 19. | $a\ ^3F - y\ ^5F^\circ$ (22) | | | | | | | | | | | |
| | | 3506.64 | 386.9 | 28896 | 9 | 11 | 0.0068 | 0.0015 | 0.16 | −1.86 | C | 1*n* |
| | | 3493.28 | 170.1 | 28788 | 7 | 9 | 0.0036 | 8.4(−4) | 0.068 | −2.23 | C | 1*n* |
| | | 3511.63 | 170.1 | 28639 | 7 | 5 | 0.0042 | 5.6(−4) | 0.045 | −2.41 | C | 1*n* |
| 20. | $a\ ^3F - w\ ^3D^\circ$ (23) | | | | | | | | | | | |
| | | 3377.58 | 170.1 | 29769 | 7 | 5 | 0.69 | 0.084 | 6.5 | −0.23 | C | 1*n* |
| | | 3370.44 | 0.0 | 29661 | 5 | 3 | 0.76 | 0.078 | 4.3 | −0.41 | C | 1*n* |
| | | 3358.27 | 0.0 | 29769 | 5 | 5 | 0.076 | 0.013 | 0.71 | −1.19 | C | 1*n* |
| 21. | $a\ ^3F - x\ ^5D^\circ$ (25) | | | | | | | | | | | |
| | | 3352.94 | 170.1 | 29986 | 7 | 7 | 0.0097 | 0.0016 | 0.13 | −1.94 | C | 1*n* |
| | | 3348.54 | 0.0 | 29855 | 5 | 3 | 0.0091 | 9.1(−4) | 0.050 | −2.34 | C | 1*n* |
| 22. | $a\ ^3F - x\ ^3G^\circ$ (24) | | | | | | | | | | | |
| | | 3371.45 | 386.9 | 30039 | 9 | 11 | 0.72 | 0.15 | 15 | 0.13 | C | 1*n*,10 |
| | | 3354.63 | 170.1 | 29971 | 7 | 9 | 0.69 | 0.15 | 12 | 0.02 | C | 1*n*,10 |
| | | 3341.88 | 0.0 | 29915 | 5 | 7 | 0.65 | 0.15 | 8.3 | −0.12 | C | 1*n* |
| | | 3379.22 | 386.9 | 29971 | 9 | 9 | 0.062 | 0.011 | 1.1 | −1.02 | C | 1*n* |
| | | 3385.66 | 386.9 | 29915 | 9 | 7 | 0.052 | 0.0070 | 0.70 | −1.20 | C | 1*n* |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8\ s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23. | $a\ ^3F - (\ ^\circ)^b$ | | | | | | | | | | | |
| | | 3385.94 | 386.9 | 29912 | 9 | 7 | 0.50 | 0.067 | 6.7 | −0.22 | C | 1*n* |
| 24. | $a\ ^3F - w\ ^3G^\circ$ (27) | | | | | | | | | | | |
| | | 3199.92 | 386.9 | 31629 | 9 | 11 | 0.94 | 0.18 | 17 | 0.20 | C | 1*n* |
| | | 3191.99 | 170.1 | 31489 | 7 | 9 | 0.85 | 0.17 | 12 | 0.07 | C | 1*n* |
| | | 3186.45 | 0.0 | 31374 | 5 | 7 | 0.80 | 0.17 | 8.9 | −0.07 | C | 1*n* |
| | | 3214.24 | 386.9 | 31489 | 9 | 9 | 0.065 | 0.010 | 0.97 | −1.04 | C | 1*n* |
| | | 3203.83 | 170.1 | 31374 | 7 | 7 | 0.072 | 0.011 | 0.82 | −1.11 | C | 1*n* |
| 25. | $a\ ^3F - w\ ^3F^\circ$ (29) | | | | | | | | | | | |
| | | 3000.87 | 386.9 | 33701 | 9 | 9 | 0.12 | 0.016 | 1.5 | −0.83 | C | 1*n* |
| | | 2983.31 | 170.1 | 33680 | 7 | 7 | 0.11 | 0.014 | 0.98 | −1.00 | C | 1*n* |
| | | 2970.38 | 0.0 | 33656 | 5 | 5 | 0.074 | 0.0098 | 0.48 | −1.31 | C | 1*n* |
| | | 2981.45 | 170.1 | 33701 | 7 | 9 | 0.0073 | 0.0012 | 0.085 | −2.06 | C | 1*n* |
| 26. | $a\ ^3F - v\ ^3F^\circ$ (uv 1) | *2950.1* | *222.5* | *34110* | 21 | 21 | 1.1 | 0.15 | 30 | 0.49 | C | 1*n* |
| | | 2956.13 | 386.9 | 34205 | 9 | 9 | 0.97 | 0.13 | 11 | 0.06 | C | 1*n* |
| | | 2948.26 | 170.1 | 34079 | 7 | 7 | 0.93 | 0.12 | 8.3 | −0.07 | C | 1*n* |
| | | 2942.00 | 0.0 | 33981 | 5 | 5 | 1.0 | 0.14 | 6.5 | −0.17 | C | 1*n* |
| | | 2967.22 | 386.9 | 34079 | 9 | 7 | 0.11 | 0.011 | 0.95 | −1.01 | C | 1*n* |
| | | 2956.80 | 170.1 | 33981 | 7 | 5 | 0.18 | 0.017 | 1.1 | −0.93 | C | 1*n* |
| | | 2937.30 | 170.1 | 34205 | 7 | 9 | 0.077 | 0.013 | 0.86 | −1.05 | C | 1*n* |
| | | 2933.53 | 0.0 | 34079 | 5 | 7 | 0.096 | 0.017 | 0.84 | −1.06 | C | 1*n* |
| 27. | $a\ ^3F - v\ ^3G^\circ$ (uv 2) | | | | | | | | | | | |
| | | 2679.95 | 386.9 | 37690 | 9 | 11 | 0.13 | 0.017 | 1.3 | −0.82 | C | 1*n* |
| | | 2669.61 | 170.1 | 37618 | 7 | 9 | 0.10 | 0.014 | 0.86 | −1.01 | C | 1*n* |
| | | 2661.97 | 0.0 | 37555 | 5 | 7 | 0.089 | 0.013 | 0.58 | −1.18 | C | 1*n* |
| 28. | $a\ ^3F - x\ ^1F^\circ$ (uv 3) | | | | | | | | | | | |
| | | 2657.19 | 0.0 | 37623 | 5 | 7 | 0.032 | 0.0048 | 0.21 | −1.62 | C | 1*n* |
| 29. | $a\ ^3F - u\ ^3D^\circ$ (uv 5) | | | | | | | | | | | |
| | | 2646.65 | 386.9 | 38160 | 9 | 7 | 1.5 | 0.12 | 9.6 | 0.04 | C | 1*n* |
| | | 2644.28 | 170.1 | 37977 | 7 | 5 | 1.4 | 0.11 | 6.5 | −0.13 | C | 1*n* |
| | | 2641.12 | 0.0 | 37852 | 5 | 3 | 1.8 | 0.11 | 4.9 | −0.25 | C | 1*n* |
| | | 2631.55 | 170.1 | 38160 | 7 | 7 | 0.17 | 0.018 | 1.1 | −0.90 | C | 1*n* |
| | | 2632.42 | 0.0 | 37977 | 5 | 5 | 0.27 | 0.028 | 1.2 | −0.86 | C | 1*n* |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30. | $a\,^3$F – $t\,^3$F° (uv 6) | *2606.5* | *222.5* | *38576* | 21 | 21 | 0.87 | 0.089 | 16 | 0.27 | C | 1$n$ |
| | | 2611.29 | 386.9 | 38671 | 9 | 9 | 0.64 | 0.065 | 5.1 | −0.23 | C | 1$n$ |
| | | 2605.16 | 170.1 | 38544 | 7 | 7 | 0.64 | 0.065 | 3.9 | −0.34 | C | 1$n$ |
| | | 2599.91 | 0.0 | 38451 | 5 | 5 | 0.67 | 0.068 | 2.9 | −0.47 | C | 1$n$ |
| | | 2619.94 | 386.9 | 38544 | 9 | 7 | 0.21 | 0.016 | 1.3 | −0.83 | C | 1$n$ |
| | | 2611.47 | 170.1 | 38451 | 7 | 5 | 0.33 | 0.024 | 1.5 | −0.77 | C | 1$n$ |
| | | 2596.60 | 170.1 | 38671 | 7 | 9 | 0.069 | 0.0090 | 0.54 | −1.20 | C | 1$n$ |
| | | 2593.65 | 0.0 | 38544 | 5 | 7 | 0.069 | 0.0098 | 0.42 | −1.31 | C | 1$n$ |
| 31. | $a\,^3$F – $t\,^3$D° (uv 7) | | | | | | | | | | | |
| | | 2590.27 | 170.1 | 38765 | 7 | 7 | 0.047 | 0.0047 | 0.28 | −1.48 | C | 1$n$ |
| 32. | $a\,^3$F – $s\,^3$D° (uv 8) | | | | | | | | | | | |
| | | 2541.92 | 386.9 | 39715 | 9 | 7 | 0.43 | 0.032 | 2.4 | −0.54 | C | 1$n$ |
| | | 2529.87 | 170.1 | 39686 | 7 | 5 | 0.38 | 0.026 | 1.5 | −0.74 | C | 1$n$ |
| | | 2520.54 | 0.0 | 39662 | 5 | 3 | 0.38 | 0.022 | 0.91 | −0.96 | C | 1$n$ |
| | | 2527.99 | 170.1 | 39715 | 7 | 7 | 0.068 | 0.0065 | 0.38 | −1.34 | C | 1$n$ |
| | | 2519.01 | 0.0 | 39686 | 5 | 5 | 0.059 | 0.0056 | 0.23 | −1.55 | C | 1$n$ |
| 33. | $a\,^3$F – $u\,^3$G° (uv 10) | | | | | | | | | | | |
| | | 2440.98 | 386.9 | 41342 | 9 | 11 | 0.072 | 0.0079 | 0.57 | −1.15 | C | 1$n$ |
| | | 2428.24 | 0.0 | 41170 | 5 | 7 | 0.077 | 0.0096 | 0.38 | −1.32 | C | 1$n$ |
| 34. | $a\,^3$F – $s\,^3$F° (uv 11) | | | | | | | | | | | |
| | | 2424.26 | 386.9 | 41624 | 9 | 9 | 0.17 | 0.015 | 1.1 | −0.88 | C | 1$n$ |
| | | 2421.31 | 170.1 | 41458 | 7 | 7 | 0.13 | 0.011 | 0.63 | −1.10 | C | 1$n$ |
| | | 2418.37 | 0.0 | 41337 | 5 | 5 | 0.12 | 0.010 | 0.41 | −1.29 | C | 1$n$ |
| 35. | $a\,^3$F – $q\,^3$D° (uv 12) | | | | | | | | | | | |
| | | 2384.52 | 386.9 | 42311 | 9 | 7 | 0.090 | 0.0060 | 0.42 | −1.27 | C | 1$n$ |
| 36. | $a\,^3$F – $r\,^3$F° (uv 14) | | | | | | | | | | | |
| | | 2305.69 | 386.9 | 43745 | 9 | 9 | 0.52 | 0.041 | 2.8 | −0.43 | C | 1$n$ |
| | | 2302.75 | 170.1 | 43583 | 7 | 7 | 0.57 | 0.045 | 2.4 | −0.50 | C | 1$n$ |
| | | 2299.86 | 0.0 | 43468 | 5 | 5 | 0.69 | 0.055 | 2.1 | −0.56 | C | 1$n$ |
| 37. | $a\,^3$F – $o\,^3$D° (uv 15) | | | | | | | | | | | |
| | | 2280.00 | 386.9 | 44234 | 9 | 7 | 0.94 | 0.057 | 3.8 | −0.29 | C | 1$n$ |
| | | 2276.75 | 170.1 | 44080 | 7 | 5 | 1.3 | 0.070 | 3.7 | −0.31 | C | 1$n$ |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38. | $a\ ^5F - z\ ^5D°$ (33) | | | | | | | | | | | |
| | | 8435.68 | 6743 | 18594 | 9 | 7 | 0.0127 | 0.0105 | 2.63 | −1.023 | C+ | 3 |
| | | 8426.50 | 6661 | 18525 | 7 | 5 | 0.0105 | 0.00798 | 1.55 | −1.253 | C+ | 3 |
| | | 8412.36 | 6599 | 18483 | 5 | 3 | 0.0103 | 0.00658 | 0.911 | −1.483 | C+ | 16 |
| | | 8353.15 | 6557 | 18525 | 3 | 5 | 4.02(−4) | 7.01(−4) | 0.0579 | −2.677 | C+ | 16 |
| 39. | $a\ ^5F - y\ ^3F°$ (35) | | | | | | | | | | | |
| | | 5361.72 | 6743 | 25388 | 9 | 9 | 2.3(−4) | 1.0(−4) | 0.016 | −3.05 | D | 4,6 |
| | | 5384.63 | 6661 | 25227 | 7 | 7 | 4.0(−4) | 1.8(−4) | 0.022 | −2.91 | D | 6 |
| | | 5401.32 | 6599 | 25107 | 5 | 5 | 5.9(−4) | 2.6(−4) | 0.023 | −2.89 | D | 4,6 |
| | | 5338.33 | 6661 | 25388 | 7 | 9 | 0.0035 | 0.0019 | 0.24 | −1.87 | D | 6 |
| | | 5366.65 | 6599 | 25227 | 5 | 7 | 8.64(−4) | 5.22(−4) | 0.0462 | −2.583 | C+ | 16 |
| | | 5389.18 | 6557 | 25107 | 3 | 5 | 0.0033 | 0.0024 | 0.13 | −2.14 | D | 4,6 |
| 40. | $a\ ^5F - y\ ^3D°$ (36) | | | | | | | | | | | |
| | | 5340.68 | 6599 | 25318 | 5 | 3 | 5.2(−4) | 1.3(−4) | 0.012 | −3.18 | C | 6 |
| | | 5328.72 | 6557 | 25318 | 3 | 3 | 0.0078 | 0.0033 | 0.18 | −2.00 | C | 6 |
| 41. | $a\ ^5F - (\ °)^b$ | | | | | | | | | | | |
| | | 5323.96 | 6661 | 25439 | 7 | 5 | 3.5(−4) | 1.1(−4) | 0.013 | −3.13 | C | 6 |
| 42. | $a\ ^5F - y\ ^5D°$ (37) | | | | | | | | | | | |
| | | 5211.22 | 6743 | 25927 | 9 | 9 | 0.0031 | 0.0012 | 0.19 | −1.95 | D | 18*n* |
| 43. | $a\ ^5F - (\ °)^b$ | | | | | | | | | | | |
| | | 5289.28 | 6743 | 25644 | 9 | 7 | 4.8(−4) | 1.6(−4) | 0.025 | −2.85 | C | 6 |
| | | 5266.49 | 6661 | 25644 | 7 | 7 | 2.8(−5) | 1.2(−5) | 0.0014 | −4.09 | D | 6 |
| 44. | $a\ ^5F - y\ ^5G°$ (38) | *4997.6* | *6722* | *26726* | 35 | 45 | 0.667 | 0.321 | 185 | 1.051 | C+ | 3,6,16 |
| | | 4981.73 | 6843 | 26911 | 11 | 13 | 0.660 | 0.290 | 52.3 | 0.504 | C+ | 3 |
| | | 4991.07 | 6743 | 26773 | 9 | 11 | 0.584 | 0.267 | 39.4 | 0.380 | C+ | 3 |
| | | 4999.50 | 6661 | 26657 | 7 | 9 | 0.527 | 0.254 | 29.3 | 0.250 | C+ | 3 |
| | | 5007.21 | 6599 | 26564 | 5 | 7 | 0.492 | 0.259 | 21.3 | 0.112 | C+ | 3 |
| | | 5014.28 | 6557 | 26494 | 3 | 5 | 0.68 | 0.43 | 21 | 0.11 | C | 6 |
| | | 5016.16 | 6843 | 26773 | 11 | 11 | 0.0643 | 0.0242 | 4.40 | −0.574 | C+ | 3 |
| | | 5020.03 | 6743 | 26657 | 9 | 9 | 0.113 | 0.0428 | 6.37 | −0.414 | C+ | 3 |
| | | 5022.87 | 6661 | 26564 | 7 | 7 | 0.139 | 0.0526 | 6.09 | −0.434 | C+ | 3 |
| | | 5024.84 | 6599 | 26494 | 5 | 5 | 0.132 | 0.0500 | 4.14 | −0.602 | C+ | 3 |
| | | 5045.40 | 6843 | 26657 | 11 | 9 | 0.00292 | 9.13(−4) | 0.167 | −1.998 | C+ | 16 |
| | | 5043.58 | 6743 | 26564 | 9 | 7 | 0.00693 | 0.00205 | 0.307 | −1.733 | C+ | 16 |
| | | 5040.64 | 6661 | 26494 | 7 | 5 | 0.00857 | 0.00233 | 0.271 | −1.787 | C+ | 16 |
| 45. | $a\ ^5F - x\ ^3F°$ (39) | | | | | | | | | | | |
| | | 4926.15 | 6599 | 26893 | 5 | 7 | 0.00265 | 0.00135 | 0.110 | −2.170 | C+ | 16 |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46. | $a\,^5\mathrm{F} - y\,^3\mathrm{G}^\circ$ (41) | | | | | | | | | | | |
| | | 4781.72 | 6843 | 27750 | 11 | 11 | 0.0029 | 0.0010 | 0.17 | −1.96 | C | 6,7 |
| | | 4789.80 | 6743 | 27615 | 9 | 9 | 4.5(−4) | 1.5(−4) | 0.022 | −2.86 | C | 6 |
| | | 4812.91 | 6843 | 27615 | 11 | 9 | 1.1(−4) | 3.2(−5) | 0.0056 | −3.45 | D | 6 |
| | | 4758.91 | 6743 | 27750 | 9 | 11 | 0.0018 | 7.5(−4) | 0.11 | −2.17 | C | 6 |
| | | 4771.10 | 6661 | 27615 | 7 | 9 | 0.0014 | 6.0(−4) | 0.066 | −2.38 | C | 6,7 |
| | | 4783.31 | 6599 | 27499 | 5 | 7 | 6.2(−4) | 3.0(−4) | 0.024 | −2.82 | C | 6,7 |
| 47. | $a\,^5\mathrm{F} - y\,^5\mathrm{F}^\circ$ (42) | | | | | | | | | | | |
| | | 4533.24 | 6843 | 28896 | 11 | 11 | 0.883 | 0.272 | 44.7 | 0.476 | C+ | 3 |
| | | 4534.78 | 6743 | 28788 | 9 | 9 | 0.687 | 0.212 | 28.4 | 0.280 | C+ | 3 |
| | | 4555.49 | 6843 | 28788 | 11 | 9 | 0.116 | 0.0296 | 4.88 | −0.488 | C+ | 3 |
| | | 4552.45 | 6743 | 28703 | 9 | 7 | 0.21 | 0.051 | 6.9 | −0.34 | D− | 8*n* |
| | | 4548.76 | 6661 | 28639 | 7 | 5 | 0.285 | 0.0632 | 6.63 | −0.354 | C+ | 3 |
| | | 4544.69 | 6599 | 28596 | 5 | 3 | 0.33 | 0.060 | 4.5 | −0.52 | D− | 8*n* |
| | | 4512.73 | 6743 | 28896 | 9 | 11 | 0.0986 | 0.0368 | 4.92 | −0.480 | C+ | 3 |
| | | 4518.02 | 6661 | 28788 | 7 | 9 | 0.172 | 0.0676 | 7.04 | −0.325 | C+ | 3 |
| | | 4522.80 | 6599 | 28703 | 5 | 7 | 0.19 | 0.081 | 6.1 | −0.39 | D− | 8*n* |
| | | 4527.31 | 6557 | 28639 | 3 | 5 | 0.22 | 0.11 | 5.1 | −0.47 | D− | 8*n* |
| 48. | $a\,^5\mathrm{F} - x\,^5\mathrm{D}^\circ$ (44) | | | | | | | | | | | |
| | | 4295.75 | 6557 | 29829 | 3 | 1 | 1.3 | 0.12 | 5.0 | −0.45 | D− | 8*n* |
| | | 4287.41 | 6743 | 30060 | 9 | 9 | 0.146 | 0.0402 | 5.10 | −0.442 | C+ | 3 |
| | | 4289.07 | 6599 | 29907 | 5 | 5 | 0.30 | 0.083 | 5.9 | −0.38 | D− | 8*n* |
| | | 4290.93 | 6557 | 29855 | 3 | 3 | 0.45 | 0.12 | 5.2 | −0.43 | D− | 8*n* |
| | | 4281.37 | 6557 | 29907 | 3 | 5 | 0.0318 | 0.0146 | 0.617 | −1.359 | C+ | 3 |
| 49. | $a\,^1\mathrm{D} - z\,^1\mathrm{D}^\circ$ (48) | 6743.12 | 7255 | 22081 | 5 | 5 | 0.0069 | 0.0047 | 0.52 | −1.63 | D | 18*n* |
| 50. | $a\,^1\mathrm{D} - z\,^1\mathrm{F}^\circ$ (49) | 6599.11 | 7255 | 22405 | 5 | 7 | 0.00180 | 0.00164 | 0.179 | −2.085 | C+ | 16 |
| 51. | $a\,^1\mathrm{D} - y\,^3\mathrm{F}^\circ$ | | | | | | | | | | | |
| | | 5562.74 | 7255 | 25227 | 5 | 7 | 4.2(−4) | 2.7(−4) | 0.025 | −2.87 | D | 6 |
| | | 5600.05 | 7255 | 25107 | 5 | 5 | 1.9(−4) | 8.9(−5) | 0.0082 | −3.35 | D | 6 |
| 52. | $a\,^1\mathrm{D} - (\ ^\circ)^b$ | 5497.92 | 7255 | 25439 | 5 | 5 | 6.2(−4) | 2.8(−4) | 0.026 | −2.85 | C | 6 |
| 53. | $a\,^1\mathrm{D} - (\ ^\circ)^b$ | 5436.70 | 7255 | 25644 | 5 | 7 | 0.0010 | 6.3(−4) | 0.056 | −2.50 | C | 4,6 |
| 54. | $a\,^1\mathrm{D} - y\,^1\mathrm{D}^\circ$ (53) | 4840.87 | 7255 | 27907 | 5 | 5 | 0.176 | 0.0619 | 4.94 | −0.509 | C+ | 3 |
| 55. | $a\,^1\mathrm{D} - z\,^1\mathrm{P}^\circ$ (57) | 3786.04 | 7255 | 33661 | 5 | 3 | 1.4 | 0.18 | 11 | −0.05 | D− | 8*n* |
| 56. | $a\,^1\mathrm{D} - v\,^1\mathrm{F}^\circ$ (uv 23) | 2912.07 | 7255 | 41585 | 5 | 7 | 1.3 | 0.23 | 11 | 0.06 | D | 9*n* |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57. | $a\ ^3P - z\ ^3D°$ (68) | | | | | | | | | | | |
| | | 8675.38 | 8602 | 20126 | 5 | 7 | 0.00271 | 0.00429 | 0.612 | −1.669 | C+ | 16 |
| | | 8682.99 | 8492 | 20006 | 3 | 5 | 0.00203 | 0.00382 | 0.327 | −1.941 | C+ | 16 |
| | | 8692.34 | 8437 | 19938 | 1 | 3 | 0.00149 | 0.00507 | 0.145 | −2.295 | C+ | 16 |
| | | 8734.70 | 8492 | 19938 | 3 | 3 | 0.00120 | 0.00138 | 0.119 | −2.384 | C+ | 16 |
| 58. | $a\ ^3P - z\ ^3S°$ (69) | | | | | | | | | | | |
| | | 6126.22 | 8602 | 24921 | 5 | 3 | 0.0223 | 0.00752 | 0.758 | −1.425 | C+ | 16 |
| | | 6064.63 | 8437 | 24921 | 1 | 3 | 0.00688 | 0.0114 | 0.227 | −1.944 | C+ | 16 |
| 59. | $a\ ^3P - y\ ^3F°$ | | | | | | | | | | | |
| | | 6013.42 | 8602 | 25227 | 5 | 7 | 2.1(−4) | 1.6(−4) | 0.016 | −3.10 | D | 6 |
| | | 6017.00 | 8492 | 25107 | 3 | 5 | 8.6(−5) | 7.8(−5) | 0.0046 | −3.63 | D | 6 |
| 60. | $a\ ^3P - z\ ^3P°$ (71) | | | | | | | | | | | |
| | | 5918.55 | 8602 | 25494 | 5 | 5 | 0.013 | 0.0069 | 0.68 | −1.46 | C | 4 |
| | | 5903.32 | 8602 | 25537 | 5 | 3 | 0.00457 | 0.00143 | 0.139 | −2.145 | C+ | 16 |
| | | 5880.31 | 8492 | 25494 | 3 | 5 | 0.00348 | 0.00301 | 0.175 | −2.045 | C+ | 16 |
| 61. | $a\ ^3P - y\ ^3D°$ (72) | | | | | | | | | | | |
| | | 5922.11 | 8437 | 25318 | 1 | 3 | 0.0217 | 0.0342 | 0.667 | −1.466 | C+ | 3,16 |
| | | 5941.76 | 8492 | 25318 | 3 | 3 | 0.019 | 0.010 | 0.60 | −1.51 | C | 6 |
| 62. | $a\ ^3P - (\ °)^b$ | | | | | | | | | | | |
| | | 5899.30 | 8492 | 25439 | 3 | 5 | 0.0269 | 0.0234 | 1.36 | −1.154 | C+ | 3 |
| | | 5937.81 | 8602 | 25439 | 5 | 5 | 0.0049 | 0.0026 | 0.25 | −1.89 | C | 4,6 |
| 63. | $a\ ^3P - (\ °)^b$ | | | | | | | | | | | |
| | | 5866.45 | 8602 | 25644 | 5 | 7 | 0.0400 | 0.0289 | 2.79 | −0.840 | C+ | 3 |
| 64. | $a\ ^3P - x\ ^3D°$ (74) | | | | | | | | | | | |
| | | 5295.78 | 8602 | 27480 | 5 | 7 | 0.00791 | 0.00466 | 0.406 | −1.633 | C+ | 16 |
| | | 5282.38 | 8492 | 27418 | 3 | 5 | 0.024 | 0.017 | 0.87 | −1.30 | D | 18*n* |
| | | 5300.01 | 8492 | 27355 | 3 | 3 | 0.027 | 0.011 | 0.59 | −1.47 | D | 18*n* |
| 65. | $a\ ^3P - w\ ^3D°$ (75) | | | | | | | | | | | |
| | | 4722.60 | 8492 | 29661 | 3 | 3 | 0.047 | 0.016 | 0.73 | −1.33 | D | 18*n* |
| 66. | $a\ ^3P - x\ ^3G°$ (76) | | | | | | | | | | | |
| | | 4690.83 | 8602 | 29915 | 5 | 7 | 0.0044 | 0.0020 | 0.16 | −1.99 | D | 18*n* |
| 67. | $a\ ^3P - x\ ^5D°$ (77) | | | | | | | | | | | |
| | | 4675.12 | 8602 | 29986 | 5 | 7 | 0.0185 | 0.00847 | 0.652 | −1.373 | C+ | 3 |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 68. | $a\ ^3P - x\ ^3P^\circ$ (80) | | | | | | | | | | | |
| | | 4064.20 | 8492 | 33090 | 3 | 3 | 0.24 | 0.061 | 2.4 | −0.74 | D− | 8*n* |
| | | 4065.09 | 8492 | 33085 | 3 | 1 | 0.70 | 0.058 | 2.3 | −0.76 | D− | 8*n* |
| | | 4060.26 | 8492 | 33114 | 3 | 5 | 0.24 | 0.10 | 4.0 | −0.52 | D− | 8*n* |
| | | 4055.01 | 8437 | 33090 | 1 | 3 | 0.28 | 0.21 | 2.8 | −0.68 | D− | 8*n* |
| 69. | $a\ ^3P - y\ ^3S^\circ$ (83) | | | | | | | | | | | |
| | | 3725.16 | 8602 | 35439 | 5 | 3 | 0.73 | 0.091 | 5.6 | −0.34 | D− | 8*n* |
| 70. | $a\ ^3P - t\ ^3P^\circ$ (uv 32) | | | | | | | | | | | |
| | | 2733.27 | 8602 | 45178 | 5 | 5 | 1.9 | 0.21 | 9.4 | 0.02 | D | 9*n* |
| | | 2735.30 | 8492 | 45041 | 3 | 1 | 4.1 | 0.15 | 4.1 | −0.34 | D | 9*n* |
| 71. | $b\ ^3F - y\ ^3F^\circ$ (97) | *7354.2* | *11673* | *25267* | 21 | 21 | 0.015 | 0.012 | 6.3 | −0.58 | D | 4,6,17 |
| | | 7344.72 | 11777 | 25388 | 9 | 9 | 0.014 | 0.011 | 2.4 | −1.00 | D | 4,6 |
| | | 7357.74 | 11640 | 25227 | 7 | 7 | 0.0133 | 0.0108 | 1.83 | −1.122 | C+ | 17 |
| | | 7364.11 | 11532 | 25107 | 5 | 5 | 0.016 | 0.013 | 1.6 | −1.19 | D | 4,6 |
| | | 7432.69 | 11777 | 25227 | 9 | 7 | 6.9(−5) | 4.4(−5) | 0.0097 | −3.40 | D | 6 |
| | | 7423.17 | 11640 | 25107 | 7 | 5 | 5.5(−4) | 3.3(−4) | 0.056 | −2.64 | D | 4 |
| | | 7271.41 | 11640 | 25388 | 7 | 9 | 7.8(−4) | 7.9(−4) | 0.13 | −2.26 | D | 4,6 |
| | | 7299.67 | 11532 | 25227 | 5 | 7 | 0.0021 | 0.0023 | 0.28 | −1.94 | D | 4,6 |
| 72. | $b\ ^3F - z\ ^3P^\circ$ (98) | | | | | | | | | | | |
| | | 7216.20 | 11640 | 25494 | 7 | 5 | 0.018 | 0.010 | 1.7 | −1.15 | D | 18*n* |
| 73. | $b\ ^3F - y\ ^3D^\circ$ (99) | | | | | | | | | | | |
| | | 7251.74 | 11532 | 25318 | 5 | 3 | 0.072 | 0.034 | 4.1 | −0.77 | C | 6 |
| 74. | $b\ ^3F - (\ ^\circ)^b$ | | | | | | | | | | | |
| | | 7244.86 | 11640 | 25439 | 7 | 5 | 0.039 | 0.022 | 3.7 | −0.81 | C | 4,6 |
| | | 7188.55 | 11532 | 25439 | 5 | 5 | 0.0045 | 0.0035 | 0.41 | −1.76 | C | 4,6 |
| 75. | $b\ ^3F - (\ ^\circ)^b$ | | | | | | | | | | | |
| | | 7209.44 | 11777 | 25644 | 9 | 7 | 0.058 | 0.035 | 7.5 | −0.50 | C | 4.6 |
| | | 7138.91 | 11640 | 25644 | 7 | 7 | 0.0048 | 0.0037 | 0.61 | −1.59 | C | 4,6 |
| | | 7084.25 | 11532 | 25644 | 5 | 7 | 1.3(−4) | 1.4(−4) | 0.016 | −3.15 | D | 4,6 |
| 76. | $b\ ^3F - y\ ^5G^\circ$ (101) | | | | | | | | | | | |
| | | 6666.55 | 11777 | 26773 | 9 | 11 | 0.0033 | 0.0027 | 0.54 | −1.61 | C | 6 |
| | | 6657.03 | 11640 | 26657 | 7 | 9 | 5.1(−4) | 4.3(−4) | 0.066 | −2.52 | C | 6 |
| | | 6650.38 | 11532 | 26564 | 5 | 7 | 3.3(−4) | 3.0(−4) | 0.033 | −2.82 | C | 6 |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 77. | $b\ ^3F - x\ ^3F°$ (102) | | | | | | | | | | | |
| | | 6556.07 | 11777 | 27026 | 9 | 9 | 0.0145 | 0.00937 | 1.82 | −1.074 | C+ | 17 |
| | | 6554.23 | 11640 | 26893 | 7 | 7 | 0.0134 | 0.00865 | 1.31 | −1.218 | C+ | 17 |
| 78. | $b\ ^3F - x\ ^3D°$ (103) | | | | | | | | | | | |
| | | 6336.10 | 11640 | 27418 | 7 | 5 | 0.00601 | 0.00258 | 0.377 | −1.743 | C+ | 17 |
| 79. | $b\ ^3F - y\ ^3G°$ (104) | *6261.2* | *11673* | *27640* | 21 | 27 | 0.089 | 0.067 | 29 | 0.15 | C+ | 6, 7, 17 |
| | | 6258.71 | 11777 | 27750 | 9 | 11 | 0.089 | 0.064 | 12 | −0.24 | C | 6,7 |
| | | 6258.10 | 11640 | 27615 | 7 | 9 | 0.0836 | 0.0631 | 9.10 | −0.355 | C+ | 17 |
| | | 6261.10 | 11532 | 27499 | 5 | 7 | 0.0807 | 0.0664 | 6.84 | −0.479 | C+ | 17 |
| | | 6312.24 | 11777 | 27615 | 9 | 9 | 0.00522 | 0.00312 | 0.583 | −1.552 | C+ | 17 |
| | | 6303.75 | 11640 | 27499 | 7 | 7 | 0.00651 | 0.00388 | 0.564 | −1.566 | C+ | 17 |
| | | 6358.66 | 11777 | 27499 | 9 | 7 | 6.8(−4) | 3.2(−4) | 0.060 | −2.54 | C | 6 |
| 80. | $b\ ^3F - y\ ^5F°$ (105) | | | | | | | | | | | |
| | | 5906.50 | 11777 | 28703 | 9 | 7 | 0.0067 | 0.0027 | 0.48 | −1.61 | D | 18*n* |
| 81. | $b\ ^3F - (\ °)^b$ | | | | | | | | | | | |
| | | 5471.20 | 11640 | 29912 | 7 | 7 | 0.013 | 0.0057 | 0.72 | −1.40 | D | 18*n* |
| 82. | $b\ ^3F - x\ ^5D°$ (107) | | | | | | | | | | | |
| | | 5490.15 | 11777 | 29986 | 9 | 7 | 0.0369 | 0.0130 | 2.11 | −0.933 | C+ | 17 |
| 83. | $b\ ^3F - x\ ^3G°$ (108) | | | | | | | | | | | |
| | | 5474.23 | 11777 | 30039 | 9 | 11 | 0.012 | 0.0065 | 1.1 | −1.23 | D | 18*n* |
| | | 5453.65 | 11640 | 29971 | 7 | 9 | 0.0061 | 0.0035 | 0.44 | −1.61 | D | 18*n* |
| 84. | $b\ ^3F - v\ ^3D°$ (109) | | | | | | | | | | | |
| | | 5145.47 | 11777 | 31206 | 9 | 7 | 0.0960 | 0.0296 | 4.52 | −0.574 | C+ | 17 |
| | | 5113.45 | 11640 | 31191 | 7 | 5 | 0.0841 | 0.0235 | 2.77 | −0.783 | C+ | 17 |
| | | 5087.06 | 11532 | 31184 | 5 | 3 | 0.14 | 0.033 | 2.8 | −0.78 | D | 18*n* |
| 85. | $b\ ^3F - w\ ^3G°$ (110) | | | | | | | | | | | |
| | | 5036.47 | 11640 | 31489 | 7 | 9 | 0.394 | 0.193 | 22.4 | 0.130 | C+ | 17 |
| | | 5038.40 | 11532 | 31374 | 5 | 7 | 0.387 | 0.206 | 17.1 | 0.013 | C+ | 17 |
| | | 5071.48 | 11777 | 31489 | 9 | 9 | 0.0249 | 0.00961 | 1.44 | −1.063 | C+ | 17 |
| 86. | $b\ ^3F - y\ ^1F°$ (111) | | | | | | | | | | | |
| | | 4742.32 | 11777 | 32858 | 9 | 7 | 0.032 | 0.0084 | 1.2 | −1.12 | D | 18*n* |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 87. | $b\,^3F - w\,^3F°$ (112) | | | | | | | | | | | |
| | | 4518.70 | 11532 | 33656 | 5 | 5 | 0.065 | 0.020 | 1.5 | −1.00 | D | 18*n* |
| 88. | $b\,^3F - v\,^3F°$ (113) | | | | | | | | | | | |
| | | 4457.43 | 11777 | 34205 | 9 | 9 | 0.56 | 0.17 | 22 | 0.18 | D− | 8*n* |
| | | 4455.32 | 11640 | 34079 | 7 | 7 | 0.48 | 0.14 | 15 | 0.00 | D− | 8*n* |
| | | 4453.31 | 11532 | 33981 | 5 | 5 | 0.598 | 0.178 | 13.0 | −0.051 | C+ | 17 |
| 89. | $a\,^1G - z\,^1G°$ (125) | 7949.17 | 12118 | 24695 | 9 | 9 | 0.0041 | 0.0039 | 0.91 | −1.46 | C | 14 |
| 90. | $a\,^1G - y\,^3G°$ | | | | | | | | | | | |
| | | 6395.47 | 12118 | 27750 | 9 | 11 | 3.3(−4) | 2.5(−4) | 0.047 | −2.65 | C | 6 |
| | | 6499.92 | 12118 | 27499 | 9 | 7 | 1.9(−5) | 9.2(−6) | 0.0018 | −4.08 | D | 6 |
| 91. | $a\,^1G - y\,^1F°$ (126) | 4820.41 | 12118 | 32858 | 9 | 7 | 0.149 | 0.0402 | 5.75 | −0.441 | C+ | 17 |
| 92. | $a\,^1G - y\,^1G°$ (129) | 4186.12 | 12118 | 36000 | 9 | 9 | 0.210 | 0.0551 | 6.83 | −0.305 | C+ | 17 |
| 93. | $a\,^1G - x\,^1G°$ (131) | 3724.57 | 12118 | 38959 | 9 | 9 | 0.91 | 0.19 | 21 | 0.23 | D− | 8*n* |
| 94. | $a\,^5P - z\,^5P°$ (143) | | | | | | | | | | | |
| | | 7266.29 | 13982 | 27740 | 3 | 5 | 0.017 | 0.022 | 1.6 | −1.18 | D | 18*n* |
| 95. | $a\,^5P - w\,^5D°$ (145) | | | | | | | | | | | |
| | | 4617.27 | 14106 | 35758 | 7 | 9 | 0.851 | 0.350 | 37.2 | 0.389 | C+ | 17 |
| | | 4623.10 | 14028 | 35653 | 5 | 7 | 0.574 | 0.258 | 19.6 | 0.110 | C+ | 17 |
| | | 4639.94 | 13982 | 35528 | 3 | 3 | 0.664 | 0.214 | 9.82 | −0.192 | C+ | 17 |
| | | 4656.05 | 14106 | 35577 | 7 | 5 | 0.093 | 0.022 | 2.3 | −0.82 | D | 18*n* |
| | | 4650.02 | 14028 | 35528 | 5 | 3 | 0.26 | 0.051 | 3.9 | −0.59 | D | 18*n* |
| | | 4645.19 | 13982 | 35503 | 3 | 1 | 0.857 | 0.0924 | 4.24 | −0.557 | C+ | 17 |
| 96. | $a\,^5P - y\,^5P°$ (146) | | | | | | | | | | | |
| | | 4481.26 | 14106 | 36415 | 7 | 7 | 0.57 | 0.17 | 18 | 0.08 | D− | 8*n* |
| | | 4496.15 | 14106 | 36341 | 7 | 5 | 0.44 | 0.094 | 9.8 | −0.18 | D− | 8*n* |
| | | 4465.81 | 14028 | 36415 | 5 | 7 | 0.328 | 0.137 | 10.1 | −0.163 | C+ | 17 |
| 97. | $a\,^5P - y\,^5S°$ (148) | | | | | | | | | | | |
| | | 4284.99 | 14028 | 37359 | 5 | 5 | 0.32 | 0.089 | 6.3 | −0.35 | D− | 8*n* |
| 98. | $a\,^3G - y\,^3F°$ (149) | | | | | | | | | | | |
| | | 9832.15 | 15220 | 25388 | 11 | 9 | 0.0049 | 0.0059 | 2.1 | −1.19 | D | 6 |
| | | 9927.35 | 15157 | 25227 | 9 | 7 | 0.0025 | 0.0029 | 0.86 | −1.58 | D | 6 |
| | | 9997.94 | 15108 | 25107 | 7 | 5 | 0.0019 | 0.0021 | 0.48 | −1.84 | D | 6 |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99. | $a\ ^3G - y\ ^3G°$ (151) | | | | | | | | | | | |
| | | 8024.84 | 15157 | 27615 | 9 | 9 | 0.0083 | 0.0080 | 1.9 | −1.14 | C | 6 |
| | | 8068.24 | 15108 | 27499 | 7 | 7 | 0.0077 | 0.0075 | 1.4 | −1.28 | C | 6 |
| | | 8066.05 | 15220 | 27615 | 11 | 9 | 3.4(−4) | 2.7(−4) | 0.080 | −2.52 | C | 6 |
| | | 8100.10 | 15157 | 27499 | 9 | 7 | 4.5(−4) | 3.4(−4) | 0.082 | −2.51 | C | 6 |
| | | 7938.53 | 15157 | 27750 | 9 | 11 | 3.8(−4) | 4.4(−4) | 0.10 | −2.40 | C | 6 |
| 100. | $a\ ^3G - w\ ^3G°$ (153) | | | | | | | | | | | |
| | | 6092.81 | 15220 | 31629 | 11 | 11 | 0.00683 | 0.00380 | 0.838 | −1.379 | C+ | 17 |
| 101. | $a\ ^3G - z\ ^3H°$ (154) | | | | | | | | | | | |
| | | 5953.16 | 15220 | 32014 | 11 | 13 | 0.0679 | 0.0426 | 9.19 | −0.329 | C+ | 17 |
| | | 5965.83 | 15157 | 31914 | 9 | 11 | 0.0664 | 0.0433 | 7.66 | −0.409 | C+ | 17 |
| | | 5978.54 | 15108 | 31830 | 7 | 9 | 0.0662 | 0.0456 | 6.28 | −0.496 | C+ | 17 |
| 102. | $a\ ^3G - y\ ^3H°$ (157) | | | | | | | | | | | |
| | | 4885.08 | 15220 | 35685 | 11 | 13 | 0.490 | 0.207 | 36.7 | 0.358 | C+ | 17 |
| | | 4913.62 | 15108 | 35454 | 7 | 9 | 0.444 | 0.206 | 23.4 | 0.160 | C+ | 17 |
| | | 4915.24 | 15220 | 35560 | 11 | 11 | 0.0240 | 0.00870 | 1.55 | −1.019 | C+ | 17 |
| 103. | $a\ ^3G - v\ ^3G°$ (160) | | | | | | | | | | | |
| | | 4449.14 | 15220 | 37690 | 11 | 11 | 0.97 | 0.29 | 46 | 0.50 | D− | 8*n* |
| | | 4450.90 | 15157 | 37618 | 9 | 9 | 0.96 | 0.29 | 38 | 0.41 | D− | 8*n* |
| | | 4453.71 | 15108 | 37555 | 7 | 7 | 0.47 | 0.14 | 14 | −0.01 | D− | 8*n* |
| | | 4441.27 | 15108 | 37618 | 7 | 9 | 0.061 | 0.023 | 2.4 | −0.79 | D | 18*n* |
| 104. | $a\ ^3G - u\ ^3F°$ (161) | | | | | | | | | | | |
| | | 4417.27 | 15220 | 37852 | 11 | 9 | 0.36 | 0.087 | 14 | −0.02 | D− | 8*n* |
| 105. | $z\ ^5G° - e\ ^5F$ (173) | | | | | | | | | | | |
| | | 5000.99 | 16106 | 36096 | 9 | 7 | 0.352 | 0.103 | 15.2 | −0.034 | C+ | 17 |
| | | 4989.14 | 15976 | 36014 | 7 | 5 | 0.325 | 0.0867 | 9.97 | −0.217 | C+ | 17 |
| | | 4964.71 | 15877 | 36014 | 5 | 5 | 0.0722 | 0.0267 | 2.18 | −0.875 | C+ | 17 |
| 106. | $z\ ^5F° - e\ ^5F$ (183) | | | | | | | | | | | |
| | | 5224.30 | 17215 | 36351 | 11 | 11 | 0.36 | 0.15 | 28 | 0.21 | D | 18*n* |
| | | 5223.62 | 16875 | 36014 | 5 | 5 | 0.135 | 0.0553 | 4.76 | −0.558 | C+ | 17 |
| | | 5222.69 | 16817 | 35959 | 3 | 3 | 0.195 | 0.0798 | 4.11 | −0.621 | C+ | 17 |
| | | 5247.29 | 16961 | 36014 | 7 | 5 | 0.0908 | 0.0268 | 3.24 | −0.727 | C+ | 17 |
| | | 5194.04 | 16961 | 36209 | 7 | 9 | 0.076 | 0.039 | 4.7 | −0.56 | D | 18*n* |
| | | 5201.10 | 16875 | 36096 | 5 | 7 | 0.0628 | 0.0356 | 3.05 | −0.749 | C+ | 17 |
| 107. | $z\ ^5F° - g\ ^3F$ (186) | | | | | | | | | | | |
| | | 4013.24 | 16961 | 41872 | 7 | 5 | 0.20 | 0.034 | 3.2 | −0.62 | D | 18*n* |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 108. | $a\ ^3$D – $w\ ^3$P° (199) | | | | | | | | | | | |
| | | 5062.11 | 17424 | 37173 | 5 | 3 | 0.298 | 0.0687 | 5.73 | −0.464 | C+ | 17 |
| 109. | $a\ ^3$D – $u\ ^3$F° (200) | | | | | | | | | | | |
| | | 4928.34 | 17370 | 37655 | 3 | 5 | 0.62 | 0.37 | 18 | 0.05 | D | 18*n* |
| | | 4941.56 | 17424 | 37655 | 5 | 5 | 0.053 | 0.020 | 1.6 | −1.01 | D | 18*n* |
| 110. | $a\ ^3$H – $w\ ^3$G° (225) | | | | | | | | | | | |
| | | 7440.60 | 18193 | 31629 | 13 | 11 | 0.022 | 0.015 | 4.9 | −0.70 | D | 18*n* |
| 111. | $a\ ^3$H – $y\ ^3$H° (228) | | | | | | | | | | | |
| | | 5739.46 | 18141 | 35560 | 11 | 11 | 0.046 | 0.023 | 4.7 | −0.60 | D | 18*n* |
| | | 5739.98 | 18037 | 35454 | 9 | 9 | 0.048 | 0.024 | 4.0 | −0.67 | D | 18*n* |
| 112. | $a\ ^3$H – $z\ ^3$I° (231) | | | | | | | | | | | |
| | | 4856.01 | 18193 | 38780 | 13 | 15 | 0.52 | 0.21 | 44 | 0.44 | D | 18*n* |
| 113. | $a\ ^3$H – $x\ ^1$G° (232) | | | | | | | | | | | |
| | | 4778.26 | 18037 | 38959 | 9 | 9 | 0.20 | 0.067 | 9.5 | −0.22 | D | 18*n* |
| 114. | $a\ ^3$H – $x\ ^3$H° (233) | | | | | | | | | | | |
| | | 4759.27 | 18193 | 39198 | 13 | 13 | 0.740 | 0.251 | 51.2 | 0.514 | C+ | 17 |
| | | 4758.12 | 18141 | 39152 | 11 | 11 | 0.713 | 0.242 | 41.7 | 0.425 | C+ | 17 |
| | | 4742.79 | 18037 | 39116 | 9 | 9 | 0.53 | 0.18 | 25 | 0.21 | D | 18*n* |
| 115. | $b\ ^1$G – $y\ ^1$F° (237) | 6861.47 | 18288 | 32858 | 9 | 7 | 0.037 | 0.020 | 4.1 | −0.74 | D | 18*n* |
| 116. | $b\ ^1$G – $z\ ^1$H° (238) | 6091.18 | 18288 | 34700 | 9 | 11 | 0.0617 | 0.0420 | 7.57 | −0.423 | C+ | 17 |
| 117. | $b\ ^1$G – $y\ ^1$H° (244) | 4393.93 | 18288 | 41040 | 9 | 11 | 0.33 | 0.12 | 15 | 0.02 | D− | 8*n* |
| 118. | $z\ ^5$D° – $e\ ^5$F (249) | | | | | | | | | | | |
| | | 5662.15 | 18695 | 36351 | 9 | 11 | 0.147 | 0.0864 | 14.5 | −0.109 | C+ | 17 |
| | | 5689.47 | 18525 | 36096 | 5 | 7 | 0.100 | 0.0679 | 6.36 | −0.469 | C+ | 17 |
| | | 5702.67 | 18483 | 36104 | 3 | 5 | 0.11 | 0.088 | 4.9 | −0.58 | D | 18*n* |
| | | 5716.45 | 18525 | 36014 | 5 | 5 | 0.081 | 0.040 | 3.8 | −0.70 | D | 18*n* |
| | | 5720.45 | 18483 | 35959 | 3 | 3 | 0.086 | 0.042 | 2.4 | −0.90 | D | 18*n* |
| 119. | $z\ ^5$D° – $e\ ^5$D (252) | | | | | | | | | | | |
| | | 4266.23 | 18525 | 41959 | 5 | 5 | 0.31 | 0.083 | 5.9 | −0.38 | D | 18*n* |

Ti I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 120. | $c\ ^3P - s\ ^3D°$ (260) | | | | | | | | | | | |
| | | 4805.42 | 18911 | 39715 | 5 | 7 | 0.58 | 0.28 | 22 | 0.15 | D | 18*n* |
| 121. | $c\ ^3P - v\ ^3P°$ (261) | | | | | | | | | | | |
| | | 4640.43 | 18826 | 40370 | 3 | 1 | 0.50 | 0.054 | 2.5 | −0.79 | D | 18*n* |
| 122. | $z\ ^3F° - e\ ^3G$ (266) | | | | | | | | | | | |
| | | 4563.43 | 19574 | 41481 | 9 | 11 | 0.21 | 0.080 | 11 | −0.14 | D | 18*n* |
| 123. | $z\ ^3D° - e\ ^3F$ (269) | | | | | | | | | | | |
| | | 5648.57 | 20126 | 37825 | 7 | 9 | 0.13 | 0.079 | 10 | −0.26 | D | 18*n* |
| | | 5679.91 | 19938 | 37539 | 3 | 5 | 0.11 | 0.090 | 5.0 | −0.57 | D | 18*n* |
| 124. | $z\ ^3D° - g\ ^3F$ (270) | | | | | | | | | | | |
| | | 4548.09 | 20126 | 42107 | 7 | 9 | 0.084 | 0.033 | 3.5 | −0.63 | D | 18*n* |
| 125. | $a\ ^1H - x\ ^1G°$ (287) | 5503.90 | 20796 | 38959 | 11 | 9 | 0.26 | 0.095 | 19 | 0.02 | D | 18*n* |
| 126. | $z\ ^3G° - e\ ^3F$ (293) | | | | | | | | | | | |
| | | 6220.46 | 21588 | 37660 | 9 | 7 | 0.18 | 0.080 | 15 | −0.14 | D | 18*n* |
| 127. | $z\ ^3G° - e\ ^3G$ (294) | | | | | | | | | | | |
| | | 5064.07 | 21740 | 41481 | 11 | 11 | 0.13 | 0.049 | 9.0 | −0.27 | D | 18*n* |
| 128. | $z\ ^1D° - e\ ^1F$ (298) | 5259.98 | 22081 | 41087 | 5 | 7 | 0.23 | 0.13 | 11 | −0.18 | D | 18*n* |
| 129. | $z\ ^1F° - e\ ^1F$ (300) | 5351.07 | 22405 | 41087 | 7 | 7 | 0.34 | 0.15 | 18 | 0.01 | D | 18*n* |
| 130. | $z\ ^1G° - e\ ^1F$ (304) | 6098.66 | 24695 | 41087 | 9 | 7 | 0.25 | 0.11 | 20 | −0.01 | D | 18*n* |
| 131. | $y\ ^5G° - f\ ^5H$ (309) | | | | | | | | | | | |
| | | 5804.27 | 26911 | 44135 | 13 | 15 | 0.68 | 0.39 | 98 | 0.71 | D | 18*n* |
| | | 5785.98 | 26773 | 44051 | 11 | 13 | 0.61 | 0.36 | 76 | 0.60 | D | 18*n* |
| | | 5774.04 | 26657 | 43972 | 9 | 11 | 0.55 | 0.34 | 57 | 0.48 | D | 18*n* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.
[b]The *LS*-coupling designation of the upper term of this multiplet was not provided in the NBS energy-level compilation (J. Sugar and C. Corliss, J. Phys. Chem. Ref. Data 14, Suppl. 2 (1985)), so we have accordingly omitted it from this work.

# Ti II

Sc Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^63d^24s\ ^4F_{3/2}$

Ionization Energy: 13.58 eV = 109500 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2440.91 | 80 | 2827.12 | 104 | 3057.40 | 5 | 3202.56 | 30 |
| 2443.43 | 80 | 2828.06 | 105 | 3058.08 | 51 | 3203.43 | 3 |
| 2448.64 | 80 | 2828.64 | 104 | 3066.23 | 5 | 3206.01 | 30 |
| 2451.18 | 80 | 2828.83 | 105 | 3066.34 | 5 | 3213.15 | 3 |
| 2474.22 | 7 | 2832.19 | 19 | 3071.25 | 51 | 3214.12 | 82 |
| 2477.21 | 7 | 2834.02 | 104 | 3072.12 | 5 | 3214.78 | 3 |
| 2478.64 | 7 | 2836.47 | 104 | 3072.99 | 5 | 3217.07 | 2 |
| 2482.24 | 22 | 2839.64 | 105 | 3075.23 | 5 | 3222.84 | 2 |
| 2499.71 | 22 | 2841.94 | 19 | 3078.65 | 5 | 3224.25 | 82 |
| 2510.87 | 12 | 2843.94 | 104 | 3081.52 | 103 | 3226.77 | 3 |
| 2517.42 | 12 | 2845.93 | 104 | 3088.04 | 5 | 3228.62 | 29 |
| 2519.82 | 12 | 2851.11 | 61 | 3089.44 | 88 | 3231.31 | 10 |
| 2524.66 | 12 | 2853.93 | 19 | 3096.42 | 77 | 3232.29 | 41 |
| 2525.59 | 12 | 2855.40 | 104 | 3097.20 | 69 | 3234.51 | 2 |
| 2529.79 | 12 | 2856.10 | 104 | 3101.54 | 60 | 3236.13 | 28 |
| 2531.28 | 12 | 2858.41 | 18 | 3102.98 | 60 | 3236.58 | 2 |
| 2534.63 | 12 | 2861.30 | 61 | 3103.81 | 88 | 3239.04 | 2 |
| 2535.89 | 12 | 2862.33 | 61 | 3104.60 | 88 | 3239.66 | 28 |
| 2555.99 | 21 | 2868.75 | 18 | 3105.10 | 69 | 3241.99 | 2 |
| 2571.08 | 21 | 2874.11 | 42 | 3106.26 | 69 | 3249.37 | 28 |
| 2573.67 | 21 | 2877.47 | 42 | 3110.10 | 77 | 3251.91 | 2 |
| 2635.44 | 109 | 2880.30 | 79 | 3110.69 | 69 | 3252.92 | 2 |
| 2638.56 | 109 | 2884.13 | 42 | 3112.07 | 69 | 3254.25 | 2 |
| 2642.02 | 109 | 2887.44 | 42 | 3117.67 | 69 | 3260.25 | 50 |
| 2645.86 | 109 | 2891.08 | 18 | 3118.83 | 32 | 3263.69 | 50 |
| 2713.74 | 34 | 2909.96 | 6 | 3119.83 | 69 | 3271.64 | 68 |
| 2716.25 | 34 | 2910.65 | 108 | 3121.62 | 4 | 3272.07 | 68 |
| 2717.30 | 43 | 2918.63 | 111 | 3122.07 | 60 | 3275.28 | 29 |
| 2719.41 | 34 | 2926.64 | 108 | 3127.86 | 110 | 3276.77 | 50 |
| 2725.78 | 43 | 2931.10 | 111 | 3128.50 | 110 | 3278.28 | 68 |
| 2746.54 | 112 | 2936.02 | 107 | 3130.82 | 4 | 3278.91 | 29 |
| 2751.59 | 112 | 2938.57 | 107 | 3143.77 | 4 | 3280.00 | 40 |
| 2752.68 | 115 | 2941.90 | 107 | 3144.74 | 11 | 3282.32 | 68 |
| 2757.62 | 115 | 2942.97 | 111 | 3145.42 | 11 | 3286.77 | 87 |
| 2758.35 | 115 | 2945.30 | 107 | 3148.06 | 4 | 3287.66 | 87 |
| 2758.79 | 115 | 2952.00 | 107 | 3152.27 | 11 | 3301.66 | 49 |
| 2761.30 | 33 | 2954.59 | 118 | 3154.22 | 11 | 3308.80 | 9 |
| 2762.23 | 33 | 2958.17 | 107 | 3155.68 | 11 | 3312.92 | 59 |
| 2762.92 | 115 | 2958.80 | 118 | 3157.40 | 4 | 3315.32 | 67 |
| 2763.90 | 20 | 2979.06 | 114 | 3161.23 | 11 | 3318.02 | 9 |
| 2764.28 | 115 | 2990.06 | 114 | 3161.80 | 11 | 3321.70 | 67 |
| 2764.82 | 33 | 3008.31 | 83 | 3162.59 | 11 | 3322.94 | 9 |
| 2780.55 | 20 | 3017.17 | 83 | 3168.55 | 11 | 3326.77 | 9 |
| 2784.63 | 20 | 3022.64 | 117 | 3181.73 | 113 | 3329.46 | 9 |
| 2804.82 | 105 | 3023.67 | 117 | 3182.54 | 113 | 3332.11 | 67 |
| 2806.46 | 62 | 3029.76 | 83 | 3184.12 | 3 | 3335.18 | 9 |
| 2810.30 | 105 | 3038.73 | 83 | 3189.49 | 106 | 3337.85 | 58 |
| 2817.83 | 105 | 3043.86 | 78 | 3190.91 | 30 | 3340.34 | 9 |
| 2819.87 | 105 | 3046.69 | 51 | 3192.26 | 31 | 3343.77 | 9 |
| 2820.36 | 19 | 3048.77 | 78 | 3195.71 | 31 | 3346.75 | 9 |
| 2821.26 | 104 | 3056.75 | 51 | 3197.53 | 3 | 3352.07 | 57 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 3361.23 | 1 | 3593.08 | 76 | 4300.06 | 47 | 4529.48 | 81 |
| 3366.19 | 57 | 3596.04 | 16 | 4301.92 | 47 | 4533.97 | 53 |
| 3369.19 | 66 | 3624.82 | 55 | 4307.87 | 47 | 4544.02 | 64 |
| 3372.22 | 17 | 3641.33 | 55 | 4312.87 | 47 | 4549.61 | 81 |
| 3372.80 | 1 | 3659.75 | 75 | 4314.97 | 47 | 4563.77 | 53 |
| 3374.36 | 56 | 3662.24 | 75 | 4316.80 | 92 | 4568.31 | 64 |
| 3380.28 | 1 | 3679.68 | 75 | 4320.96 | 47 | 4571.96 | 81 |
| 3383.77 | 1 | 3706.23 | 73 | 4330.24 | 92 | 4580.45 | 64 |
| 3387.84 | 1 | 3721.64 | 15 | 4330.72 | 47 | 4583.41 | 45 |
| 3388.77 | 56 | 3741.64 | 73 | 4337.88 | 26 | 4589.92 | 53 |
| 3394.58 | 1 | 3748.03 | 99 | 4341.37 | 38 | 4609.26 | 45 |
| 3402.44 | 57 | 3757.70 | 74 | 4344.30 | 26 | 4629.29 | 44 |
| 3407.22 | 1 | 3759.30 | 15 | 4350.85 | 91 | 4657.20 | 63 |
| 3409.82 | 1 | 3761.33 | 15 | 4367.65 | 97 | 4708.65 | 52 |
| 3416.95 | 57 | 3761.88 | 99 | 4374.84 | 91 | 4762.78 | 23 |
| 3443.39 | 94 | 3770.40 | 99 | 4386.85 | 97 | 4779.98 | 90 |
| 3444.32 | 8 | 3774.65 | 14 | 4391.04 | 65 | 4794.83 | 35 |
| 3452.49 | 94 | 3776.06 | 74 | 4394.02 | 54 | 4798.53 | 23 |
| 3456.40 | 94 | 3786.33 | 14 | 4395.00 | 25 | 4805.09 | 90 |
| 3461.51 | 8 | 3796.90 | 14 | 4395.83 | 65 | 4865.62 | 35 |
| 3465.56 | 94 | 3799.79 | 15 | 4399.79 | 54 | 4874.01 | 101 |
| 3477.19 | 8 | 3813.39 | 14 | 4407.68 | 54 | 4911.18 | 101 |
| 3483.63 | 116 | 3814.58 | 14 | 4411.10 | 102 | 4981.35 | 72 |
| 3489.75 | 8 | 3882.28 | 39 | 4417.72 | 46 | 5005.17 | 72 |
| 3492.37 | 116 | 3900.56 | 39 | 4418.31 | 54 | 5069.08 | 100 |
| 3500.34 | 8 | 3913.48 | 39 | 4421.95 | 92 | 5072.27 | 100 |
| 3504.90 | 86 | 3932.02 | 39 | 4427.91 | 65 | 5129.16 | 84 |
| 3505.91 | 86 | 3987.61 | 13 | 4432.09 | 54 | 5154.06 | 71 |
| 3509.81 | 86 | 4012.40 | 13 | 4441.73 | 46 | 5185.90 | 84 |
| 3510.86 | 86 | 4025.12 | 13 | 4443.78 | 25 | 5188.69 | 71 |
| 3520.27 | 93 | 4028.36 | 85 | 4444.54 | 37 | 5226.53 | 71 |
| 3533.85 | 93 | 4053.83 | 85 | 4450.50 | 25 | 5268.61 | 96 |
| 3535.41 | 93 | 4161.53 | 27 | 4464.46 | 46 | 5336.78 | 70 |
| 3561.57 | 16 | 4163.63 | 98 | 4468.52 | 37 | 5381.01 | 70 |
| 3561.90 | 48 | 4171.92 | 98 | 4470.84 | 46 | 6606.97 | 89 |
| 3565.30 | 76 | 4174.05 | 98 | 4488.34 | 102 | 7214.74 | 95 |
| 3565.96 | 48 | 4287.88 | 26 | 4493.53 | 24 | | |
| 3573.72 | 16 | 4290.22 | 47 | 4501.27 | 37 | | |
| 3587.13 | 16 | 4294.09 | 26 | 4506.74 | 36 | | |

The compiled data for this spectrum are based mainly on the experiments of Roberts, Andersen, and Sorensen[1] (RAS); Roberts, Voigt, and Czernichowski[3] (RVC); and Danzmann and Kock.[4] The data of RAS were obtained by a comprehensive experimental approach in which an emission method using a gas-flow stabilized arc for the measurement of relative oscillator strengths was combined with a lifetime experiment using the beam-foil technique to obtain an absolute scale. In the later work of RVC, emission measurements were made with a wall-stabilized arc. With this more advanced arc source, the temperature of the plasma was determined spectroscopically, and a uniform scale for all relative $f$-values was established. By remeasuring selected lines, the authors of Ref. 3 were able to place the log $gf$-values of RAS on a more reliable relative scale.

The data of Danzmann and Kock were obtained by a combination of anomalous dispersion (hook) and emission measurements. Wall-stabilized arcs and hollow-cathode discharges served as plasma light sources for these measurements. This method has proved to be quite reliable in the case of Ti I (see Ref. 5), and here too the data should generally be accurate to within ±25 percent.

The most reliable data for this spectrum are those of Blackwell *et al.*,[8] who determined oscillator strengths for eighteen lines by an advanced absorption technique. On a *relative* scale, these data are of outstanding accuracy, i.e., with uncertainties within 0.5 percent. However, because of the much larger uncertainty in the *absolute* scale obtained by utilizing the lifetime data of Ref. 1, we estimate the overall accuracy to be in the "C+" range.

Another data source which we utilized in this compilation is the work of Kostyk and Orlova.[9] These authors derived log $gf$-values from solar spectra, i.e., they used equivalent widths taken from the Liege solar atlas.[10] We estimate these oscillator strengths to be accurate within 50 percent. The results of shock-tube emission measurements by Wolnik and Berthel[2] were used for three lines not treated in Refs. 1, 3, 4, 8, and 9. For another eighteen lines, the data of Wolnik and Berthel overlap with those of RAS. Here, the agreement is generally within 50 percent, except for a few of the weaker lines.

In this compilation, we have given first priority to the data of Blackwell *et al.*, followed by Kostyk and Orlova, then Danzmann and Kock and/or RVC. Since RVC present a detailed error budget, which includes uncertainty estimates for the temperature and lifetime determinations, line intensity calibrations, the (partial) thermodynamic equilibrium assumption, and general statistical measurement errors, we follow their error estimates closely. For all lines originating from the highest energy levels, i.e., for states approximately 8 eV above the ground state, the uncertainties become rather large, since these lines are quite sensitive to temperature errors.

It should be noted that the normalized log *gf*-values taken from RAS and tabulated here differ slightly from those in our earlier compilation.[6] The reason for this change is that some of the data of RAS were found to contain typographical or arithmetical errors,[7] leading to inconsistencies between their relative scale and that of RVC, and the correction factors to log *gf* (RAS) had to be changed accordingly. The maximum change to the original correction factors is 0.03 in the logarithm, but most changes are smaller. For lines arising from highly excited levels, i.e., those for which $E_k > 46000\ \mathrm{cm}^{-1}$, we have tabulated additional lines from RAS. In these cases, the relative scales of RAS and RVC were generally found to agree, and the RAS data were then normalized accordingly.

Some of the normalized data of RAS disagree appreciably with those of Danzmann and Kock. For wavelengths longer than 4300 Å (or for lower energy levels $E_i > 8500\ \mathrm{cm}^{-1}$) the *f*-values of RAS are, on the average, about 36 percent lower than those of Ref. 4. Danzmann and Kock recognized this discrepancy and rechecked their measurements, obtaining the same results as before. Nevertheless, no obvious problems seem to exist with the RAS experiment. In fact, the wavelength-dependent deviations can also be considered lower-energy-level-dependent deviations, indicating possible problems with the hook measurements of Ref. 4. Because we could not determine a definite source of error in either Ref. 1 or Ref. 4, we have assigned lower accuracies ("D−") to lines above 4300 Å.

## References


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Ti II: Allowed transitions

| No. | Multiplet | λ (Å) | $E_i$ ($\mathrm{cm}^{-1}$) | $E_k$ ($\mathrm{cm}^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8\ \mathrm{s}^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $a\ ^4F - z\ ^4G°$ (1) | | | | | | | | | | | |
| | | 3361.23 | 225.7 | 29968 | 8 | 10 | 1.1 | 0.24 | 21 | 0.28 | C | 4 |
| | | 3372.80 | 94.1 | 29735 | 6 | 8 | 1.11 | 0.252 | 16.8 | 0.180 | C+ | 8 |
| | | 3383.77 | 0.0 | 29544 | 4 | 6 | 1.09 | 0.282 | 12.6 | 0.052 | C+ | 8 |
| | | 3380.28 | 393.4 | 29968 | 10 | 10 | 0.16 | 0.027 | 3.0 | −0.57 | C | 3,4 |
| | | 3387.84 | 225.7 | 29735 | 8 | 8 | 0.218 | 0.0376 | 3.35 | −0.522 | C+ | 8 |
| | | 3394.58 | 94.1 | 29544 | 6 | 6 | 0.25 | 0.043 | 2.9 | −0.59 | C | 3,4 |
| | | 3407.22 | 393.4 | 29735 | 10 | 8 | 0.0072 | 0.0010 | 0.11 | −2.00 | C | 3,4 |
| | | 3409.82 | 225.7 | 29544 | 8 | 6 | 0.012 | 0.0016 | 0.14 | −1.89 | C | 3,4 |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | $a\,^4F - z\,^4F^\circ$ (2) | | | | | | | | | | | |
| | | 3234.51 | 393.4 | 31301 | 10 | 10 | 1.38 | 0.217 | 23.1 | 0.336 | C+ | 8 |
| | | 3236.58 | 225.7 | 31114 | 8 | 8 | 1.11 | 0.174 | 14.8 | 0.144 | C+ | 8 |
| | | 3239.04 | 94.1 | 30959 | 6 | 6 | 0.987 | 0.155 | 9.93 | −0.031 | C+ | 8 |
| | | 3241.99 | 0.0 | 30836 | 4 | 4 | 1.16 | 0.183 | 7.82 | −0.135 | C+ | 8 |
| | | 3254.25 | 393.4 | 31114 | 10 | 8 | 0.20 | 0.026 | 2.8 | −0.59 | C | 3,4 |
| | | 3252.92 | 225.7 | 30959 | 8 | 6 | 0.39 | 0.046 | 3.9 | −0.43 | C | 3,4 |
| | | 3251.91 | 94.1 | 30836 | 6 | 4 | 0.338 | 0.0357 | 2.29 | −0.669 | C+ | 8 |
| | | 3217.07 | 225.7 | 31301 | 8 | 10 | 0.169 | 0.0327 | 2.77 | −0.582 | C+ | 8 |
| | | 3222.84 | 94.1 | 31114 | 6 | 8 | 0.26 | 0.055 | 3.5 | −0.48 | C | 3,4 |
| 3. | $a\,^4F - z\,^2F^\circ$ (3) | | | | | | | | | | | |
| | | 3214.78 | 393.4 | 31491 | 10 | 8 | 0.033 | 0.0041 | 0.43 | −1.39 | C | 3,4 |
| | | 3226.77 | 225.7 | 31207 | 8 | 6 | 0.016 | 0.0019 | 0.16 | −1.82 | C | 3,4 |
| | | 3197.53 | 225.7 | 31491 | 8 | 8 | 0.011 | 0.0016 | 0.14 | −1.88 | D | 3 |
| | | 3213.15 | 94.1 | 31207 | 6 | 6 | 0.0061 | 9.4(−4)[a] | 0.059 | −2.25 | D− | 1*n* |
| | | 3184.12 | 94.1 | 31491 | 6 | 8 | 0.0046 | 9.4(−4) | 0.059 | −2.25 | D− | 1*n* |
| | | 3203.43 | 0.0 | 31207 | 4 | 6 | 0.021 | 0.0048 | 0.20 | −1.72 | D− | 1*n* |
| 4. | $a\,^4F - z\,^2D^\circ$ (4) | | | | | | | | | | | |
| | | 3143.77 | 225.7 | 32025 | 8 | 6 | 0.062 | 0.0069 | 0.57 | −1.26 | D | 1*n* |
| | | 3157.40 | 94.1 | 31757 | 6 | 4 | 0.012 | 0.0012 | 0.077 | −2.13 | D | 3 |
| | | 3130.82 | 94.1 | 32025 | 6 | 6 | 0.082 | 0.012 | 0.75 | −1.14 | D | 1*n* |
| | | 3148.06 | 0.0 | 31757 | 4 | 4 | 0.11 | 0.016 | 0.65 | −1.20 | C | 3 |
| | | 3121.62 | 0.0 | 32025 | 4 | 6 | 0.0059 | 0.0013 | 0.053 | −2.29 | D− | 1*n* |
| 5. | $a\,^4F - z\,^4D^\circ$ (5) | | | | | | | | | | | |
| | | 3088.04 | 393.4 | 32767 | 10 | 8 | 1.25 | 0.143 | 14.6 | 0.156 | C+ | 8 |
| | | 3078.65 | 225.7 | 32698 | 8 | 6 | 1.09 | 0.116 | 9.39 | −0.033 | C+ | 8 |
| | | 3075.23 | 94.1 | 32603 | 6 | 4 | 1.13 | 0.106 | 6.46 | −0.195 | C+ | 8 |
| | | 3072.99 | 0.0 | 32532 | 4 | 2 | 1.6 | 0.11 | 4.5 | −0.36 | C | 3,4 |
| | | 3072.12 | 225.7 | 32767 | 8 | 8 | 0.20 | 0.028 | 2.3 | −0.65 | C | 3,4 |
| | | 3066.23 | 94.1 | 32698 | 6 | 6 | 0.253 | 0.0357 | 2.16 | −0.669 | C+ | 8 |
| | | 3066.34 | 0.0 | 32603 | 4 | 4 | 0.33 | 0.047 | 1.9 | −0.73 | C | 4 |
| | | 3057.40 | 0.0 | 32698 | 4 | 6 | 0.022 | 0.0047 | 0.19 | −1.73 | D− | 1*n* |
| 6. | $a\,^4F - z\,^2G^\circ$ (uv 1) | | | | | | | | | | | |
| | | 2909.96 | 393.4 | 34748 | 10 | 10 | 0.0079 | 0.0010 | 0.096 | −2.00 | D | 3 |
| 7. | $a\,^4F - y\,^4D^\circ$ (uv 2) | | | | | | | | | | | |
| | | 2474.22 | 393.4 | 40798 | 10 | 8 | 0.0057 | 4.2(−4) | 0.034 | −2.38 | D− | 1*n* |
| | | 2477.21 | 225.7 | 40581 | 8 | 6 | 0.0079 | 5.5(−4) | 0.036 | −2.36 | D− | 1*n* |
| | | 2478.64 | 94.1 | 40426 | 6 | 4 | 0.016 | 0.0010 | 0.049 | −2.22 | D− | 1*n* |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | $b\,^4F - z\,^4G^{\circ}$ (6) | | | | | | | | | | | |
| | | 3444.32 | 1216 | 30241 | 10 | 12 | 0.073 | 0.015 | 1.8 | −0.81 | D | 1*n* |
| | | 3461.51 | 1087 | 29968 | 8 | 10 | 0.0627 | 0.0141 | 1.28 | −0.948 | C+ | 8 |
| | | 3477.19 | 983.9 | 29735 | 6 | 8 | 0.0605 | 0.0146 | 1.00 | −1.057 | C+ | 8 |
| | | 3489.75 | 1087 | 29735 | 8 | 8 | 0.0082 | 0.0015 | 0.14 | −1.92 | D | 3 |
| | | 3500.34 | 983.9 | 29544 | 6 | 6 | 0.0079 | 0.0015 | 0.10 | −2.06 | D | 3 |
| 9. | $b\,^4F - z\,^4F^{\circ}$ (7) | | | | | | | | | | | |
| | | 3322.94 | 1216 | 31301 | 10 | 10 | 0.396 | 0.0656 | 7.18 | −0.183 | C+ | 8 |
| | | 3329.46 | 1087 | 31114 | 8 | 8 | 0.325 | 0.0541 | 4.74 | −0.364 | C+ | 8 |
| | | 3335.18 | 983.9 | 30959 | 6 | 6 | 0.293 | 0.0488 | 3.22 | −0.533 | C+ | 8 |
| | | 3340.34 | 908.0 | 30836 | 4 | 4 | 0.36 | 0.061 | 2.7 | −0.61 | C | 3,4 |
| | | 3343.77 | 1216 | 31114 | 10 | 8 | 0.040 | 0.0054 | 0.59 | −1.27 | C | 4 |
| | | 3346.75 | 1087 | 30959 | 8 | 6 | 0.079 | 0.010 | 0.88 | −1.10 | C | 3,4 |
| | | 3308.80 | 1087 | 31301 | 8 | 10 | 0.045 | 0.0093 | 0.81 | −1.13 | C | 4 |
| | | 3318.02 | 983.9 | 31114 | 6 | 8 | 0.060 | 0.013 | 0.87 | −1.10 | C | 4 |
| | | 3326.77 | 908.0 | 30959 | 4 | 6 | 0.084 | 0.021 | 0.92 | −1.08 | C | 3,4 |
| 10. | $b\,^4F - z\,^2D^{\circ}$ (9) | | | | | | | | | | | |
| | | 3231.31 | 1087 | 32025 | 8 | 6 | 0.034 | 0.0040 | 0.34 | −1.50 | C | 3 |
| 11. | $b\,^4F - z\,^4D^{\circ}$ (10) | *3163.1* | *1085* | *32690* | 28 | 20 | 0.51 | 0.055 | 16 | 0.19 | C | 1*n*,3,4 |
| | | 3168.55 | 1216 | 32767 | 10 | 8 | 0.41 | 0.049 | 5.1 | −0.31 | C | 3 |
| | | 3162.59 | 1087 | 32698 | 8 | 6 | 0.39 | 0.044 | 3.7 | −0.45 | C | 3,4 |
| | | 3161.80 | 983.9 | 32603 | 6 | 4 | 0.46 | 0.046 | 2.9 | −0.56 | C | 3,4 |
| | | 3161.23 | 908.0 | 32532 | 4 | 2 | 0.59 | 0.044 | 1.8 | −0.75 | C | 3,4 |
| | | 3155.68 | 1087 | 32767 | 8 | 8 | 0.074 | 0.011 | 0.91 | −1.06 | C | 3,4 |
| | | 3152.27 | 983.9 | 32698 | 6 | 6 | 0.094 | 0.014 | 0.87 | −1.08 | C | 3,4 |
| | | 3154.22 | 908.0 | 32603 | 4 | 4 | 0.11 | 0.017 | 0.71 | −1.17 | C | 3,4 |
| | | 3145.42 | 983.9 | 32767 | 6 | 8 | 0.0017 | 3.4(−4) | 0.021 | −2.69 | D− | 1*n* |
| | | 3144.74 | 908.0 | 32698 | 4 | 6 | 0.0042 | 9.3(−4) | 0.038 | −2.43 | D− | 1*n* |
| 12. | $b\,^4F - y\,^4D^{\circ}$ (uv 4) | 2529.2 | *1085* | *40612* | 28 | 20 | 0.64 | 0.044 | 10 | 0.09 | D | 1*n*,3 |
| | | 2525.59 | 1216 | 40798 | 10 | 8 | 0.56 | 0.043 | 3.5 | −0.37 | D | 1*n* |
| | | 2531.28 | 1087 | 40581 | 8 | 6 | 0.49 | 0.035 | 2.3 | −0.55 | D | 1*n* |
| | | 2534.63 | 983.9 | 40426 | 6 | 4 | 0.54 | 0.035 | 1.7 | −0.68 | D | 1*n* |
| | | 2535.89 | 908.0 | 40330 | 4 | 2 | 0.68 | 0.033 | 1.1 | −0.88 | D | 1*n* |
| | | 2517.42 | 1087 | 40798 | 8 | 8 | 0.060 | 0.0057 | 0.38 | −1.34 | D | 3 |
| | | 2524.66 | 983.9 | 40581 | 6 | 6 | 0.12 | 0.012 | 0.59 | −1.15 | D | 3 |
| | | 2529.79 | 908.0 | 40426 | 4 | 4 | 0.17 | 0.017 | 0.55 | −1.18 | D | 3 |
| | | 2510.87 | 983.9 | 40798 | 6 | 8 | 0.0028 | 3.6(−4) | 0.018 | −2.67 | D− | 1*n* |
| | | 2519.82 | 908.0 | 40581 | 4 | 6 | 0.0049 | 7.0(−4) | 0.023 | −2.55 | D− | 1*n* |
| 13. | $a\,^2F - z\,^4G^{\circ}$ (11) | | | | | | | | | | | |
| | | 3987.61 | 4898 | 29968 | 8 | 10 | 7.8(−4) | 2.3(−4) | 0.024 | −2.73 | D | 4 |
| | | 4025.12 | 4898 | 29735 | 8 | 8 | 0.0054 | 0.0013 | 0.14 | −1.98 | D− | 1*n* |
| | | 4012.40 | 4629 | 29544 | 6 | 6 | 0.017 | 0.0041 | 0.32 | −1.61 | C | 4 |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14. | $a\ ^2F - z\ ^4F°$ (12) | | | | | | | | | | | |
| | | 3786.33 | 4898 | 31301 | 8 | 10 | 0.0043 | 0.0012 | 0.12 | −2.03 | D− | 1*n* |
| | | 3774.65 | 4629 | 31114 | 6 | 8 | 0.0011 | 3.1(−4) | 0.023 | −2.73 | D− | 1*n* |
| | | 3813.39 | 4898 | 31114 | 8 | 8 | 0.0055 | 0.0012 | 0.12 | −2.02 | D− | 1*n* |
| | | 3796.90 | 4629 | 30959 | 6 | 6 | 0.0019 | 4.2(−4) | 0.031 | −2.60 | D− | 1*n* |
| | | 3814.58 | 4629 | 30836 | 6 | 4 | 0.022 | 0.0032 | 0.24 | −1.72 | D− | 1*n* |
| 15. | $a\ ^2F - z\ ^2F°$ (13) | *3760.3* | *4783* | *31369* | 14 | 14 | 1.0 | 0.21 | 37 | 0.48 | C | 1*n*,4 |
| | | 3759.30 | 4898 | 31491 | 8 | 8 | 0.94 | 0.20 | 20 | 0.20 | C | 4 |
| | | 3761.33 | 4629 | 31207 | 6 | 6 | 0.99 | 0.21 | 16 | 0.10 | C | 4 |
| | | 3799.79 | 4898 | 31207 | 8 | 6 | 9.3(−4) | 1.5(−4) | 0.015 | −2.92 | D− | 1*n* |
| | | 3721.64 | 4629 | 31491 | 6 | 8 | 0.039 | 0.011 | 0.79 | −1.19 | C | 4 |
| 16. | $a\ ^2F - z\ ^4D°$ (15) | | | | | | | | | | | |
| | | 3587.13 | 4898 | 32767 | 8 | 8 | 0.011 | 0.0021 | 0.20 | −1.77 | D | 1*n* |
| | | 3561.57 | 4629 | 32698 | 6 | 6 | 0.0044 | 8.4(−4) | 0.059 | −2.30 | D | 1*n* |
| | | 3596.04 | 4898 | 32698 | 8 | 6 | 0.052 | 0.0075 | 0.71 | −1.22 | C | 4 |
| | | 3573.72 | 4629 | 32603 | 6 | 4 | 0.028 | 0.0036 | 0.25 | −1.67 | D | 1*n* |
| 17. | $a\ ^2F - z\ ^2G°$ (16) | | | | | | | | | | | |
| | | 3372.22 | 4898 | 34543 | 8 | 8 | 0.073 | 0.013 | 1.1 | −1.00 | D− | 1*n* |
| 18. | $a\ ^2F - y\ ^2D°$ (uv 5) | *2877.4* | *4783* | *39527* | 14 | 10 | 0.18 | 0.016 | 2.1 | −0.65 | C− | 1*n*,3 |
| | | 2891.08 | 4898 | 39477 | 8 | 6 | 0.15 | 0.014 | 1.1 | −0.94 | D | 1*n* |
| | | 2858.41 | 4629 | 39603 | 6 | 4 | 0.047 | 0.0038 | 0.22 | −1.64 | D | 3 |
| | | 2868.75 | 4629 | 39477 | 6 | 6 | 0.11 | 0.014 | 0.79 | −1.08 | C | 3 |
| 19. | $a\ ^2F - y\ ^2F°$ (uv 7) | *2837.7* | *4783* | *40012* | 14 | 14 | 0.31 | 0.037 | 4.8 | −0.29 | C | 1*n*,3 |
| | | 2841.94 | 4898 | 40075 | 8 | 8 | 0.29 | 0.035 | 2.6 | −0.55 | C | 3 |
| | | 2832.19 | 4629 | 39927 | 6 | 6 | 0.25 | 0.030 | 1.7 | −0.75 | C | 3 |
| | | 2853.93 | 4898 | 39927 | 8 | 6 | 0.052 | 0.0048 | 0.36 | −1.42 | D | 3 |
| | | 2820.36 | 4629 | 40075 | 6 | 8 | 0.019 | 0.0030 | 0.17 | −1.75 | D− | 1*n* |
| 20. | $a\ ^2F - y\ ^4D°$ (uv 8) | | | | | | | | | | | |
| | | 2784.63 | 4898 | 40798 | 8 | 8 | 0.016 | 0.0019 | 0.14 | −1.82 | D | 3 |
| | | 2780.55 | 4629 | 40581 | 6 | 6 | 0.025 | 0.0029 | 0.16 | −1.76 | D | 3 |
| | | 2763.90 | 4629 | 40798 | 6 | 8 | 0.0017 | 2.6(−4) | 0.014 | −2.80 | D− | 1*n* |
| 21. | $a\ ^2F - y\ ^2G°$ (uv 9) | *2564.7* | *4783* | *43763* | 14 | 18 | 0.30 | 0.038 | 4.5 | −0.27 | D | 1*n*,3 |
| | | 2571.08 | 4898 | 43781 | 8 | 10 | 0.27 | 0.033 | 2.2 | −0.58 | D | 1*n* |
| | | 2555.99 | 4629 | 43741 | 6 | 8 | 0.32 | 0.042 | 2.1 | −0.60 | D | 1*n* |
| | | 2573.67 | 4898 | 43741 | 8 | 8 | 0.027 | 0.0027 | 0.18 | −1.67 | C | 3 |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22. | $a\ ^2F - x\ ^2D°$ (uv 10) | | | | | | | | | | | |
| | | 2499.71 | 4898 | 44902 | 8 | 6 | 0.029 | 0.0020 | 0.13 | −1.79 | D | 1*n* |
| | | 2482.24 | 4629 | 44915 | 6 | 4 | 0.020 | 0.0012 | 0.061 | −2.13 | D− | 1*n* |
| 23. | $a\ ^2D - z\ ^4G°$ (17) | | | | | | | | | | | |
| | | 4762.78 | 8744 | 29735 | 6 | 8 | 7.2(−4) | 3.2(−4) | 0.031 | −2.71 | D | 9 |
| | | 4798.53 | 8710 | 29544 | 4 | 6 | 0.0018 | 9.3(−4) | 0.059 | −2.43 | D | 9 |
| 24. | $a\ ^2D - z\ ^4F°$ (18) | | | | | | | | | | | |
| | | 4493.53 | 8710 | 30959 | 4 | 6 | 0.0010 | 4.7(−4) | 0.028 | −2.73 | D | 9 |
| 25. | $a\ ^2D - z\ ^2F°$ (19) | *4415.9* | *8730* | *31369* | 10 | 14 | 0.11 | 0.045 | 6.6 | −0.34 | D− | 1*n*,4 |
| | | 4395.00 | 8744 | 31491 | 6 | 8 | 0.094 | 0.036 | 3.2 | −0.66 | D− | 1*n* |
| | | 4443.78 | 8710 | 31207 | 4 | 6 | 0.11 | 0.050 | 2.9 | −0.70 | D− | 4 |
| | | 4450.50 | 8744 | 31207 | 6 | 6 | 0.020 | 0.0059 | 0.52 | −1.45 | D− | 4 |
| 26. | $a\ ^2D - z\ ^2D°$ (20) | *4311.4* | *8730* | *31918* | 10 | 10 | 0.063 | 0.018 | 2.5 | −0.75 | D− | 1*n* |
| | | 4294.09 | 8744 | 32025 | 6 | 6 | 0.047 | 0.013 | 1.1 | −1.11 | D− | 1*n* |
| | | 4337.88 | 8710 | 31757 | 4 | 4 | 0.066 | 0.019 | 1.1 | −1.13 | D− | 1*n* |
| | | 4344.30 | 8744 | 31757 | 6 | 4 | 0.0072 | 0.0014 | 0.12 | −2.09 | D− | 1*n* |
| | | 4287.88 | 8710 | 32026 | 4 | 6 | 0.0058 | 0.0024 | 0.13 | −2.02 | D− | 1*n* |
| 27. | $a\ ^2D - z\ ^4D°$ (21) | | | | | | | | | | | |
| | | 4161.53 | 8744 | 32767 | 6 | 8 | 0.0021 | 7.3(−4) | 0.060 | −2.36 | D | 1*n* |
| 28. | $a\ ^2D - y\ ^2D°$ (23) | | | | | | | | | | | |
| | | 3236.13 | 8710 | 39603 | 4 | 4 | 0.70 | 0.11 | 4.7 | −0.36 | D | 1*n* |
| | | 3239.66 | 8744 | 39603 | 6 | 4 | 0.94 | 0.098 | 6.3 | −0.23 | D | 1*n* |
| | | 3249.37 | 8710 | 39477 | 4 | 6 | 0.045 | 0.011 | 0.46 | −1.37 | D | 1*n* |
| 29. | $a\ ^2D - z\ ^2P°$ (24) | *3261.7* | *8730* | *39380* | 10 | 6 | 1.4 | 0.13 | 14 | 0.12 | D | 1*n*,3 |
| | | 3278.91 | 8744 | 39233 | 6 | 4 | 1.0 | 0.11 | 7.3 | −0.17 | D | 1*n* |
| | | 3228.62 | 8710 | 39675 | 4 | 2 | 2.0 | 0.16 | 6.7 | −0.20 | C | 3 |
| | | 3275.28 | 8710 | 39233 | 4 | 4 | 0.055 | 0.0089 | 0.38 | −1.45 | D | 3 |
| 30. | $a\ ^2D - y\ ^2F°$ (26) | *3195.8* | *8730* | *40012* | 10 | 14 | 1.2 | 0.26 | 27 | 0.41 | C | 1*n*,3 |
| | | 3190.91 | 8744 | 40075 | 6 | 8 | 1.3 | 0.26 | 16 | 0.19 | C | 3 |
| | | 3202.56 | 8710 | 39927 | 4 | 6 | 1.1 | 0.26 | 11 | 0.02 | C | 3 |
| | | 3206.01 | 8744 | 39927 | 6 | 6 | 0.0067 | 0.0010 | 0.065 | −2.21 | D− | 1*n* |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31. | $a\ ^2D - z\ ^4S°$ (25) | | | | | | | | | | | |
| | | 3195.71 | 8744 | 40027 | 6 | 4 | 0.080 | 0.0082 | 0.52 | −1.31 | C | 3 |
| | | 3192.26 | 8710 | 40027 | 4 | 4 | 0.033 | 0.0050 | 0.21 | −1.70 | D | 1*n* |
| 32. | $a\ ^2D - y\ ^4D°$ (27) | | | | | | | | | | | |
| | | 3118.83 | 8744 | 40798 | 6 | 8 | 0.018 | 0.0034 | 0.21 | −1.69 | D | 1*n* |
| 33. | $a\ ^2D - x\ ^2D°$ (uv 12) | | | | | | | | | | | |
| | | 2764.82 | 8744 | 44902 | 6 | 6 | 0.16 | 0.018 | 1.0 | −0.96 | C | 3 |
| | | 2761.30 | 8710 | 44915 | 4 | 4 | 0.13 | 0.015 | 0.54 | −1.23 | D | 3 |
| | | 2762.23 | 8710 | 44902 | 4 | 6 | 0.047 | 0.0081 | 0.29 | −1.49 | D | 3 |
| 34. | $a\ ^2D - y\ ^2P°$ (uv 13) | *2717.1* | *8730* | *45523* | 10 | 6 | 0.11 | 0.0075 | 0.67 | −1.13 | D | 1*n*,3 |
| | | 2716.25 | 8744 | 45549 | 6 | 4 | 0.096 | 0.0071 | 0.38 | −1.37 | D | 3 |
| | | 2719.41 | 8710 | 45472 | 4 | 2 | 0.12 | 0.0064 | 0.23 | −1.59 | D | 1*n* |
| | | 2713.74 | 8710 | 45549 | 4 | 4 | 0.015 | 0.0017 | 0.059 | −2.18 | D | 1*n* |
| 35. | $a\ ^2G - z\ ^4G°$ (29) | | | | | | | | | | | |
| | | 4794.83 | 9118 | 29968 | 10 | 10 | 2.6(−5) | 9.1(−6) | 0.0014 | −4.04 | D | 9 |
| | | 4865.62 | 8998 | 29544 | 8 | 6 | 0.0012 | 3.1(−4) | 0.039 | −2.61 | D | 9 |
| 36. | $a\ ^2G - z\ ^4F°$ (30) | | | | | | | | | | | |
| | | 4506.74 | 9118 | 31301 | 10 | 10 | 1.6(−4) | 4.8(−5) | 0.0071 | −3.32 | D | 9 |
| 37. | $a\ ^2G - z\ ^2F°$ (31) | *4482.2* | *9065* | *31369* | 18 | 14 | 0.10 | 0.024 | 6.4 | −0.36 | D− | 4,9 |
| | | 4468.52 | 9118 | 31491 | 10 | 8 | 0.10 | 0.025 | 3.7 | −0.60 | D− | 4 |
| | | 4501.27 | 8998 | 31207 | 8 | 6 | 0.098 | 0.022 | 2.6 | −0.75 | D− | 4 |
| | | 4444.54 | 8998 | 31491 | 8 | 8 | 0.0039 | 0.0012 | 0.14 | −2.03 | D | 9 |
| 38. | $a\ ^2G - z\ ^2D°$ (32) | | | | | | | | | | | |
| | | 4341.37 | 8998 | 32025 | 8 | 6 | 0.0031 | 6.6(−4) | 0.075 | −2.28 | D− | 1*n* |
| 39. | $a\ ^2G - z\ ^2G°$ (34) | *3906.4* | *9065* | *34657* | 18 | 18 | 0.17 | 0.038 | 8.9 | −0.16 | D | 1*n* |
| | | 3900.56 | 9118 | 34748 | 10 | 10 | 0.16 | 0.035 | 4.6 | −0.45 | D | 1*n* |
| | | 3913.48 | 8998 | 34543 | 8 | 8 | 0.16 | 0.037 | 3.8 | −0.53 | D | 1*n* |
| | | 3932.02 | 9118 | 34543 | 10 | 8 | 0.0089 | 0.0017 | 0.21 | −1.78 | D | 1*n* |
| | | 3882.28 | 8998 | 34748 | 8 | 10 | 0.0086 | 0.0024 | 0.25 | −1.71 | D | 1*n* |
| 40. | $a\ ^2G - y\ ^2D°$ (35) | | | | | | | | | | | |
| | | 3280.00 | 8998 | 39477 | 8 | 6 | 0.075 | 0.0091 | 0.78 | −1.14 | D | 3 |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41. | $a\,^2G - y\,^2F°$ (36) | | | | | | | | | | | |
| | | 3232.29 | 8998 | 39927 | 8 | 6 | 0.60 | 0.070 | 6.0 | −0.25 | C | 3 |
| 42. | $a\,^2G - y\,^2G°$ (uv 14) | *2881.2* | *9065* | *43763* | 18 | 18 | 0.56 | 0.070 | 12 | 0.10 | D | 1*n*,3 |
| | | 2884.13 | 9118 | 43781 | 10 | 10 | 0.52 | 0.065 | 6.1 | −0.19 | D | 3 |
| | | 2877.47 | 8998 | 43741 | 8 | 8 | 0.57 | 0.070 | 5.3 | −0.25 | D | 3 |
| | | 2887.44 | 9118 | 43741 | 10 | 8 | 0.010 | 0.0010 | 0.10 | −1.98 | D− | 1*n* |
| | | 2874.11 | 8998 | 43781 | 8 | 10 | 0.010 | 0.0016 | 0.12 | −1.90 | D− | 1*n* |
| 43. | $a\,^2G - z\,^2H°$ (uv 15) | | | | | | | | | | | |
| | | 2717.30 | 9118 | 45909 | 10 | 12 | 0.033 | 0.0044 | 0.39 | −1.36 | D | 3 |
| | | 2725.78 | 8998 | 45674 | 8 | 10 | 0.033 | 0.0046 | 0.33 | −1.43 | D | 3 |
| 44. | $a\,^4P - z\,^4F°$ (38) | | | | | | | | | | | |
| | | 4629.29 | 9518 | 31114 | 6 | 8 | 0.0022 | 9.6(−4) | 0.088 | −2.24 | D− | 1*n* |
| 45. | $a\,^4P - z\,^2F°$ (39) | | | | | | | | | | | |
| | | 4583.41 | 9396 | 31207 | 4 | 6 | 0.0010 | 4.8(−4) | 0.029 | −2.72 | D | 9 |
| | | 4609.26 | 9518 | 31207 | 6 | 6 | 2.9(−4) | 9.2(−5) | 0.0083 | −3.26 | D | 9 |
| 46. | $a\,^4P - z\,^2D°$ (40) | | | | | | | | | | | |
| | | 4441.73 | 9518 | 32025 | 6 | 6 | 0.0022 | 6.5(−4) | 0.057 | −2.41 | D− | 1*n* |
| | | 4470.84 | 9396 | 31757 | 4 | 4 | 0.0044 | 0.0013 | 0.077 | −2.28 | D− | 1*n* |
| | | 4417.72 | 9396 | 32025 | 4 | 6 | 0.021 | 0.0093 | 0.54 | −1.43 | D− | 1*n* |
| | | 4464.46 | 9364 | 31757 | 2 | 4 | 0.0070 | 0.0042 | 0.12 | −2.08 | D− | 1*n* |
| 47. | $a\,^4P - z\,^4D°$ (41) | *4302.1* | *9452* | *32690* | 12 | 20 | 0.097 | 0.045 | 7.6 | −0.27 | D− | 1*n*,4 |
| | | 4300.06 | 9518 | 32767 | 6 | 8 | 0.077 | 0.028 | 2.4 | −0.77 | D− | 1*n* |
| | | 4290.22 | 9396 | 32698 | 4 | 6 | 0.046 | 0.019 | 1.1 | −1.12 | D− | 1*n* |
| | | 4301.92 | 9364 | 32603 | 2 | 4 | 0.062 | 0.035 | 0.98 | −1.16 | D− | 4 |
| | | 4312.87 | 9518 | 32698 | 6 | 6 | 0.041 | 0.012 | 0.98 | −1.16 | D− | 4 |
| | | 4307.87 | 9396 | 32603 | 4 | 4 | 0.046 | 0.013 | 0.73 | −1.29 | D− | 1*n* |
| | | 4314.97 | 9364 | 32532 | 2 | 2 | 0.13 | 0.037 | 1.1 | −1.13 | D− | 4 |
| | | 4330.72 | 9518 | 32603 | 6 | 4 | 0.0081 | 0.0015 | 0.13 | −2.04 | D− | 4 |
| | | 4320.96 | 9396 | 32532 | 4 | 2 | 0.024 | 0.0034 | 0.19 | −1.87 | D− | 4 |
| 48. | $a\,^4P - z\,^2S°$ (42) | | | | | | | | | | | |
| | | 3565.96 | 9396 | 37431 | 4 | 2 | 0.039 | 0.0037 | 0.17 | −1.83 | D− | 1 |
| | | 3561.90 | 9364 | 37431 | 2 | 2 | 0.013 | 0.0024 | 0.057 | −2.31 | E | 1 |
| 49. | $a\,^4P - z\,^2P°$ (44) | | | | | | | | | | | |
| | | 3301.66 | 9396 | 39675 | 4 | 2 | 0.061 | 0.0050 | 0.22 | −1.70 | D− | 1*n* |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50. | $a\,^4P - z\,^4S°$ (45) | *3269.7* | *9452* | 40027 | 12 | 4 | 0.42 | 0.022 | 2.9 | −0.57 | C | 1*n*,3 |
| | | 3276.77 | 9518 | 40027 | 6 | 4 | 0.24 | 0.025 | 1.6 | −0.82 | C | 3 |
| | | 3263.69 | 9396 | 40027 | 4 | 4 | 0.12 | 0.019 | 0.83 | −1.11 | C | 3 |
| | | 3260.25 | 9364 | 40027 | 2 | 4 | 0.072 | 0.023 | 0.49 | −1.34 | D | 1*n* |
| 51. | $a\,^4P - z\,^4P°$ (47) | | | | | | | | | | | |
| | | 3058.08 | 9518 | 42209 | 6 | 6 | 0.50 | 0.069 | 4.2 | −0.38 | D | 3 |
| | | 3071.25 | 9518 | 42069 | 6 | 4 | 0.36 | 0.034 | 2.1 | −0.69 | D | 3 |
| | | 3046.69 | 9396 | 42209 | 4 | 6 | 0.22 | 0.045 | 1.8 | −0.74 | D | 3 |
| | | 3056.75 | 9364 | 42069 | 2 | 4 | 0.32 | 0.091 | 1.8 | −0.74 | D | 3 |
| 52. | $a\,^2P - z\,^2F°$ (49) | | | | | | | | | | | |
| | | 4708.65 | 9976 | 31207 | 4 | 6 | 0.0031 | 0.0015 | 0.096 | −2.21 | D | 9 |
| 53. | $a\,^2P - z\,^2D°$ (50) | *4547.5* | *9934* | *31918* | 6 | 10 | 0.095 | 0.049 | 4.4 | −0.53 | D− | 1*n* |
| | | 4533.97 | 9976 | 32025 | 4 | 6 | 0.092 | 0.042 | 2.5 | −0.77 | D− | 1*n* |
| | | 4563.77 | 9851 | 31757 | 2 | 4 | 0.088 | 0.055 | 1.6 | −0.96 | D− | 1*n* |
| | | 4589.92 | 9976 | 31757 | 4 | 4 | 0.013 | 0.0041 | 0.25 | −1.79 | D− | 1*n* |
| 54. | $a\,^2P - z\,^4D°$ (51) | | | | | | | | | | | |
| | | 4399.79 | 9976 | 32698 | 4 | 6 | 0.031 | 0.013 | 0.78 | −1.27 | D− | 4 |
| | | 4394.02 | 9851 | 32603 | 2 | 4 | 0.022 | 0.013 | 0.37 | −1.59 | D− | 4 |
| | | 4418.31 | 9976 | 32603 | 4 | 4 | 0.0030 | 8.7(−4) | 0.050 | −2.46 | D− | 1*n* |
| | | 4407.68 | 9851 | 32532 | 2 | 2 | 0.0058 | 0.0017 | 0.049 | −2.47 | D− | 4 |
| | | 4432.09 | 9976 | 32532 | 4 | 2 | 0.013 | 0.0020 | 0.12 | −2.10 | D− | 1*n* |
| 55. | $a\,^2P - z\,^2S°$ (52) | *3635.7* | *9934* | 37431 | 6 | 2 | 0.78 | 0.052 | 3.7 | −0.51 | D− | 1 |
| | | 3641.33 | 9976 | 37431 | 4 | 2 | 0.49 | 0.049 | 2.3 | −0.71 | D− | 1 |
| | | 3624.82 | 9851 | 37431 | 2 | 2 | 0.29 | 0.057 | 1.4 | −0.94 | D− | 1 |
| 56. | $a\,^2P - y\,^2D°$ (53) | | | | | | | | | | | |
| | | 3388.77 | 9976 | 39477 | 4 | 6 | 0.090 | 0.023 | 1.0 | −1.03 | C | 3 |
| | | 3374.36 | 9976 | 39603 | 4 | 4 | 0.16 | 0.028 | 1.2 | −0.95 | C | 3 |
| 57. | $a\,^2P - z\,^2P°$ (54) | *3395.1* | *9934* | *39380* | 6 | 6 | 0.25 | 0.043 | 2.9 | −0.59 | C− | 3,1*n* |
| | | 3416.95 | 9976 | 39233 | 4 | 4 | 0.038 | 0.0067 | 0.30 | −1.57 | C | 3 |
| | | 3352.07 | 9851 | 39675 | 2 | 2 | 0.14 | 0.023 | 0.50 | −1.34 | D | 1*n* |
| | | 3366.19 | 9976 | 39675 | 4 | 2 | 0.26 | 0.022 | 0.97 | −1.06 | D | 1*n* |
| | | 3402.44 | 9851 | 39233 | 2 | 4 | 0.14 | 0.050 | 1.1 | −1.00 | C | 3 |
| 58. | $a\,^2P - y\,^2F°$ (55) | | | | | | | | | | | |
| | | 3337.85 | 9976 | 39927 | 4 | 6 | 0.050 | 0.013 | 0.55 | −1.30 | D | 3 |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ (10$^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59. | $a\,^2$P – $z\,^4$S° (56) | | | | | | | | | | | |
| | | 3312.92 | 9851 | 40027 | 2 | 4 | 0.0063 | 0.0021 | 0.045 | −2.38 | D− | 1*n* |
| 60. | $a\,^2$P – $z\,^4$P° (58) | | | | | | | | | | | |
| | | 3101.54 | 9976 | 42209 | 4 | 6 | 0.028 | 0.0060 | 0.24 | −1.62 | D | 1*n* |
| | | 3102.98 | 9851 | 42069 | 2 | 4 | 0.027 | 0.0077 | 0.16 | −1.81 | D | 1*n* |
| | | 3122.07 | 9976 | 41997 | 4 | 2 | 0.11 | 0.0079 | 0.33 | −1.50 | D | 1*n* |
| 61. | $a\,^2$P – $x\,^2$D° (uv 16) | *2858.5* | *9934* | *44907* | 6 | 10 | 0.42 | 0.086 | 4.9 | −0.29 | D | 1*n*,3 |
| | | 2862.33 | 9976 | 44902 | 4 | 6 | 0.40 | 0.074 | 2.8 | −0.53 | D | 1*n* |
| | | 2851.11 | 9851 | 44915 | 2 | 4 | 0.41 | 0.10 | 1.9 | −0.70 | C | 3 |
| | | 2861.30 | 9976 | 44915 | 4 | 4 | 0.046 | 0.0056 | 0.21 | −1.65 | D | 1*n* |
| 62. | $a\,^2$P – $y\,^2$P° (uv 17) | | | | | | | | | | | |
| | | 2806.46 | 9851 | 45472 | 2 | 2 | 0.19 | 0.022 | 0.41 | −1.35 | D | 3 |
| 63. | $b\,^4$P – $z\,^2$F° (59) | | | | | | | | | | | |
| | | 4657.20 | 10025 | 31491 | 6 | 8 | 0.0027 | 0.0012 | 0.11 | −2.15 | D | 9 |
| 64. | $b\,^4$P – $z\,^2$D° (60) | | | | | | | | | | | |
| | | 4544.02 | 10025 | 32025 | 6 | 6 | 0.0021 | 6.6(−4) | 0.060 | −2.40 | D | 9 |
| | | 4580.45 | 9931 | 31757 | 4 | 4 | 0.0013 | 4.1(−4) | 0.024 | −2.79 | D− | 1*n* |
| | | 4568.31 | 9873 | 31757 | 2 | 4 | 0.0018 | 0.0011 | 0.034 | −2.65 | D | 9 |
| 65. | $b\,^4$P – $z\,^4$D° (61) | | | | | | | | | | | |
| | | 4395.83 | 10025 | 32767 | 6 | 8 | 0.0029 | 0.0011 | 0.098 | −2.17 | D− | 1*n* |
| | | 4391.04 | 9931 | 32698 | 4 | 6 | 0.0010 | 4.4(−4) | 0.026 | −2.75 | D− | 1*n* |
| | | 4427.91 | 10025 | 32603 | 6 | 4 | 6.3(−4) | 1.2(−4) | 0.011 | −3.13 | D | 9 |
| 66. | $b\,^4$P – $y\,^2$D° | | | | | | | | | | | |
| | | 3369.19 | 9931 | 39603 | 4 | 4 | 0.066 | 0.011 | 0.50 | −1.35 | D | 1*n* |
| 67. | $b\,^4$P – $z\,^4$S° (65) | *3325.8* | *9968* | 40027 | 12 | 4 | 2.2 | 0.12 | 16 | 0.16 | C | 1*n*,3 |
| | | 3332.11 | 10025 | 40027 | 6 | 4 | 1.1 | 0.12 | 7.8 | −0.15 | C | 3 |
| | | 3321.70 | 9931 | 40027 | 4 | 4 | 0.72 | 0.12 | 5.2 | −0.32 | D | 1*n* |
| | | 3315.32 | 9873 | 40027 | 2 | 4 | 0.38 | 0.13 | 2.7 | −0.60 | C | 3 |
| 68. | $b\,^4$P – $y\,^4$D° (66) | | | | | | | | | | | |
| | | 3272.07 | 9873 | 40426 | 2 | 4 | 0.32 | 0.10 | 2.2 | −0.69 | D | 1*n* |
| | | 3271.64 | 10025 | 40581 | 6 | 6 | 0.24 | 0.039 | 2.5 | −0.63 | D | 1*n* |
| | | 3278.28 | 9931 | 40426 | 4 | 4 | 0.96 | 0.15 | 6.7 | −0.21 | C | 3 |
| | | 3282.32 | 9873 | 40330 | 2 | 2 | 1.6 | 0.26 | 5.5 | −0.29 | C | 3 |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 69. | $b\ ^4P - z\ ^4P°$ (67) | *3108.7* | *9968* | *42127* | 12 | 12 | 1.3 | 0.20 | 24 | 0.37 | C | 1*n*,3 |
| | | 3106.26 | 10025 | 42209 | 6 | 6 | 0.78 | 0.11 | 6.9 | −0.17 | C | 3 |
| | | 3110.69 | 9931 | 42069 | 4 | 4 | 0.27 | 0.039 | 1.6 | −0.81 | D | 1*n* |
| | | 3112.07 | 9873 | 41997 | 2 | 2 | 0.23 | 0.034 | 0.69 | −1.17 | D | 3 |
| | | 3119.83 | 10025 | 42069 | 6 | 4 | 0.59 | 0.058 | 3.6 | −0.46 | D | 1*n* |
| | | 3117.67 | 9931 | 41997 | 4 | 2 | 1.1 | 0.079 | 3.2 | −0.50 | C | 3 |
| | | 3097.20 | 9931 | 42209 | 4 | 6 | 0.44 | 0.095 | 3.9 | −0.42 | C | 3 |
| | | 3105.10 | 9873 | 42069 | 2 | 4 | 0.63 | 0.18 | 3.7 | −0.44 | D | 3 |
| 70. | $b\ ^2D2 - z\ ^2F°$ | | | | | | | | | | | |
| | | 5336.78 | 12758 | 31491 | 6 | 8 | 0.0058 | 0.0033 | 0.35 | −1.70 | D− | 4 |
| | | 5381.01 | 12629 | 31207 | 4 | 6 | 0.0032 | 0.0021 | 0.15 | −2.08 | D | 2 |
| 71. | $b\ ^2D2 - z\ ^2D°$ | | | | | | | | | | | |
| | | 5188.69 | 12758 | 32025 | 6 | 6 | 0.025 | 0.010 | 1.1 | −1.21 | D− | 1*n* |
| | | 5226.53 | 12629 | 31757 | 4 | 4 | 0.031 | 0.013 | 0.86 | −1.30 | D− | 1*n* |
| | | 5154.06 | 12629 | 32025 | 4 | 6 | 0.0050 | 0.0030 | 0.20 | −1.92 | D− | 2 |
| 72. | $b\ ^2D2 - z\ ^4D°$ (71) | | | | | | | | | | | |
| | | 4981.35 | 12629 | 32698 | 4 | 6 | 3.1(−4) | 1.7(−4) | 0.011 | −3.16 | D | 9 |
| | | 5005.17 | 12629 | 32603 | 4 | 4 | 0.0019 | 7.0(−4) | 0.046 | −2.55 | D | 9 |
| 73. | $b\ ^2D2 - y\ ^2D°$ | | | | | | | | | | | |
| | | 3741.64 | 12758 | 39477 | 6 | 6 | 0.62 | 0.13 | 9.6 | −0.11 | D | 1*n* |
| | | 3706.23 | 12629 | 39603 | 4 | 4 | 0.31 | 0.064 | 3.1 | −0.59 | D | 1*n* |
| 74. | $b\ ^2D2 - z\ ^2P°$ | | | | | | | | | | | |
| | | 3776.06 | 12758 | 39233 | 6 | 4 | 0.053 | 0.0076 | 0.57 | −1.34 | D | 1*n* |
| | | 3757.70 | 12629 | 39233 | 4 | 4 | 0.41 | 0.087 | 4.3 | −0.46 | D | 1*n* |
| 75. | $b\ ^2D2 - y\ ^2F°$ | *3661.2* | *12706* | *40012* | 10 | 14 | 0.13 | 0.037 | 4.5 | −0.43 | D | 1*n* |
| | | 3659.75 | 12758 | 40075 | 6 | 8 | 0.11 | 0.030 | 2.2 | −0.74 | D | 1*n* |
| | | 3662.24 | 12629 | 39927 | 4 | 6 | 0.14 | 0.041 | 2.0 | −0.78 | D | 1*n* |
| | | 3679.68 | 12758 | 39927 | 6 | 6 | 0.017 | 0.0035 | 0.25 | −1.68 | D | 1*n* |
| 76. | $b\ ^2D2 - y\ ^4D°$ | | | | | | | | | | | |
| | | 3565.30 | 12758 | 40798 | 6 | 8 | 0.0058 | 0.0015 | 0.10 | −2.05 | D− | 1*n* |
| | | 3593.08 | 12758 | 40581 | 6 | 6 | 0.0039 | 7.6(−4) | 0.054 | −2.34 | D− | 1*n* |
| 77. | $b\ ^2D2 - x\ ^2D°$ | | | | | | | | | | | |
| | | 3110.10 | 12758 | 44902 | 6 | 6 | 0.071 | 0.010 | 0.63 | −1.21 | D | 1*n* |
| | | 3096.42 | 12629 | 44915 | 4 | 4 | 0.060 | 0.0087 | 0.35 | −1.46 | D | 1*n* |
| 78. | $b\ ^2D2 - y\ ^2P°$ | | | | | | | | | | | |
| | | 3048.77 | 12758 | 45549 | 6 | 4 | 0.15 | 0.014 | 0.83 | −1.08 | C | 3 |
| | | 3043.86 | 12629 | 45472 | 4 | 2 | 0.14 | 0.010 | 0.40 | −1.40 | D | 3 |
| 79. | $b\ ^2D2 - x\ ^2F°$ | | | | | | | | | | | |
| | | 2880.30 | 12758 | 47467 | 6 | 8 | 0.026 | 0.0044 | 0.25 | −1.58 | D | 1*n* |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80. | $b$ $^2$D2 – $w$ $^2$D° | *2446.3* | *12706* | *53572* | 10 | 10 | 0.53 | 0.047 | 3.8 | −0.33 | C | 1$n$,3 |
| | | 2451.18 | 12758 | 53555 | 6 | 6 | 0.45 | 0.041 | 2.0 | −0.61 | C | 3 |
| | | 2440.91 | 12629 | 53597 | 4 | 4 | 0.51 | 0.045 | 1.5 | −0.74 | C | 3 |
| | | 2448.64 | 12758 | 53597 | 6 | 4 | 0.037 | 0.0022 | 0.11 | −1.88 | D | 1$n$ |
| | | 2443.43 | 12629 | 53555 | 4 | 6 | 0.040 | 0.0053 | 0.17 | −1.67 | D | 1$n$ |
| 81. | $a$ $^2$H – $z$ $^2$G° (82) | *4559.3* | *12730* | *34657* | 22 | 18 | 0.12 | 0.030 | 9.8 | −0.19 | D− | 1$n$ |
| | | 4549.61 | 12775 | 34748 | 12 | 10 | 0.11 | 0.030 | 5.3 | −0.45 | D− | 1$n$ |
| | | 4571.96 | 12677 | 34543 | 10 | 8 | 0.12 | 0.030 | 4.4 | −0.53 | D− | 1$n$ |
| | | 4529.48 | 12677 | 34748 | 10 | 10 | 0.0030 | 9.3(−4) | 0.14 | −2.03 | D− | 1$n$ |
| 82. | $a$ $^2$H – $y$ $^2$G° (84) | | | | | | | | | | | |
| | | 3224.25 | 12775 | 43781 | 12 | 10 | 0.70 | 0.091 | 12 | 0.04 | C | 3 |
| | | 3214.12 | 12677 | 43781 | 10 | 10 | 0.085 | 0.013 | 1.4 | −0.88 | D | 1$n$ |
| 83. | $a$ $^2$H – $z$ $^2$H° (85) | *3022.8* | *12730* | *45802* | 22 | 22 | 0.39 | 0.053 | 12 | 0.07 | C | 1$n$,3 |
| | | 3017.17 | 12775 | 45909 | 12 | 12 | 0.36 | 0.049 | 5.8 | −0.23 | C | 3 |
| | | 3029.76 | 12677 | 45674 | 10 | 10 | 0.35 | 0.048 | 4.8 | −0.32 | C | 3 |
| | | 3038.73 | 12775 | 45674 | 12 | 10 | 0.042 | 0.0048 | 0.58 | −1.24 | D | 3 |
| | | 3008.31 | 12677 | 45909 | 10 | 12 | 0.026 | 0.0043 | 0.42 | −1.37 | D− | 1$n$ |
| 84. | $b$ $^2$G – $z$ $^2$G° (86) | | | | | | | | | | | |
| | | 5129.16 | 15257 | 34748 | 10 | 10 | 0.010 | 0.0041 | 0.69 | −1.39 | D− | 1$n$ |
| | | 5185.90 | 15266 | 34543 | 8 | 8 | 0.014 | 0.0056 | 0.76 | −1.35 | D | 9 |
| 85. | $b$ $^2$G – $y$ $^2$F° (87) | | | | | | | | | | | |
| | | 4028.36 | 15257 | 40075 | 10 | 8 | 0.051 | 0.010 | 1.3 | −1.00 | D | 1$n$ |
| | | 4053.83 | 15266 | 39927 | 8 | 6 | 0.042 | 0.0077 | 0.82 | −1.21 | D | 1$n$ |
| 86. | $b$ $^2$G – $y$ $^2$G° (88) | *3507.5* | *15261* | *43763* | 18 | 18 | 0.89 | 0.16 | 34 | 0.47 | D | 1$n$ |
| | | 3504.90 | 15257 | 43781 | 10 | 10 | 0.82 | 0.15 | 17 | 0.18 | D | 1$n$ |
| | | 3510.86 | 15266 | 43741 | 8 | 8 | 0.93 | 0.17 | 16 | 0.14 | D | 1$n$ |
| | | 3509.81 | 15257 | 43741 | 10 | 8 | 0.030 | 0.0044 | 0.50 | −1.36 | D | 1$n$ |
| | | 3505.91 | 15266 | 43781 | 8 | 10 | 0.0065 | 0.0015 | 0.14 | −1.92 | D− | 1$n$ |
| 87. | $b$ $^2$G – $z$ $^2$H° (89) | | | | | | | | | | | |
| | | 3287.66 | 15266 | 45674 | 8 | 10 | 1.4 | 0.27 | 24 | 0.34 | C | 3 |
| | | 3286.77 | 15257 | 45674 | 10 | 10 | 0.015 | 0.0025 | 0.27 | −1.61 | D | 1$n$ |
| 88. | $b$ $^2$G – $x$ $^2$F° (90) | *3097.6* | *15261* | *47535* | 18 | 14 | 1.3 | 0.14 | 26 | 0.41 | C | 1$n$,3 |
| | | 3103.81 | 15257 | 47467 | 10 | 8 | 1.1 | 0.13 | 13 | 0.11 | C | 3 |
| | | 3089.44 | 15266 | 47625 | 8 | 6 | 1.3 | 0.14 | 12 | 0.06 | C | 3 |
| | | 3104.60 | 15266 | 47467 | 8 | 8 | 0.064 | 0.0093 | 0.76 | −1.13 | D | 1$n$ |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 89. | $b\ ^2P - z\ ^2D°$ (91) | | | | | | | | | | | |
| | | 6606.97 | 16625 | 31757 | 4 | 4 | 6.2(−4) | 4.1(−4) | 0.035 | −2.79 | D | 9 |
| 90. | $b\ ^2P - z\ ^2S°$ (92) | *4796.7* | *16589* | 37431 | 6 | 2 | 0.18 | 0.021 | 2.0 | −0.90 | D− | 1 |
| | | 4805.09 | 16625 | 37431 | 4 | 2 | 0.11 | 0.020 | 1.3 | −1.10 | D− | 1 |
| | | 4779.98 | 16516 | 37431 | 2 | 2 | 0.062 | 0.021 | 0.67 | −1.37 | D− | 1 |
| 91. | $b\ ^2P - y\ ^2D°$ (93) | | | | | | | | | | | |
| | | 4374.84 | 16625 | 39477 | 4 | 6 | 0.030 | 0.013 | 0.74 | −1.29 | D | 9 |
| | | 4350.85 | 16625 | 39603 | 4 | 4 | 0.035 | 0.010 | 0.57 | −1.40 | D | 9 |
| 92. | $b\ ^2P - z\ ^2P°$ (94) | | | | | | | | | | | |
| | | 4421.95 | 16625 | 39233 | 4 | 4 | 0.014 | 0.0042 | 0.25 | −1.77 | D− | 1*n* |
| | | 4316.80 | 16516 | 39675 | 2 | 2 | 0.068 | 0.019 | 0.54 | −1.42 | D | 9 |
| | | 4330.24 | 16516 | 39233 | 2 | 4 | 0.027 | 0.015 | 0.44 | −1.51 | D | 9 |
| 93. | $b\ ^2P - x\ ^2D°$ (98) | *3530.3* | *16589* | *44907* | 6 | 10 | 0.53 | 0.17 | 12 | −0.01 | D | 1*n* |
| | | 3535.41 | 16625 | 44902 | 4 | 6 | 0.55 | 0.15 | 7.2 | −0.21 | D | 1*n* |
| | | 3520.27 | 16516 | 44915 | 2 | 4 | 0.48 | 0.18 | 4.1 | −0.45 | D | 1*n* |
| | | 3533.85 | 16625 | 44915 | 4 | 4 | 0.029 | 0.0053 | 0.25 | −1.67 | D | 1*n* |
| 94. | $b\ ^2P - y\ ^2P°$ (99) | *3455.2* | *16589* | *45523* | 6 | 6 | 0.98 | 0.18 | 12 | 0.02 | D | 1*n*,3 |
| | | 3456.40 | 16625 | 45549 | 4 | 4 | 0.82 | 0.15 | 6.7 | −0.23 | D | 1*n* |
| | | 3452.49 | 16516 | 45472 | 2 | 2 | 0.77 | 0.14 | 3.1 | −0.56 | C | 3 |
| | | 3465.56 | 16625 | 45472 | 4 | 2 | 0.41 | 0.037 | 1.7 | −0.83 | C | 3 |
| | | 3443.39 | 16516 | 45549 | 2 | 4 | 0.12 | 0.043 | 0.96 | −1.07 | D | 1*n* |
| 95. | $b\ ^2F - z\ ^2G°$ (101) | | | | | | | | | | | |
| | | 7214.74 | 20892 | 34748 | 8 | 10 | 0.0023 | 0.0023 | 0.43 | −1.74 | D | 9 |
| 96. | $b\ ^2F - y\ ^2F°$ (103) | | | | | | | | | | | |
| | | 5268.61 | 20952 | 39927 | 6 | 6 | 0.0096 | 0.0040 | 0.42 | −1.62 | D | 2 |
| 97. | $b\ ^2F - y\ ^2G°$ (104) | | | | | | | | | | | |
| | | 4367.65 | 20892 | 43781 | 8 | 10 | 0.019 | 0.0067 | 0.77 | −1.27 | D− | 1*n* |
| | | 4386.85 | 20952 | 43741 | 6 | 8 | 0.024 | 0.0092 | 0.79 | −1.26 | D− | 1*n* |
| 98. | $b\ ^2F - x\ ^2D°$ (105) | *4167.4* | *20918* | *44907* | 14 | 10 | 0.28 | 0.053 | 10 | −0.13 | D | 1*n* |
| | | 4163.63 | 20892 | 44902 | 8 | 6 | 0.26 | 0.050 | 5.5 | −0.40 | D | 1*n* |
| | | 4171.92 | 20952 | 44915 | 6 | 4 | 0.26 | 0.046 | 3.8 | −0.56 | D | 1*n* |
| | | 4174.05 | 20952 | 44902 | 6 | 6 | 0.036 | 0.0094 | 0.77 | −1.25 | D | 1*n* |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99. | $b\ ^2F - x\ ^2F°$ (107) | | | | | | | | | | | |
| | | 3761.88 | 20892 | 47467 | 8 | 8 | 0.14 | 0.031 | 3.0 | −0.61 | D | 1*n* |
| | | 3748.03 | 20952 | 47625 | 6 | 6 | 0.15 | 0.031 | 2.3 | −0.73 | D | 1*n* |
| | | 3770.40 | 20952 | 47467 | 6 | 8 | 0.0052 | 0.0015 | 0.11 | −2.05 | D− | 1*n* |
| 100. | $c\ ^2D - x\ ^2D°$ (113) | | | | | | | | | | | |
| | | 5072.27 | 25193 | 44902 | 6 | 6 | 0.077 | 0.030 | 3.0 | −0.75 | D | 9 |
| | | 5069.08 | 25193 | 44915 | 6 | 4 | 0.026 | 0.0068 | 0.68 | −1.39 | D | 9 |
| 101. | $c\ ^2D - y\ ^2P°$ (114) | | | | | | | | | | | |
| | | 4911.18 | 25193 | 45549 | 6 | 4 | 0.32 | 0.076 | 7.4 | −0.34 | D | 9 |
| | | 4874.01 | 24961 | 45472 | 4 | 2 | 0.23 | 0.041 | 2.6 | −0.79 | D | 9 |
| 102. | $c\ ^2D - x\ ^2F°$ (115) | | | | | | | | | | | |
| | | 4488.34 | 25193 | 47467 | 6 | 8 | 0.063 | 0.025 | 2.2 | −0.82 | D− | 1*n* |
| | | 4411.10 | 24961 | 47625 | 4 | 6 | 0.050 | 0.022 | 1.3 | −1.06 | D− | 1*n* |
| 103. | $z\ ^4G° - e\ ^4F$ (119) | | | | | | | | | | | |
| | | 3081.52 | 29968 | 62411 | 10 | 8 | 1.1 | 0.12 | 12 | 0.08 | D | 3 |
| 104. | $z\ ^4G° - e\ ^4G$ (uv 24) | | | | | | | | | | | |
| | | 2856.10 | 30241 | 65243 | 12 | 12 | 1.5 | 0.18 | 20 | 0.33 | D | 3 |
| | | 2845.93 | 29968 | 65096 | 10 | 10 | 1.2 | 0.15 | 14 | 0.18 | D | 3 |
| | | 2836.47 | 29735 | 64979 | 8 | 8 | 1.2 | 0.15 | 11 | 0.08 | D | 3 |
| | | 2828.64 | 29544 | 64886 | 6 | 6 | 1.2 | 0.15 | 8.3 | −0.05 | D | 1*n* |
| | | 2855.40 | 29968 | 64979 | 10 | 8 | 0.14 | 0.014 | 1.3 | −0.85 | D | 1*n* |
| | | 2843.94 | 29735 | 64886 | 8 | 6 | 0.15 | 0.014 | 1.1 | −0.95 | D | 1*n* |
| | | 2834.02 | 29968 | 65243 | 10 | 12 | 0.79 | 0.11 | 11 | 0.06 | D | 3 |
| | | 2827.12 | 29735 | 65096 | 8 | 10 | 1.0 | 0.15 | 11 | 0.08 | D | 3 |
| | | 2821.26 | 29544 | 64979 | 6 | 8 | 0.79 | 0.13 | 7.0 | −0.12 | D | 3 |
| 105. | $z\ ^4G° - e\ ^4H$ (uv 25) | | | | | | | | | | | |
| | | 2828.06 | 30241 | 65590 | 12 | 14 | 4.4 | 0.62 | 69 | 0.87 | D | 3 |
| | | 2817.83 | 29968 | 65446 | 10 | 12 | 3.8 | 0.54 | 50 | 0.73 | D | 3 |
| | | 2810.30 | 29735 | 65308 | 8 | 10 | 5.1 | 0.75 | 56 | 0.78 | D | 3 |
| | | 2804.82 | 29544 | 65187 | 6 | 8 | 4.6 | 0.73 | 40 | 0.64 | D | 3 |
| | | 2839.64 | 30241 | 65446 | 12 | 12 | 0.83 | 0.10 | 11 | 0.08 | D | 3 |
| | | 2828.83 | 29968 | 65308 | 10 | 10 | 0.91 | 0.11 | 10 | 0.04 | D | 1*n* |
| | | 2819.87 | 29735 | 65187 | 8 | 8 | 0.65 | 0.077 | 5.7 | −0.21 | D | 1*n* |
| 106. | $z\ ^4F° - e\ ^4F$ (120) | | | | | | | | | | | |
| | | 3189.49 | 30836 | 62180 | 4 | 4 | 0.92 | 0.14 | 5.9 | −0.25 | D | 3 |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 107. | $z\,^4F^\circ - e\,^4G$ (uv 26) | | | | | | | | | | | |
| | | 2945.30 | 31301 | 65243 | 10 | 12 | 2.7 | 0.42 | 40 | 0.62 | D | 3 |
| | | 2941.90 | 31114 | 65096 | 8 | 10 | 1.8 | 0.29 | 23 | 0.37 | D | 1n |
| | | 2938.57 | 30959 | 64979 | 6 | 8 | 2.4 | 0.42 | 24 | 0.40 | D | 3 |
| | | 2936.02 | 30836 | 64886 | 4 | 6 | 2.7 | 0.52 | 20 | 0.32 | D | 3 |
| | | 2958.17 | 31301 | 65096 | 10 | 10 | 0.14 | 0.018 | 1.8 | −0.74 | D | 1n |
| | | 2952.00 | 31114 | 64979 | 8 | 8 | 0.30 | 0.040 | 3.1 | −0.50 | D | 3 |
| 108. | $z\,^4F^\circ - f\,^2F$ (uv 27) | | | | | | | | | | | |
| | | 2926.64 | 31301 | 65460 | 10 | 8 | 0.89 | 0.091 | 8.8 | −0.04 | D | 3 |
| | | 2910.65 | 31114 | 65460 | 8 | 8 | 0.46 | 0.058 | 4.5 | −0.33 | D | 1n |
| 109. | $z\,^4F^\circ - f\,^4F$ (uv 29) | | | | | | | | | | | |
| | | 2645.86 | 31301 | 69084 | 10 | 10 | 2.7 | 0.28 | 25 | 0.45 | D | 3 |
| | | 2642.02 | 31114 | 68952 | 8 | 8 | 1.9 | 0.19 | 13 | 0.19 | D | 3 |
| | | 2638.56 | 30959 | 68847 | 6 | 6 | 1.7 | 0.17 | 9.1 | 0.02 | D | 3 |
| | | 2635.44 | 30836 | 68769 | 4 | 4 | 1.9 | 0.20 | 6.9 | −0.10 | D | 3 |
| 110. | $z\,^2F^\circ - e\,^2F$ (121) | | | | | | | | | | | |
| | | 3128.50 | 31491 | 63446 | 8 | 8 | 1.1 | 0.17 | 14 | 0.13 | D | 1n |
| | | 3127.86 | 31207 | 63169 | 6 | 6 | 1.6 | 0.23 | 14 | 0.14 | D | 1n |
| 111. | $z\,^2F^\circ - f\,^2F$ (uv 30) | | | | | | | | | | | |
| | | 2942.97 | 31491 | 65460 | 8 | 8 | 1.1 | 0.15 | 11 | 0.07 | D | 3 |
| | | 2931.10 | 31207 | 65314 | 6 | 6 | 3.2 | 0.41 | 24 | 0.39 | D | 3 |
| | | 2918.63 | 31207 | 65460 | 6 | 8 | 0.041 | 0.0069 | 0.40 | −1.38 | D | 1n |
| 112. | $z\,^2F^\circ - e\,^2G$ (uv 31) | | | | | | | | | | | |
| | | 2751.59 | 31491 | 67822 | 8 | 10 | 3.7 | 0.52 | 38 | 0.62 | D− | 3 |
| | | 2746.54 | 31207 | 67606 | 6 | 8 | 2.6 | 0.39 | 21 | 0.37 | D− | 3 |
| 113. | $z\,^2D^\circ - e\,^2F$ (122) | | | | | | | | | | | |
| | | 3181.73 | 32025 | 63446 | 6 | 8 | 0.46 | 0.094 | 5.9 | −0.25 | D | 3 |
| | | 3182.54 | 31757 | 63169 | 4 | 6 | 0.43 | 0.097 | 4.1 | −0.41 | D | 3 |
| 114. | $z\,^2D^\circ - f\,^2F$ (uv 32) | | | | | | | | | | | |
| | | 2990.06 | 32025 | 65460 | 6 | 8 | 0.56 | 0.10 | 5.9 | −0.22 | D | 1n |
| | | 2979.06 | 31757 | 65314 | 4 | 6 | 1.2 | 0.23 | 9.2 | −0.03 | D | 3 |

Ti II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 115. | $z\,^4D^\circ - f\,^4F$ (uv 33) | | | | | | | | | | | |
| | | 2752.68 | 32767 | 69084 | 8 | 10 | 1.1 | 0.16 | 11 | 0.10 | D | 3 |
| | | 2757.62 | 32698 | 68952 | 6 | 8 | 0.72 | 0.11 | 6.0 | −0.18 | D | 1*n* |
| | | 2758.35 | 32603 | 68847 | 4 | 6 | 0.99 | 0.17 | 6.1 | −0.17 | D | 1*n* |
| | | 2758.79 | 32532 | 68769 | 2 | 4 | 0.44 | 0.10 | 1.8 | −0.70 | D | 1*n* |
| | | 2762.92 | 32767 | 68952 | 8 | 8 | 0.072 | 0.0083 | 0.60 | −1.18 | D | 1*n* |
| | | 2764.28 | 32603 | 68769 | 4 | 4 | 0.74 | 0.085 | 3.1 | −0.47 | D | 1*n* |
| 116. | $z\,^2G^\circ - e\,^2F$ (125) | | | | | | | | | | | |
| | | 3483.63 | 34748 | 63446 | 10 | 8 | 0.97 | 0.14 | 16 | 0.15 | D | 3 |
| | | 3492.37 | 34543 | 63169 | 8 | 6 | 0.98 | 0.13 | 12 | 0.03 | D | 3 |
| 117. | $z\,^2G^\circ - e\,^2G$ (126) | | | | | | | | | | | |
| | | 3022.64 | 34748 | 67822 | 10 | 10 | 1.2 | 0.17 | 17 | 0.23 | D− | 3 |
| | | 3023.67 | 34543 | 67606 | 8 | 8 | 1.0 | 0.14 | 11 | 0.06 | D− | 3 |
| 118. | $z\,^2G^\circ - e\,^2H$ (uv 34) | | | | | | | | | | | |
| | | 2954.59 | 34748 | 68584 | 10 | 12 | 4.0 | 0.63 | 61 | 0.80 | D | 3 |
| | | 2958.80 | 34543 | 68331 | 8 | 10 | 4.0 | 0.66 | 51 | 0.72 | D | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti III

Ca Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^63d^2\ ^3F_2$

Ionization Energy: 27.4919 eV = 221736 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 865.79 | 10 | 1420.44 | 6 | 2103.60 | 17 | 2567.56 | 11 |
| 1002.37 | 9 | 1421.63 | 6 | 2104.86 | 17 | 2576.47 | 11 |
| 1004.67 | 9 | 1422.41 | 6 | 2105.09 | 17 | 2984.75 | 14 |
| 1005.80 | 9 | 1424.14 | 6 | 2199.22 | 20 | 3066.51 | 29 |
| 1007.16 | 9 | 1455.19 | 7 | 2237.77 | 19 | 3167.83 | 25 |
| 1008.12 | 9 | 1498.70 | 3 | 2331.35 | 13 | 3193.77 | 25 |
| 1286.37 | 2 | 1499.17 | 5 | 2331.66 | 13 | 3228.89 | 24 |
| 1289.30 | 2 | 1948.51 | 8 | 2334.34 | 13 | 3240.71 | 24 |
| 1291.62 | 2 | 2007.36 | 18 | 2339.00 | 13 | 3245.59 | 28 |
| 1293.23 | 2 | 2007.60 | 18 | 2346.79 | 13 | 3278.31 | 21 |
| 1298.97 | 1 | 2010.80 | 18 | 2374.99 | 16 | 3320.94 | 23 |
| 1327.59 | 4 | 2097.30 | 17 | 2413.99 | 15 | 3333.46 | 23 |
| 1420.04 | 6 | 2099.86 | 17 | 2516.05 | 12 | 3340.20 | 27 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 3346.18 | 27 | 4343.25 | 101 | 4971.19 | 102 | 7379.96 | 54 |
| 3354.71 | 27 | 4352.28 | 112 | 5010.14 | 106 | 7397.27 | 131 |
| 3358.10 | 27 | 4368.56 | 66 | 5020.43 | 106 | 7408.13 | 120 |
| 3370.63 | 27 | 4378.94 | 68 | 5024.52 | 102 | 7417.60 | 125 |
| 3371.62 | 26 | 4400.57 | 115 | 5068.22 | 47 | 7432.20 | 131 |
| 3377.90 | 22 | 4406.20 | 84 | 5069.39 | 43 | 7441.72 | 124 |
| 3396.43 | 26 | 4424.40 | 83 | 5083.80 | 106 | 7450.45 | 54 |
| 3397.24 | 30 | 4433.91 | 86 | 5119.08 | 110 | 7460.04 | 136 |
| 3404.46 | 30 | 4440.66 | 84 | 5147.31 | 41 | 7484.58 | 132 |
| 3417.62 | 30 | 4446.56 | 83 | 5162.55 | 105 | 7491.92 | 136 |
| 3872.50 | 34 | 4462.56 | 98 | 5218.43 | 45 | 7495.18 | 124 |
| 3881.21 | 34 | 4466.08 | 85 | 5226.28 | 42 | 7506.87 | 130 |
| 3915.47 | 33 | 4466.69 | 85 | 5247.49 | 104 | 7507.68 | 55 |
| 3924.86 | 32 | 4480.36 | 116 | 5257.33 | 42 | 7508.65 | 89 |
| 3986.40 | 31 | 4496.51 | 69 | 5278.12 | 45 | 7511.59 | 124 |
| 4069.99 | 37 | 4519.42 | 69 | 5278.33 | 109 | 7515.98 | 131 |
| 4079.96 | 37 | 4520.38 | 70 | 5282.14 | 104 | 7531.15 | 136 |
| 4098.88 | 37 | 4521.15 | 70 | 5293.60 | 104 | 7540.99 | 54 |
| 4100.05 | 37 | 4533.26 | 100 | 5328.40 | 104 | 7544.29 | 130 |
| 4119.14 | 37 | 4555.46 | 38 | 5367.17 | 108 | 7552.05 | 131 |
| 4139.42 | 73 | 4576.53 | 117 | 5395.69 | 49 | 7566.25 | 89 |
| 4144.77 | 72 | 4578.52 | 40 | 5481.31 | 49 | 7704.80 | 135 |
| 4145.05 | 72 | 4611.04 | 107 | 5533.01 | 113 | 7742.64 | 129 |
| 4176.54 | 74 | 4619.78 | 107 | 5566.58 | 46 | 7775.95 | 56 |
| 4191.09 | 36 | 4628.07 | 107 | 6490.14 | 93 | 8164.06 | 142 |
| 4201.66 | 36 | 4649.45 | 103 | 6547.75 | 92 | 8235.58 | 143 |
| 4212.95 | 61 | 4652.86 | 114 | 6611.38 | 92 | 8252.85 | 143 |
| 4213.26 | 61 | 4673.40 | 107 | 6629.37 | 92 | 8338.54 | 141 |
| 4215.53 | 39 | 4680.58 | 103 | 6647.47 | 51 | 8394.20 | 141 |
| 4218.52 | 77 | 4720.90 | 111 | 6667.99 | 92 | 8406.15 | 141 |
| 4220.28 | 63 | 4731.11 | 97 | 6674.19 | 92 | 8439.19 | 141 |
| 4247.62 | 76 | 4763.58 | 118 | 6896.12 | 50 | 8505.88 | 139 |
| 4248.54 | 62 | 4771.46 | 118 | 6932.44 | 94 | 8516.40 | 141 |
| 4250.09 | 35 | 4784.09 | 118 | 7015.38 | 53 | 8527.03 | 139 |
| 4254.11 | 75 | 4793.50 | 118 | 7017.31 | 128 | 8544.89 | 139 |
| 4259.01 | 80 | 4800.27 | 88 | 7031.40 | 134 | 8563.50 | 145 |
| 4269.84 | 79 | 4821.80 | 87 | 7071.93 | 123 | 8566.24 | 140 |
| 4275.53 | 78 | 4831.33 | 96 | 7072.64 | 91 | 8584.05 | 140 |
| 4284.67 | 80 | 4838.25 | 118 | 7141.76 | 52 | 8605.75 | 145 |
| 4285.61 | 80 | 4849.66 | 119 | 7203.66 | 127 | 8618.79 | 139 |
| 4288.66 | 79 | 4856.22 | 44 | 7228.40 | 126 | 8731.24 | 138 |
| 4289.25 | 79 | 4858.13 | 44 | 7252.88 | 122 | 8887.71 | 144 |
| 4293.34 | 82 | 4874.00 | 95 | 7288.98 | 121 | 8916.95 | 146 |
| 4296.70 | 65 | 4884.32 | 99 | 7315.14 | 54 | 9017.10 | 60 |
| 4310.48 | 81 | 4892.84 | 44 | 7316.68 | 90 | 9024.05 | 57 |
| 4319.56 | 67 | 4907.61 | 71 | 7335.41 | 137 | 9081.40 | 58 |
| 4325.93 | 64 | 4914.32 | 99 | 7370.14 | 133 | 9271.12 | 59 |
| 4328.25 | 101 | 4961.36 | 48 | 7371.34 | 90 | | |

The data for this ion were obtained directly from the calculations of Kurucz and Peytremann[1] and Warner and Kirkpatrick.[2] Kurucz and Peytremann used a semiempirical scaled Thomas-Fermi-Dirac approach with very limited configuration interaction. Warner and Kirkpatrick obtained radial wavefunctions via the scaled Thomas-Fermi method in a single configuration approximation and calculated individual line strengths in intermediate coupling. We have given first priority to the data of Kurucz and Peytremann because of their consideration of configuration interaction.

References 1 and (especially) 2 have provided data for more lines than we have tabulated here. However, we have often found that calculations of the above type yield uncertain results for the weaker lines. Therefore, we have included only observed lines of at least moderate strength, i.e., lines having log *gf*-values greater than $-1.0$. In selecting the lines, we have used the experimental line list of Edlen and Swensson.[3] Since it was pointed out by them that Warner and Kirkpatrick have erroneously interchanged the labels $^3$F and $^3$D for the $3d4p\ ^3D^\circ_{2,3}$ and $3d4p\ ^3F^\circ_{2,3}$ levels, we have omitted all lines from Ref. 2 originating from these four levels. In addition, we found a few other levels to be similarly misidentified by Warner and Kirkpatrick. Therefore, we have included their data only if their tabulated wavelengths and associated transition designations for each line corresponded exactly to those of Ref. 3. An exception to this rule is that we also included lines arising from the $3d5g$ configuration, labeled in $jl$-coupling notation by Edlen and Swensson (but in $LS$ coupling by Warner and Kirkpatrick).

Having selected the lines for this compilation by the above-mentioned criterion, we found the data of Refs. 1 and 2 to be in excellent agreement for overlapping lines. Specifically, all log $gf$-values agreed within 20%, and 91% of the data for common lines agreed within 7%.

We were able to check the reliability of Kurucz and Peytremann's and Warner and Kirkpatrick's data on an absolute scale by comparing reciprocals of sums of their calculated transition probabilities, $(\sum_i A_{ki})^{-1}$, to several beam-foil lifetimes measured by Baudinet-Robinet *et al.*[4] and by Roberts *et al.*[5] These comparisons indicate agreement generally within 50% for eight different levels. However, the calculated reciprocals are always smaller than the experimental lifetimes, which seems to indicate that uncorrected cascading effects are likely to be present in the beam-foil data.

## References


[1] R. L. Kurucz and E. Peytremann, Smithsonian Astrophysical Observatory Special Report 362 (1975).

[2] B. Warner and R. C. Kirkpatrick, Mon. Not. R. Astron. Soc. **144**, 397 (1969); Publications of the Department of Astronomy, University of Texas at Austin, Vol. III, No. 2 (1969).

[3] B. Edlen and J. W. Swensson, Phys. Scr. **12**, 21 (1975).

[4] Y. Baudinet-Robinet, P. D. Dumont, H. P. Garnir, N. Grevesse, and E. Biemont, J. Opt. Soc. Am. **70**, 464 (1980).

[5] J. R. Roberts, T. Andersen, and G. Sorensen, Astrophys. J. **181**, 567 (1973).


Ti III: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^2$–$3d4p$ | $^3$F - $^3$D° | | | | | | | | | | | |
| | | | 1298.97 | 184.9 | 77167 | 7 | 5 | 4.9 | 0.088 | 2.6 | −0.21 | D | 1 |
| 2. | | $^3$F - $^3$F° | | | | | | | | | | | |
| | | | 1286.37 | 420.4 | 78159 | 9 | 9 | 2.0 | 0.049 | 1.8 | −0.36 | D | 1 |
| | | | 1289.30 | 184.9 | 77746 | 7 | 7 | 2.2 | 0.054 | 1.6 | −0.42 | D | 1 |
| | | | 1291.62 | 0.0 | 77422 | 5 | 5 | 2.4 | 0.060 | 1.3 | −0.52 | D | 1 |
| | | | 1293.23 | 420.4 | 77746 | 9 | 7 | 1.0 | 0.020 | 0.76 | −0.75 | D | 1 |
| 3. | | $^1$D - $^1$D° | 1498.70 | 8474 | 75198 | 5 | 5 | 2.8 | 0.094 | 2.3 | −0.33 | D | 1 |
| 4. | | $^1$D - $^1$P° | 1327.59 | 8474 | 83797 | 5 | 3 | 3.2 | 0.051 | 1.1 | −0.59 | D | 1 |
| 5. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 1499.17 | 10721 | 77424 | 5 | 7 | 0.49 | 0.023 | 0.57 | −0.94 | D | 1 |
| 6. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 1422.41 | 10721 | 81024 | 5 | 5 | 3.0 | 0.091 | 2.1 | −0.34 | D | 1 |
| | | | 1424.14 | 10721 | 80939 | 5 | 3 | 1.6 | 0.029 | 0.68 | −0.84 | D | 1 |
| | | | 1421.63 | 10604 | 80945 | 3 | 1 | 4.0 | 0.040 | 0.56 | −0.92 | D | 1 |
| | | | 1420.04 | 10604 | 81024 | 3 | 5 | 0.89 | 0.045 | 0.63 | −0.87 | D | 1 |
| | | | 1420.44 | 10538 | 80939 | 1 | 3 | 1.2 | 0.11 | 0.52 | −0.95 | D | 1 |
| 7. | | $^1$G - $^1$F° | 1455.19 | 14398 | 83117 | 9 | 7 | 6.4 | 0.16 | 6.8 | 0.15 | D | 1 |
| 8. | | $^1$S - $^1$P° | 1948.51 | 32476 | 83797 | 1 | 3 | 0.72 | 0.12 | 0.79 | −0.91 | D | 1 |
| 9. | $3d4s$–$4s4p$ | $^3$D - $^3$P° | | | | | | | | | | | |
| | | | 1004.67 | 38426 | 137961 | 7 | 5 | 43 | 0.46 | 11 | 0.51 | D | 1 |
| | | | 1007.16 | 38199 | 137488 | 5 | 3 | 38 | 0.35 | 5.8 | 0.24 | D | 1 |
| | | | 1008.12 | 38064 | 137259 | 3 | 1 | 51 | 0.26 | 2.6 | −0.11 | D | 1 |
| | | | 1002.37 | 38199 | 137961 | 5 | 5 | 7.6 | 0.12 | 1.9 | −0.24 | D | 1 |
| | | | 1005.80 | 38064 | 137488 | 3 | 3 | 13 | 0.19 | 1.9 | −0.24 | D | 1 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | | $^1$D - $^1$P° | 865.79 | 41704 | 157204 | 5 | 3 | 66 | 0.45 | 6.4 | 0.35 | D | 2 |
| 11. | 3*d*4*s*-3*d*4*p* | $^3$D - $^3$D° | | | | | | | | | | | |
| | | | 2567.56 | 38064 | 77000 | 3 | 3 | 2.3 | 0.23 | 5.7 | −0.17 | D | 2 |
| | | | 2576.47 | 38199 | 77000 | 5 | 3 | 0.92 | 0.055 | 2.3 | −0.56 | D | 2 |
| 12. | | $^3$D - $^3$F° | | | | | | | | | | | |
| | | | 2516.05 | 38426 | 78159 | 7 | 9 | 3.4 | 0.41 | 24 | 0.46 | D | 2 |
| 13. | | $^3$D - $^3$P° | | | | | | | | | | | |
| | | | 2346.79 | 38426 | 81024 | 7 | 5 | 3.3 | 0.20 | 11 | 0.14 | D | 2 |
| | | | 2339.00 | 38199 | 80939 | 5 | 3 | 3.0 | 0.15 | 5.7 | −0.13 | D | 2 |
| | | | 2331.35 | 38064 | 80945 | 3 | 1 | 4.3 | 0.12 | 2.7 | −0.46 | D | 2 |
| | | | 2334.34 | 38199 | 81024 | 5 | 5 | 0.77 | 0.063 | 2.4 | −0.50 | D | 2 |
| | | | 2331.66 | 38064 | 80939 | 3 | 3 | 1.2 | 0.10 | 2.3 | −0.52 | D | 2 |
| 14. | | $^1$D - $^1$D° | 2984.75 | 41704 | 75198 | 5 | 5 | 1.9 | 0.26 | 13 | 0.11 | D | 2 |
| 15. | | $^1$D - $^1$F° | 2413.99 | 41704 | 83117 | 5 | 7 | 3.8 | 0.47 | 19 | 0.37 | D | 2 |
| 16. | | $^1$D - $^1$P° | 2374.99 | 41704 | 83797 | 5 | 3 | 4.0 | 0.20 | 8.0 | 0.01 | D | 2 |
| 17. | 3*d*4*p*-3*d*4*d* | $^3$P° - $^3$D | | | | | | | | | | | |
| | | | 2097.30 | 81024 | 128690 | 5 | 7 | 3.3 | 0.30 | 10 | 0.18 | D | 2 |
| | | | 2099.86 | 80939 | 128546 | 3 | 5 | 2.5 | 0.28 | 5.7 | −0.08 | D | 2 |
| | | | 2105.09 | 80945 | 128433 | 1 | 3 | 1.7 | 0.34 | 2.3 | −0.47 | D | 2 |
| | | | 2103.60 | 81024 | 128546 | 5 | 5 | 0.56 | 0.037 | 1.3 | −0.73 | D | 2 |
| | | | 2104.86 | 80939 | 128433 | 3 | 3 | 1.1 | 0.076 | 1.6 | −0.64 | D | 2 |
| 18. | | $^3$P° - $^3$S | *2009.3* | *80987* | 130740 | 9 | 3 | 10 | 0.20 | 12 | 0.26 | D | 2 |
| | | | 2010.80 | 81024 | 130740 | 5 | 3 | 5.4 | 0.20 | 6.5 | −0.01 | D | 2 |
| | | | 2007.36 | 80939 | 130740 | 3 | 3 | 3.4 | 0.21 | 4.1 | −0.21 | D | 2 |
| | | | 2007.60 | 80945 | 130740 | 1 | 3 | 1.2 | 0.22 | 1.4 | −0.66 | D | 2 |
| 19. | | $^1$F° - $^1$F | 2237.77 | 83117 | 127791 | 7 | 7 | 2.4 | 0.18 | 9.3 | 0.10 | D | 2 |
| 20. | | $^1$P° - $^1$P | 2199.22 | 83797 | 129253 | 3 | 3 | 5.7 | 0.41 | 8.9 | 0.09 | D | 2 |
| 21. | 3*d*4*d*-3*d*4*f* | $^1$F - $^1$G° | 3278.31 | 127791 | 158285 | 7 | 9 | 3.4 | 0.70 | 53 | 0.69 | D | 2 |
| 22. | | $^3$D - $^1$G° | | | | | | | | | | | |
| | | | 3377.90 | 128690 | 158285 | 7 | 9 | 0.075 | 0.016 | 1.3 | −0.94 | D | 2 |
| 23. | | $^3$D - $^3$F° | | | | | | | | | | | |
| | | | 3320.94 | 128433 | 158537 | 3 | 5 | 2.8 | 0.76 | 25 | 0.36 | D | 2 |
| | | | 3333.46 | 128546 | 158537 | 5 | 5 | 0.20 | 0.033 | 1.8 | −0.78 | D | 2 |
| 24. | | $^3$D - $^3$D° | | | | | | | | | | | |
| | | | 3228.89 | 128433 | 159395 | 3 | 3 | 1.5 | 0.23 | 7.4 | −0.16 | D | 2 |
| | | | 3240.71 | 128546 | 159395 | 5 | 3 | 0.37 | 0.035 | 1.9 | −0.76 | D | 2 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25. | | $^3$D - $^3$P° | | | | | | | | | | | |
| | | | 3193.77 | 128690 | 159992 | 7 | 5 | 0.38 | 0.041 | 3.0 | −0.54 | D | 2 |
| | | | 3167.83 | 128546 | 160105 | 5 | 3 | 0.34 | 0.030 | 1.6 | −0.82 | D | 2 |
| 26. | | $^3$G - $^3$G° | | | | | | | | | | | |
| | | | 3396.43 | 129469 | 158904 | 11 | 11 | 0.47 | 0.081 | 10 | −0.05 | D | 2 |
| | | | 3371.62 | 129253 | 158904 | 9 | 11 | 0.48 | 0.099 | 9.9 | −0.05 | D | 2 |
| 27. | | $^3$G - $^3$H° | | | | | | | | | | | |
| | | | 3354.71 | 129469 | 159270 | 11 | 13 | 4.4 | 0.87 | 110 | 0.98 | D | 2 |
| | | | 3346.18 | 129253 | 159129 | 9 | 11 | 3.7 | 0.75 | 74 | 0.83 | D | 2 |
| | | | 3340.20 | 129093 | 159023 | 7 | 9 | 3.7 | 0.79 | 60 | 0.74 | D | 2 |
| | | | 3370.63 | 129469 | 159129 | 11 | 11 | 0.36 | 0.061 | 7.5 | −0.17 | D | 2 |
| | | | 3358.10 | 129253 | 159023 | 9 | 9 | 0.40 | 0.067 | 6.7 | −0.22 | D | 2 |
| 28. | | $^3$G - $^1$H° | | | | | | | | | | | |
| | | | 3245.59 | 129253 | 160055 | 9 | 11 | 0.060 | 0.012 | 1.1 | −0.98 | D | 2 |
| 29. | | $^1$P - $^1$P° | 3066.51 | 129253 | 161854 | 3 | 3 | 2.5 | 0.36 | 11 | 0.03 | D | 2 |
| 30. | | $^3$S - $^3$P° | *3410.9* | 130740 | *160049* | 3 | 9 | 1.8 | 0.95 | 32 | 0.45 | D | 2 |
| | | | 3417.62 | 130740 | 159992 | 3 | 5 | 1.9 | 0.54 | 18 | 0.21 | D | 2 |
| | | | 3404.46 | 130740 | 160105 | 3 | 3 | 1.8 | 0.31 | 10 | −0.03 | D | 2 |
| | | | 3397.24 | 130740 | 160167 | 3 | 1 | 1.8 | 0.10 | 3.5 | −0.51 | D | 2 |
| 31. | | $^3$F - $^1$G° | | | | | | | | | | | |
| | | | 3986.40 | 133207 | 158285 | 7 | 9 | 0.21 | 0.064 | 5.9 | −0.35 | D | 2 |
| 32. | | $^3$F - $^3$F° | | | | | | | | | | | |
| | | | 3924.86 | 133065 | 158537 | 5 | 5 | 0.74 | 0.17 | 11 | −0.07 | D | 2 |
| 33. | | $^3$F - $^3$G° | | | | | | | | | | | |
| | | | 3915.47 | 133371 | 158904 | 9 | 11 | 2.1 | 0.58 | 68 | 0.72 | D | 2 |
| 34. | | $^3$F - $^3$H° | | | | | | | | | | | |
| | | | 3881.21 | 133371 | 159129 | 9 | 11 | 0.17 | 0.046 | 5.3 | −0.38 | D | 2 |
| | | | 3872.50 | 133207 | 159023 | 7 | 9 | 0.16 | 0.045 | 4.0 | −0.50 | D | 2 |
| 35. | | $^3$P - $^1$D° | | | | | | | | | | | |
| | | | 4250.09 | 135601 | 159124 | 3 | 5 | 0.95 | 0.43 | 18 | 0.11 | D | 2 |
| 36. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 4191.09 | 135541 | 159395 | 1 | 3 | 0.80 | 0.63 | 8.7 | −0.20 | D | 2 |
| | | | 4201.66 | 135601 | 159395 | 3 | 3 | 0.42 | 0.11 | 4.6 | −0.48 | D | 2 |
| 37. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 4119.14 | 135722 | 159992 | 5 | 5 | 0.99 | 0.25 | 17 | 0.10 | D | 2 |
| | | | 4079.96 | 135601 | 160105 | 3 | 3 | 0.42 | 0.11 | 4.2 | −0.50 | D | 2 |
| | | | 4100.05 | 135722 | 160105 | 5 | 3 | 0.48 | 0.073 | 4.9 | −0.44 | D | 2 |
| | | | 4098.88 | 135601 | 159992 | 3 | 5 | 0.085 | 0.036 | 1.4 | −0.97 | D | 2 |
| | | | 4069.99 | 135541 | 160105 | 1 | 3 | 0.24 | 0.18 | 2.4 | −0.75 | D | 2 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38. | | $^1$G - $^1$G° | 4555.46 | 136340 | 158285 | 9 | 9 | 0.23 | 0.070 | 9.5 | −0.20 | D | 2 |
| 39. | | $^1$G - $^1$H° | 4215.53 | 136340 | 160055 | 9 | 11 | 2.2 | 0.70 | 88 | 0.80 | D | 2 |
| 40. | | $^1$S - $^1$P° | 4578.52 | 140019 | 161854 | 1 | 3 | 0.79 | 0.74 | 11 | −0.13 | D | 2 |
| 41. | $3d4d$–$3d5p$ | $^1$F - $^1$D° | 5147.31 | 127791 | 147213 | 7 | 5 | 0.56 | 0.16 | 19 | 0.05 | D | 2 |
| 42. | | $^3$D - $^3$D° | | | | | | | | | | | |
| | | | 5226.28 | 128433 | 147562 | 3 | 3 | 0.31 | 0.13 | 6.5 | −0.42 | D | 2 |
| | | | 5257.33 | 128546 | 147562 | 5 | 3 | 0.082 | 0.020 | 1.8 | −0.99 | D | 2 |
| 43. | | $^3$D - $^3$F° | | | | | | | | | | | |
| | | | 5069.39 | 128690 | 148410 | 7 | 9 | 0.033 | 0.016 | 1.9 | −0.94 | D | 2 |
| 44. | | $^3$D - $^3$P° | | | | | | | | | | | |
| | | | 4858.13 | 128690 | 149268 | 7 | 5 | 0.42 | 0.11 | 12 | −0.13 | D | 2 |
| | | | 4892.84 | 128546 | 148979 | 5 | 3 | 0.33 | 0.071 | 5.7 | −0.45 | D | 2 |
| | | | 4856.22 | 128433 | 149020 | 3 | 1 | 0.47 | 0.055 | 2.7 | −0.78 | D | 2 |
| 45. | | $^3$G - $^3$F° | | | | | | | | | | | |
| | | | 5278.12 | 129469 | 148410 | 11 | 9 | 0.79 | 0.27 | 51 | 0.47 | D | 2 |
| | | | 5218.43 | 129253 | 148410 | 9 | 9 | 0.038 | 0.015 | 2.4 | −0.86 | D | 2 |
| 46. | | $^1$P - $^1$D° | 5566.58 | 129253 | 147213 | 3 | 5 | 0.057 | 0.044 | 2.4 | −0.88 | D | 2 |
| 47. | | $^1$P - $^3$P° | | | | | | | | | | | |
| | | | 5068.22 | 129253 | 148979 | 3 | 3 | 0.11 | 0.041 | 2.1 | −0.91 | D | 2 |
| 48. | | $^1$P - $^1$P° | 4961.36 | 129253 | 149404 | 3 | 3 | 0.45 | 0.17 | 8.2 | −0.30 | D | 2 |
| 49. | | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | 5395.69 | 130740 | 149268 | 3 | 5 | 0.19 | 0.14 | 7.4 | −0.38 | D | 2 |
| | | | 5481.31 | 130740 | 148979 | 3 | 3 | 0.13 | 0.061 | 3.3 | −0.74 | D | 2 |
| 50. | | $^3$F - $^3$D° | | | | | | | | | | | |
| | | | 6896.12 | 133065 | 147562 | 5 | 3 | 0.26 | 0.11 | 12 | −0.26 | D | 2 |
| 51. | | $^3$F - $^3$F° | | | | | | | | | | | |
| | | | 6647.47 | 133371 | 148410 | 9 | 9 | 0.10 | 0.067 | 13 | −0.22 | D | 2 |
| 52. | | $^1$D - $^1$P° | 7141.76 | 135405 | 149404 | 5 | 3 | 0.49 | 0.22 | 26 | 0.05 | D | 2 |
| 53. | | $^1$D - $^1$F° | 7015.38 | 135405 | 149656 | 5 | 7 | 0.58 | 0.60 | 70 | 0.48 | D | 2 |
| 54. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 7379.96 | 135722 | 149268 | 5 | 5 | 0.13 | 0.11 | 13 | −0.26 | D | 2 |
| | | | 7540.99 | 135722 | 148979 | 5 | 3 | 0.041 | 0.021 | 2.6 | −0.98 | D | 2 |
| | | | 7450.45 | 135601 | 149020 | 3 | 1 | 0.16 | 0.044 | 3.2 | −0.88 | D | 2 |
| | | | 7315.14 | 135601 | 149268 | 3 | 5 | 0.044 | 0.059 | 4.3 | −0.75 | D | 2 |
| 55. | | $^1$G - $^1$F° | 7507.68 | 136340 | 149656 | 9 | 7 | 0.28 | 0.18 | 41 | 0.22 | D | 2 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 56. | $3d4f$–$3d5d$ | $^1$G° - $^1$G | 7775.95 | 158285 | 171142 | 9 | 9 | 0.023 | 0.021 | 4.9 | −0.72 | D | 2 |
| 57. | | $^3$F° - $^3$F | | | | | | | | | | | |
| | | | 9024.05 | 158537 | 169615 | 5 | 5 | 0.034 | 0.042 | 6.2 | −0.68 | D | 2 |
| 58. | | $^3$G° - $^3$F | | | | | | | | | | | |
| | | | 9081.40 | 158904 | 169912 | 11 | 9 | 0.11 | 0.11 | 36 | 0.08 | D | 2 |
| 59. | | $^3$H° - $^3$F | | | | | | | | | | | |
| | | | 9271.12 | 159129 | 169912 | 11 | 9 | 0.010 | 0.011 | 3.6 | −0.93 | D | 2 |
| 60. | | $^1$H° - $^1$G | 9017.10 | 160055 | 171142 | 11 | 9 | 0.15 | 0.15 | 48 | 0.21 | D | 2 |
| 61. | $3d4f$–$3d(^2D_{3/2})5g$ | $^1$G° - $^2$[9/2] | | | | | | | | | | | |
| | | | 4213.26 | 158285 | 182013 | 9 | 11 | 2.2 | 0.70 | 88 | 0.80 | D | 2 |
| | | | 4212.95 | 158285 | 182015 | 9 | 9 | 0.13 | 0.034 | 4.2 | −0.52 | D | 2 |
| 62. | | $^3$F° - $^2$[7/2] | | | | | | | | | | | |
| | | | 4248.54 | 158537 | 182067 | 5 | 7 | 2.3 | 0.87 | 61 | 0.64 | D | 2 |
| 63. | | $^3$F° - $^2$[5/2] | | | | | | | | | | | |
| | | | 4220.28 | 158537 | 182225 | 5 | 5 | 0.42 | 0.11 | 7.8 | −0.25 | D | 2 |
| 64. | | $^3$G° - $^2$[9/2] | | | | | | | | | | | |
| | | | 4325.93 | 158904 | 182013 | 11 | 11 | 0.066 | 0.019 | 2.9 | −0.69 | D | 2 |
| 65. | | $^3$G° - $^2$[11/2] | | | | | | | | | | | |
| | | | 4296.70 | 158904 | 182171 | 11 | 13 | 1.6 | 0.54 | 83 | 0.77 | D | 2 |
| 66. | | $^3$H° - $^2$[9/2] | | | | | | | | | | | |
| | | | 4368.56 | 159129 | 182013 | 11 | 11 | 0.10 | 0.029 | 4.7 | −0.49 | D | 2 |
| 67. | | $^3$H° - $^2$[11/2] | | | | | | | | | | | |
| | | | 4319.56 | 159023 | 182167 | 9 | 11 | 1.1 | 0.39 | 49 | 0.54 | D | 2 |
| 68. | | $^3$D° - $^2$[5/2] | | | | | | | | | | | |
| | | | 4378.94 | 159395 | 182225 | 3 | 5 | 1.6 | 0.75 | 32 | 0.35 | D | 2 |
| 69. | | $^3$P° - $^2$[5/2] | | | | | | | | | | | |
| | | | 4496.51 | 159992 | 182225 | 5 | 7 | 0.37 | 0.16 | 12 | −0.10 | D | 2 |
| | | | 4519.42 | 160105 | 182225 | 3 | 5 | 0.16 | 0.082 | 3.7 | −0.61 | D | 2 |
| 70. | | $^1$H° - $^2$[11/2] | | | | | | | | | | | |
| | | | 4520.38 | 160055 | 182171 | 11 | 13 | 0.48 | 0.17 | 28 | 0.28 | D | 2 |
| | | | 4521.15 | 160055 | 182167 | 11 | 11 | 0.044 | 0.013 | 2.2 | −0.83 | D | 2 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71. | | $^1P° - ^2[^5/_2]$ | | | | | | | | | | | |
| | | | 4907.61 | 161854 | 182225 | 3 | 5 | 0.29 | 0.17 | 8.5 | −0.28 | D | 2 |
| 72. | $3d4f-3d(^2D_{5/2})5g$ | $^1G° - ^2[^9/_2]$ | | | | | | | | | | | |
| | | | 4145.05 | 158285 | 182404 | 9 | 11 | 0.077 | 0.024 | 3.0 | −0.66 | D | 2 |
| | | | 4144.77 | 158285 | 182405 | 9 | 9 | 0.094 | 0.024 | 3.0 | −0.66 | D | 2 |
| 73. | | $^1G° - ^2[^{11}/_2]$ | | | | | | | | | | | |
| | | | 4139.42 | 158285 | 182436 | 9 | 11 | 0.32 | 0.10 | 12 | −0.04 | D | 2 |
| 74. | | $^3F° - ^2[^7/_2]$ | | | | | | | | | | | |
| | | | 4176.54 | 158537 | 182473 | 5 | 7 | 0.17 | 0.062 | 4.2 | −0.51 | D | 2 |
| 75. | | $^3G° - ^2[^9/_2]$ | | | | | | | | | | | |
| | | | 4254.11 | 158904 | 182404 | 11 | 11 | 0.43 | 0.12 | 18 | 0.11 | D | 2 |
| 76. | | $^3G° - ^2[^{11}/_2]$ | | | | | | | | | | | |
| | | | 4247.62 | 158904 | 182440 | 11 | 13 | 1.1 | 0.36 | 56 | 0.60 | D | 2 |
| 77. | | $^3G° - ^2[^{13}/_2]$ | | | | | | | | | | | |
| | | | 4218.52 | 158904 | 182602 | 11 | 13 | 0.037 | 0.012 | 1.8 | −0.89 | D | 2 |
| 78. | | $^3H° - ^2[^9/_2]$ | | | | | | | | | | | |
| | | | 4275.53 | 159023 | 182405 | 9 | 9 | 0.23 | 0.062 | 7.9 | −0.25 | D | 2 |
| 79. | | $^3H° - ^2[^{11}/_2]$ | | | | | | | | | | | |
| | | | 4288.66 | 159129 | 182440 | 11 | 13 | 1.1 | 0.37 | 58 | 0.61 | D | 2 |
| | | | 4269.84 | 159023 | 182436 | 9 | 11 | 1.7 | 0.56 | 70 | 0.70 | D | 2 |
| | | | 4289.25 | 159129 | 182436 | 11 | 11 | 0.21 | 0.059 | 9.1 | −0.19 | D | 2 |
| 80. | | $^3H° - ^2[^{13}/_2]$ | | | | | | | | | | | |
| | | | 4285.61 | 159270 | 182597 | 13 | 15 | 3.0 | 0.95 | 170 | 1.09 | D | 2 |
| | | | 4259.01 | 159129 | 182602 | 11 | 13 | 0.94 | 0.30 | 46 | 0.52 | D | 2 |
| | | | 4284.67 | 159270 | 182602 | 13 | 13 | 0.038 | 0.010 | 1.9 | −0.87 | D | 2 |
| 81. | | $^3D° - ^2[^5/_2]$ | | | | | | | | | | | |
| | | | 4310.48 | 159395 | 182588 | 3 | 5 | 0.35 | 0.16 | 7.0 | −0.31 | D | 2 |
| 82. | | $^3D° - ^2[^3/_2]$ | | | | | | | | | | | |
| | | | 4293.34 | 159395 | 182680 | 3 | 3 | 0.31 | 0.086 | 3.6 | −0.59 | D | 2 |
| 83. | | $^3P° - ^2[^5/_2]$ | | | | | | | | | | | |
| | | | 4424.40 | 159992 | 182587 | 5 | 7 | 0.15 | 0.062 | 4.5 | −0.51 | D | 2 |
| | | | 4446.56 | 160105 | 182588 | 3 | 5 | 0.60 | 0.30 | 13 | −0.05 | D | 2 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 84. | | $^3P^\circ - {}^2[^3/_2]$ | | | | | | | | | | | |
| | | | 4440.66 | 160167 | 182680 | 1 | 3 | 1.2 | 1.0 | 15 | 0.01 | D | 2 |
| | | | 4406.20 | 159992 | 182681 | 5 | 5 | 0.51 | 0.15 | 11 | −0.13 | D | 2 |
| 85. | | $^1H^\circ - {}^2[^{11}/_2]$ | | | | | | | | | | | |
| | | | 4466.08 | 160055 | 182440 | 11 | 13 | 0.38 | 0.13 | 22 | 0.17 | D | 2 |
| | | | 4466.69 | 160055 | 182436 | 11 | 11 | 0.12 | 0.037 | 6.0 | −0.39 | D | 2 |
| 86. | | $^1H^\circ - {}^2[^{13}/_2]$ | | | | | | | | | | | |
| | | | 4433.91 | 160055 | 182602 | 11 | 13 | 1.8 | 0.63 | 100 | 0.84 | D | 2 |
| 87. | | $^1P^\circ - {}^2[^5/_2]$ | | | | | | | | | | | |
| | | | 4821.80 | 161854 | 182588 | 3 | 5 | 0.49 | 0.28 | 14 | −0.07 | D | 2 |
| 88. | | $^1P^\circ - {}^2[^3/_2]$ | | | | | | | | | | | |
| | | | 4800.27 | 161854 | 182681 | 3 | 5 | 0.84 | 0.48 | 23 | 0.16 | D | 2 |
| 89. | $3d5s$–$3d5p$ | $^3D - {}^1D^\circ$ | | | | | | | | | | | |
| | | | 7566.25 | 134000 | 147213 | 5 | 5 | 0.089 | 0.076 | 9.5 | −0.42 | D | 2 |
| | | | 7508.65 | 133899 | 147213 | 3 | 5 | 0.044 | 0.062 | 4.6 | −0.73 | D | 2 |
| 90. | | $^3D - {}^3D^\circ$ | | | | | | | | | | | |
| | | | 7316.68 | 133899 | 147562 | 3 | 3 | 0.36 | 0.29 | 21 | −0.06 | D | 2 |
| | | | 7371.34 | 134000 | 147562 | 5 | 3 | 0.16 | 0.078 | 9.4 | −0.41 | D | 2 |
| 91. | | $^3D - {}^3F^\circ$ | | | | | | | | | | | |
| | | | 7072.64 | 134275 | 148410 | 7 | 9 | 0.58 | 0.56 | 91 | 0.59 | D | 2 |
| 92. | | $^3D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | 6667.99 | 134275 | 149268 | 7 | 5 | 0.55 | 0.26 | 40 | 0.26 | D | 2 |
| | | | 6674.19 | 134000 | 148979 | 5 | 3 | 0.40 | 0.16 | 17 | −0.10 | D | 2 |
| | | | 6611.38 | 133899 | 149020 | 3 | 1 | 0.71 | 0.16 | 10 | −0.33 | D | 2 |
| | | | 6547.75 | 134000 | 149268 | 5 | 5 | 0.13 | 0.081 | 8.8 | −0.39 | D | 2 |
| | | | 6629.37 | 133899 | 148979 | 3 | 3 | 0.21 | 0.14 | 9.1 | −0.38 | D | 2 |
| 93. | | $^3D - {}^1P^\circ$ | | | | | | | | | | | |
| | | | 6490.14 | 134000 | 149404 | 5 | 3 | 0.084 | 0.032 | 3.4 | −0.80 | D | 2 |
| 94. | | $^1D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | 6932.44 | 134558 | 148979 | 5 | 3 | 0.048 | 0.021 | 2.4 | −0.98 | D | 2 |
| 95. | $3d5p$–$3d5d$ | $^1D^\circ - {}^1F$ | 4874.00 | 147213 | 167724 | 5 | 7 | 1.5 | 0.73 | 58 | 0.56 | D | 2 |
| 96. | | $^1D^\circ - {}^3D$ | | | | | | | | | | | |
| | | | 4831.33 | 147213 | 167905 | 5 | 3 | 0.20 | 0.042 | 3.3 | −0.68 | D | 2 |
| 97. | | $^1D^\circ - {}^1P$ | 4731.11 | 147213 | 168344 | 5 | 3 | 0.36 | 0.073 | 5.7 | −0.44 | D | 2 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 98. | | $^1D° - ^3F$ | | | | | | | | | | | |
| | | | 4462.56 | 147213 | 169615 | 5 | 5 | 0.41 | 0.12 | 9.1 | −0.21 | D | 2 |
| 99. | | $^3D° - ^3D$ | | | | | | | | | | | |
| | | | 4914.32 | 147562 | 167905 | 3 | 3 | 1.1 | 0.38 | 19 | 0.06 | D | 2 |
| | | | 4884.32 | 147562 | 168030 | 3 | 5 | 0.20 | 0.12 | 5.8 | −0.44 | D | 2 |
| 100. | | $^3D° - ^3F$ | | | | | | | | | | | |
| | | | 4533.26 | 147562 | 169615 | 3 | 5 | 1.5 | 0.78 | 35 | 0.37 | D | 2 |
| 101. | | $^3D° - ^3P$ | | | | | | | | | | | |
| | | | 4343.25 | 147562 | 170580 | 3 | 1 | 1.0 | 0.094 | 4.0 | −0.55 | D | 2 |
| | | | 4328.25 | 147562 | 170660 | 3 | 3 | 0.13 | 0.037 | 1.6 | −0.95 | D | 2 |
| 102. | | $^3F° - ^3G$ | | | | | | | | | | | |
| | | | 4971.19 | 148410 | 168521 | 9 | 11 | 2.1 | 0.97 | 140 | 0.94 | D | 2 |
| | | | 5024.52 | 148410 | 168307 | 9 | 9 | 0.10 | 0.039 | 5.7 | −0.46 | D | 2 |
| 103. | | $^3F° - ^3F$ | | | | | | | | | | | |
| | | | 4649.45 | 148410 | 169912 | 9 | 9 | 0.86 | 0.28 | 38 | 0.40 | D | 2 |
| | | | 4680.58 | 148410 | 169769 | 9 | 7 | 0.083 | 0.021 | 2.9 | −0.72 | D | 2 |
| 104. | | $^3P° - ^3D$ | | | | | | | | | | | |
| | | | 5247.49 | 148979 | 168030 | 3 | 5 | 0.50 | 0.34 | 18 | 0.01 | D | 2 |
| | | | 5293.60 | 149020 | 167905 | 1 | 3 | 0.31 | 0.39 | 6.8 | −0.41 | D | 2 |
| | | | 5328.40 | 149268 | 168030 | 5 | 5 | 0.092 | 0.039 | 3.4 | −0.71 | D | 2 |
| | | | 5282.14 | 148979 | 167905 | 3 | 3 | 0.25 | 0.11 | 5.5 | −0.50 | D | 2 |
| 105. | | $^3P° - ^1P$ | | | | | | | | | | | |
| | | | 5162.55 | 148979 | 168344 | 3 | 3 | 0.31 | 0.12 | 6.3 | −0.43 | D | 2 |
| 106. | | $^3P° - ^3S$ | *5051.9* | *149144* | 168933 | 9 | 3 | 1.7 | 0.21 | 32 | 0.28 | D | 2 |
| | | | 5083.80 | 149268 | 168933 | 5 | 3 | 0.97 | 0.22 | 19 | 0.05 | D | 2 |
| | | | 5010.14 | 148979 | 168933 | 3 | 3 | 0.43 | 0.16 | 8.1 | −0.31 | D | 2 |
| | | | 5020.43 | 149020 | 168933 | 1 | 3 | 0.25 | 0.28 | 4.7 | −0.55 | D | 2 |
| 107. | | $^3P° - ^3P$ | | | | | | | | | | | |
| | | | 4611.04 | 148979 | 170660 | 3 | 3 | 0.37 | 0.12 | 5.4 | −0.45 | D | 2 |
| | | | 4673.40 | 149268 | 170660 | 5 | 3 | 0.91 | 0.18 | 14 | −0.05 | D | 2 |
| | | | 4628.07 | 148979 | 170580 | 3 | 1 | 1.5 | 0.16 | 7.3 | −0.32 | D | 2 |
| | | | 4619.78 | 149020 | 170660 | 1 | 3 | 0.56 | 0.54 | 8.2 | −0.27 | D | 2 |
| 108. | | $^1P° - ^3D$ | | | | | | | | | | | |
| | | | 5367.17 | 149404 | 168030 | 3 | 5 | 0.064 | 0.046 | 2.4 | −0.86 | D | 2 |
| 109. | | $^1P° - ^1P$ | 5278.33 | 149404 | 168344 | 3 | 3 | 0.94 | 0.39 | 20 | 0.07 | D | 2 |
| 110. | | $^1P° - ^3S$ | | | | | | | | | | | |
| | | | 5119.08 | 149404 | 168933 | 3 | 3 | 0.39 | 0.15 | 7.7 | −0.34 | D | 2 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 111. | | $^1P° - ^3P$ | | | | | | | | | | | |
| | | | 4720.90 | 149404 | 170580 | 3 | 1 | 0.31 | 0.035 | 1.6 | −0.98 | D | 2 |
| 112. | | $^1P° - ^1S$ | 4352.28 | 149404 | 172374 | 3 | 1 | 0.27 | 0.26 | 11 | −0.11 | D | 2 |
| 113. | | $^1F° - ^1F$ | 5533.01 | 149656 | 167724 | 7 | 7 | 0.41 | 0.19 | 24 | 0.12 | D | 2 |
| 114. | | $^1F° - ^1G$ | 4652.86 | 149656 | 171142 | 7 | 9 | 2.6 | 1.1 | 120 | 0.88 | D | 2 |
| 115. | $3d5p-3d6s$ | $^1D° - ^3D$ | | | | | | | | | | | |
| | | | 4400.57 | 147213 | 169931 | 5 | 5 | 0.34 | 0.098 | 7.1 | −0.31 | D | 2 |
| 116. | | $^3D° - ^3D$ | | | | | | | | | | | |
| | | | 4480.36 | 147562 | 169876 | 3 | 3 | 0.73 | 0.22 | 9.7 | −0.18 | D | 2 |
| 117. | | $^3F° - ^3D$ | | | | | | | | | | | |
| | | | 4576.53 | 148410 | 170255 | 9 | 7 | 1.3 | 0.31 | 42 | 0.45 | D | 2 |
| 118. | | $^3P° - ^3D$ | | | | | | | | | | | |
| | | | 4763.58 | 149268 | 170255 | 5 | 7 | 0.50 | 0.24 | 19 | 0.08 | D | 2 |
| | | | 4771.46 | 148979 | 169931 | 3 | 5 | 0.34 | 0.19 | 9.0 | −0.24 | D | 2 |
| | | | 4793.50 | 149020 | 169876 | 1 | 3 | 0.29 | 0.30 | 4.8 | −0.52 | D | 2 |
| | | | 4838.25 | 149268 | 169931 | 5 | 5 | 0.12 | 0.044 | 3.5 | −0.66 | D | 2 |
| | | | 4784.09 | 148979 | 169876 | 3 | 3 | 0.26 | 0.090 | 4.2 | −0.57 | D | 2 |
| 119. | | $^1F° - ^1D$ | 4849.66 | 149656 | 170270 | 7 | 5 | 0.11 | 0.028 | 3.1 | −0.71 | D | 2 |
| 120. | $3d5d-3d5f$ | $^1F - ^1G°$ | 7408.13 | 167724 | 181219 | 7 | 9 | 0.87 | 0.92 | 160 | 0.81 | D | 2 |
| 121. | | $^1F - ^3H°$ | | | | | | | | | | | |
| | | | 7288.98 | 167724 | 181440 | 7 | 9 | 0.061 | 0.062 | 10 | −0.36 | D | 2 |
| 122. | | $^1F - ^3G°$ | | | | | | | | | | | |
| | | | 7252.88 | 167724 | 181508 | 7 | 7 | 0.14 | 0.11 | 19 | −0.10 | D | 2 |
| 123. | | $^1F - ^1F°$ | 7071.93 | 167724 | 181861 | 7 | 7 | 0.22 | 0.16 | 27 | 0.06 | D | 2 |
| 124. | | $^3D - ^3F°$ | | | | | | | | | | | |
| | | | 7495.18 | 168030 | 181368 | 5 | 7 | 0.57 | 0.68 | 84 | 0.53 | D | 2 |
| | | | 7441.72 | 167905 | 181339 | 3 | 5 | 0.74 | 1.0 | 76 | 0.49 | D | 2 |
| | | | 7511.59 | 168030 | 181339 | 5 | 5 | 0.039 | 0.033 | 4.1 | −0.78 | D | 2 |
| 125. | | $^3D - ^3G°$ | | | | | | | | | | | |
| | | | 7417.60 | 168030 | 181508 | 5 | 7 | 0.18 | 0.20 | 25 | 0.01 | D | 2 |
| 126. | | $^3D - ^1F°$ | | | | | | | | | | | |
| | | | 7228.40 | 168030 | 181861 | 5 | 7 | 0.036 | 0.039 | 4.6 | −0.71 | D | 2 |
| 127. | | $^3D - ^3D°$ | | | | | | | | | | | |
| | | | 7203.66 | 168030 | 181908 | 5 | 5 | 0.34 | 0.26 | 31 | 0.12 | D | 2 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 128. | | $^3D - ^3P^\circ$ | | | | | | | | | | | |
| | | | 7017.31 | 168030 | 182277 | 5 | 3 | 0.12 | 0.051 | 5.9 | −0.59 | D | 2 |
| 129. | | $^3G - ^1G^\circ$ | | | | | | | | | | | |
| | | | 7742.64 | 168307 | 181219 | 9 | 9 | 0.047 | 0.042 | 9.7 | −0.42 | D | 2 |
| 130. | | $^3G - ^3H^\circ$ | | | | | | | | | | | |
| | | | 7506.87 | 168521 | 181838 | 11 | 13 | 1.1 | 1.1 | 310 | 1.10 | D | 2 |
| | | | 7544.29 | 168307 | 181558 | 9 | 11 | 0.93 | 0.97 | 220 | 0.94 | D | 2 |
| 131. | | $^3G - ^3G^\circ$ | | | | | | | | | | | |
| | | | 7515.98 | 168521 | 181822 | 11 | 11 | 0.23 | 0.19 | 53 | 0.33 | D | 2 |
| | | | 7432.20 | 168307 | 181758 | 9 | 9 | 0.15 | 0.12 | 27 | 0.05 | D | 2 |
| | | | 7552.05 | 168521 | 181758 | 11 | 9 | 0.019 | 0.013 | 3.6 | −0.84 | D | 2 |
| | | | 7397.27 | 168307 | 181822 | 9 | 11 | 0.16 | 0.16 | 35 | 0.16 | D | 2 |
| 132. | | $^1P - ^1D^\circ$ | 7484.58 | 168344 | 181701 | 3 | 5 | 0.56 | 0.78 | 58 | 0.37 | D | 2 |
| 133. | | $^1P - ^3D^\circ$ | | | | | | | | | | | |
| | | | 7370.14 | 168344 | 181908 | 3 | 5 | 0.11 | 0.15 | 11 | −0.34 | D | 2 |
| 134. | | $^1P - ^1P^\circ$ | 7031.40 | 168344 | 182562 | 3 | 3 | 0.50 | 0.37 | 26 | 0.05 | D | 2 |
| 135. | | $^3S - ^3D^\circ$ | | | | | | | | | | | |
| | | | 7704.80 | 168933 | 181908 | 3 | 5 | 0.087 | 0.13 | 9.9 | −0.41 | D | 2 |
| 136. | | $^3S - ^3P^\circ$ | *7510.5* | 168933 | *182244* | 3 | 9 | 0.41 | 1.0 | 77 | 0.49 | D | 2 |
| | | | 7531.15 | 168933 | 182207 | 3 | 5 | 0.45 | 0.64 | 47 | 0.28 | D | 2 |
| | | | 7491.92 | 168933 | 182277 | 3 | 3 | 0.34 | 0.28 | 21 | −0.07 | D | 2 |
| | | | 7460.04 | 168933 | 182334 | 3 | 1 | 0.44 | 0.12 | 8.9 | −0.44 | D | 2 |
| 137. | | $^3S - ^1P^\circ$ | | | | | | | | | | | |
| | | | 7335.41 | 168933 | 182562 | 3 | 3 | 0.13 | 0.11 | 7.6 | −0.50 | D | 2 |
| 138. | | $^3F - ^1G^\circ$ | | | | | | | | | | | |
| | | | 8731.24 | 169769 | 181219 | 7 | 9 | 0.064 | 0.094 | 19 | −0.18 | D | 2 |
| 139. | | $^3F - ^3F^\circ$ | | | | | | | | | | | |
| | | | 8544.89 | 169912 | 181612 | 9 | 9 | 0.10 | 0.11 | 28 | 0.00 | D | 2 |
| | | | 8618.79 | 169769 | 181368 | 7 | 7 | 0.051 | 0.057 | 11 | −0.40 | D | 2 |
| | | | 8527.03 | 169615 | 181339 | 5 | 5 | 0.22 | 0.24 | 34 | 0.08 | D | 2 |
| | | | 8505.88 | 169615 | 181368 | 5 | 7 | 0.26 | 0.40 | 56 | 0.30 | D | 2 |
| 140. | | $^3F - ^3H^\circ$ | | | | | | | | | | | |
| | | | 8584.05 | 169912 | 181558 | 9 | 11 | 0.12 | 0.17 | 43 | 0.18 | D | 2 |
| | | | 8566.24 | 169769 | 181440 | 7 | 9 | 0.12 | 0.17 | 34 | 0.08 | D | 2 |

Ti III: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 141. | | $^3$F - $^3$G° | | | | | | | | | | | |
| | | | 8394.20 | 169912 | 181822 | 9 | 11 | 0.56 | 0.72 | 180 | 0.81 | D | 2 |
| | | | 8338.54 | 169769 | 181758 | 7 | 9 | 0.42 | 0.57 | 110 | 0.60 | D | 2 |
| | | | 8406.15 | 169615 | 181508 | 5 | 7 | 0.34 | 0.50 | 70 | 0.40 | D | 2 |
| | | | 8439.19 | 169912 | 181758 | 9 | 9 | 0.15 | 0.16 | 40 | 0.16 | D | 2 |
| | | | 8516.40 | 169769 | 181508 | 7 | 7 | 0.13 | 0.14 | 28 | 0.00 | D | 2 |
| 142. | | $^3$F - $^1$F° | | | | | | | | | | | |
| | | | 8164.06 | 169615 | 181861 | 5 | 7 | 0.029 | 0.040 | 5.4 | −0.70 | D | 2 |
| 143. | | $^3$F - $^3$D° | | | | | | | | | | | |
| | | | 8252.85 | 169912 | 182026 | 9 | 7 | 0.021 | 0.016 | 4.0 | −0.83 | D | 2 |
| | | | 8235.58 | 169769 | 181908 | 7 | 5 | 0.043 | 0.031 | 5.9 | −0.66 | D | 2 |
| 144. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 8887.71 | 170660 | 181908 | 3 | 5 | 0.23 | 0.45 | 39 | 0.13 | D | 2 |
| 145. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 8605.75 | 170660 | 182277 | 3 | 3 | 0.22 | 0.24 | 21 | −0.14 | D | 2 |
| | | | 8563.50 | 170660 | 182334 | 3 | 1 | 0.43 | 0.16 | 13 | −0.33 | D | 2 |
| 146. | | $^1$G - $^1$H° | 8916.95 | 171142 | 182353 | 9 | 11 | 0.68 | 0.99 | 260 | 0.95 | D | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti III

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2397.1 | 12 | 3207.7 | 16 | 3661.1 | 18 | 9595.5 | 3 |
| 2407.8 | 12 | 3214.4 | 16 | 4160.6 | 17 | 9705.3 | 3 |
| 2421.5 | 12 | 3226.6 | 16 | 4165.1 | 8 | 10833 | 19 |
| 2601.6 | 11 | 3337.7 | 13 | 4200.3 | 17 | 11798 | 2 |
| 2614.2 | 11 | 3363.2 | 13 | 4570.8 | 10 | 12061 | 2 |
| 2617.1 | 11 | 3378.5 | 13 | 4595.5 | 10 | 12414 | 2 |
| 2626.3 | 11 | 3593.2 | 15 | 6943.7 | 4 | 16876 | 7 |
| 2629.8 | 11 | 3608.5 | 15 | 7034.0 | 4 | 44478 | 6 |
| 2630.4 | 11 | 3614.2 | 15 | 7152.5 | 4 | 46933 | 6 |
| 2639.2 | 11 | 3622.8 | 15 | 9324.8 | 3 | 424500 | 1 |
| 2646.2 | 11 | 3638.3 | 15 | 9428.2 | 3 | 540700 | 1 |
| 3008.4 | 14 | 3640.5 | 15 | 9486.5 | 3 | 850100 | 9 |
| 3078.4 | 5 | 3656.2 | 15 | 9488.4 | 3 | 1533000 | 9 |

For this ion, we selected the work of Warner and Kirkpatrick,[1] and that of Beck.[2] Warner and Kirkpatrick used a single-configuration approximation and calculated radial integrals with scaled Thomas-Fermi wavefunctions. They provided M1 and E2 transition probabilities for numerous lines within the $3d^2$ (ground) configuration and in the $3d^2$–$3d4s$ transition array. Beck, on the other hand, calculated electric quadrupole transition probabilities using restricted Hartree-Fock and correlated wavefunctions. He provided both length and velocity results for the following transitions: $3d^2\ ^3$F – $3d^2\ ^3$P and $3d^2$ $^3$F –$3d4s\ ^3$D. In this compilation, we have tabulated data for the stronger lines of Ref. 1 and $A$-values derived from correlated wavefunctions of Ref. 2 using the dipole length transition operator.

The data of Ref. 2 should be more reliable, since the principal configuration interaction effects are included. For long-wavelength lines within the $3d^2\ ^3$F and $3d^2\ ^3$P terms, we have recalculated Warner and Kirkpatrick's $A$-values by using observed energy-level data instead of theoretically derived values.

### References

[1]B. Warner and R. C. Kirkpatrick, Mon. Not. R. Astron. Soc. **144**, 397 (1969).

[2]D. R. Beck, Phys. Rev. A **23**, 159 (1981).

Ti III: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^2$–$3d^2$ | $^3$F - $^3$F | | | | | | | | | | |
| | | | [424500] | 184.9 | 420.4 | 7 | 9 | M1 | 2.5(−4)[a] | 6.4 | C | 1*n* |
| | | | [540700] | 0.0 | 184.9 | 5 | 7 | M1 | 1.6(−4) | 6.6 | C | 1*n* |
| 2. | | $^3$F - $^1$D (1F) | | | | | | | | | | |
| | | | [12414] | 420.4 | 8473.5 | 9 | 5 | E2 | 4.2(−5) | 0.037 | E | 1 |
| | | | [12061] | 184.9 | 8473.5 | 7 | 5 | M1 | 0.010 | 0.0033 | E | 1 |
| | | | [11798] | 0.0 | 8473.5 | 5 | 5 | M1 | 0.0054 | 0.0016 | E | 1 |
| 3. | | $^3$F - $^3$P (2F) | | | | | | | | | | |
| | | | [9705.3] | 420.4 | 10721 | 9 | 5 | E2 | 0.023 | 5.9 | E | 2 |
| | | | [9595.5] | 184.9 | 10604 | 7 | 3 | E2 | 0.021 | 3.1 | E | 2 |
| | | | [9486.5] | 0.0 | 10538 | 5 | 1 | E2 | 0.034 | 1.6 | E | 2 |
| | | | [9488.4] | 184.9 | 10721 | 7 | 5 | M1 | 6.8(−5) | 1.1(−5) | E | 1 |
| | | | " | " | " | 7 | 5 | E2 | 0.0068 | 1.6 | E | 2 |
| | | | [9428.2] | 0.0 | 10604 | 5 | 3 | E2 | 0.012 | 1.6 | E | 2 |
| | | | [9324.8] | 0.0 | 10721 | 5 | 5 | M1 | 1.2(−5) | 1.8(−6) | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.0011 | 0.23 | E | 2 |
| 4. | | $^3$F - $^1$G (3F) | | | | | | | | | | |
| | | | [7152.5] | 420.4 | 14398 | 9 | 9 | M1 | 0.0068 | 8.3(−4) | E | 1 |
| | | | [7034.0] | 184.9 | 14398 | 7 | 9 | M1 | 0.0043 | 5.0(−4) | E | 1 |
| | | | [6943.7] | 0.0 | 14398 | 5 | 9 | E2 | 1.6(−5) | 0.0014 | E | 1 |
| 5. | | $^3$F - $^1$S | | | | | | | | | | |
| | | | [3078.4] | 0.0 | 32476 | 5 | 1 | E2 | 0.0042 | 6.9(−4) | E | 1 |
| 6. | | $^1$D - $^3$P | | | | | | | | | | |
| | | | [44478] | 8473.5 | 10721 | 5 | 5 | M1 | 0.0025 | 0.041 | E | 1 |
| | | | [46933] | 8473.5 | 10604 | 5 | 3 | M1 | 0.0012 | 0.014 | E | 1 |
| 7. | | $^1$D - $^1$G | [16876] | 8473.5 | 14398 | 5 | 9 | E2 | 3.7(−4) | 2.7 | E | 1 |

Ti III: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^1D - ^1S$ | [4165.1] | 8473.5 | 32476 | 5 | 1 | E2 | 4.9 | 3.7 | E | 1 |
| 9. | | $^3P - ^3P$ | | | | | | | | | | |
| | | | [850100] | 10604 | 10721 | 3 | 5 | M1 | 1.5(−5) | 1.7 | C | 1*n* |
| | | | [1533000] | 10538 | 10604 | 1 | 3 | M1 | 5.5(−6) | 2.2 | C | 1*n* |
| 10. | | $^3P - ^1S$ | | | | | | | | | | |
| | | | [4595.5] | 10721 | 32476 | 5 | 1 | E2 | 0.020 | 0.024 | E | 1 |
| | | | [4570.8] | 10604 | 32476 | 3 | 1 | M1 | 0.10 | 3.5(−4) | E | 1 |
| 11. | $3d^2$–$3d4s$ | $^3F - ^3D$ | | | | | | | | | | |
| | | | [2646.2] | 420.4 | 38199 | 9 | 5 | E2 | 11 | 4.2 | E | 2 |
| | | | [2639.2] | 184.9 | 38064 | 7 | 3 | E2 | 17 | 3.9 | E | 2 |
| | | | [2630.4] | 420.4 | 38426 | 9 | 7 | E2 | 40 | 21 | E | 2 |
| | | | [2629.8] | 184.9 | 38199 | 7 | 5 | E2 | 26 | 9.7 | E | 2 |
| | | | [2626.3] | 0.0 | 38064 | 5 | 3 | E2 | 35 | 7.8 | E | 2 |
| | | | [2614.2] | 184.9 | 38426 | 7 | 7 | E2 | 12 | 6.1 | E | 2 |
| | | | [2617.1] | 0.0 | 38199 | 5 | 5 | E2 | 15 | 5.5 | E | 2 |
| | | | [2601.6] | 0.0 | 38426 | 5 | 7 | E2 | 1.1 | 0.55 | E | 2 |
| 12. | | $^3F - ^1D$ | | | | | | | | | | |
| | | | [2421.5] | 420.4 | 41704 | 9 | 5 | E2 | 0.013 | 0.0032 | E | 1 |
| | | | [2407.8] | 184.9 | 41704 | 7 | 5 | E2 | 0.092 | 0.022 | E | 1 |
| | | | [2397.1] | 0.0 | 41704 | 5 | 5 | E2 | 0.0051 | 0.0012 | E | 1 |
| 13. | | $^1D - ^3D$ (4F) | | | | | | | | | | |
| | | | [3337.7] | 8473.5 | 38426 | 5 | 7 | E2 | 0.025 | 0.043 | E | 1 |
| | | | [3363.2] | 8473.5 | 38199 | 5 | 5 | E2 | 0.062 | 0.079 | E | 1 |
| | | | [3378.5] | 8473.5 | 38064 | 5 | 3 | E2 | 0.023 | 0.018 | E | 1 |
| 14. | | $^1D - ^1D$ (5F) | [3008.4] | 8473.5 | 41704 | 5 | 5 | E2 | 17 | 12 | E | 1 |
| 15. | | $^3P - ^3D$ (6F) | | | | | | | | | | |
| | | | [3593.2] | 10604 | 38426 | 3 | 7 | E2 | 1.4 | 3.5 | E | 1 |
| | | | [3614.2] | 10538 | 38199 | 1 | 5 | E2 | 1.3 | 2.4 | E | 1 |
| | | | [3608.5] | 10721 | 38426 | 5 | 7 | E2 | 2.7 | 6.9 | E | 1 |
| | | | [3622.8] | 10604 | 38199 | 3 | 5 | E2 | 0.33 | 0.61 | E | 1 |
| | | | [3638.3] | 10721 | 38199 | 5 | 5 | E2 | 2.2 | 4.2 | E | 1 |
| | | | [3640.5] | 10604 | 38064 | 3 | 3 | E2 | 2.9 | 3.3 | E | 1 |
| | | | [3656.2] | 10721 | 38064 | 5 | 3 | E2 | 0.94 | 1.1 | E | 1 |
| 16. | | $^3P - ^1D$ (7F) | | | | | | | | | | |
| | | | [3226.6] | 10721 | 41704 | 5 | 5 | E2 | 0.13 | 0.14 | E | 1 |
| | | | [3214.4] | 10604 | 41704 | 3 | 5 | E2 | 0.0015 | 0.0015 | E | 1 |
| | | | [3207.7] | 10538 | 41704 | 1 | 5 | E2 | 0.0034 | 0.0034 | E | 1 |
| 17. | | $^1G - ^3D$ (10F) | | | | | | | | | | |
| | | | [4200.3] | 14398 | 38199 | 9 | 5 | E2 | 0.013 | 0.051 | E | 1 |
| | | | [4160.6] | 14398 | 38426 | 9 | 7 | E2 | 2.6(−4) | 0.0014 | E | 1 |

Ti III: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18. | | $^1G - ^1D$ (11F) | [3661.1] | 14398 | 41704 | 9 | 5 | E2 | 11 | 22 | E | 1 |
| 19. | | $^1S - ^1D$ | [10833] | 32476 | 41704 | 1 | 5 | E2 | 0.0055 | 2.4 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti IV

K Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^63d\ ^2D_{3/2}$

Ionization Energy: 43.2675 eV = 348973 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 423.49 | 2 | 763.84 | 8 | 1469.19 | 6 | 2957.31 | 11 |
| 424.16 | 2 | 768.42 | 8 | 2067.56 | 4 | 3541.36 | 14 |
| 424.17 | 2 | 768.65 | 8 | 2103.16 | 4 | 3576.44 | 14 |
| 433.04 | 3 | 776.762 | 1 | 2541.79 | 10 | 3581.39 | 14 |
| 433.63 | 3 | 779.074 | 1 | 2546.88 | 10 | 4395.92 | 12 |
| 433.76 | 3 | 781.730 | 1 | 2547.31 | 10 | 4397.33 | 12 |
| 664.30 | 5 | 1183.64 | 7 | 2836.97 | 15 | 4403.45 | 12 |
| 665.69 | 5 | 1195.21 | 7 | 2862.60 | 15 | 5398.93 | 13 |
| 725.03 | 9 | 1451.74 | 6 | 2929.96 | 11 | 5492.51 | 13 |
| 729.36 | 9 | 1467.34 | 6 | 2937.33 | 11 | | |

For this relatively simple alkali-like spectrum, we have used the compilation of Kurucz and Peytremann,[1] who calculated *gf*-values by a semiempirical, scaled Thomas-Fermi-Dirac approach. These data are in excellent agreement with the Hartree-Fock calculations of Biemont[2] and the Coulomb approximation.[3] Since, starting with Ti IV, the $3p^53d^2$ configuration moves below the first ionization limit, increased configuration interaction is expected, especially for transitions arising from higher upper levels. Because of the likelihood of configuration mixing effects, we have omitted all lines having upper levels near or greater than 275000 $cm^{-1}$.

Our tabulated data can be compared to the recent beam-foil lifetimes of Baudinet-Robinet *et al.*[4] and Dumont *et al.*[5] The authors of Refs. 4 and 5 derived their published lifetimes from a complex analysis of their raw data, via various curve-fitting techniques. These data are very consistent with our adopted absolute scale.

## References


[1]R. L. Kurucz and E. Peytremann, Smithsonian Astrophysical Observatory Special Report 362 (1975).

[2]E. Biemont, Physica C **81**, 158 (1976).

[3]D. R. Bates and A. Damgaard, Philos. Trans. Roy. Soc. London, Ser. A **242**, 101 (1949).

[4]Y. Baudinet-Robinet, P. D. Dumont, H. P. Garnir, N. Grevesse, and E. Biemont, J. Opt. Soc. Am. **70**, 464 (1980).

[5]P. D. Dumont, H. P. Garnir, Y. Baudinet-Robinet, and M. Kapenyak, J. Opt. Soc. Am. **71**, 502 (1981).

Ti IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 3$d$–4$p$ | $^2$D - $^2$P° | *779.80* | *229.3* | *128467* | 10 | 6 | 14 | 0.078 | 2.0 | −0.11 | D | 1 |
| 2. | 3$d$–4$f$ | $^2$D - $^2$F° | *423.89* | *229.3* | *236139* | 10 | 14 | 53 | 0.20 | 2.8 | 0.30 | D | 1 |
| | | | [424.16] | 382.1 | 236142 | 6 | 8 | 53 | 0.19 | 1.6 | 0.06 | D | 1 |
| | | | [423.49] | 0.0 | 236135 | 4 | 6 | 49 | 0.20 | 1.1 | −0.10 | D | 1 |
| | | | [424.17] | 382.1 | 236135 | 6 | 6 | 3.6 | 0.0096 | 0.080 | −1.24 | D− | 1 |
| 3. | 3$d$–5$p$ | $^2$D - $^2$P° | *433.67* | *229.3* | *230819* | 10 | 6 | 5.4 | 0.0091 | 0.13 | −1.04 | D− | 1 |
| | | | [433.76] | 382.1 | 230924 | 6 | 4 | 5.0 | 0.0094 | 0.080 | −1.25 | D− | 1 |
| | | | [433.63] | 0.0 | 230609 | 4 | 2 | 5.5 | 0.0077 | 0.044 | −1.51 | E | 1 |
| | | | [433.04] | 0.0 | 230924 | 4 | 4 | 0.55 | 0.0015 | 0.0088 | −2.21 | E | 1 |
| 4. | 4$s$–4$p$ | $^2$S - $^2$P° (uv 2) | *2079.3* | 80389 | *128467* | 2 | 6 | 5.3 | 1.0 | 14 | 0.31 | D | 1 |
| | | | 2067.56 | 80389 | 128740 | 2 | 4 | 5.1 | 0.66 | 9.0 | 0.12 | D | 1 |
| | | | 2103.16 | 80389 | 127921 | 2 | 2 | 5.0 | 0.33 | 4.6 | −0.18 | D | 1 |
| 5. | 4$s$–5$p$ | $^2$S - $^2$P° | *664.76* | 80389 | *230819* | 2 | 6 | 0.74 | 0.015 | 0.064 | −1.53 | E | 1 |
| | | | [664.30] | 80389 | 230924 | 2 | 4 | 0.70 | 0.0093 | 0.041 | −1.73 | E | 1 |
| | | | [665.69] | 80389 | 230609 | 2 | 2 | 0.81 | 0.0054 | 0.023 | −1.97 | E | 1 |
| 6. | 4$p$–4$d$ | $^2$P° - $^2$D (uv 3) | *1462.2* | *128467* | *196856* | 6 | 10 | 21 | 1.1 | 33 | 0.84 | D | 1 |
| | | | 1467.34 | 128740 | 196890 | 4 | 6 | 21 | 1.0 | 20 | 0.61 | D | 1 |
| | | | 1451.74 | 127921 | 196804 | 2 | 4 | 18 | 1.1 | 11 | 0.36 | D | 1 |
| | | | 1469.19 | 128740 | 196804 | 4 | 4 | 3.5 | 0.11 | 2.2 | −0.34 | D | 1 |
| 7. | 4$p$–5$s$ | $^2$P° - $^2$S | *1191.3* | *128467* | 212407 | 6 | 2 | 20 | 0.14 | 3.4 | −0.06 | D | 1 |
| | | | 1195.21 | 128740 | 212407 | 4 | 2 | 14 | 0.15 | 2.3 | −0.23 | D | 1 |
| | | | 1183.64 | 127921 | 212407 | 2 | 2 | 6.9 | 0.14 | 1.1 | −0.54 | D | 1 |
| 8. | 4$p$–5$d$ | $^2$P° - $^2$D | *766.91* | *128467* | *258861* | 6 | 10 | 1.5 | 0.022 | 0.34 | −0.87 | D | 1 |
| | | | [768.42] | 128740 | 258877 | 4 | 6 | 1.5 | 0.019 | 0.20 | −1.11 | D− | 1 |
| | | | [763.84] | 127921 | 258838 | 2 | 4 | 1.3 | 0.023 | 0.12 | −1.33 | D− | 1 |
| | | | [768.65] | 128740 | 258838 | 4 | 4 | 0.25 | 0.0022 | 0.022 | −2.06 | E | 1 |
| 9. | 4$p$–6$s$ | $^2$P° - $^2$S | *727.91* | *128467* | 265847 | 6 | 2 | 8.7 | 0.023 | 0.33 | −0.86 | D | 1 |
| | | | [729.36] | 128740 | 265847 | 4 | 2 | 5.7 | 0.023 | 0.22 | −1.04 | D− | 1 |
| | | | [725.03] | 127921 | 265847 | 2 | 2 | 2.8 | 0.022 | 0.11 | −1.35 | D− | 1 |
| 10. | 4$d$–4$f$ | $^2$D - $^2$F° (uv 4) | *2544.9* | *196856* | *236139* | 10 | 14 | 7.3 | 0.99 | 83 | 1.00 | D | 1 |
| | | | 2546.88 | 196890 | 236142 | 6 | 8 | 7.4 | 0.96 | 48 | 0.76 | D | 1 |
| | | | 2541.79 | 196804 | 236135 | 4 | 6 | 6.9 | 1.0 | 33 | 0.60 | D | 1 |
| | | | 2547.31 | 196890 | 236135 | 6 | 6 | 0.49 | 0.048 | 2.4 | −0.54 | D | 1 |

Ti IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11. | $4d$–$5p$ | $^2$D - $^2$P° | *2943.5* | *196856* | *230819* | 10 | 6 | 3.3 | 0.26 | 25 | 0.41 | D | 1 |
| | | | 2937.33 | 196890 | 230924 | 6 | 4 | 3.0 | 0.26 | 15 | 0.19 | D | 1 |
| | | | 2957.31 | 196804 | 230609 | 4 | 2 | 3.3 | 0.22 | 8.5 | −0.06 | D | 1 |
| | | | 2929.96 | 196804 | 230924 | 4 | 4 | 0.34 | 0.043 | 1.7 | −0.76 | D | 1 |
| 12. | $4f$–$5d$ | $^2$F° - $^2$D | *4399.8* | *236139* | *258861* | 14 | 10 | 0.76 | 0.16 | 32 | 0.34 | D | 1 |
| | | | 4397.33 | 236142 | 258877 | 8 | 6 | 0.71 | 0.15 | 18 | 0.09 | D | 1 |
| | | | 4403.45 | 236135 | 258838 | 6 | 4 | 0.75 | 0.15 | 13 | −0.06 | D | 1 |
| | | | 4395.92 | 236135 | 258877 | 6 | 6 | 0.035 | 0.010 | 0.89 | −1.21 | D− | 1 |
| 13. | $5s$–$5p$ | $^2$S - $^2$P° | *5429.7* | 212407 | *230819* | 2 | 6 | 1.0 | 1.3 | 48 | 0.43 | D | 1 |
| | | | 5398.93 | 212407 | 230924 | 2 | 4 | 1.0 | 0.91 | 32 | 0.26 | D | 1 |
| | | | 5492.51 | 212407 | 230609 | 2 | 2 | 0.99 | 0.45 | 16 | −0.05 | D | 1 |
| 14. | $5p$–$5d$ | $^2$P° - $^2$D | *3565.1* | *230819* | *258861* | 6 | 10 | 4.5 | 1.4 | 100 | 0.93 | D | 1 |
| | | | 3576.44 | 230924 | 258877 | 4 | 6 | 4.6 | 1.3 | 62 | 0.72 | D | 1 |
| | | | 3541.36 | 230609 | 258838 | 2 | 4 | 3.8 | 1.4 | 34 | 0.46 | D | 1 |
| | | | 3581.39 | 230924 | 258838 | 4 | 4 | 0.77 | 0.15 | 6.9 | −0.23 | D | 1 |
| 15. | $5p$–$6s$ | $^2$P° - $^2$S | *2854.0* | *230819* | 265847 | 6 | 2 | 6.1 | 0.25 | 14 | 0.17 | D | 1 |
| | | | 2862.60 | 230924 | 265847 | 4 | 2 | 4.1 | 0.25 | 9.4 | −0.00 | D | 1 |
| | | | 2836.97 | 230609 | 265847 | 2 | 2 | 2.0 | 0.24 | 4.6 | −0.31 | D | 1 |

# Ti V

Ar Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^6\ ^1S_0$

Ionization Energy: 99.30 eV = 800900 cm$^{-1}$

## Allowed Transitions

Line strengths for the $3p^6$–$3p^53d$ resonance transitions of this argon-like ion were interpolated from the superposition-of-configurations (SOC) calculations of Weiss,[1] which are expected to be fairly accurate.

Oscillator strengths for transitions of the $3p^6$–$3p^54s$ array were interpolated from the Dirac-Hartree-Fock data of Lin *et al.*,[2] who included correlation only in the lower state. Because the $3p^54s$ configuration lies slightly above $3p^53d$ in energy, it is possible that errors in the results of Lin *et al.* due to the exclusion of configuration interaction in the upper state are rather significant; hence the low accuracy ratings. The results of Ref. 2 for lines of the $3p^6$–$3p^54d$ array in nearby Ar-like species have not been interpolated to provide $f$-values for Ti V, since cancellation effects at or near V VI—one of the ions treated—introduce considerable uncertainty into the results at the low-$Z$ end of the Ar sequence.

Lifetimes for a number of levels in Ti V have been measured by Baudinet-Robinet *et al.*[3] and Dumont *et al.*[4] using the beam-foil technique, but they could not be converted to transition probabilities since the branching ratios are not known.

## References

[1]A. W. Weiss, private communication.
[2]D. L. Lin, W. Fielder, Jr., and L. Armstrong, Jr., Phys. Rev. A 16, 589 (1977).
[3]Y. Baudinet-Robinet, P. D. Dumont, H. P. Garnir, N. Grevesse, and E. Biemont, J. Opt. Soc. Am. 70, 464 (1980).
[4]P. D. Dumont, H. P. Garnir, Y. Baudinet-Robinet, and M. Kapenyak, J. Opt. Soc. Am. 71, 502 (1981).


Ti V: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^6$–$3p^5 3d$ | $^1$S - $^3$D° | | | | | | | | | | | |
| | | | 323.365 | 0 | 309252 | 1 | 3 | 0.40 | 0.0019 | 0.0020 | −2.73 | E | *interp.* |
| 2. | | $^1$S - $^1$P° | 252.958 | 0 | 395321 | 1 | 3 | 1260 | 3.63 | 3.02 | 0.56 | C | *interp.* |
| 3. | $3p^6$–$3p^5 4s$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | 228.909 | 0 | 436850 | 1 | 3 | 41 | 0.097 | 0.073 | −1.01 | E | *interp.* |
| 4. | | $^1$S - $^1$P° | 225.347 | 0 | 443753 | 1 | 3 | 140 | 0.33 | 0.24 | −0.48 | E | *interp.* |

# Ti VI

Cl Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s^2 3p^5\ ^2P^\circ_{3/2}$

Ionization Energy: 119.53 eV = 964100 cm$^{-1}$

## Allowed Transitions

Line strengths for transitions of the arrays $3s^2 3p^5$–$3s 3p^6$ and $3p^5$–$3p^4 3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang *et al.*[1] These relativistic calculations include a perturbative treatment of the Breit interaction and the Lamb shift. Configuration mixing was limited to some configurations within the $n=3$ complex. Those configurations which were assumed to lie far above $3p^5$ or $3p^4 3d$ in energy were excluded, as were all configurations outside the complex.

According to the semi-empirical HX (Hartree-Fock with statistical allowance for exchange) calculations of Bromage *et al.*[2] for Fe X, some levels of the $3p^4 3d$ configuration are strongly mixed in the *LS* basis, and in a few cases the *LS* designations given in Ref. 2 differed from those of Huang *et al.* The level designations used in this compilation are in accord with the theoretical results of Refs. 1 and 2 for Fe X. Percentage compositions published by Bromage[3] for the levels of the $3p^4 3d$ configuration in V VII and Ni XII indicate that the designations for the iron ion are appropriate for the neighboring ions of the chlorine isoelectronic sequence. Transitions involving highly mixed levels have been excluded, as have the very weak transitions.

The calculated wavelengths of Huang *et al.* differ appreciably from the observed ones found in the literature. Thus the available experimentally determined wavelengths were used in making the conversion from line strengths to *f*- and *A*-values. (Otherwise, the calculated wavelengths of Huang *et al.* were used, but they provide only a rough idea of the spectral-line positions.) Bromage *et al.* indicate that it was necessary to scale down some configuration-interaction parameters by a greater amount than usual in order to fit their calculated energy levels for Fe X to the experimental data. This could be an indication that neglecting to take configuration interaction into account on a larger scale yields significant errors in the energy levels and/or *f*-values.

The lifetime of the $3s3p^6\ ^2S_{1/2}$ level has been measured by Dumont *et al.*[4] using the beam-foil technique. The sum of our tabulated $A$-values for the two possible downward transitions from this level, along with our estimated accuracy ratings, yields a value for the lifetime which is smaller than the measured value (incorporating the author's stated error estimate). Thus it is possible that undetected cascading could have led to an underestimate of the uncertainty in the experimental result.

## References


[1]K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables **28**, 355 (1983).
[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Phys. Scr. **15**, 177 (1977).
[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).
[4]P. D. Dumont, H. P. Garnir, Y. Baudinet-Robinet, and M. Kapenyak, J. Opt. Soc. Am. **71**, 502 (1981).


Ti VI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^5-3s3p^6$ | $^2P^o-^2S$ | *513.65* | *1943* | 196628 | 6 | 2 | 26.7 | 0.0352 | 0.357 | −0.68 | C− | 1 |
| | | | 508.575 | 0 | 196628 | 4 | 2 | 18.3 | 0.0355 | 0.238 | −0.85 | C− | 1 |
| | | | 524.113 | 5829 | 196628 | 2 | 2 | 8.4 | 0.0345 | 0.119 | −1.161 | C− | 1 |
| 2. | $3p^5-3p^4(^3P)3d$ | $^2P^o-^4F$ | | | | | | | | | | | |
| | | | [330] | | | 2 | 4 | 0.035 | 1.2(−4)[a] | 2.5(−4) | −3.64 | E | 1 |
| 3. | | $^2P^o-^4P$ | | | | | | | | | | | |
| | | | [322] | | | 2 | 4 | 0.73 | 0.0023 | 0.0048 | −2.34 | E | 1 |
| | | | [316] | | | 4 | 4 | 0.51 | 7.7(−4) | 0.0032 | −2.51 | E | 1 |
| | | | [324] | | | 2 | 2 | 0.12 | 1.9(−4) | 4.1(−4) | −3.42 | E | 1 |
| | | | [319] | | | 4 | 2 | 0.25 | 1.9(−4) | 8.1(−4) | −3.11 | E | 1 |
| 4. | | $^2P^o-^2D$ | *250.47* | *1943* | *401187* | 6 | 10 | 1200 | 1.9 | 9.3 | 1.05 | C− | 1 |
| | | | 250.482 | 0 | 399230 | 4 | 6 | 1200 | 1.7 | 5.6 | 0.83 | C | 1 |
| | | | 251.071 | 5829 | 404122 | 2 | 4 | 1130 | 2.14 | 3.53 | 0.63 | C | 1 |
| | | | 247.450 | 0 | 404122 | 4 | 4 | 70 | 0.064 | 0.21 | −0.59 | D | 1 |
| 5. | $3p^5-3p^4(^1D)3d$ | $^2P^o-^2F$ | | | | | | | | | | | |
| | | | 301.913 | 0 | 331221 | 4 | 6 | 0.18 | 3.8(−4) | 0.0015 | −2.82 | E | 1 |
| 6. | | $^2P^o-^2S$ | *264.60* | *1943* | 379873 | 6 | 2 | 1030 | 0.362 | 1.89 | 0.336 | C− | 1 |
| | | | 263.246 | 0 | 379873 | 4 | 2 | 730 | 0.381 | 1.32 | 0.183 | C− | 1 |
| | | | 267.343 | 5829 | 379873 | 2 | 2 | 300 | 0.32 | 0.57 | −0.19 | C− | 1 |
| 7. | $3p^5-3p^4(^1S)3d$ | $^2P^o-^2D$ | | | | | | | | | | | |
| | | | 282.215 | 0 | 354340 | 4 | 6 | 0.59 | 0.0010 | 0.0039 | −2.38 | E | 1 |
| | | | 288.355 | 5829 | 352624 | 2 | 4 | 2.7 | 0.0068 | 0.013 | −1.86 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti VI

## Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $3p^5$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for mixing among odd-parity configurations was limited to the set $3s^23p^5$, $3s3p^53d$, $3p^53d^2$, and $3s^23p^33d^2$. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables **28**, 355 (1983).

Ti VI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^5$–$3p^5$ | $^2$P° – $^2$P° | | | | | | | | | | |
| | | | [17150] | 0 | 5829 | 4 | 2 | M1 | 3.56 | 1.33 | B | 1 |
| | | | " | " | " | 4 | 2 | E2 | 3.7(−4)[a] | 0.66 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti VII

S Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^4\ ^3P_2$

Ionization Energy: 140.8 eV = 1136000 cm$^{-1}$

## Allowed Transitions

The $A$-value for the single transition tabulated here is the reciprocal of the lifetime of the $3s3p^5\ ^1P_1^\circ$ level as determined by Dumont *et al.*[1] with the beam-foil technique. A few additional downward transitions from this level are possible, but theoretically calculated transition probabilities for these lines in Fe XI[2] indicate that they are weak in comparison to the $3s^23p^4\ ^1D_2 - 3s3p^5\ ^1P_1^\circ$ transition. (The lifetime of the $3s3p^5\ ^3P_2^\circ$ level could not be converted to a single transition probability, since in Fe XI there are two significant downward branches, the weaker of which has an $A$-value which represents approximately one-fourth of the total radiative decay.)

Since Ti VII has such a complex structure, with many possibilities for cascading, and in view of the assumptions made concerning the branching ratio, we have assigned a very conservative accuracy rating to the tabulated $A$-value.

## References


[1]P. D. Dumont, H. P. Garnir, Y. Baudinet-Robinet, and M. Kapenyak, J. Opt. Soc. Am. **71**, 502 (1981).

[2]H. E. Mason, Mon. Not. R. Astron. Soc. **170**, 651 (1975).


Ti VII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^4$–$3s3p^5$ | $^1D$ - $^1P°$ | 440.361 | 24123 | 251209 | 5 | 3 | 33 | 0.058 | 0.42 | −0.54 | D | 1 |

# Ti VII

## Forbidden Transitions

Transition probabilities for magnetic dipole and electric quadrupole lines within the $3p^4$ configuration are the results of the scaled Thomas-Fermi calculations of Mendoza and Zeippen.[1] They included a number of correlation configurations in their basis set and introduced Breit-Pauli relativistic corrections as a perturbation to the nonrelativistic Hamiltonian.

## Reference


[1]C. Mendoza and C. J. Zeippen, Mon. Not. R. Astron. Soc. **202**, 981 (1983).


Ti VII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^4$–$3p^4$ | $^3P$ - $^3P$ | | | | | | | | | | |
| | | | [22050] | 0 | 4533 | 5 | 3 | M1 | 2.06 | 2.46 | C+ | 1 |
| | | | " | " | " | 5 | 3 | E2 | 6.5(−5)[a] | 0.61 | D− | 1 |
| | | | [73840] | 4533 | 5887 | 3 | 1 | M1 | 0.132 | 1.97 | C+ | 1 |
| | | | [16980] | 0 | 5887 | 5 | 1 | E2 | 3.4(−4) | 0.29 | D− | 1 |
| 2. | | $^3P$ - $^1D$ | | | | | | | | | | |
| | | | [4144.3] | 0 | 24123 | 5 | 5 | M1 | 8.3 | 0.11 | D− | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.017 | 0.062 | E | 1 |
| | | | [5103.2] | 4533 | 24123 | 3 | 5 | M1 | 1.5 | 0.037 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 9.0(−4) | 0.0093 | E | 1 |
| | | | [5482.1] | 5887 | 24123 | 1 | 5 | E2 | 2.4(−4) | 0.0035 | E | 1 |
| 3. | | $^3P$ - $^1S$ | | | | | | | | | | |
| | | | [1825.0] | 0 | 54794 | 5 | 1 | E2 | 0.39 | 0.0047 | E | 1 |
| | | | [1989.6] | 4533 | 54794 | 3 | 1 | M1 | 98 | 0.029 | E | 1 |

Ti VII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^1$D - $^1$S | [3259.5] | 24123 | 54794 | 5 | 1 | E2 | 4.9 | 1.1 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti VIII

P Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^3\ ^4S^\circ_{3/2}$

Ionization Energy: 170.4 eV = 1374000 cm$^{-1}$

## Allowed Transitions

Line strengths for transitions of the arrays $3s^23p^3$–$3s3p^4$ and $3p^3$–$3p^23d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to configurations within the $n=3$ complex having no more than two electrons in the $3d$ subshell.

Huang published diagrams of energy levels (designated in *LS* coupling) in the $3s^23p^3$, $3s3p^4$, and $3s^23p^23d$ configurations of Cl III, Ti VIII, and Fe XII, but he has not provided percentage compositions. We have used the percentages given by Bromage *et al.*[2] for Fe XII, and by Bromage[3] for V IX and Ni XIV, as a guide to naming the levels; their values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to a few configurations within the $n=3$ complex. Whenever a term designation of a level in Fe XII, as given in Ref. 1, is different from that indicated in Ref. 2, all transitions involving the corresponding level in Ti VIII are omitted from this compilation. Furthermore, any level indicated by Huang to have changed its energy ranking relative to other levels of the same $J$-value and parity, in proceeding along the isoelectronic sequence from Cl III to Ti VIII, is omitted here, since, unlike the case of V IX through Ni XIV, there are no data available on percentage compositions of these levels in Ti VIII.

Transitions involving levels which are indicated to be of low purity in *LS* coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **30**, 313 (1984).
[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).
[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).

Ti VIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^3$–$3s3p^4$ | $^4$S° - $^4$P | *508.66* | 0 | *196596* | 4 | 12 | 8.5 | 0.099 | 0.66 | −0.40 | D | 1 |
| | | | 514.206 | 0 | 194475 | 4 | 6 | 8.2 | 0.049 | 0.33 | −0.71 | D | 1 |
| | | | 504.801 | 0 | 198098 | 4 | 4 | 8.7 | 0.033 | 0.22 | −0.88 | D | 1 |
| | | | 500.116 | 0 | 199954 | 4 | 2 | 8.9 | 0.017 | 0.11 | −1.18 | D | 1 |
| 2. | | $^2$D° - $^2$D | *479.81* | | | 10 | 10 | 16 | 0.056 | 0.88 | −0.25 | E | 1 |
| | | | 480.376 | | | 6 | 6 | 15 | 0.052 | 0.49 | −0.51 | D | 1 |
| | | | 478.971 | | | 4 | 4 | 17 | 0.057 | 0.36 | −0.64 | D | 1 |
| | | | 481.428 | | | 6 | 4 | 0.73 | 0.0017 | 0.016 | −2.00 | E | 1 |
| | | | [476] | | | 4 | 6 | 0.41 | 0.0021 | 0.013 | −2.08 | E | 1 |

Ti VIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | | $^2P^\circ - ^2D$ | | | | | | | | | | | |
| | | | 538.241 | | | 4 | 6 | 2.8 | 0.018 | 0.13 | −1.13 | D | 1 |
| | | | 535.381 | | | 2 | 4 | 1.7 | 0.014 | 0.051 | −1.54 | D | 1 |
| 4. | $3p^3$-$3p^2(^3P)3d$ | $^4S^\circ - ^4P$ | | | | | | | | | | | |
| | | | 269.533 | 0 | 371012 | 4 | 6 | 600 | 0.99 | 3.5 | 0.60 | D | 1 |
| 5. | | $^2D^\circ - ^4P$ | | | | | | | | | | | |
| | | | [287] | | | 6 | 6 | 3.1 | 0.0039 | 0.022 | −1.63 | E | 1 |
| | | | [286] | | | 4 | 6 | 0.65 | 0.0012 | 0.0045 | −2.32 | E | 1 |
| 6. | | $^2D^\circ - ^2F$ | | | | | | | | | | | |
| | | | 258.610 | | | 6 | 8 | 750 | 1.0 | 5.1 | 0.78 | E | 1 |
| 7. | $3p^3$-$3p^2(^1D)3d$ | $^2D^\circ - ^2D$ | | | | | | | | | | | |
| | | | 272.037 | | | 4 | 4 | 430 | 0.47 | 1.7 | 0.28 | D | 1 |
| | | | 272.843 | | | 6 | 4 | 62 | 0.046 | 0.25 | −0.56 | D | 1 |
| 8. | | $^2D^\circ - ^2P$ | | | | | | | | | | | |
| | | | [249] | | | 6 | 4 | 10 | 0.0065 | 0.032 | −1.41 | E | 1 |
| | | | [249] | | | 4 | 4 | 3.1 | 0.0029 | 0.0095 | −1.94 | E | 1 |
| 9. | | $^2P^\circ - ^2D$ | | | | | | | | | | | |
| | | | 289.375 | | | 2 | 4 | 36 | 0.089 | 0.17 | −0.75 | D | 1 |
| 10. | | $^2P^\circ - ^2P$ | | | | | | | | | | | |
| | | | 277.813 | | | 4 | 4 | 380 | 0.44 | 1.6 | 0.24 | E | 1 |
| | | | 276.701 | | | 2 | 4 | 93 | 0.21 | 0.39 | −0.37 | E | 1 |

## Ti VIII

### Forbidden Transitions

Line strengths for magnetic dipole and electric quadrupole transitions within the $3p^3$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to configurations within the $n=3$ complex having no more than two electrons in the $3d$ subshell. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor $2/3$ which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. We have excluded from this compilation the electric quadrupole contributions to the $^4S^\circ_{3/2} - ^2P^\circ_{3/2}$ and $^4S^\circ_{3/2} - ^2P^\circ_{1/2}$ transitions, since their strengths are very small and thus subject to considerable uncertainty.

Data for these same transitions calculated by Mendoza and Zeippen[2] with the scaled Thomas-Fermi approach with allowance for correlation are generally in very good agreement with the results of Ref. 1. These latter calculations treated relativistic effects by introducing Breit-Pauli corrections as a perturbation to the nonrelativistic Hamiltonian.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **30**, 313 (1984).
[2]C. Mendoza and C. J. Zeippen, Mon. Not. R. Astron. Soc. **198**, 127 (1982).

Ti VIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^3$–$3p^3$ | $^4S°$ – $^2D°$ | | | | | | | | | | |
| | | | [3006] | | | 4 | 6 | M1 | 0.045 | 2.7(−4)[a] | E | 1 |
| | | | " | | | 4 | 6 | E2 | 0.015 | 0.013 | E | 1 |
| | | | [3106] | | | 4 | 4 | M1 | 2.0 | 0.0089 | E | 1 |
| | | | " | | | 4 | 4 | E2 | 0.0083 | 0.0057 | E | 1 |
| 2. | | $^4S°$ – $^2P°$ | | | | | | | | | | |
| | | | [1798] | | | 4 | 4 | M1 | 39 | 0.034 | D | 1 |
| | | | [1845] | | | 4 | 2 | M1 | 18 | 0.0082 | E | 1 |
| 3. | | $^2D°$ – $^2D°$ | | | | | | | | | | |
| | | | [93780] | | | 4 | 6 | M1 | 0.0125 | 2.29 | C+ | 1 |
| | | | " | | | 4 | 6 | E2 | 3.7(−9) | 0.096 | E | 1 |
| 4. | | $^2D°$ – $^2P°$ | | | | | | | | | | |
| | | | [4776.0] | | | 6 | 2 | E2 | 0.21 | 0.61 | D− | 1 |
| | | | [4467.0] | | | 6 | 4 | M1 | 8.3 | 0.11 | C | 1 |
| | | | " | | | 6 | 4 | E2 | 0.47 | 2.0 | D− | 1 |
| | | | [4544.6] | | | 4 | 2 | M1 | 8.9 | 0.062 | D | 1 |
| | | | " | | | 4 | 2 | E2 | 0.38 | 0.88 | D− | 1 |
| | | | [4264.3] | | | 4 | 4 | M1 | 17 | 0.20 | C | 1 |
| | | | " | | | 4 | 4 | E2 | 0.22 | 0.74 | D− | 1 |
| 5. | | $^2P°$ – $^2P°$ | | | | | | | | | | |
| | | | [69230] | | | 2 | 4 | M1 | 0.0256 | 1.26 | C+ | 1 |
| | | | " | | | 2 | 4 | E2 | 8.7(−9) | 0.033 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti IX

Si Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^2\ ^3P_0$

Ionization Energy: 192.1 eV = 1549000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 242.82 | 7 | 296.28 | 9 | 439.745 | 2 | 516.215 | 1 |
| 253.49 | 6 | 324 | 3 | 447.484 | 2 | 518.100 | 1 |
| 267.941 | 10 | 354 | 8 | 447.701 | 2 | 518.33 | 1 |
| 278.713 | 5 | 433.567 | 2 | 499.479 | 1 | | |
| 281.446 | 4 | 439.302 | 2 | 507.174 | 1 | | |
| 285.128 | 11 | 439.513 | 2 | 507.38 | 1 | | |

Line strengths for transitions of the arrays $3s^23p^2$–$3s3p^3$ and $3p^2$–$3p3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published diagrams of energy levels (designated in *LS* coupling) in the $3s^23p^2$, $3s3p^3$, and $3s^23p3d$ configurations of siliconlike S, Ar, Ti, Fe, and Zn, but he has not provided percentage compositions. We have used the percentages given by Bromage *et al.*[2] for Fe XIII, and by Bromage[3] for V X and Ni XV, as a guide to naming the levels; their values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to a partial set of configurations within the $n=3$ complex. Whenever the term designation of a level in Fe XIII, as given in Ref. 1, is different from that indicated in Ref. 2, all transitions involving the corresponding level in Ti IX are omitted from this compilation. Furthermore, any level indicated by Huang to have changed its energy ranking relative to other levels of the same $J$-value and parity, in proceeding along the isoelectronic sequence from S III to Ti IX, is omitted here, since, unlike the case of V X through Ni XV, there are no data available on percentage compositions of these levels in Ti IX.

Transitions involving levels which are indicated to be of low purity in *LS* coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded.

## References


[1] K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985).

[2] G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).

[3] G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).


Ti IX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^2$–$3s3p^3$ | $^3$P – $^3$D° | *511.45* | *5085* | *200606* | 9 | 15 | 7.2 | 0.047 | 0.71 | −0.38 | D− | 1 |
| | | | 516.215 | 7281 | 200999 | 5 | 7 | 6.9 | 0.039 | 0.33 | −0.71 | D | 1 |
| | | | 507.174 | 3120 | 200294 | 3 | 5 | 6.5 | 0.042 | 0.21 | −0.90 | D | 1 |
| | | | 499.479 | 0 | 200209 | 1 | 3 | 5.2 | 0.058 | 0.096 | −1.23 | D | 1 |
| | | | 518.100 | 7281 | 200294 | 5 | 5 | 0.79 | 0.0032 | 0.027 | −1.80 | D− | 1 |
| | | | [507.38] | 3120 | 200209 | 3 | 3 | 2.4 | 0.0092 | 0.046 | −1.56 | D− | 1 |
| | | | [518.33] | 7281 | 200209 | 5 | 3 | 0.073 | 1.8(−4)[a] | 0.0015 | −3.06 | E | 1 |
| 2. | | $^3$P – $^3$P° | *443.25* | *5085* | *230691* | 9 | 9 | 20 | 0.060 | 0.79 | −0.27 | D | 1 |
| | | | 447.484 | 7281 | 230753 | 5 | 5 | 16 | 0.049 | 0.36 | −0.61 | D | 1 |
| | | | 439.513 | 3120 | 230644 | 3 | 3 | 7.5 | 0.022 | 0.094 | −1.19 | D | 1 |
| | | | 447.701 | 7281 | 230644 | 5 | 3 | 6.5 | 0.012 | 0.087 | −1.23 | D | 1 |
| | | | 439.745 | 3120 | 230525 | 3 | 1 | 21 | 0.020 | 0.089 | −1.21 | C− | 1 |
| | | | 439.302 | 3120 | 230753 | 3 | 5 | 3.6 | 0.017 | 0.075 | −1.29 | D | 1 |
| | | | 433.567 | 0 | 230644 | 1 | 3 | 6.9 | 0.058 | 0.083 | −1.24 | D | 1 |
| 3. | $3p^2$–$3p3d$ | $^3$P – $^3$F° | | | | | | | | | | | |
| | | | [324] | | | 5 | 7 | 0.50 | 0.0011 | 0.0059 | −2.26 | E | 1 |
| 4. | | $^3$P – $^3$P° | | | | | | | | | | | |
| | | | 281.446 | 3120 | 358428 | 3 | 1 | 320 | 0.13 | 0.35 | −0.42 | D | 1 |
| 5. | | $^3$P – $^3$D° | | | | | | | | | | | |
| | | | 278.713 | 7281 | 366073 | 5 | 7 | 470 | 0.76 | 3.5 | 0.58 | D | 1 |
| 6. | | $^3$P – $^1$F° | | | | | | | | | | | |
| | | | [253.49] | 7281 | 401770 | 5 | 7 | 5.3 | 0.0072 | 0.030 | −1.44 | E | 1 |
| 7. | | $^3$P – $^1$P° | | | | | | | | | | | |
| | | | [242.82] | 0 | 411831 | 1 | 3 | 1.4 | 0.0036 | 0.0029 | −2.44 | E | 1 |

Ti IX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^1$D - $^3$F° | | | | | | | | | | | |
| | | | [354] | | | 5 | 5 | 0.65 | 0.0012 | 0.0071 | −2.22 | E | 1 |
| 9. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [296.28] | 28554 | 366073 | 5 | 7 | 4.0 | 0.0074 | 0.036 | −1.43 | E | 1 |
| 10. | | $^1$D - $^1$F° | 267.941 | 28554 | 401770 | 5 | 7 | 510 | 0.76 | 3.37 | 0.58 | C | 1 |
| 11. | | $^1$S - $^1$P° | 285.128 | 61111 | 411831 | 1 | 3 | 410 | 1.5 | 1.4 | 0.17 | D | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti IX

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 605.79 | 11 | 1857.7 | 3 | 3306.9 | 8 | 32040 | 1 |
| 632.38 | 10 | 3070.6 | 4 | 3359.9 | 8 | 127000 | 7 |
| 840 | 9 | 3273.0 | 8 | 3372.3 | 8 | 142000 | 7 |
| 860 | 9 | 3282.2 | 8 | 3930.6 | 2 | 1200000 | 7 |
| 1100 | 6 | 3284.7 | 8 | 4699.5 | 2 | | |
| 1700 | 5 | 3293.9 | 8 | 13730 | 1 | | |
| 1724.4 | 3 | 3297.6 | 8 | 24030 | 1 | | |

Line strengths for magnetic dipole and electric quadrupole transitions are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration interaction encompassed all configurations within the $n=3$ complex. Huang calculated line strengths for transitions within the $3p^2$ configuration, as well as for transitions between pairs of odd-parity levels whose lower level is one of the four lowest-lying odd-parity levels in the $n=3$ complex. Transitions involving odd-parity levels which are indicated by Bromage *et al.*[2] (for Fe XIII) or Bromage[3] (for V X and Ni XV) to be of low purity in *LS* coupling in Fe-group species are omitted here, as are lines whose strengths are very small. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985) and private communication.
[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).
[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).

Ti IX: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^2$–$3p^2$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | [24030] | 3120 | 7281 | 3 | 5 | M1 | 0.952 | 2.45 | C+ | 1 |
| | | | " | " | " | 3 | 5 | E2 | 2.0(−5)[a] | 0.48 | D− | 1 |
| | | | [32040] | 0 | 3120 | 1 | 3 | M1 | 0.539 | 1.97 | C+ | 1 |
| | | | [13730] | 0 | 7281 | 1 | 5 | E2 | 1.6(−4) | 0.23 | D− | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [4699.5] | 7281 | 28554 | 5 | 5 | M1 | 7.8 | 0.15 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.010 | 0.070 | E | 1 |
| | | | [3930.6] | 3120 | 28554 | 3 | 5 | M1 | 4.5 | 0.051 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.0035 | 0.0099 | E | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [1857.7] | 7281 | 61111 | 5 | 1 | E2 | 0.55 | 0.0072 | E | 1 |
| | | | [1724.4] | 3120 | 61111 | 3 | 1 | M1 | 120 | 0.022 | E | 1 |
| 4. | | $^1$D - $^1$S | [3070.6] | 28554 | 61111 | 5 | 1 | E2 | 5.7 | 0.93 | D− | 1 |
| 5. | $3s3p^3$–$3s3p^3$ | $^5$S° - $^3$D° | | | | | | | | | | |
| | | | [1700] | | | 5 | 7 | E2 | 0.081 | 0.0048 | E | 1 |
| | | | [1700] | | | 5 | 5 | M1 | 1.3 | 0.0012 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.076 | 0.0032 | E | 1 |
| 6. | | $^5$S° - $^3$P° | | | | | | | | | | |
| | | | [1100] | | | 5 | 5 | M1 | 77 | 0.019 | E | 1 |
| | | | [1100] | | | 5 | 3 | M1 | 43 | 0.0063 | E | 1 |
| 7. | | $^3$D° - $^3$D° | | | | | | | | | | |
| | | | [142000] | 200294 | 200999 | 5 | 7 | M1 | 0.0062 | 4.6 | D+ | 1 |
| | | | " | " | " | 5 | 7 | E2 | 2.0(−10) | 0.048 | E | 1 |
| | | | [1200000] | 200209 | 200294 | 3 | 5 | M1 | 1.4(−5) | 4.5 | E | 1 |
| | | | [127000] | 200209 | 200999 | 3 | 7 | E2 | 8.0(−11) | 0.011 | E | 1 |
| 8. | | $^3$D° - $^3$P° | | | | | | | | | | |
| | | | [3372.3] | 200999 | 230644 | 7 | 3 | E2 | 1.2 | 0.94 | D− | 1 |
| | | | [3306.9] | 200294 | 230525 | 5 | 1 | E2 | 2.8 | 0.65 | D− | 1 |
| | | | [3359.9] | 200999 | 230753 | 7 | 5 | M1 | 11 | 0.075 | E | 1 |
| | | | " | " | " | 7 | 5 | E2 | 1.4 | 1.8 | D− | 1 |
| | | | [3293.9] | 200294 | 230644 | 5 | 3 | E2 | 0.22 | 0.15 | D− | 1 |
| | | | [3297.6] | 200209 | 230525 | 3 | 1 | M1 | 13 | 0.017 | E | 1 |
| | | | [3282.2] | 200294 | 230753 | 5 | 5 | M1 | 7.3 | 0.048 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.97 | 1.1 | D− | 1 |
| | | | [3284.7] | 200209 | 230644 | 3 | 3 | M1 | 12 | 0.049 | E | 1 |
| | | | " | " | " | 3 | 3 | E2 | 1.3 | 0.87 | D− | 1 |
| | | | [3273.0] | 200209 | 230753 | 3 | 5 | M1 | 2.5 | 0.016 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.29 | 0.32 | D− | 1 |
| 9. | $3s3p^3$–$3s^23p3d$ | $^3$D° - $^3$F° | | | | | | | | | | |
| | | | [840] | | | 5 | 9 | E2 | 3.0 | 0.0068 | E | 1 |
| | | | [860] | | | 3 | 7 | E2 | 1.5 | 0.0030 | E | 1 |
| | | | [840] | | | 7 | 9 | M1 | 340 | 0.067 | E | 1 |

Ti IX: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | | $^3$D° - $^3$P° | | | | | | | | | | |
| | | | [632.38] | 200294 | 358428 | 5 | 1 | E2 | 150 | 0.0091 | E | 1 |
| 11. | | $^3$D° - $^3$D° | | | | | | | | | | |
| | | | [605.79] | 200999 | 366073 | 7 | 7 | M1 | 31 | 0.0018 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti X

Al Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p$ $^2$P$^\circ_{1/2}$

Ionization Energy: 215.92 eV = 1741500 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 232 | 20 | 296.05 | 15 | 355.815 | 3 | 471.574 | 1 |
| 245 | 27 | 297 | 23 | 360.133 | 3 | 478 | 6 |
| 253 | 26 | 298 | 23,29,30 | 363 | 13,14 | 479 | 6,10 |
| 254 | 26 | 300 | 17 | 365.628 | 3 | 481 | 6 |
| 259 | 19 | 302 | 24 | 378.135 | 2 | 482 | 6 |
| 281 | 28 | 305 | 24 | 379.74 | 4 | 487.654 | 1 |
| 289 | 17 | 317 | 25 | 382 | 12 | 488.971 | 1 |
| 289.579 | 15 | 321 | 25 | 383 | 12 | 491 | 8 |
| 290.294 | 18 | 322 | 25 | 383.93 | 4 | 492 | 10 |
| 291 | 17,18 | 325 | 25 | 385 | 12 | 493 | 8,10 |
| 292 | 23 | 326 | 5 | 389.237 | 2 | 535 | 9 |
| 293.684 | 18 | 329 | 5 | 389.99 | 4 | 537 | 9 |
| 293.798 | 18 | 333 | 16 | 391 | 7 | 547 | 9 |
| 294 | 18,30 | 338 | 22 | 392 | 7 | 549 | 9 |
| 295.584 | 15 | 345 | 21 | 404 | 11 | | |
| 296 | 17 | 350.610 | 3 | 405 | 11 | | |

Line strengths for transitions of the arrays $3s^23p$–$3s3p^2$, $3s3p^2$–$3p^3$, $3s^23d$–$3s3p3d$, $3s^23p$–$3s^23d$, and $3s3p^2$–$3s3p3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published two diagrams of energy levels (designated in $LS$ coupling) in the $3s^23p$, $3s3p^2$, $3s^23d$, $3p^3$, and $3s3p3d$ configurations of Ti X, but he has not provided percentage compositions. We have used the percentages given by Fawcett[2] as a guide to naming the levels; the latter's values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to all configurations within the $n=3$ complex.

Transitions involving levels which are indicated to be of low purity in $LS$ coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded. A few wavelengths computed by Huang differ significantly from those which resulted from the fitting and scaling procedure applied by Fawcett;[2] whose lines for which the wavelengths are in serious disagreement have been omitted.

## References

[1]K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986) and private communication.
[2]B. C. Fawcett, At. Data Nucl. Data Tables **28**, 557 (1983).

Ti x: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p-3s3p^2$ | $^2P^\circ - ^2D$ | *482.26* | *5030* | *212387* | 6 | 10 | 11 | 0.065 | 0.62 | −0.41 | E | 1 |
| | | | 487.654 | 7545 | 212608 | 4 | 6 | 11 | 0.058 | 0.37 | −0.64 | D | 1 |
| | | | 471.574 | 0 | 212056 | 2 | 4 | 11 | 0.074 | 0.23 | −0.83 | D | 1 |
| | | | 488.971 | 7545 | 212056 | 4 | 4 | 0.95 | 0.0034 | 0.022 | −1.86 | E | 1 |
| 2. | | $^2P^\circ - ^2S$ | *385.47* | *5030* | 264456 | 6 | 2 | 94 | 0.070 | 0.53 | −0.38 | D | 1 |
| | | | 389.237 | 7545 | 264456 | 4 | 2 | 27 | 0.031 | 0.16 | −0.90 | D | 1 |
| | | | 378.135 | 0 | 264456 | 2 | 2 | 69 | 0.15 | 0.37 | −0.53 | D | 1 |
| 3. | | $^2P^\circ - ^2P$ | *358.69* | *5030* | *283826* | 6 | 6 | 260 | 0.51 | 3.6 | 0.48 | D | 1 |
| | | | 360.133 | 7545 | 285217 | 4 | 4 | 219 | 0.426 | 2.02 | 0.231 | C− | 1 |
| | | | 355.815 | 0 | 281045 | 2 | 2 | 130 | 0.26 | 0.60 | −0.29 | D | 1 |
| | | | 365.628 | 7545 | 281045 | 4 | 2 | 120 | 0.12 | 0.57 | −0.32 | D | 1 |
| | | | 350.610 | 0 | 285217 | 2 | 4 | 46.8 | 0.172 | 0.398 | −0.462 | C− | 1 |
| 4. | $3s3p^2-3p^3$ | $^4P - ^4S^\circ$ | *386.22* | | | 12 | 4 | 230 | 0.17 | 2.6 | 0.31 | D | 1 |
| | | | 389.99 | | | 6 | 4 | 110 | 0.17 | 1.3 | 0.01 | D | 1 |
| | | | 383.93 | | | 4 | 4 | 79 | 0.17 | 0.88 | −0.16 | D | 1 |
| | | | 379.74 | | | 2 | 4 | 41 | 0.18 | 0.44 | −0.45 | D | 1 |
| 5. | | $^4P - ^2P^\circ$ | | | | | | | | | | | |
| | | | [329] | | | 4 | 4 | 0.98 | 0.0016 | 0.0069 | −2.20 | E | 1 |
| | | | [326] | | | 2 | 4 | 0.41 | 0.0013 | 0.0028 | −2.58 | E | 1 |
| 6. | | $^2D - ^2D^\circ$ | *480* | | | 10 | 10 | 20 | 0.070 | 1.1 | −0.16 | E | 1 |
| | | | [479] | | | 6 | 6 | 19 | 0.067 | 0.63 | −0.40 | E | 1 |
| | | | [481] | | | 4 | 4 | 16 | 0.057 | 0.36 | −0.64 | E | 1 |
| | | | [482] | | | 6 | 4 | 4.1 | 0.0095 | 0.090 | −1.25 | E | 1 |
| | | | [478] | | | 4 | 6 | 1.7 | 0.0086 | 0.054 | −1.46 | E | 1 |
| 7. | | $^2D - ^2P^\circ$ | *392* | | | 10 | 6 | 78 | 0.11 | 1.4 | 0.04 | D | 1 |
| | | | [392] | | | 6 | 4 | 68 | 0.10 | 0.81 | −0.20 | D | 1 |
| | | | [392] | | | 4 | 2 | 82 | 0.095 | 0.49 | −0.42 | D | 1 |
| | | | [391] | | | 4 | 4 | 8.3 | 0.019 | 0.098 | −1.12 | D | 1 |
| 8. | | $^2S - ^2P^\circ$ | *492* | | | 2 | 6 | 9.1 | 0.099 | 0.32 | −0.70 | D | 1 |
| | | | [491] | | | 2 | 4 | 12 | 0.084 | 0.27 | −0.78 | D | 1 |
| | | | [493] | | | 2 | 2 | 4.2 | 0.015 | 0.050 | −1.51 | D | 1 |
| 9. | | $^2P - ^2P^\circ$ | *544* | | | 6 | 6 | 19 | 0.084 | 0.90 | −0.30 | E | 1 |
| | | | [547] | | | 4 | 4 | 16 | 0.072 | 0.52 | −0.54 | D | 1 |
| | | | [537] | | | 2 | 2 | 18 | 0.076 | 0.27 | −0.82 | D | 1 |
| | | | [549] | | | 4 | 2 | 5.2 | 0.012 | 0.085 | −1.33 | D | 1 |
| | | | [535] | | | 2 | 4 | 0.69 | 0.0060 | 0.021 | −1.92 | E | 1 |

Ti x: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | $3s^23d$–$3s3p(^3P^\circ)3d$ | $^2D$ – $^2F^\circ$ | *485* | | | 10 | 14 | 14 | 0.069 | 1.1 | −0.16 | E | 1 |
| | | | [479] | | | 6 | 8 | 15 | 0.067 | 0.63 | −0.40 | E | 1 |
| | | | [492] | | | 4 | 6 | 11 | 0.060 | 0.39 | −0.62 | E | 1 |
| | | | [493] | | | 6 | 6 | 1.5 | 0.0056 | 0.055 | −1.47 | E | 1 |
| 11. | | $^2D$ – $^2P^\circ$ | | | | | | | | | | | |
| | | | [405] | | | 6 | 4 | 0.84 | 0.0014 | 0.011 | −2.08 | E | 1 |
| | | | [404] | | | 4 | 4 | 1.0 | 0.0024 | 0.013 | −2.01 | E | 1 |
| 12. | $3s^23d$–$3s3p(^1P^\circ)3d$ | $^2D$ – $^2F^\circ$ | *384* | | | 10 | 14 | 180 | 0.57 | 7.2 | 0.76 | E | 1 |
| | | | [385] | | | 6 | 8 | 180 | 0.54 | 4.1 | 0.51 | E | 1 |
| | | | [382] | | | 4 | 6 | 180 | 0.58 | 2.9 | 0.36 | E | 1 |
| | | | [383] | | | 6 | 6 | 9.6 | 0.021 | 0.16 | −0.90 | E | 1 |
| 13. | | $^2D$ – $^2D^\circ$ | | | | | | | | | | | |
| | | | [363] | | | 6 | 6 | 130 | 0.26 | 1.9 | 0.20 | E | 1 |
| | | | [363] | | | 4 | 6 | 5.4 | 0.016 | 0.077 | −1.19 | E | 1 |
| 14. | | $^2D$ – $^2P^\circ$ | | | | | | | | | | | |
| | | | [363] | | | 4 | 2 | 210 | 0.21 | 1.0 | −0.08 | D | 1 |
| 15. | $3p$–$3d$ | $^2P^\circ$ – $^2D$ | *293.59* | *5030* | *345646* | 6 | 10 | 300 | 0.64 | 3.7 | 0.58 | D | 1 |
| | | | 295.584 | 7545 | 345858 | 4 | 6 | 290 | 0.57 | 2.2 | 0.35 | D | 1 |
| | | | 289.579 | 0 | 345329 | 2 | 4 | 250 | 0.63 | 1.2 | 0.10 | D | 1 |
| | | | [296.05] | 7545 | 345329 | 4 | 4 | 53 | 0.069 | 0.27 | −0.56 | D | 1 |
| 16. | $3s3p^2$–$3s3p(^3P^\circ)3d$ | $^4P$ – $^4F^\circ$ | | | | | | | | | | | |
| | | | [333] | | | 6 | 8 | 0.51 | 0.0011 | 0.0075 | −2.16 | E | 1 |
| 17. | | $^4P$ – $^4P^\circ$ | | | | | | | | | | | |
| | | | [300] | | | 6 | 6 | 41 | 0.056 | 0.33 | −0.48 | D | 1 |
| | | | [289] | | | 2 | 2 | 76 | 0.095 | 0.18 | −0.72 | E | 1 |
| | | | [291] | | | 4 | 2 | 180 | 0.11 | 0.44 | −0.34 | E | 1 |
| | | | [296] | | | 4 | 6 | 140 | 0.28 | 1.1 | 0.05 | D | 1 |
| 18. | | $^4P$ – $^4D^\circ$ | | | | | | | | | | | |
| | | | 293.684 | | | 6 | 8 | 297 | 0.51 | 2.97 | 0.487 | C− | 1 |
| | | | 290.294 | | | 4 | 6 | 110 | 0.21 | 0.82 | −0.07 | D | 1 |
| | | | 293.798 | | | 6 | 6 | 170 | 0.22 | 1.3 | 0.13 | D | 1 |
| | | | [291] | | | 2 | 2 | 230 | 0.29 | 0.55 | −0.24 | E | 1 |
| | | | [294] | | | 4 | 2 | 16 | 0.010 | 0.040 | −1.38 | E | 1 |
| 19. | | $^4P$ – $^2F^\circ$ | | | | | | | | | | | |
| | | | [259] | | | 6 | 8 | 0.82 | 0.0011 | 0.0056 | −2.18 | E | 1 |
| 20. | | $^4P$ – $^2P^\circ$ | | | | | | | | | | | |
| | | | [232] | | | 2 | 4 | 0.73 | 0.0012 | 0.0018 | −2.63 | E | 1 |

Ti x: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21. | | $^2D - ^4P^o$ | | | | | | | | | | | |
| | | | [345] | | | 6 | 6 | 2.1 | 0.0038 | 0.026 | −1.64 | E | 1 |
| 22. | | $^2D - ^4D^o$ | | | | | | | | | | | |
| | | | [338] | | | 6 | 8 | 0.65 | 0.0015 | 0.0099 | −2.05 | E | 1 |
| 23. | | $^2D - ^2F^o$ | *294* | | | 10 | 14 | 110 | 0.21 | 2.0 | 0.32 | E | 1 |
| | | | [292] | | | 6 | 8 | 110 | 0.19 | 1.1 | 0.06 | E | 1 |
| | | | [297] | | | 4 | 6 | 99 | 0.20 | 0.77 | −0.10 | E | 1 |
| | | | [298] | | | 6 | 6 | 12 | 0.016 | 0.093 | −1.02 | E | 1 |
| 24. | | $^2S - ^2P^o$ | *304* | | | 2 | 6 | 220 | 0.90 | 1.8 | 0.25 | D | 1 |
| | | | [305] | | | 2 | 4 | 250 | 0.70 | 1.4 | 0.14 | D | 1 |
| | | | [302] | | | 2 | 2 | 160 | 0.22 | 0.44 | −0.35 | D | 1 |
| 25. | | $^2P - ^2P^o$ | *322* | | | 6 | 6 | 120 | 0.19 | 1.2 | 0.05 | D | 1 |
| | | | [325] | | | 4 | 4 | 87 | 0.14 | 0.59 | −0.26 | D | 1 |
| | | | [317] | | | 2 | 2 | 150 | 0.22 | 0.46 | −0.36 | D | 1 |
| | | | [322] | | | 4 | 2 | 36 | 0.028 | 0.12 | −0.95 | D | 1 |
| | | | [321] | | | 2 | 4 | 11 | 0.033 | 0.069 | −1.19 | D | 1 |
| 26. | $3s3p^2$– $3s3p(^1P^o)3d$ | $^2D - ^2F^o$ | *254* | | | 10 | 14 | 230 | 0.31 | 2.6 | 0.49 | E | 1 |
| | | | [254] | | | 6 | 8 | 230 | 0.30 | 1.5 | 0.25 | E | 1 |
| | | | [253] | | | 4 | 6 | 210 | 0.30 | 1.0 | 0.08 | E | 1 |
| | | | [254] | | | 6 | 6 | 13 | 0.013 | 0.064 | −1.12 | E | 1 |
| 27. | | $^2D - ^2P^o$ | | | | | | | | | | | |
| | | | [245] | | | 4 | 2 | 1.9 | 8.4(−4)[a] | 0.0027 | −2.48 | E | 1 |
| 28. | | $^2S - ^2P^o$ | | | | | | | | | | | |
| | | | [281] | | | 2 | 2 | 110 | 0.14 | 0.25 | −0.57 | D | 1 |
| 29. | | $^2P - ^2D^o$ | | | | | | | | | | | |
| | | | [298] | | | 4 | 6 | 430 | 0.87 | 3.4 | 0.54 | E | 1 |
| 30. | | $^2P - ^2P^o$ | | | | | | | | | | | |
| | | | [294] | | | 2 | 2 | 72 | 0.093 | 0.18 | −0.73 | D | 1 |
| | | | [298] | | | 4 | 2 | 59 | 0.0395 | 0.155 | −0.80 | C− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti X

## Forbidden Transitions

Line strengths for magnetic dipole and electric quadrupole transitions within the $3s^23p$ $^2P°$ and $3s3p^2$ $^4P$ terms are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986).

Ti X: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p$–$3p$ | $^2P°$ - $^2P°$ | | | | | | | | | | |
| | | | [13250] | 0 | 7545 | 2 | 4 | M1 | 3.86 | 1.33 | C+ | 1 |
| | | | " | " | " | 2 | 4 | E2 | 4.2(−4)[a] | 0.41 | D− | 1 |
| 2. | $3s3p^2$–$3s3p^2$ | $^4P$ - $^4P$ | | | | | | | | | | |
| | | | [24700] | | | 4 | 6 | M1 | 1.07 | 3.59 | C | 1 |
| | | | " | | | 4 | 6 | E2 | 1.9(−5) | 0.64 | D− | 1 |
| | | | [34700] | | | 2 | 4 | M1 | 0.54 | 3.32 | C | 1 |
| | | | " | | | 2 | 4 | E2 | 4.3(−7) | 0.052 | E | 1 |
| | | | [14400] | | | 2 | 6 | E2 | 2.1(−4) | 0.46 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XI

Mg Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^2$ $^1S_0$

Ionization Energy: 265.07 eV = 2137900 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 65.403 | 13 | 318 | 19 | 417.85 | 3 | 522.66 | 6 |
| 87.725 | 12 | 322.75 | 20 | 419.45 | 3 | 533.55 | 6 |
| 261 | 18 | 323 | 21 | 425.74 | 3 | 535.0 | 6 |
| 266 | 17 | 327.192 | 15 | 429.60 | 3 | 543.23 | 6 |
| 306.144 | 14 | 332 | 23 | 434.0 | 8 | 544.1 | 6 |
| 308.250 | 14 | 349.91 | 16 | 434.94 | 8 | 545.6 | 6 |
| 308.568 | 14 | 386.140 | 2 | 439 | 7 | 569.3 | 1 |
| 313.229 | 14 | 408 | 22 | 440 | 11 | 667.12 | 4 |
| 313.710 | 14 | 408.28 | 3 | 446.69 | 5 | 768.88 | 9 |
| 314.0 | 14 | 415.07 | 3 | 453 | 10 | | |

Oscillator strengths for the three transitions $3s^2\ ^1S_0 - 3snp\ ^1P_1^\circ$ ($n = 3$–$5$) and the intercombination transition $3s^2\ ^1S_0 - 3s3p\ ^3P_1^\circ$ are the results of the relativistic random phase approximation (RRPA) calculations of Shorer *et al.*,[1] who allowed for correlation within the context of a frozen core. Oscillator strength data of Fawcett,[2] quoted for transitions of the arrays $3s3p$–$3p^2$, $3s3d$–$3p3d$, $3s3p$–$3s3d$, and $3p^2$–$3p3d$ were derived by means of Hartree-Fock calculations which included relativistic effects and statistical allowance for exchange (HXR); he incorporated correlation effects due to all configurations in the $n = 3$ complex. Froese Fischer and Godefroid[3] determined $f$-values for singlet–singlet transitions within the complex by applying a nonrelativistic multiconfiguration Hartree-Fock (MCHF) technique with large-scale allowance for configuration interaction; their results are quoted for two transitions of the $3p3d$-$3d^2$ array for which we estimate the contribution of singlet–triplet mixing to the $f$-value to be insignificant.

Transitions involving levels which are indicated in Ref. 2 to be of low purity in $LS$ coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings.

## References


[1]P. Shorer, C. D. Lin, and W. R. Johnson, Phys. Rev. A **16**, 1109 (1977).

[2]B. C. Fawcett, At. Data Nucl. Data Tables **28**, 579 (1983).

[3]C. Froese Fischer and M. Godefroid, Nucl. Instrum. Methods **202**, 307 (1982).


Ti XI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm⁻¹) | $E_k$ (cm⁻¹) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s⁻¹) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^2$–$3s3p$ | $^1S - ^3P^\circ$ | | | | | | | | | | | |
| | | | 569.3 | 0 | 175700 | 1 | 3 | 0.089 | 0.0013 | 0.0024 | −2.89 | E | 1 |
| 2. | | $^1S - ^1P^\circ$ | 386.140 | 0 | 258973 | 1 | 3 | 148 | 0.995 | 1.26 | −0.002 | B | 1 |
| 3. | $3s3p$–$3p^2$ | $^3P^\circ - ^3P$ | *418.8* | *178500* | *417300* | 9 | 9 | 118 | 0.311 | 3.86 | 0.447 | C− | 2 |
| | | | 417.85 | 181300 | 420600 | 5 | 5 | 86 | 0.224 | 1.54 | 0.049 | C− | 2 |
| | | | 419.45 | 175700 | 414100 | 3 | 3 | 31 | 0.083 | 0.34 | −0.60 | C | 2 |
| | | | 429.60 | 181300 | 414100 | 5 | 3 | 49 | 0.082 | 0.58 | −0.39 | C | 2 |
| | | | 425.74 | 175700 | 410600 | 3 | 1 | 120 | 0.11 | 0.46 | −0.48 | C | 2 |
| | | | 408.28 | 175700 | 420600 | 3 | 5 | 29 | 0.12 | 0.48 | −0.44 | C− | 2 |
| | | | 415.07 | 173200 | 414100 | 1 | 3 | 44 | 0.34 | 0.46 | −0.47 | C | 2 |
| 4. | | $^1P^\circ - ^1D$ | 667.12 | 258973 | 408870 | 3 | 5 | 9.9 | 0.11 | 0.72 | −0.48 | D | 2 |
| 5. | | $^1P^\circ - ^1S$ | 446.69 | 258973 | 482840 | 3 | 1 | 120 | 0.12 | 0.53 | −0.44 | C | 2 |
| 6. | $3s3d$–$3p3d$ | $^3D - ^3F^\circ$ | *531.3* | *500300* | *688500* | 15 | 21 | 33 | 0.19 | 5.1 | 0.46 | D | 2 |
| | | | 522.66 | 500600 | 691900 | 7 | 9 | 35.3 | 0.186 | 2.24 | 0.115 | C | 2 |
| | | | 533.55 | 500100 | 687500 | 5 | 7 | 28 | 0.17 | 1.5 | −0.07 | C | 2 |
| | | | 543.23 | 499800 | 683900 | 3 | 5 | 23 | 0.17 | 0.91 | −0.29 | D | 2 |
| | | | [535.0] | 500600 | 687500 | 7 | 7 | 4.9 | 0.021 | 0.26 | −0.83 | C | 2 |
| | | | [544.1] | 500100 | 683900 | 5 | 5 | 5.4 | 0.024 | 0.21 | −0.92 | D | 2 |
| | | | [545.6] | 500600 | 683900 | 7 | 5 | 0.12 | 3.9(−4)[a] | 0.0049 | −2.56 | E | 2 |
| 7. | | $^3D - ^3P^\circ$ | | | | | | | | | | | |
| | | | [439] | | | 3 | 1 | 70 | 0.067 | 0.29 | −0.70 | C | 2 |
| 8. | | $^3D - ^3D^\circ$ | | | | | | | | | | | |
| | | | 434.94 | 500600 | 730500 | 7 | 7 | 51 | 0.146 | 1.46 | 0.009 | C | 2 |
| | | | [434.0] | 500100 | 730500 | 5 | 7 | 9.1 | 0.036 | 0.26 | −0.74 | C | 2 |
| 9. | | $^1D - ^1D^\circ$ | [768.88] | 564604 | 694660 | 5 | 5 | 4.5 | 0.040 | 0.51 | −0.70 | D | 2 |
| 10. | | $^1D - ^1F^\circ$ | [453] | | | 5 | 7 | 130 | 0.54 | 4.0 | 0.43 | D | 2 |
| 11. | | $^1D - ^1P^\circ$ | [440] | | | 5 | 3 | 86 | 0.15 | 1.1 | −0.12 | D | 2 |

Ti XI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | $3s^2$–$3s4p$ | $^1$S - $^1$P° | 87.725 | 0 | 1139900 | 1 | 3 | 850 | 0.294 | 0.085 | −0.53 | C | 1 |
| 13. | $3s^2$–$3s5p$ | $^1$S - $^1$P° | 65.403 | 0 | 1529000 | 1 | 3 | 510 | 0.099 | 0.021 | −1.00 | C | 1 |
| 14. | $3s3p$–$3s3d$ | $^3$P° - $^3$D | *310.8* | *178500* | *500300* | 9 | 15 | 163 | 0.394 | 3.63 | 0.55 | C | 2 |
| | | | 313.229 | 181300 | 500600 | 5 | 7 | 160 | 0.330 | 1.70 | 0.217 | C | 2 |
| | | | 308.250 | 175700 | 500100 | 3 | 5 | 130 | 0.30 | 0.91 | −0.05 | C | 2 |
| | | | 306.144 | 173200 | 499800 | 1 | 3 | 95 | 0.40 | 0.40 | −0.40 | C | 2 |
| | | | 313.710 | 181300 | 500100 | 5 | 5 | 39 | 0.058 | 0.30 | −0.54 | C | 2 |
| | | | 308.568 | 175700 | 499800 | 3 | 3 | 70 | 0.10 | 0.30 | −0.52 | C | 2 |
| | | | [314.0] | 181300 | 499800 | 5 | 3 | 4.5 | 0.0040 | 0.021 | −1.70 | D | 2 |
| 15. | | $^1$P° - $^1$D | 327.192 | 258973 | 564604 | 3 | 5 | 290 | 0.78 | 2.5 | 0.37 | D | 2 |
| 16. | $3p^2$–$3p3d$ | $^1$D - $^1$D° | 349.91 | 408870 | 694660 | 5 | 5 | 110 | 0.21 | 1.2 | 0.02 | D | 2 |
| 17. | | $^1$D - $^1$F° | [266] | | | 5 | 7 | 180 | 0.26 | 1.1 | 0.11 | D | 2 |
| 18. | | $^1$D - $^1$P° | [261] | | | 5 | 3 | 2.4 | 0.0015 | 0.0064 | −2.12 | E | 2 |
| 19. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | [318] | | | 3 | 1 | 140 | 0.070 | 0.22 | −0.68 | C | 2 |
| 20. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 322.75 | 420600 | 730500 | 5 | 7 | 199 | 0.434 | 2.31 | 0.336 | C− | 2 |
| 21. | | $^1$S - $^1$P° | [323] | | | 1 | 3 | 180 | 0.85 | 0.90 | −0.07 | C | 2 |
| 22. | $3p3d$–$3d^2$ | $^1$F° - $^1$G | [408] | | | 7 | 9 | 137 | 0.440 | 4.14 | 0.489 | C− | 3 |
| 23. | | $^1$P° - $^1$S | [332] | | | 3 | 1 | 325 | 0.179 | 0.59 | −0.270 | C− | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XII

Na Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s\ ^2S_{1/2}$

Ionization Energy: 291.502 eV = 2351080 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 47.906 | 6 | 53.457 | 4 | 59.133 | 13 | 62.433 | 27 |
| 49.912 | 5 | 55.181 | 15 | 59.435 | 13 | 62.469 | 27 |
| 52.896 | 17 | 55.443 | 15 | 60.701 | 3 | 62.470 | 27 |
| 53.138 | 17 | 55.445 | 15 | 60.762 | 3 | 63.072 | 26 |
| 53.140 | 17 | 56.161 | 14 | 60.971 | 12 | 63.107 | 26 |
| 53.433 | 4 | 56.431 | 14 | 61.286 | 12 | 65.540 | 25 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 65.577 | 25 | 116.497 | 19 | 182.0 | 45 | 307.1 | 43 |
| 65.578 | 25 | 116.597 | 19 | 185.5 | 52 | 308.3 | 43 |
| 66.596 | 24 | 116.62 | 19 | 194.6 | 29 | 326.4 | 69 |
| 66.636 | 24 | 124.0 | 39 | 195.2 | 29 | 326.6 | 69 |
| 67.171 | 11 | 124.5 | 39 | 207.2 | 35 | 329.2 | 74 |
| 67.555 | 11 | 127.8 | 50 | 207.8 | 58 | 329.3 | 74 |
| 67.563 | 11 | 127.9 | 50 | 208.5 | 35 | 340.672 | 7 |
| 70.986 | 23 | 129.1 | 38 | 208.6 | 35 | 349.929 | 7 |
| 71.031 | 23 | 129.6 | 38 | 220.7 | 65 | 351.024 | 7 |
| 71.033 | 23 | 130.5 | 49 | 221.5 | 65 | 376.8 | 56 |
| 71.545 | 10 | 130.6 | 49 | 246.0 | 72 | 377.9 | 56 |
| 71.987 | 10 | 135.4 | 54 | 246.1 | 72 | 394.2 | 61 |
| 73.014 | 22 | 135.5 | 30 | 251.6 | 57 | 396.7 | 61 |
| 73.057 | 22 | 135.7 | 30 | 252.8 | 44 | 460.741 | 1 |
| 73.062 | 22 | 139.71 | 18 | 253.1 | 44 | 468.4 | 68 |
| 82.121 | 2 | 139.884 | 18 | 255.3 | 34 | 468.8 | 68 |
| 82.307 | 21 | 140.361 | 18 | 256.2 | 71 | 479.881 | 1 |
| 82.344 | 2 | 141.6 | 48 | 256.3 | 71 | 492.9 | 60 |
| 82.366 | 21 | 141.7 | 48 | 257.5 | 34 | 496.8 | 60 |
| 82.368 | 21 | 146.0 | 37 | 261.8 | 75 | 547.6 | 73 |
| 87.298 | 20 | 146.6 | 47 | 266.8 | 63 | 573.4 | 67 |
| 87.364 | 20 | 146.7 | 37,47 | 267.9 | 63 | 574.1 | 67 |
| 87.426 | 20 | 151.4 | 53 | 268.0 | 63 | 576.0 | 67 |
| 89.844 | 9 | 151.5 | 53 | 291.3 | 62 | 934.6 | 33 |
| 90.512 | 9 | 157.7 | 36 | 292.7 | 62 | 959.945 | 33 |
| 90.547 | 9 | 158.5 | 36 | 296.7 | 51 | 964.3 | 33 |
| 104.8 | 32 | 169.7 | 46 | 296.9 | 51 | 1188.8 | 28 |
| 113.1 | 41 | 169.8 | 46 | 302.5 | 70 | 1237.7 | 28 |
| 113.5 | 41 | 181.8 | 45 | 302.7 | 70 | | |
| 115.0 | 31 | 181.9 | 45 | 306.7 | 43 | | |

Strengths of the lines of the $3s$–$3p$ and $3p$–$3d$ transitions were taken from Edlén's interpolation formulae.[1] These were based on the results of Weiss' Hartree-Fock calculations,[2] in which ratios of relativistic Dirac to nonrelativistic line strengths in hydrogenic ions were applied as scaling factors to the nonrelativistic Hartree-Fock line strengths in the corresponding sodiumlike species. Oscillator strengths for the $4p$–$4d$ transitions were derived by Gruzdev and Sherstyuk[3] using the relativistic variant of their effective orbital quantum number method, which utilizes a Coulomb potential in conjunction with a semiempirical orbital quantum number which is determined from experimental energy levels.

Multiplet $f$-values calculated by Biemont[4] using a fully variational Hartree-Fock approach are quoted for numerous transitions $nl$–$n'l'$($3 \leqslant n \leqslant 5$; $4 \leqslant n' \leqslant 8$; $l,l' = s,p,d,f$). Data for additional transitions (namely, those for which $n > 5$, where $n$ is the principal quantum number of the lower state) can be found in Ref. 4. Whenever wavelengths of individual lines within a multiplet either were available directly or could be determined from the energy levels, the multiplet strength was distributed among the lines according to $LS$-coupling rules, except in cases where the wavelengths of all the lines in the multiplet are identical. The strength of the $3p\ ^2P^\circ - 4s\ ^2S$ multiplet was not distributed between the two lines in the multiplet, however, since the relativistic single-configuration Hartree-Fock calculations of Kim and Cheng[5] indicate that in the corresponding transition in sodiumlike iron the ratio of the two line strengths deviates somewhat from the value that would be obtained in the case of pure $LS$ coupling.

Transitions with small $f$-values were generally assigned lower accuracy ratings.

## References


[1]B. Edlén, Phys. Scr. **17**, 565 (1978).
[2]A. W. Weiss, J. Quant. Spectrosc. Radiat. Transfer **18**, 481 (1977).
[3]P. F. Gruzdev and A. I. Sherstyuk, Opt. Spectrosc. (USSR) **46**, 353 (1979).
[4]E. Biemont, Astron. Astrophys., Suppl. Ser. **31**, 285 (1978).
[5]Y.-K. Kim and K.-T. Cheng, J. Opt. Soc. Am. **68**, 836 (1978).

Ti XII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s$–$3p$ | $^2S$ – $^2P^\circ$ | *466.95* | 0 | *214156* | 2 | 6 | 48.1 | 0.472 | 1.45 | −0.025 | B | 1 |
| | | | 460.741 | 0 | 217042 | 2 | 4 | 50.2 | 0.320 | 0.970 | −0.194 | B | 1 |
| | | | 479.881 | 0 | 208385 | 2 | 2 | 44.0 | 0.152 | 0.480 | −0.517 | B | 1 |
| 2. | $3s$–$4p$ | $^2S$ – $^2P^\circ$ | *82.196* | 0 | *1216585* | 2 | 6 | 590 | 0.180 | 0.097 | −0.444 | C | 4 |
| | | | 82.121 | 0 | 1217692 | 2 | 4 | 590 | 0.12 | 0.065 | −0.62 | C | *ls* |
| | | | 82.344 | 0 | 1214371 | 2 | 2 | 580 | 0.059 | 0.032 | −0.93 | C | *ls* |
| 3. | $3s$–$5p$ | $^2S$ – $^2P^\circ$ | *60.720* | 0 | *1646900* | 2 | 6 | 350 | 0.058 | 0.023 | −0.94 | C | 4 |
| | | | 60.701 | 0 | 1647400 | 2 | 4 | 340 | 0.038 | 0.015 | −1.12 | C | *ls* |
| | | | 60.762 | 0 | 1645800 | 2 | 2 | 350 | 0.019 | 0.0077 | −1.41 | C | *ls* |
| 4. | $3s$–$6p$ | $^2S$ – $^2P^\circ$ | *53.442* | 0 | *1871200* | 2 | 6 | 207 | 0.0266 | 0.0094 | −1.274 | C | 4 |
| | | | 53.433 | 0 | 1871500 | 2 | 4 | 210 | 0.018 | 0.0063 | −1.45 | C | *ls* |
| | | | 53.457 | 0 | 1870700 | 2 | 2 | 210 | 0.0088 | 0.0031 | −1.75 | D | *ls* |
| 5. | $3s$–$7p$ | $^2S$ – $^2P^\circ$ | 49.912 | 0 | 2003500 | 2 | 6 | 132 | 0.0148 | 0.00486 | −1.53 | C | 4 |
| 6. | $3s$–$8p$ | $^2S$ – $^2P^\circ$ | 47.906 | 0 | 2087400 | 2 | 6 | 88 | 0.0091 | 0.0029 | −1.74 | D | 4 |
| 7. | $3p$–$3d$ | $^2P^\circ$ – $^2D$ | *346.86* | *214156* | *502457* | 6 | 10 | 123 | 0.369 | 2.53 | 0.345 | B | 1 |
| | | | 349.929 | 217042 | 502814 | 4 | 6 | 120 | 0.330 | 1.52 | 0.120 | B | 1 |
| | | | 340.672 | 208385 | 501922 | 2 | 4 | 108 | 0.376 | 0.843 | −0.124 | B | 1 |
| | | | 351.024 | 217042 | 501922 | 4 | 4 | 19.7 | 0.0363 | 0.168 | −0.837 | B | 1 |
| 8. | $3p$–$4s$ | $^2P^\circ$ – $^2S$ | *108.76* | *214156* | 1133573 | 6 | 2 | 1200 | 0.071 | 0.15 | −0.37 | C | 4 |
| 9. | $3p$–$4d$ | $^2P^\circ$ – $^2D$ | *90.302* | *214156* | *1321600* | 6 | 10 | 1170 | 0.238 | 0.425 | 0.155 | C | 4 |
| | | | 90.512 | 217042 | 1321800 | 4 | 6 | 1160 | 0.214 | 0.255 | −0.068 | C | *ls* |
| | | | 89.844 | 208385 | 1321400 | 2 | 4 | 990 | 0.240 | 0.142 | −0.319 | C | *ls* |
| | | | 90.547 | 217042 | 1321400 | 4 | 4 | 190 | 0.023 | 0.028 | −1.03 | D | *ls* |
| 10. | $3p$–$5s$ | $^2P^\circ$ – $^2S$ | *71.844* | *214156* | 1606100 | 6 | 2 | 520 | 0.0135 | 0.0192 | −1.092 | C | 4 |
| | | | 71.987 | 217042 | 1606100 | 4 | 2 | 348 | 0.0135 | 0.0128 | −1.268 | C | *ls* |
| | | | 71.545 | 208385 | 1606100 | 2 | 2 | 180 | 0.014 | 0.0064 | −1.57 | C | *ls* |
| 11. | $3p$–$5d$ | $^2P^\circ$ – $^2D$ | *67.431* | *214156* | *1697200* | 6 | 10 | 730 | 0.083 | 0.11 | −0.30 | C | 4 |
| | | | 67.555 | 217042 | 1697300 | 4 | 6 | 720 | 0.074 | 0.066 | −0.53 | C | *ls* |
| | | | 67.171 | 208385 | 1697100 | 2 | 4 | 620 | 0.084 | 0.037 | −0.78 | C | *ls* |
| | | | [67.563] | 217042 | 1697100 | 4 | 4 | 120 | 0.0082 | 0.0073 | −1.48 | D | *ls* |
| 12. | $3p$–$6s$ | $^2P^\circ$ – $^2S$ | *61.181* | *214156* | 1848700 | 6 | 2 | 280 | 0.0052 | 0.0063 | −1.51 | D | 4 |
| | | | 61.286 | 217042 | 1848700 | 4 | 2 | 180 | 0.0052 | 0.0042 | −1.68 | D | *ls* |
| | | | 60.971 | 208385 | 1848700 | 2 | 2 | 94 | 0.0052 | 0.0021 | −1.98 | D | *ls* |

Ti XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13. | 3p–6d | $^2P^\circ$ – $^2D$ | *59.337* | *214156* | 1899500 | 6 | 10 | 442 | 0.0389 | 0.0456 | −0.63 | C | 4 |
| | | | 59.435 | 217042 | 1899500 | 4 | 6 | 441 | 0.0350 | 0.0274 | −0.85 | C | *ls* |
| | | | 59.133 | 208385 | 1899500 | 2 | 4 | 372 | 0.0390 | 0.0152 | −1.107 | C | *ls* |
| | | | [59.435] | 217042 | 1899500 | 4 | 4 | 72 | 0.0038 | 0.0030 | −1.81 | D | *ls* |
| 14. | 3p–7s | $^2P^\circ$ – $^2S$ | *56.341* | *214156* | 1989100 | 6 | 2 | 160 | 0.0026 | 0.0029 | −1.81 | D | 4 |
| | | | 56.431 | 217042 | 1989100 | 4 | 2 | 110 | 0.0026 | 0.0019 | −1.99 | D | *ls* |
| | | | 56.161 | 208385 | 1989100 | 2 | 2 | 55 | 0.0026 | 9.7(−4)[a] | −2.28 | D | *ls* |
| 15. | 3p–7d | $^2P^\circ$ – $^2D$ | *55.356* | *214156* | *2020700* | 6 | 10 | 283 | 0.0217 | 0.0237 | −0.89 | C | 4 |
| | | | 55.443 | 217042 | 2020700 | 4 | 6 | 281 | 0.0194 | 0.0142 | −1.109 | C | *ls* |
| | | | 55.181 | 208385 | 2020600 | 2 | 4 | 240 | 0.022 | 0.0079 | −1.36 | C | *ls* |
| | | | [55.445] | 217042 | 2020600 | 4 | 4 | 48 | 0.0022 | 0.0016 | −2.06 | D | *ls* |
| 16. | 3p–8s | $^2P^\circ$ – $^2S$ | | | | 6 | 2 | | 0.0016 | | −2.02 | D | 4 |
| 17. | 3p–8d | $^2P^\circ$ – $^2D$ | *53.062* | *214156* | *2098800* | 6 | 10 | 192 | 0.0135 | 0.0141 | −1.092 | C | 4 |
| | | | 53.140 | 217042 | 2098800 | 4 | 6 | 190 | 0.012 | 0.0085 | −1.31 | C | *ls* |
| | | | 52.896 | 208385 | 2098900 | 2 | 4 | 161 | 0.0135 | 0.00470 | −1.57 | C | *ls* |
| | | | [53.138] | 217042 | 2098900 | 4 | 4 | 32 | 0.0013 | 9.4(−4) | −2.27 | D | *ls* |
| 18. | 3d–4p | $^2D$ – $^2P^\circ$ | *140.03* | *502457* | *1216585* | 10 | 6 | 290 | 0.052 | 0.24 | −0.28 | C | 4 |
| | | | 139.884 | 502814 | 1217692 | 6 | 4 | 260 | 0.051 | 0.14 | −0.52 | C | *ls* |
| | | | 140.361 | 501922 | 1214371 | 4 | 2 | 290 | 0.043 | 0.080 | −0.76 | C | *ls* |
| | | | [139.71] | 501922 | 1217692 | 4 | 4 | 30 | 0.0087 | 0.016 | −1.46 | D | *ls* |
| 19. | 3d–4f | $^2D$ – $^2F^\circ$ | *166.56* | *502457* | *1360402* | 10 | 14 | 3200 | 0.91 | 3.5 | 0.96 | C | 4 |
| | | | 116.597 | 502814 | 1360469 | 6 | 8 | 3200 | 0.87 | 2.0 | 0.72 | C | *ls* |
| | | | 116.497 | 501922 | 1360313 | 4 | 6 | 3000 | 0.91 | 1.4 | 0.56 | C | *ls* |
| | | | [116.62] | 502814 | 1360313 | 6 | 6 | 210 | 0.043 | 0.10 | −0.58 | D | *ls* |
| 20. | 3d–5p | $^2D$ – $^2P^\circ$ | *87.382* | *502457* | *1646900* | 10 | 6 | 110 | 0.0078 | 0.022 | −1.11 | D | 4 |
| | | | 87.364 | 502814 | 1647400 | 6 | 4 | 99 | 0.0075 | 0.013 | −1.34 | D | *ls* |
| | | | 87.426 | 501922 | 1645800 | 4 | 2 | 110 | 0.0063 | 0.0073 | −1.60 | D | *ls* |
| | | | [87.298] | 501922 | 1647400 | 4 | 4 | 11 | 0.0013 | 0.0015 | −2.28 | E | *ls* |
| 21. | 3d–5f | $^2D$ – $^2F^\circ$ | *82.345* | *502457* | 1716900 | 10 | 14 | 1200 | 0.171 | 0.464 | 0.233 | C | 4 |
| | | | 82.368 | 502814 | 1716900 | 6 | 8 | 1200 | 0.163 | 0.265 | −0.010 | C | *ls* |
| | | | 82.307 | 501922 | 1716900 | 4 | 6 | 1130 | 0.172 | 0.186 | −0.163 | C | *ls* |
| | | | [82.366] | 502814 | 1716900 | 6 | 6 | 79 | 0.0080 | 0.013 | −1.32 | D | *ls* |
| 22. | 3d–6p | $^2D$ – $^2P^\circ$ | *73.062* | *502457* | *1871200* | 10 | 6 | 58 | 0.0028 | 0.0067 | −1.55 | D | 4 |
| | | | [73.062] | 502814 | 1871500 | 6 | 4 | 52 | 0.0028 | 0.0040 | −1.78 | D | *ls* |
| | | | [73.057] | 501922 | 1870700 | 4 | 2 | 57 | 0.0023 | 0.0022 | −2.04 | D | *ls* |
| | | | [73.014] | 501922 | 1871500 | 4 | 4 | 5.9 | 4.7(−4) | 4.5(−4) | −2.73 | E | *ls* |

Ti XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23. | $3d$–$6f$ | $^2$D – $^2$F° | *71.018* | *502457* | 1910600 | 10 | 14 | 600 | 0.064 | 0.15 | −0.19 | C | 4 |
| | | | 71.031 | 502814 | 1910600 | 6 | 8 | 610 | 0.061 | 0.086 | −0.43 | C | *ls* |
| | | | 70.986 | 501922 | 1910600 | 4 | 6 | 570 | 0.064 | 0.060 | −0.59 | C | *ls* |
| | | | [71.033] | 502814 | 1910600 | 6 | 6 | 41 | 0.0031 | 0.0043 | −1.74 | D | *ls* |
| 24. | $3d$–$7p$ | $^2$D – $^2$P° | *66.622* | *502457* | 2003500 | 10 | 6 | 33 | 0.0013 | 0.0029 | −1.89 | D | 4 |
| | | | [66.636] | 502814 | 2003500 | 6 | 4 | 29 | 0.0013 | 0.0017 | −2.11 | D | *ls* |
| | | | [66.596] | 501922 | 2003500 | 4 | 2 | 33 | 0.0011 | 9.7(−4) | −2.35 | D | *ls* |
| | | | [66.596] | 501922 | 2003500 | 4 | 4 | 3.3 | 2.2(−4) | 1.9(−4) | −3.06 | E | *ls* |
| 25. | $3d$–$7f$ | $^2$D – $^2$F° | *65.565* | *502457* | 2027700 | 10 | 14 | 349 | 0.0315 | 0.068 | −0.50 | C | 4 |
| | | | 65.577 | 502814 | 2027700 | 6 | 8 | 350 | 0.030 | 0.039 | −0.74 | C | *ls* |
| | | | 65.540 | 501922 | 2027700 | 4 | 6 | 320 | 0.031 | 0.027 | −0.90 | C | *ls* |
| | | | [65.578] | 502814 | 2027700 | 6 | 6 | 23 | 0.0015 | 0.0019 | −2.06 | D | *ls* |
| 26. | $3d$–$8p$ | $^2$D – $^2$P° | *63.095* | *502457* | 2087400 | 10 | 6 | 21 | 7.6(−4) | 0.0016 | −2.12 | E | 4 |
| | | | [63.107] | 502814 | 2087400 | 6 | 4 | 19 | 7.7(−4) | 9.6(−4) | −2.34 | E | *ls* |
| | | | [63.072] | 501922 | 2087400 | 4 | 2 | 21 | 6.4(−4) | 5.3(−4) | −2.59 | E | *ls* |
| | | | [63.072] | 501922 | 2087400 | 4 | 4 | 2.2 | 1.3(−4) | 1.1(−4) | −3.28 | E | *ls* |
| 27. | $3d$–$8f$ | $^2$D – $^2$F° | *62.457* | *502457* | 2103600 | 10 | 14 | 222 | 0.0182 | 0.0374 | −0.74 | C | 4 |
| | | | 62.470 | 502814 | 2103600 | 6 | 8 | 222 | 0.0173 | 0.0214 | −0.98 | C | *ls* |
| | | | 62.433 | 501922 | 2103600 | 4 | 6 | 208 | 0.0182 | 0.0150 | −1.137 | C | *ls* |
| | | | [62.469] | 502814 | 2103600 | 6 | 6 | 15 | 8.9(−4) | 0.0011 | −2.27 | E | *ls* |
| 28. | $4s$–$4p$ | $^2$S – $^2$P° | *1204.6* | 1133573 | *1216585* | 2 | 6 | 10 | 0.67 | 5.3 | 0.13 | C | 4 |
| | | | [1188.8] | 1133573 | 1217692 | 2 | 4 | 11 | 0.45 | 3.5 | −0.05 | C | *ls* |
| | | | [1237.7] | 1133573 | 1214371 | 2 | 2 | 9.6 | 0.22 | 1.8 | −0.35 | C | *ls* |
| 29. | $4s$–$5p$ | $^2$S – $^2$P° | *194.8* | 1133573 | *1646900* | 2 | 6 | 110 | 0.188 | 0.241 | −0.425 | C | 4 |
| | | | [194.6] | 1133573 | 1647400 | 2 | 4 | 111 | 0.126 | 0.161 | −0.60 | C | *ls* |
| | | | [195.2] | 1133573 | 1645800 | 2 | 2 | 110 | 0.062 | 0.080 | −0.90 | C | *ls* |
| 30. | $4s$–$6p$ | $^2$S – $^2$P° | *135.6* | 1133573 | *1871200* | 2 | 6 | 75 | 0.062 | 0.055 | −0.91 | C | 4 |
| | | | [135.5] | 1133573 | 1871500 | 2 | 4 | 75 | 0.041 | 0.037 | −1.08 | C | *ls* |
| | | | [135.7] | 1133573 | 1870700 | 2 | 2 | 73 | 0.020 | 0.018 | −1.39 | C | *ls* |
| 31. | $4s$–$7p$ | $^2$S – $^2$P° | [115.0] | 1133573 | 2003500 | 2 | 6 | 50 | 0.0296 | 0.0224 | −1.228 | C | 4 |
| 32. | $4s$–$8p$ | $^2$S – $^2$P° | [104.8] | 1133573 | 2087400 | 2 | 6 | 34.0 | 0.0168 | 0.0116 | −1.474 | C | 4 |
| 33. | $4p$–$4d$ | $^2$P° – $^2$D | *952.4* | *1216585* | *1321600* | 6 | 10 | 23 | 0.53 | 9.9 | 0.50 | C | 3 |
| | | | 959.945 | 1217692 | 1321800 | 4 | 6 | 23 | 0.47 | 5.9 | 0.27 | C | 3 |
| | | | [934.6] | 1214371 | 1321400 | 2 | 4 | 21 | 0.54 | 3.3 | 0.03 | C | 3 |
| | | | [964.3] | 1217692 | 1321400 | 4 | 4 | 3.7 | 0.052 | 0.66 | −0.68 | C | 3 |
| 34. | $4p$–$5s$ | $^2$P° – $^2$S | *256.7* | *1216585* | 1606100 | 6 | 2 | 370 | 0.122 | 0.62 | −0.135 | C | 4 |
| | | | [257.5] | 1217692 | 1606100 | 4 | 2 | 240 | 0.12 | 0.41 | −0.32 | C | *ls* |
| | | | [255.3] | 1214371 | 1606100 | 2 | 2 | 130 | 0.12 | 0.21 | −0.60 | C | *ls* |

Ti XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35. | 4p–5d | $^2$P° – $^2$D | *208.1* | *1216585* | *1697200* | 6 | 10 | 180 | 0.195 | 0.80 | 0.068 | C | 4 |
| | | | [208.5] | 1217692 | 1697300 | 4 | 6 | 180 | 0.17 | 0.48 | –0.16 | C | *ls* |
| | | | [207.2] | 1214371 | 1697100 | 2 | 4 | 150 | 0.20 | 0.27 | –0.40 | C | *ls* |
| | | | [208.6] | 1217692 | 1697100 | 4 | 4 | 30 | 0.019 | 0.053 | –1.11 | D | *ls* |
| 36. | 4p–6s | $^2$P° – $^2$S | *158.2* | *1216585* | 1848700 | 6 | 2 | 185 | 0.0232 | 0.072 | –0.86 | C | 4 |
| | | | [158.5] | 1217692 | 1848700 | 4 | 2 | 120 | 0.023 | 0.048 | –1.04 | C | *ls* |
| | | | [157.7] | 1214371 | 1848700 | 2 | 2 | 62 | 0.023 | 0.024 | –1.34 | C | *ls* |
| 37. | 4p–6d | $^2$P° – $^2$D | *146.4* | *1216585* | 1899500 | 6 | 10 | 140 | 0.073 | 0.21 | –0.36 | C | 4 |
| | | | [146.7] | 1217692 | 1899500 | 4 | 6 | 140 | 0.067 | 0.13 | –0.57 | C | *ls* |
| | | | [146.0] | 1214371 | 1899500 | 2 | 4 | 110 | 0.073 | 0.070 | –0.84 | C | *ls* |
| | | | [146.7] | 1217692 | 1899500 | 4 | 4 | 22 | 0.0072 | 0.014 | –1.54 | D | *ls* |
| 38. | 4p–7s | $^2$P° – $^2$S | *129.4* | *1216585* | 1989100 | 6 | 2 | 110 | 0.0090 | 0.023 | –1.27 | D | 4 |
| | | | [129.6] | 1217692 | 1989100 | 4 | 2 | 70 | 0.0088 | 0.015 | –1.45 | D | *ls* |
| | | | [129.1] | 1214371 | 1989100 | 2 | 2 | 36 | 0.0091 | 0.0077 | –1.74 | D | *ls* |
| 39. | 4p–7d | $^2$P° – $^2$D | *124.4* | *1216585* | *2020700* | 6 | 10 | 93 | 0.0361 | 0.089 | –0.66 | C | 4 |
| | | | [124.5] | 1217692 | 2020700 | 4 | 6 | 93 | 0.032 | 0.053 | –0.89 | C | *ls* |
| | | | [124.0] | 1214371 | 2020600 | 2 | 4 | 80 | 0.037 | 0.030 | –1.13 | C | *ls* |
| | | | [124.5] | 1217692 | 2020600 | 4 | 4 | 15 | 0.0036 | 0.0059 | –1.84 | D | *ls* |
| 40. | 4p–8s | $^2$P° – $^2$S | | | | 6 | 2 | | 0.0046 | | –1.56 | D | 4 |
| 41. | 4p–8d | $^2$P° – $^2$D | *113.4* | *1216585* | *2098800* | 6 | 10 | 65 | 0.0209 | 0.0468 | –0.90 | C | 4 |
| | | | [113.5] | 1217692 | 2098800 | 4 | 6 | 65 | 0.0188 | 0.0281 | –1.124 | C | *ls* |
| | | | [113.1] | 1214371 | 2098900 | 2 | 4 | 55 | 0.0209 | 0.0156 | –1.378 | C | *ls* |
| | | | [113.5] | 1217692 | 2098900 | 4 | 4 | 11 | 0.0021 | 0.0031 | –2.08 | D | *ls* |
| 42. | 4d–4f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.131 | | 0.117 | C | 4 |
| 43. | 4d–5p | $^2$D – $^2$P° | *307.4* | *1321600* | *1646900* | 10 | 6 | 133 | 0.113 | 1.14 | 0.053 | C | 4 |
| | | | [307.1] | 1321800 | 1647400 | 6 | 4 | 120 | 0.11 | 0.68 | –0.17 | C | *ls* |
| | | | [308.3] | 1321400 | 1645800 | 4 | 2 | 131 | 0.094 | 0.380 | –0.427 | C | *ls* |
| | | | [306.7] | 1321400 | 1647400 | 4 | 4 | 13 | 0.019 | 0.076 | –1.12 | D | *ls* |
| 44. | 4d–5f | $^2$D – $^2$F° | *253.0* | *1321600* | 1716900 | 10 | 14 | 520 | 0.70 | 5.8 | 0.85 | C | 4 |
| | | | [253.1] | 1321800 | 1716900 | 6 | 8 | 520 | 0.66 | 3.3 | 0.60 | C | *ls* |
| | | | [252.8] | 1321400 | 1716900 | 4 | 6 | 480 | 0.69 | 2.3 | 0.44 | C | *ls* |
| | | | [253.1] | 1321800 | 1716900 | 6 | 6 | 35 | 0.034 | 0.17 | –0.69 | D | *ls* |
| 45. | 4d–6p | $^2$D – $^2$P° | *182.0* | *1321600* | *1871200* | 10 | 6 | 61 | 0.0182 | 0.109 | –0.74 | C | 4 |
| | | | [181.9] | 1321800 | 1871500 | 6 | 4 | 55 | 0.018 | 0.065 | –0.96 | C | *ls* |
| | | | [182.0] | 1321400 | 1870700 | 4 | 2 | 61 | 0.0151 | 0.0363 | –1.218 | C | *ls* |
| | | | [181.8] | 1321400 | 1871500 | 4 | 4 | 6.2 | 0.0030 | 0.0073 | –1.91 | D | *ls* |
| 46. | 4d–6f | $^2$D – $^2$F° | *169.8* | *1321600* | 1910600 | 10 | 14 | 292 | 0.177 | 0.99 | 0.248 | C | 4 |
| | | | [169.8] | 1321800 | 1910600 | 6 | 8 | 290 | 0.17 | 0.57 | 0.01 | C | *ls* |
| | | | [169.7] | 1321400 | 1910600 | 4 | 6 | 280 | 0.18 | 0.40 | –0.15 | C | *ls* |
| | | | [169.8] | 1321800 | 1910600 | 6 | 6 | 19 | 0.0083 | 0.028 | –1.30 | D | *ls* |

Ti XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47. | 4*d*–7*p* | $^2$D – $^2$P° | *146.6* | *1321600* | 2003500 | 10 | 6 | 34 | 0.0066 | 0.032 | −1.18 | D | 4 |
| | | | [146.7] | 1321800 | 2003500 | 6 | 4 | 30 | 0.0066 | 0.019 | −1.41 | D | *ls* |
| | | | [146.6] | 1321400 | 2003500 | 4 | 2 | 35 | 0.0057 | 0.011 | −1.64 | D | *ls* |
| | | | [146.6] | 1321400 | 2003500 | 4 | 4 | 3.4 | 0.0011 | 0.0021 | −2.36 | E | *ls* |
| 48. | 4*d*–7*f* | $^2$D – $^2$F° | *141.6* | *1321600* | 2027700 | 10 | 14 | 180 | 0.074 | 0.34 | −0.13 | C | 4 |
| | | | [141.7] | 1321800 | 2027700 | 6 | 8 | 170 | 0.068 | 0.19 | −0.39 | C | *ls* |
| | | | [141.6] | 1321400 | 2027700 | 4 | 6 | 170 | 0.075 | 0.14 | −0.52 | C | *ls* |
| | | | [141.7] | 1321800 | 2027700 | 6 | 6 | 12 | 0.0035 | 0.0097 | −1.68 | D | *ls* |
| 49. | 4*d*–8*p* | $^2$D – $^2$P° | *130.6* | *1321600* | 2087400 | 10 | 6 | 22 | 0.0033 | 0.014 | −1.48 | D | 4 |
| | | | [130.6] | 1321800 | 2087400 | 6 | 4 | 19 | 0.0033 | 0.0084 | −1.71 | D | *ls* |
| | | | [130.5] | 1321400 | 2087400 | 4 | 2 | 21 | 0.0027 | 0.0047 | −1.96 | D | *ls* |
| | | | [130.5] | 1321400 | 2087400 | 4 | 4 | 2.1 | 5.4(−4) | 9.3(−4) | −2.66 | E | *ls* |
| 50. | 4*d*–8*f* | $^2$D – $^2$F° | *127.9* | *1321600* | 2103600 | 10 | 14 | 114 | 0.0390 | 0.164 | −0.409 | C | 4 |
| | | | [127.9] | 1321800 | 2103600 | 6 | 8 | 110 | 0.037 | 0.094 | −0.65 | C | *ls* |
| | | | [127.8] | 1321400 | 2103600 | 4 | 6 | 110 | 0.039 | 0.066 | −0.80 | C | *ls* |
| | | | [127.9] | 1321800 | 2103600 | 6 | 6 | 7.6 | 0.0019 | 0.0047 | −1.95 | D | *ls* |
| 51. | 4*f*–5*d* | $^2$F° – $^2$D | *296.9* | *1360402* | *1697200* | 14 | 10 | 22.4 | 0.0211 | 0.289 | −0.53 | C | 4 |
| | | | [296.9] | 1360469 | 1697300 | 8 | 6 | 21.3 | 0.0211 | 0.165 | −0.77 | C | *ls* |
| | | | [296.9] | 1360313 | 1697100 | 6 | 4 | 22.5 | 0.0198 | 0.116 | −0.93 | C | *ls* |
| | | | [296.7] | 1360313 | 1697300 | 6 | 6 | 1.1 | 0.0014 | 0.0083 | −2.07 | D | *ls* |
| 52. | 4*f*–6*d* | $^2$F° – $^2$D | [185.5] | *1360402* | 1899500 | 14 | 10 | 9.5 | 0.0035 | 0.030 | −1.31 | D | 4 |
| 53. | 4*f*–7*d* | $^2$F° – $^2$D | *151.4* | *1360402* | *2020700* | 14 | 10 | 4.9 | 0.0012 | 0.0084 | −1.77 | D | 4 |
| | | | [151.5] | 1360469 | 2020700 | 8 | 6 | 4.7 | 0.0012 | 0.0048 | −2.02 | D | *ls* |
| | | | [151.4] | 1360313 | 2020600 | 6 | 4 | 5.0 | 0.0011 | 0.0034 | −2.17 | D | *ls* |
| | | | [151.4] | 1360313 | 2020700 | 6 | 6 | 0.23 | 8.0(−5) | 2.4(−4) | −3.32 | E | *ls* |
| 54. | 4*f*–8*d* | $^2$F° – $^2$D | [135.4] | *1360402* | 2098800 | 14 | 10 | 3.1 | 6.0(−4) | 0.0037 | −2.08 | E | 4 |
| 55. | 5*s*–5*p* | $^2$S – $^2$P° | | | | 2 | 6 | | 0.87 | | 0.24 | C | 4 |
| 56. | 5*s*–6*p* | $^2$S – $^2$P° | *377.2* | 1606100 | *1871200* | 2 | 6 | 31.3 | 0.200 | 0.497 | −0.398 | C | 4 |
| | | | [376.8] | 1606100 | 1871500 | 2 | 4 | 31.3 | 0.133 | 0.331 | −0.57 | C | *ls* |
| | | | [377.9] | 1606100 | 1870700 | 2 | 2 | 31.2 | 0.067 | 0.166 | −0.87 | C | *ls* |
| 57. | 5*s*–7*p* | $^2$S – $^2$P° | [251.6] | 1606100 | 2003500 | 2 | 6 | 24 | 0.067 | 0.11 | −0.87 | C | 4 |
| 58. | 5*s*–8*p* | $^2$S – $^2$P° | [207.8] | 1606100 | 2087400 | 2 | 6 | 16.6 | 0.0323 | 0.0442 | −1.190 | C | 4 |
| 59. | 5*p*–5*d* | $^2$P° – $^2$D | | | | 6 | 10 | | 0.76 | | 0.66 | C | 4 |
| 60. | 5*p*–6*s* | $^2$P° – $^2$S | *495.5* | *1646900* | 1848700 | 6 | 2 | 141 | 0.173 | 1.69 | 0.016 | C | 4 |
| | | | [496.8] | 1647400 | 1848700 | 4 | 2 | 93 | 0.173 | 1.13 | −0.161 | C | *ls* |
| | | | [492.9] | 1645800 | 1848700 | 2 | 2 | 47 | 0.17 | 0.56 | −0.46 | C | *ls* |
| 61. | 5*p*–6*d* | $^2$P° – $^2$D | *395.9* | *1646900* | 1899500 | 6 | 10 | 44.9 | 0.176 | 1.38 | 0.024 | C | 4 |
| | | | [396.7] | 1647400 | 1899500 | 4 | 6 | 45 | 0.16 | 0.83 | −0.20 | C | *ls* |
| | | | [394.2] | 1645800 | 1899500 | 2 | 4 | 38.0 | 0.177 | 0.460 | −0.450 | C | *ls* |
| | | | [396.7] | 1647400 | 1899500 | 4 | 4 | 7.5 | 0.018 | 0.092 | −1.15 | D | *ls* |

Ti XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 62. | 5p–7s | $^2$P° – $^2$S | *292.2* | *1646900* | 1989100 | 6 | 2 | 77 | 0.0329 | 0.190 | −0.70 | C | 4 |
| | | | [292.7] | 1647400 | 1989100 | 4 | 2 | 51 | 0.0329 | 0.127 | −0.88 | C | ls |
| | | | [291.3] | 1645800 | 1989100 | 2 | 2 | 26 | 0.033 | 0.063 | −1.18 | C | ls |
| 63. | 5p–7d | $^2$P° – $^2$D | *267.5* | *1646900* | *2020700* | 6 | 10 | 38 | 0.068 | 0.36 | −0.39 | C | 4 |
| | | | [267.9] | 1647400 | 2020700 | 4 | 6 | 39 | 0.062 | 0.22 | −0.60 | C | ls |
| | | | [266.8] | 1645800 | 2020600 | 2 | 4 | 32 | 0.068 | 0.12 | −0.86 | C | ls |
| | | | [268.0] | 1647400 | 2020600 | 4 | 4 | 6.3 | 0.0068 | 0.024 | −1.57 | D | ls |
| 64. | 5p–8s | $^2$P° – $^2$S | | | | 6 | 2 | | 0.0128 | | −1.115 | C | 4 |
| 65. | 5p–8d | $^2$P° – $^2$D | *221.3* | *1646900* | *2098800* | 6 | 10 | 28.2 | 0.0345 | 0.151 | −0.68 | C | 4 |
| | | | [221.5] | 1647400 | 2098800 | 4 | 6 | 28 | 0.031 | 0.091 | −0.90 | C | ls |
| | | | [220.7] | 1645800 | 2098900 | 2 | 4 | 24 | 0.034 | 0.050 | −1.16 | C | ls |
| | | | [221.5] | 1647400 | 2098900 | 4 | 4 | 4.7 | 0.0034 | 0.010 | −1.86 | D | ls |
| 66. | 5d–5f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.231 | | 0.364 | C | 4 |
| 67. | 5d–6p | $^2$D – $^2$P° | *574.7* | *1697200* | *1871200* | 10 | 6 | 60 | 0.179 | 3.39 | 0.253 | C | 4 |
| | | | [574.1] | 1697300 | 1871500 | 6 | 4 | 54 | 0.179 | 2.03 | 0.031 | C | ls |
| | | | [576.0] | 1697100 | 1870700 | 4 | 2 | 60 | 0.149 | 1.13 | −0.225 | C | ls |
| | | | [573.4] | 1697100 | 1871500 | 4 | 4 | 6.2 | 0.030 | 0.23 | −0.91 | D | ls |
| 68. | 5d–6f | $^2$D – $^2$F° | *468.6* | *1697200* | 1910600 | 10 | 14 | 130 | 0.61 | 9.4 | 0.79 | C | 4 |
| | | | [468.8] | 1697300 | 1910600 | 6 | 8 | 130 | 0.58 | 5.4 | 0.54 | C | ls |
| | | | [468.4] | 1697100 | 1910600 | 4 | 6 | 120 | 0.62 | 3.8 | 0.39 | C | ls |
| | | | [468.8] | 1697300 | 1910600 | 6 | 6 | 8.8 | 0.029 | 0.27 | −0.76 | D | ls |
| 69. | 5d–7p | $^2$D – $^2$P° | *326.5* | *1697200* | 2003500 | 10 | 6 | 30.8 | 0.0295 | 0.317 | −0.53 | C | 4 |
| | | | [326.6] | 1697300 | 2003500 | 6 | 4 | 27.6 | 0.0295 | 0.190 | −0.75 | C | ls |
| | | | [326.4] | 1697100 | 2003500 | 4 | 2 | 30.9 | 0.0247 | 0.106 | −1.006 | C | ls |
| | | | [326.4] | 1697100 | 2003500 | 4 | 4 | 3.1 | 0.0049 | 0.021 | −1.71 | D | ls |
| 70. | 5d–7f | $^2$D – $^2$F° | *302.6* | *1697200* | 2027700 | 10 | 14 | 89 | 0.172 | 1.71 | 0.236 | C | 4 |
| | | | [302.7] | 1697300 | 2027700 | 6 | 8 | 89 | 0.16 | 0.98 | −0.01 | C | ls |
| | | | [302.5] | 1697100 | 2027700 | 4 | 6 | 83 | 0.17 | 0.68 | −0.17 | C | ls |
| | | | [302.7] | 1697300 | 2027700 | 6 | 6 | 6.0 | 0.0082 | 0.049 | −1.31 | D | ls |
| 71. | 5d–8p | $^2$D – $^2$P° | *256.3* | *1697200* | 2087400 | 10 | 6 | 18.3 | 0.0108 | 0.091 | −0.97 | C | 4 |
| | | | [256.3] | 1697300 | 2087400 | 6 | 4 | 17 | 0.011 | 0.055 | −1.19 | C | ls |
| | | | [256.2] | 1697100 | 2087400 | 4 | 2 | 18 | 0.0089 | 0.030 | −1.45 | D | ls |
| | | | [256.2] | 1697100 | 2087400 | 4 | 4 | 1.8 | 0.0018 | 0.0061 | −2.14 | D | ls |
| 72. | 5d–8f | $^2$D – $^2$F° | *246.1* | *1697200* | 2103600 | 10 | 14 | 60 | 0.076 | 0.62 | −0.12 | C | 4 |
| | | | [246.1] | 1697300 | 2103600 | 6 | 8 | 59 | 0.072 | 0.35 | −0.36 | C | ls |
| | | | [246.0] | 1679100 | 2103600 | 4 | 6 | 57 | 0.077 | 0.25 | −0.51 | C | ls |
| | | | [246.1] | 1697300 | 2103600 | 6 | 6 | 4.1 | 0.0037 | 0.018 | −1.65 | D | ls |
| 73. | 5f–6d | $^2$F° – $^2$D | [547.6] | 1716900 | 1899500 | 14 | 10 | 16 | 0.051 | 1.3 | −0.15 | C | 4 |
| 74. | 5f–7d | $^2$F° – $^2$D | *329.2* | 1716900 | *2020700* | 14 | 10 | 7.8 | 0.0090 | 0.14 | −0.90 | D | 4 |
| | | | [329.2] | 1716900 | 2020700 | 8 | 6 | 7.6 | 0.0092 | 0.080 | −1.13 | D | ls |
| | | | [329.3] | 1716900 | 2020600 | 6 | 4 | 7.9 | 0.0086 | 0.056 | −1.29 | D | ls |
| | | | [329.2] | 1716900 | 2020700 | 6 | 6 | 0.38 | 6.2(−4) | 0.0040 | −2.43 | E | ls |

Ti XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 75. | $5f$–$8d$ | $^2$F° – $^2$D | [261.8] | 1716900 | *2098800* | 14 | 10 | 4.5 | 0.0033 | 0.040 | −1.34 | D | 4 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XII

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 52.645 | 38 | 144.3 | 50 | 263.0 | 65 | 518.1 | 31 |
| 58.917 | 37 | 149.8 | 15,55 | 266.0 | 9 | 531.3 | 43 |
| 58.924 | 37 | 149.9 | 15,55 | 266.2 | 9 | 532.5 | 43 |
| 59.046 | 41 | 152.2 | 6 | 266.3 | 9 | 565.6 | 80 |
| 66.291 | 40 | 153.0 | 6 | 266.5 | 9 | 581.4 | 73 |
| 66.671 | 40 | 153.1 | 6 | 269.9 | 71 | 581.7 | 73 |
| 69.493 | 2 | 155.5 | 58 | 279.6 | 18 | 636.9 | 76 |
| 69.911 | 2 | 158.32 | 42 | 280.4 | 13 | 640.2 | 76 |
| 69.989 | 2 | 158.54 | 42 | 280.6 | 13 | 646.8 | 69 |
| 75.654 | 36 | 173.0 | 10 | 280.8 | 18 | 650.2 | 69 |
| 75.677 | 36 | 173.1 | 10 | 309.0 | 21 | 659.6 | 67 |
| 83.668 | 4 | 177.4 | 44 | 309.1 | 21 | 660.5 | 67 |
| 83.717 | 4 | 177.5 | 44 | 309.2 | 21 | 685.20 | 48 |
| 86.811 | 39 | 181.7 | 14 | 309.3 | 21 | 700.39 | 48 |
| 87.456 | 39 | 181.8 | 14 | 321.8 | 24 | 701.16 | 48 |
| 87.468 | 39 | 189.6 | 54 | 340.8 | 60 | 753.0 | 26 |
| 99.078 | 1 | 189.8 | 54 | 342.5 | 68 | 757.6 | 26 |
| 99.935 | 1 | 195.6 | 57 | 342.7 | 68 | 825.1 | 28 |
| 100.27 | 1 | 195.7 | 57 | 348.3 | 56 | 825.8 | 28 |
| 103.6 | 47 | 195.9 | 57 | 348.6 | 56 | 854.0 | 30 |
| 112.5 | 52 | 198.88 | 35 | 348.9 | 70 | 910.7 | 82 |
| 112.7 | 46 | 199.0 | 49 | 350.3 | 56 | 911.6 | 82 |
| 112.9 | 52 | 199.23 | 35 | 351.2 | 53 | 999.0 | 84 |
| 114.5 | 8 | 200.3 | 49 | 351.7 | 53 | 1080 | 79 |
| 115.0 | 8 | 202.9 | 62 | 377.6 | 64 | 1100 | 59 |
| 122.0 | 3 | 203.0 | 62 | 379.9 | 64 | 1120 | 78 |
| 122.1 | 3 | 218.4 | 66 | 399.7 | 74 | 1190 | 32 |
| 122.2 | 3 | 219.2 | 66 | 399.8 | 74 | 1280 | 33 |
| 123.0 | 51 | 226.4 | 19 | 429.4 | 77 | 1320 | 34 |
| 123.5 | 51 | 227.3 | 19 | 430.8 | 77 | 1410 | 63 |
| 126.7 | 7 | 230.9 | 5 | 443.1 | 17 | 1440 | 63 |
| 127.3 | 7 | 232.7 | 5 | 446.2 | 17 | 1680 | 85 |
| 128.6 | 12 | 233.6 | 5 | 447.8 | 17 | 1970 | 72 |
| 128.7 | 12 | 241.2 | 61 | 461.5 | 27 | 2510 | 75 |
| 130.6 | 45 | 241.3 | 61 | 463.2 | 27 | 2560 | 75 |
| 134.5 | 16 | 248.9 | 22 | 494.1 | 20 | 3160 | 81 |
| 134.6 | 16 | 249.0 | 22 | 494.6 | 20 | 3170 | 81 |
| 143.0 | 11 | 249.1 | 22 | 501.5 | 29 | 4130 | 83 |
| 143.1 | 11 | 258.6 | 25 | 501.8 | 29 | 6170 | 86 |
| 143.6 | 50 | 261.8 | 65 | 516.3 | 23 | | |

Electric quadrupole $gf$-values for numerous multiplets in this sodiumlike ion were determined by Biemont and Godefroid[1] using a fully variational Hartree-Fock approach with no allowance for configuration mixing. These $f$-values were converted to multiplet strengths, and $LS$-coupling rules were applied to obtain strengths of lines within multiplets. The $gf$-values for $d$–$d$ and $f$–$f$ transitions as given in Ref. 1 are overstated,[2] and had to be reduced by factors of 9 and 25, respectively. The strongest lines for which fairly accurate wavelengths could be derived from experimentally determined energy levels are quoted in this compilation.

## References


[1]E. Biemont and M. Godefroid, Phys. Scr. **18**, 323 (1978).
[2]E. Biemont, private communication (1986).


Ti XII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p$–$4p$ | $^2P^o$ - $^2P^o$ | | | | | | | | | | |
| | | | [99.935] | 217042 | 1217692 | 4 | 4 | E2 | 6.9(+6)[a] | 0.164 | C | 1,*ls* |
| | | | [100.27] | 217042 | 1214371 | 4 | 2 | E2 | 1.36(+7) | 0.164 | C | 1,*ls* |
| | | | [99.078] | 208385 | 1217692 | 2 | 4 | E2 | 7.2(+6) | 0.164 | C | 1,*ls* |
| 2. | $3p$–$5p$ | $^2P^o$ - $^2P^o$ | | | | | | | | | | |
| | | | [69.911] | 217042 | 1647400 | 4 | 4 | E2 | 3.8(+6) | 0.015 | D | 1,*ls* |
| | | | [69.989] | 217042 | 1645800 | 4 | 2 | E2 | 7.5(+6) | 0.015 | D | 1,*ls* |
| | | | [69.493] | 208385 | 1647400 | 2 | 4 | E2 | 3.9(+6) | 0.015 | D | 1,*ls* |
| 3. | $3d$–$4d$ | $^2D$ - $^2D$ | | | | | | | | | | |
| | | | [122.1] | 502814 | 1321800 | 6 | 6 | E2 | 3.20(+6) | 0.310 | C | 1,*ls* |
| | | | [122.0] | 501922 | 1321400 | 4 | 4 | E2 | 2.81(+6) | 0.181 | C | 1,*ls* |
| | | | [122.2] | 502814 | 1321400 | 6 | 4 | E2 | 1.2(+6) | 0.078 | D | 1,*ls* |
| | | | [122.0] | 501922 | 1321800 | 4 | 6 | E2 | 8.1(+5) | 0.078 | D | 1,*ls* |
| 4. | $3d$–$5d$ | $^2D$ - $^2D$ | | | | | | | | | | |
| | | | [83.717] | 502814 | 1697300 | 6 | 6 | E2 | 1.5(+6) | 0.022 | D | 1,*ls* |
| | | | [83.668] | 501922 | 1697100 | 4 | 4 | E2 | 1.3(+6) | 0.013 | D | 1,*ls* |
| 5. | $4p$–$5p$ | $^2P^o$ - $^2P^o$ | | | | | | | | | | |
| | | | [232.7] | 1217692 | 1647400 | 4 | 4 | E2 | 1.05(+6) | 1.70 | C | 1,*ls* |
| | | | [233.6] | 1217692 | 1645800 | 4 | 2 | E2 | 2.05(+6) | 1.70 | C | 1,*ls* |
| | | | [230.9] | 1214371 | 1647400 | 2 | 4 | E2 | 1.09(+6) | 1.70 | C | 1,*ls* |
| 6. | $4p$–$6p$ | $^2P^o$ - $^2P^o$ | | | | | | | | | | |
| | | | [153.0] | 1217692 | 1871500 | 4 | 4 | E2 | 6.6(+5) | 0.132 | C | 1,*ls* |
| | | | [153.1] | 1217692 | 1870700 | 4 | 2 | E2 | 1.32(+6) | 0.132 | C | 1,*ls* |
| | | | [152.2] | 1214371 | 1871500 | 2 | 4 | E2 | 6.8(+5) | 0.132 | C | 1,*ls* |
| 7. | $4p$–$7p$ | $^2P^o$ - $^2P^o$ | | | | | | | | | | |
| | | | [127.3] | 1217692 | 2003500 | 4 | 4 | E2 | 4.3(+5) | 0.034 | D | 1,*ls* |
| | | | [127.3] | 1217692 | 2003500 | 4 | 2 | E2 | 8.5(+5) | 0.034 | D | 1,*ls* |
| | | | [126.7] | 1214371 | 2003500 | 2 | 4 | E2 | 4.4(+5) | 0.034 | D | 1,*ls* |
| 8. | $4p$–$8p$ | $^2P^o$ - $^2P^o$ | | | | | | | | | | |
| | | | [115.0] | 1217692 | 2087400 | 4 | 4 | E2 | 2.9(+5) | 0.014 | D | 1,*ls* |
| | | | [115.0] | 1217692 | 2087400 | 4 | 2 | E2 | 5.8(+5) | 0.014 | D | 1,*ls* |
| | | | [114.5] | 1214371 | 2087400 | 2 | 4 | E2 | 3.0(+5) | 0.014 | D | 1,*ls* |
| 9. | $4d$–$5d$ | $^2D$ - $^2D$ | | | | | | | | | | |
| | | | [266.3] | 1321800 | 1697300 | 6 | 6 | E2 | 7.1(+5) | 3.42 | C | 1,*ls* |
| | | | [266.2] | 1321400 | 1697100 | 4 | 4 | E2 | 6.3(+5) | 2.00 | C | 1,*ls* |
| | | | [266.5] | 1321800 | 1697100 | 6 | 4 | E2 | 2.7(+5) | 0.86 | C– | 1,*ls* |
| | | | [266.0] | 1321400 | 1697300 | 4 | 6 | E2 | 1.8(+5) | 0.86 | C– | 1,*ls* |

Ti XII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | $4d$–$6d$ | $^2$D - $^2$D | | | | | | | | | | |
| | | | [173.1] | 1321800 | 1899500 | 6 | 6 | E2 | 4.22(+5) | 0.234 | C | 1,*ls* |
| | | | [173.0] | 1321400 | 1899500 | 4 | 4 | E2 | 3.69(+5) | 0.136 | C | 1,*ls* |
| | | | [173.1] | 1321800 | 1899500 | 6 | 4 | E2 | 1.6(+5) | 0.058 | D | 1,*ls* |
| | | | [173.0] | 1321400 | 1899500 | 4 | 6 | E2 | 1.0(+5) | 0.058 | D | 1,*ls* |
| 11. | $4d$–$7d$ | $^2$D - $^2$D | | | | | | | | | | |
| | | | [143.1] | 1321800 | 2020700 | 6 | 6 | E2 | 2.6(+5) | 0.056 | D | 1,*ls* |
| | | | [143.0] | 1321400 | 2020600 | 4 | 4 | E2 | 2.3(+5) | 0.033 | D | 1,*ls* |
| | | | [143.1] | 1321800 | 2020600 | 6 | 4 | E2 | 9.8(+4) | 0.014 | E | 1,*ls* |
| | | | [143.0] | 1321400 | 2020700 | 4 | 6 | E2 | 6.6(+4) | 0.014 | E | 1,*ls* |
| 12. | $4d$–$8d$ | $^2$D - $^2$D | | | | | | | | | | |
| | | | [128.7] | 1321800 | 2098800 | 6 | 6 | E2 | 1.7(+5) | 0.022 | D | 1,*ls* |
| | | | [128.6] | 1321400 | 2098900 | 4 | 4 | E2 | 1.6(+5) | 0.013 | D | 1,*ls* |
| 13. | $4f$–$5f$ | $^2$F° - $^2$F° | | | | | | | | | | |
| | | | [280.6] | 1360469 | 1716900 | 8 | 8 | E2 | 4.08(+5) | 3.38 | C | 1,*ls* |
| | | | [280.4] | 1360313 | 1716900 | 6 | 6 | E2 | 3.94(+5) | 2.44 | C | 1,*ls* |
| | | | [280.6] | 1360469 | 1716900 | 8 | 6 | E2 | 6.5(+4) | 0.406 | C– | 1,*ls* |
| | | | [280.4] | 1360313 | 1716900 | 6 | 8 | E2 | 4.92(+4) | 0.406 | C– | 1,*ls* |
| 14. | $4f$–$6f$ | $^2$F° - $^2$F° | | | | | | | | | | |
| | | | [181.8] | 1360469 | 1910600 | 8 | 8 | E2 | 2.02(+5) | 0.191 | C | 1,*ls* |
| | | | [181.7] | 1360313 | 1910600 | 6 | 6 | E2 | 1.94(+5) | 0.137 | C | 1,*ls* |
| | | | [181.8] | 1360469 | 1910600 | 8 | 6 | E2 | 3.2(+4) | 0.023 | D | 1,*ls* |
| | | | [181.7] | 1360313 | 1910600 | 6 | 8 | E2 | 2.4(+4) | 0.023 | D | 1,*ls* |
| 15. | $4f$–$7f$ | $^2$F° - $^2$F° | | | | | | | | | | |
| | | | [149.9] | 1360469 | 2027700 | 8 | 8 | E2 | 1.1(+5) | 0.041 | D | 1,*ls* |
| | | | [149.8] | 1360313 | 2027700 | 6 | 6 | E2 | 1.1(+5) | 0.030 | D | 1,*ls* |
| 16. | $4f$–$8f$ | $^2$F° - $^2$F° | | | | | | | | | | |
| | | | [134.6] | 1360469 | 2103600 | 8 | 8 | E2 | 7.1(+4) | 0.015 | D | 1,*ls* |
| | | | [134.5] | 1360313 | 2103600 | 6 | 6 | E2 | 7.0(+4) | 0.011 | D | 1,*ls* |
| 17. | $5p$–$6p$ | $^2$P° - $^2$P° | | | | | | | | | | |
| | | | [446.2] | 1647400 | 1871500 | 4 | 4 | E2 | 2.37(+5) | 10.0 | C | 1,*ls* |
| | | | [447.8] | 1647400 | 1870700 | 4 | 2 | E2 | 4.66(+5) | 10.0 | C | 1,*ls* |
| | | | [443.1] | 1645800 | 1871500 | 2 | 4 | E2 | 2.46(+5) | 10.0 | C | 1,*ls* |
| 18. | $5p$–$7p$ | $^2$P° - $^2$P° | | | | | | | | | | |
| | | | [280.8] | 1647400 | 2003500 | 4 | 4 | E2 | 1.7(+5) | 0.71 | C | 1,*ls* |
| | | | [280.8] | 1647400 | 2003500 | 4 | 2 | E2 | 2.4(+5) | 0.71 | C | 1,*ls* |
| | | | [279.6] | 1645800 | 2003500 | 2 | 4 | E2 | 1.7(+5) | 0.71 | C | 1,*ls* |
| 19. | $5p$–$8p$ | $^2$P° - $^2$P° | | | | | | | | | | |
| | | | [227.3] | 1647400 | 2087400 | 4 | 4 | E2 | 1.19(+5) | 0.172 | C | 1,*ls* |
| | | | [227.3] | 1647400 | 2087400 | 4 | 2 | E2 | 2.38(+5) | 0.172 | C | 1,*ls* |
| | | | [226.4] | 1645800 | 2087400 | 2 | 4 | E2 | 1.21(+5) | 0.172 | C | 1,*ls* |

Ti XII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20. | 5d–6d | $^2D - ^2D$ | | | | | | | | | | |
| | | | [494.6] | 1697300 | 1899500 | 6 | 6 | E2 | 1.89(+5) | 20.0 | C | 1,ls |
| | | | [494.1] | 1697100 | 1899500 | 4 | 4 | E2 | 1.65(+5) | 11.6 | C | 1,ls |
| | | | [494.6] | 1697300 | 1899500 | 6 | 4 | E2 | 7.1(+4) | 4.99 | C− | 1,ls |
| | | | [494.1] | 1697100 | 1899500 | 4 | 6 | E2 | 4.74(+4) | 4.99 | C− | 1,ls |
| 21. | 5d–7d | $^2D - ^2D$ | | | | | | | | | | |
| | | | [309.2] | 1697300 | 2020700 | 6 | 6 | E2 | 1.30(+5) | 1.31 | C | 1,ls |
| | | | [309.1] | 1697100 | 2020600 | 4 | 4 | E2 | 1.1(+5) | 0.76 | C | 1,ls |
| | | | [309.3] | 1697300 | 2020600 | 6 | 4 | E2 | 4.84(+4) | 0.326 | C− | 1,ls |
| | | | [309.0] | 1697100 | 2020700 | 4 | 6 | E2 | 3.24(+4) | 0.326 | C− | 1,ls |
| 22. | 5d–8d | $^2D - ^2D$ | | | | | | | | | | |
| | | | [249.1] | 1697300 | 2098800 | 6 | 6 | E2 | 8.8(+4) | 0.303 | C | 1,ls |
| | | | [248.9] | 1697100 | 2098900 | 4 | 4 | E2 | 7.8(+4) | 0.177 | C | 1,ls |
| | | | [249.0] | 1697300 | 2098900 | 6 | 4 | E2 | 3.3(+4) | 0.076 | D | 1,ls |
| | | | [248.9] | 1697100 | 2098800 | 4 | 6 | E2 | 2.2(+4) | 0.076 | D | 1,ls |
| 23. | 5f–6f | $^2F^\circ - ^2F^\circ$ | | | | | | | | | | |
| | | | [516.3] | 1716900 | 1910600 | 8 | 8 | E2 | 1.41(+5) | 24.7 | C | 1,ls |
| | | | [516.3] | 1716900 | 1910600 | 6 | 6 | E2 | 1.36(+5) | 17.8 | C | 1,ls |
| | | | [516.3] | 1716900 | 1910600 | 8 | 6 | E2 | 2.27(+4) | 2.97 | C− | 1,ls |
| | | | [516.3] | 1716900 | 1910600 | 6 | 8 | E2 | 1.70(+4) | 2.97 | C− | 1,ls |
| 24. | 5f–7f | $^2F^\circ - ^2F^\circ$ | | | | | | | | | | |
| | | | [321.8] | 1716900 | 2027700 | 8 | 8 | E2 | 8.8(+4) | 1.44 | C | 1,ls |
| | | | [321.8] | 1716900 | 2027700 | 6 | 6 | E2 | 8.4(+4) | 1.04 | C | 1,ls |
| | | | [321.8] | 1716900 | 2027700 | 8 | 6 | E2 | 1.40(+4) | 0.173 | C− | 1,ls |
| | | | [321.8] | 1716900 | 2027700 | 6 | 8 | E2 | 1.05(+4) | 0.173 | C− | 1,ls |
| 25. | 5f–7f | $^2F^\circ - ^2F^\circ$ | | | | | | | | | | |
| | | | [258.6] | 1716900 | 2103600 | 8 | 8 | E2 | 5.6(+4) | 0.310 | C | 1,ls |
| | | | [258.6] | 1716900 | 2103600 | 6 | 6 | E2 | 5.4(+4) | 0.223 | C | 1,ls |
| | | | [258.6] | 1716900 | 2103600 | 8 | 6 | E2 | 9000 | 0.037 | D | 1,ls |
| | | | [258.6] | 1716900 | 2103600 | 6 | 8 | E2 | 6700 | 0.037 | D | 1,ls |
| 26. | 6p–7p | $^2P^\circ - ^2P^\circ$ | | | | | | | | | | |
| | | | [757.6] | 1871500 | 2003500 | 4 | 4 | E2 | 7.0(+4) | 41.7 | C | 1,ls |
| | | | [757.6] | 1871500 | 2003500 | 4 | 2 | E2 | 1.40(+5) | 41.7 | C | 1,ls |
| | | | [753.0] | 1870700 | 2003500 | 2 | 4 | E2 | 7.2(+4) | 41.7 | C | 1,ls |
| 27. | 6p–8p | $^2P^\circ - ^2P^\circ$ | | | | | | | | | | |
| | | | [463.2] | 1871500 | 2087400 | 4 | 4 | E2 | 5.5(+4) | 2.77 | C | 1,ls |
| | | | [463.2] | 1871500 | 2087400 | 4 | 2 | E2 | 1.09(+5) | 2.77 | C | 1,ls |
| | | | [461.5] | 1870700 | 2087400 | 2 | 4 | E2 | 5.6(+4) | 2.77 | C | 1,ls |
| 28. | 6d–7d | $^2D - ^2D$ | | | | | | | | | | |
| | | | [825.1] | 1899500 | 2020700 | 6 | 6 | E2 | 6.1(+4) | 83 | C | 1,ls |
| | | | [825.8] | 1899500 | 2020600 | 4 | 4 | E2 | 5.3(+4) | 48.4 | C | 1,ls |
| | | | [825.8] | 1899500 | 2020600 | 6 | 4 | E2 | 2.27(+4) | 20.8 | C− | 1,ls |
| | | | [825.1] | 1899500 | 2020700 | 4 | 6 | E2 | 1.52(+4) | 20.8 | C− | 1,ls |

Ti XII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | 6*d*–8*d* | $^2$D – $^2$D | | | | | | | | | | |
| | | | [501.8] | 1899500 | 2098800 | 6 | 6 | E2 | 4.6(+4) | 5.2 | C | 1,*ls* |
| | | | [501.5] | 1899500 | 2098900 | 4 | 4 | E2 | 4.04(+4) | 2.05 | C | 1,*ls* |
| | | | [501.5] | 1899500 | 2098900 | 6 | 4 | E2 | 1.73(+4) | 1.31 | C– | 1,*ls* |
| | | | [501.8] | 1899500 | 2908800 | 4 | 6 | E2 | 1.15(+4) | 1.31 | C– | 1,*ls* |
| 30. | 6*f*–7*f* | $^2$F° – $^2$F° | | | | | | | | | | |
| | | | [854.0] | 1910600 | 2027700 | 8 | 8 | E2 | 5.1(+4) | 110 | C | 1,*ls* |
| | | | [854.0] | 1910600 | 2027700 | 6 | 6 | E2 | 4.9(+4) | 79 | C | 1,*ls* |
| | | | [854.0] | 1910600 | 2027700 | 8 | 6 | E2 | 8100 | 13.2 | C– | 1,*ls* |
| | | | [854.0] | 1910600 | 2027700 | 6 | 8 | E2 | 6100 | 13.2 | C– | 1,*ls* |
| 31. | 6*f*–8*f* | $^2$F° – $^2$F° | | | | | | | | | | |
| | | | [518.1] | 1910600 | 2103600 | 8 | 8 | E2 | 3.5(+4) | 6.3 | C | 1,*ls* |
| | | | [518.1] | 1910600 | 2103600 | 6 | 6 | E2 | 3.42(+4) | 4.56 | C | 1,*ls* |
| | | | [518.1] | 1910600 | 2103600 | 8 | 6 | E2 | 5700 | 0.76 | C– | 1,*ls* |
| | | | [518.1] | 1910600 | 2103600 | 6 | 8 | E2 | 4300 | 0.76 | C– | 1,*ls* |
| 32. | 7*p*–8*p* | $^2$P° – $^2$P° | | | | | | | | | | |
| | | | [1190] | 2003500 | 2087400 | 4 | 4 | E2 | 2.50(+4) | 142 | C | 1,*ls* |
| | | | [1190] | 2003500 | 2087400 | 4 | 2 | E2 | 5.0(+4) | 142 | C | 1,*ls* |
| | | | [1190] | 2003500 | 2087400 | 2 | 4 | E2 | 2.50(+4) | 142 | C | 1,*ls* |
| 33. | 7*d*–8*d* | $^2$D – $^2$D | | | | | | | | | | |
| | | | [1280] | 2020700 | 2098800 | 6 | 6 | E2 | 2.27(+4) | 278 | C | 1,*ls* |
| | | | [1280] | 2020600 | 2098900 | 4 | 4 | E2 | 1.98(+4) | 162 | C | 1,*ls* |
| | | | [1280] | 2020700 | 2098900 | 6 | 4 | E2 | 8600 | 70 | C– | 1,*ls* |
| | | | [1280] | 2020600 | 2098800 | 4 | 6 | E2 | 5700 | 70 | C– | 1,*ls* |
| 34. | 7*f*–8*f* | $^2$F° – $^2$F° | | | | | | | | | | |
| | | | [1320] | 2027700 | 2103600 | 8 | 8 | E2 | 1.99(+4) | 380 | C | 1,*ls* |
| | | | [1320] | 2027700 | 2103600 | 6 | 6 | E2 | 1.91(+4) | 274 | C | 1,*ls* |
| | | | [1320] | 2027700 | 2103600 | 8 | 6 | E2 | 3190 | 45.6 | C– | 1,*ls* |
| | | | [1320] | 2027700 | 2103600 | 6 | 8 | E2 | 2390 | 45.6 | C– | 1,*ls* |
| 35. | 3*s*–3*d* | $^2$S – $^2$D | | | | | | | | | | |
| | | | [198.88] | 0 | 502814 | 2 | 6 | E2 | 4.35(+5) | 0.483 | C | 1,*ls* |
| | | | [199.23] | 0 | 501922 | 2 | 4 | E2 | 4.31(+5) | 0.322 | C | 1,*ls* |
| 36. | 3*s*–4*d* | $^2$S – $^2$D | | | | | | | | | | |
| | | | [75.654] | 0 | 1321800 | 2 | 6 | E2 | 2.76(+7) | 0.244 | C | 1,*ls* |
| | | | [75.677] | 0 | 1321400 | 2 | 4 | E2 | 2.74(+7) | 0.162 | C | 1,*ls* |
| 37. | 3*s*–5*d* | $^2$S – $^2$D | | | | | | | | | | |
| | | | [58.917] | 0 | 1697300 | 2 | 6 | E2 | 1.6(+7) | 0.041 | D | 1,*ls* |
| | | | [58.924] | 0 | 1697100 | 2 | 4 | E2 | 1.7(+7) | 0.028 | D | 1,*ls* |
| 38. | 3*s*–6*d* | $^2$S – $^2$D | | | | | | | | | | |
| | | | [52.645] | 0 | 1899500 | 2 | 6 | E2 | 9.7(+6) | 0.014 | D | 1,*ls* |

Ti XII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39. | $3p$–$4f$ | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [87.456] | 217042 | 1360469 | 4 | 8 | E2 | 5.5(+7) | 1.35 | C | 1,*ls* |
| | | | [86.811] | 208385 | 1360313 | 2 | 6 | E2 | 4.5(+7) | 0.79 | C | 1,*ls* |
| | | | [87.468] | 217042 | 1360313 | 4 | 6 | E2 | 1.23(+7) | 0.225 | C– | 1,*ls* |
| 40. | $3p$–$5f$ | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [66.671] | 217042 | 1716900 | 4 | 8 | E2 | 1.2(+7) | 0.078 | D | 1,*ls* |
| | | | [66.291] | 208385 | 1716900 | 2 | 6 | E2 | 9.8(+6) | 0.045 | D | 1,*ls* |
| | | | [66.671] | 217042 | 1716900 | 4 | 6 | E2 | 2.8(+6) | 0.013 | E | 1,*ls* |
| 41. | $3p$–$6f$ | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [59.046] | 217042 | 1910600 | 4 | 8 | E2 | 4.1(+6) | 0.014 | D | 1,*ls* |
| 42. | $3d$–$4s$ | $^2$D – $^2$S | | | | | | | | | | |
| | | | [158.54] | 502814 | 1133573 | 6 | 2 | E2 | 2.13(+6) | 0.254 | C | 1,*ls* |
| | | | [158.32] | 501922 | 1133573 | 4 | 2 | E2 | 1.44(+6) | 0.170 | C | 1,*ls* |
| 43. | $4s$–$4d$ | $^2$S – $^2$D | | | | | | | | | | |
| | | | [531.3] | 1133573 | 1321800 | 2 | 6 | E2 | 5.0(+4) | 7.6 | C | 1,*ls* |
| | | | [532.5] | 1133573 | 1321400 | 2 | 4 | E2 | 4.9(+4) | 5.0 | C | 1,*ls* |
| 44. | $4s$–$5d$ | $^2$S – $^2$D | | | | | | | | | | |
| | | | [177.4] | 1133573 | 1697300 | 2 | 6 | E2 | 2.58(+6) | 1.62 | C | 1,*ls* |
| | | | [177.5] | 1133573 | 1697100 | 2 | 4 | E2 | 2.57(+6) | 1.08 | C | 1,*ls* |
| 45. | $4s$–$6d$ | $^2$S – $^2$D | | | | | | | | | | |
| | | | [130.6] | 1133573 | 1899500 | 2 | 6 | E2 | 1.98(+6) | 0.269 | C | 1,*ls* |
| | | | [130.6] | 1133573 | 1899500 | 2 | 4 | E2 | 1.98(+6) | 0.179 | C | 1,*ls* |
| 46. | $4s$–$7d$ | $^2$S – $^2$D | | | | | | | | | | |
| | | | [112.7] | 1133573 | 2020700 | 2 | 6 | E2 | 1.4(+6) | 0.089 | D | 1,*ls* |
| | | | [112.7] | 1133573 | 2020600 | 2 | 4 | E2 | 1.4(+6) | 0.060 | D | 1,*ls* |
| 47. | $4s$–$8d$ | $^2$S – $^2$D | | | | | | | | | | |
| | | | [103.6] | 1133573 | 2098800 | 2 | 6 | E2 | 9.6(+5) | 0.041 | D | 1,*ls* |
| | | | [103.6] | 1133573 | 2098900 | 2 | 4 | E2 | 9.5(+5) | 0.027 | D | 1,*ls* |
| 48. | $4p$–$4f$ | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [700.39] | 1217692 | 1360469 | 4 | 8 | E2 | 1.1(+4) | 8.6 | C | 1,*ls* |
| | | | [685.20] | 1214371 | 1360313 | 2 | 6 | E2 | 9300 | 5.0 | C | 1,*ls* |
| | | | [701.16] | 1217692 | 1360313 | 4 | 6 | E2 | 2360 | 1.43 | C– | 1,*ls* |
| 49. | $4p$–$5f$ | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [200.3] | 1217692 | 1716900 | 4 | 8 | E2 | 5.7(+6) | 8.7 | C | 1,*ls* |
| | | | [199.0] | 1214371 | 1716900 | 2 | 6 | E2 | 4.6(+6) | 5.1 | C | 1,*ls* |
| | | | [200.3] | 1217692 | 1716900 | 4 | 6 | E2 | 1.27(+6) | 1.46 | C– | 1,*ls* |
| 50. | $4p$–$6f$ | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [144.3] | 1217692 | 1910600 | 4 | 8 | E2 | 2.9(+6) | 0.85 | C | 1,*ls* |
| | | | [143.6] | 1214371 | 1910600 | 2 | 6 | E2 | 2.26(+6) | 0.493 | C | 1,*ls* |
| | | | [144.3] | 1217692 | 1910600 | 4 | 6 | E2 | 6.3(+5) | 0.141 | C– | 1,*ls* |

Ti XII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51. | 4*p*–7*f* | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [123.5] | 1217692 | 2027700 | 4 | 8 | E2 | 1.45(+6) | 0.199 | C | 1,*ls* |
| | | | [123.0] | 1214371 | 2027700 | 2 | 6 | E2 | 1.15(+6) | 0.116 | C | 1,*ls* |
| | | | [123.5] | 1217692 | 2027700 | 4 | 6 | E2 | 3.2(+5) | 0.033 | D | 1,*ls* |
| 52. | 4*p*–8*f* | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [112.9] | 1217692 | 2103600 | 4 | 8 | E2 | 8.4(+5) | 0.073 | D | 1,*ls* |
| | | | [112.5] | 1214371 | 2103600 | 2 | 6 | E2 | 6.7(+5) | 0.043 | D | 1,*ls* |
| | | | [112.9] | 1217692 | 2103600 | 4 | 6 | E2 | 1.8(+5) | 0.012 | E | 1,*ls* |
| 53. | 4*d*–5*s* | $^2$D – $^2$S | | | | | | | | | | |
| | | | [351.7] | 1321800 | 1606100 | 6 | 2 | E2 | 5.9(+5) | 3.77 | C | 1,*ls* |
| | | | [351.2] | 1321400 | 1606100 | 4 | 2 | E2 | 3.96(+5) | 2.52 | C | 1,*ls* |
| 54. | 4*d*–6*s* | $^2$D – $^2$D | | | | | | | | | | |
| | | | [189.8] | 1321800 | 1848700 | 6 | 2 | E2 | 3.0(+5) | 0.089 | D | 1,*ls* |
| | | | [189.6] | 1321400 | 1848700 | 4 | 2 | E2 | 2.1(+5) | 0.060 | D | 1,*ls* |
| 55. | 4*d*–7*s* | $^2$D – $^2$S | | | | | | | | | | |
| | | | [149.9] | 1321800 | 1989100 | 6 | 2 | E2 | 1.9(+5) | 0.017 | D | 1,*ls* |
| | | | [149.8] | 1321400 | 1989100 | 4 | 2 | E2 | 1.2(+5) | 0.011 | D | 1,*ls* |
| 56. | 4*f*–5*p* | $^2$F° – $^2$P° | | | | | | | | | | |
| | | | [348.6] | 1360469 | 1647400 | 8 | 4 | E2 | 1.58(+5) | 1.94 | C | 1,*ls* |
| | | | [350.3] | 1360313 | 1645800 | 6 | 2 | E2 | 1.80(+5) | 1.13 | c | 1,*ls* |
| | | | [348.3] | 1360313 | 1647400 | 6 | 4 | E2 | 2.65(+4) | 0.324 | C– | 1,*ls* |
| 57. | 4*f*–6*p* | $^2$F° – $^2$P° | | | | | | | | | | |
| | | | [195.7] | 1360469 | 1871500 | 8 | 4 | E2 | 9.5(+4) | 0.065 | D | 1,*ls* |
| | | | [195.9] | 1360313 | 1870700 | 6 | 2 | E2 | 1.1(+5) | 0.038 | D | 1,*ls* |
| | | | [195.6] | 1360313 | 1871500 | 6 | 4 | E2 | 1.6(+4) | 0.011 | E | 1,*ls* |
| 58. | 4*f*–7*p* | $^2$F° – $^2$P° | | | | | | | | | | |
| | | | [155.5] | 1360469 | 2003500 | 8 | 4 | E2 | 6.0(+4) | 0.013 | D | 1,*ls* |
| 59. | 5*s*–5*d* | $^2$S – $^2$D | | | | | | | | | | |
| | | | [1100] | 1606100 | 1697300 | 2 | 6 | E2 | 9600 | 55 | C | 1,*ls* |
| | | | [1100] | 1606100 | 1697100 | 2 | 4 | E2 | 9500 | 36.4 | C | 1,*ls* |
| 60. | 5*s*–6*d* | $^2$S – $^2$D | | | | | | | | | | |
| | | | [340.8] | 1606100 | 1899500 | 2 | 6 | E2 | 4.3(+5) | 7.0 | C | 1,*ls* |
| | | | [340.8] | 1606100 | 1899500 | 2 | 4 | E2 | 4.28(+5) | 4.68 | C | 1,*ls* |
| 61. | 5*s*–7*d* | $^2$S – $^2$D | | | | | | | | | | |
| | | | [241.2] | 1606100 | 2020700 | 2 | 6 | E2 | 3.98(+5) | 1.16 | C | 1,*ls* |
| | | | [241.3] | 1606100 | 2020600 | 2 | 4 | E2 | 4.0(+5) | 0.78 | C | 1,*ls* |
| 62. | 5*s*–8*d* | $^2$S – $^2$D | | | | | | | | | | |
| | | | [203.0] | 1606100 | 2098800 | 2 | 6 | E2 | 3.08(+5) | 0.379 | C | 1,*ls* |
| | | | [202.9] | 1606100 | 2098900 | 2 | 4 | E2 | 3.08(+5) | 0.252 | C | 1,*ls* |

Ti XII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 63. | 5p–5f | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [1440] | 1647400 | 1716900 | 4 | 8 | E2 | 2800 | 82 | C | 1,ls |
| | | | [1410] | 1645800 | 1716900 | 2 | 6 | E2 | 2400 | 47.7 | C | 1,ls |
| | | | [1440] | 1647400 | 1716900 | 4 | 6 | E2 | 610 | 13.6 | C– | 1,ls |
| 64. | 5p–6f | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [379.9] | 1647400 | 1910600 | 4 | 8 | E2 | 9.8(+5) | 37.0 | C | 1,ls |
| | | | [377.6] | 1645800 | 1910600 | 2 | 6 | E2 | 7.9(+5) | 21.6 | C | 1,ls |
| | | | [379.9] | 1647400 | 1910600 | 4 | 6 | E2 | 2.2(+5) | 6.2 | C– | 1,ls |
| 65. | 5p–7f | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [263.0] | 1647400 | 2027700 | 4 | 8 | E2 | 6.7(+5) | 4.02 | C | 1,ls |
| | | | [261.8] | 1645800 | 2027700 | 2 | 6 | E2 | 5.3(+5) | 2.34 | C | 1,ls |
| | | | [263.0] | 1647400 | 2027700 | 4 | 6 | E2 | 1.5(+5) | 0.67 | C– | 1,ls |
| 66. | 5p–8f | $^2$P° – $^2$F° | | | | | | | | | | |
| | | | [219.2] | 1647400 | 2103600 | 4 | 8 | E2 | 4.27(+5) | 1.03 | C | 1,ls |
| | | | [218.4] | 1645800 | 2103600 | 2 | 6 | E2 | 2.4(+5) | 0.60 | C | 1,ls |
| | | | [219.2] | 1647400 | 2103600 | 4 | 6 | E2 | 9.5(+4) | 0.172 | C– | 1,ls |
| 67. | 5d–6s | $^2$D – $^2$S | | | | | | | | | | |
| | | | [660.5] | 1697300 | 1848700 | 6 | 2 | E2 | 1.80(+5) | 26.9 | C | 1,ls |
| | | | [659.6] | 1697100 | 1848700 | 4 | 2 | E2 | 1.20(+5) | 17.9 | C | 1,ls |
| 68. | 5d–7s | $^2$D – $^2$S | | | | | | | | | | |
| | | | [342.7] | 1697300 | 1989100 | 6 | 2 | E2 | 9.6(+4) | 0.54 | C | 1,ls |
| | | | [342.5] | 1697100 | 1989100 | 4 | 2 | E2 | 6.4(+4) | 0.360 | C | 1,ls |
| 69. | 5f–6p | $^2$F° – $^2$P° | | | | | | | | | | |
| | | | [646.8] | 1716900 | 1871500 | 8 | 4 | E2 | 7.6(+4) | 20.4 | C | 1,ls |
| | | | [650.2] | 1716900 | 1870700 | 6 | 2 | E2 | 8.6(+4) | 11.9 | C | 1,ls |
| | | | [646.8] | 1716900 | 1871500 | 6 | 4 | E2 | 1.26(+4) | 3.40 | C– | 1,ls |
| 70. | 5f–7p | $^2$F° – $^2$P° | | | | | | | | | | |
| | | | [348.9] | 1716900 | 2003500 | 8 | 4 | E2 | 5.0(+4) | 0.61 | C | 1,ls |
| | | | [348.9] | 1716900 | 2003500 | 6 | 2 | E2 | 5.7(+4) | 0.353 | C | 1,ls |
| | | | [348.9] | 1716900 | 2003500 | 6 | 4 | E2 | 8200 | 0.101 | C– | 1,ls |
| 71. | 5f–8p | $^2$F° – $^2$P° | | | | | | | | | | |
| | | | [269.9] | 1716900 | 2087400 | 8 | 4 | E2 | 3.43(+4) | 0.117 | C | 1,ls |
| | | | [269.9] | 1716900 | 2087400 | 6 | 2 | E2 | 4.0(+4) | 0.068 | D | 1,ls |
| | | | [269.9] | 1716900 | 2087400 | 6 | 4 | E2 | 5900 | 0.020 | E | 1,ls |
| 72. | 6s–6d | $^2$S – $^2$D | | | | | | | | | | |
| | | | [1970] | 1848700 | 1899500 | 2 | 6 | E2 | 2280 | 242 | C– | 1,ls |
| | | | [1970] | 1848700 | 1899500 | 2 | 4 | E2 | 2290 | 162 | C– | 1,ls |
| 73. | 6s–7d | $^2$S – $^2$D | | | | | | | | | | |
| | | | [581.4] | 1848700 | 2020700 | 2 | 6 | E2 | 1.03(+5) | 24.4 | C | 1,ls |
| | | | [581.7] | 1848700 | 2020600 | 2 | 4 | E2 | 1.02(+5) | 16.2 | C | 1,ls |

Ti XII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 74. | $6s$–$8d$ | $^2S$ – $^2D$ | | | | | | | | | | |
| | | | [399.8] | 1848700 | 2098800 | 2 | 6 | E2 | 1.07(+5) | 3.90 | C | 1,*ls* |
| | | | [399.7] | 1848700 | 2098900 | 2 | 4 | E2 | 1.07(+5) | 2.60 | C | 1,*ls* |
| 75. | $6p$–$6f$ | $^2P^o$ – $^3F^o$ | | | | | | | | | | |
| | | | [2560] | 1871500 | 1910600 | 4 | 8 | E2 | 820 | 430 | D+ | 1,*ls* |
| | | | [2510] | 1870700 | 1910600 | 2 | 6 | E2 | 700 | 250 | D+ | 1,*ls* |
| | | | [2560] | 1871500 | 1910600 | 4 | 6 | E2 | 180 | 71 | D− | 1,*ls* |
| 76. | $6p$–$7f$ | $^2P^o$ – $^2F^o$ | | | | | | | | | | |
| | | | [640.2] | 1871500 | 2027700 | 4 | 8 | E2 | 2.30(+5) | 118 | C | 1,*ls* |
| | | | [636.9] | 1870700 | 2027700 | 2 | 6 | E2 | 1.8(+5) | 69 | C | 1,*ls* |
| | | | [640.2] | 1871500 | 2027700 | 4 | 6 | E2 | 5.1(+4) | 19.7 | C− | 1,*ls* |
| 77. | $6p$–$8f$ | $^2P^o$ – $^2F^o$ | | | | | | | | | | |
| | | | [430.8] | 1871500 | 2103600 | 4 | 8 | E2 | 1.94(+5) | 13.7 | C | 1,*ls* |
| | | | [429.4] | 1870700 | 2103600 | 2 | 6 | E2 | 1.5(+5) | 8.0 | C | 1,*ls* |
| | | | [430.8] | 1871500 | 2103600 | 4 | 6 | E2 | 4.30(+4) | 2.28 | C− | 1,*ls* |
| 78. | $6d$–$7s$ | $^2D$ – $^2S$ | | | | | | | | | | |
| | | | [1120] | 1899500 | 1989100 | 6 | 2 | E2 | 6.1(+4) | 128 | C | 1,*ls* |
| | | | [1120] | 1899500 | 1989100 | 4 | 2 | E2 | 4.1(+4) | 86 | C | 1,*ls* |
| 79. | $6f$–$7p$ | $^2F^o$ – $^2P^o$ | | | | | | | | | | |
| | | | [1080] | 1910600 | 2003500 | 8 | 4 | E2 | 3.26(+4) | 114 | C | 1,*ls* |
| | | | [1080] | 1910600 | 2003500 | 6 | 2 | E2 | 3.8(+4) | 67 | C | 1,*ls* |
| | | | [1080] | 1910600 | 2003500 | 6 | 4 | E2 | 5400 | 19.0 | C− | 1,*ls* |
| 80. | $6f$–$8p$ | $^2F^o$ – $^2P^o$ | | | | | | | | | | |
| | | | [565.6] | 1910600 | 2087400 | 8 | 4 | E2 | 2.25(+4) | 3.10 | C | 1,*ls* |
| | | | [565.6] | 1910600 | 2087400 | 6 | 2 | E2 | 2.63(+4) | 1.81 | C | 1,*ls* |
| | | | [565.6] | 1910600 | 2087400 | 6 | 4 | E2 | 3800 | 0.52 | C− | 1,*ls* |
| 81. | $7s$–$7d$ | $^2S$ – $^2D$ | | | | | | | | | | |
| | | | [3160] | 1989100 | 2020700 | 2 | 6 | E2 | 760 | 850 | D+ | 1,*ls* |
| | | | [3170] | 1980100 | 2020600 | 2 | 4 | E2 | 750 | 570 | D+ | 1,*ls* |
| 82. | $7s$–$8d$ | $^2S$ – $^2D$ | | | | | | | | | | |
| | | | [911.6] | 1989100 | 2098800 | 2 | 6 | E2 | 3.1(+4) | 70 | C | 1,*ls* |
| | | | [910.7] | 1989100 | 2098900 | 2 | 4 | E2 | 2.14(+4) | 46.8 | C | 1,*ls* |
| 83. | $7p$–$7f$ | $^2P^o$ – $^2F^o$ | | | | | | | | | | |
| | | | [4130] | 2003500 | 2027700 | 4 | 8 | E2 | 300 | 1700 | D | 1,*ls* |
| | | | [4130] | 2003500 | 2027700 | 2 | 6 | E2 | 230 | 970 | D | 1,*ls* |
| | | | [4130] | 2003500 | 2027700 | 4 | 6 | E2 | 65 | 280 | E | 1,*ls* |
| 84. | $7p$–$8f$ | $^2P^o$ – $^2F^o$ | | | | | | | | | | |
| | | | [999.0] | 2003500 | 2103600 | 4 | 8 | E2 | 7.0(+4) | 330 | C | 1,*ls* |
| | | | [999.0] | 2003500 | 2103600 | 2 | 6 | E2 | 5.4(+4) | 192 | C | 1,*ls* |
| | | | [999.0] | 2003500 | 2103600 | 4 | 6 | E2 | 1.5(+4) | 55 | C− | 1,*ls* |

Ti XII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 85. | $7f$–$8p$ | $^2$F° - $^2$P° | | | | | | | | | | |
| | | | [1680] | 2027700 | 2087400 | 8 | 4 | E2 | 1.45(+4) | 462 | C− | 1,*ls* |
| | | | [1680] | 2027700 | 2087400 | 6 | 2 | E2 | 1.69(+4) | 270 | C− | 1,*ls* |
| | | | [1680] | 2027700 | 2087400 | 6 | 4 | E2 | 2400 | 77 | D+ | 1,*ls* |
| 86. | $8p$–$8f$ | $^2$P° - $^2$F° | | | | | | | | | | |
| | | | [6170] | 2087400 | 2103600 | 4 | 8 | E2 | 120 | 5000 | D | 1,*ls* |
| | | | [6170] | 2087400 | 2103600 | 2 | 6 | E2 | 91 | 2900 | D | 1,*ls* |
| | | | [6170] | 2087400 | 2103600 | 4 | 6 | E2 | 26 | 830 | E | 1,*ls* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XIII

Ne Isoelectronic Sequence

Ground State: $1s^22s^22p^6\ ^1S_0$

Ionization Energy: 787.84 eV = 6354300 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 23.356 | 9 | 117.1 | 3 | 346.163 | 13 | 373.1 | 14 |
| 23.698 | 8 | 117.3 | 3 | 351.58 | 13 | 458.1 | 16 |
| 23.991 | 7 | 120.2 | 1,4 | 362.86 | 15 | 474.611 | 11 |
| 26.641 | 6 | 128.7 | 2 | 369.531 | 15 | 552.115 | 10 |
| 26.960 | 5 | 336.029 | 13 | 370.5 | 17 | 745.7 | 12 |

For resonance transitions to $J = 1$ levels of the $2p^53s$ and $2p^53d$ configurations, we quote $A$-values which were calculated by Vainshtein and Safronova[1] using a charge-expansion perturbation theory approach with allowance for mixing of the $2p^53s$, $2p^53d$, and $2s2p^63p$ configurations. Their results for the $2p^6$–$2p^53d$ transitions in the isoelectronic ions Ar IX and Fe XVII are in rather good agreement with those of Shorer,[2] who used the relativistic random phase approximation (RRPA) with allowance for mixing between configurations of type $2p^5ns$ and $2p^5nd$, as well as correlation effects due to configurations having a vacancy in the $1s$ or $2s$ subshell. But the data of Ref. 1 for the two $2p^6$–$2p^53s$ transitions are approximately a factor of two smaller than those of Shorer for the abovementioned neonlike species, so we have increased the transition probabilities of Ref. 1 for these two lines by a factor of two.

$A$-values quoted here for a number of transitions involving an electron jump of the type $2s$–$2p$, $3s$–$3p$, or $3p$–$3d$ were taken from the work of Pokleba and Safronova,[3] who used wavefunctions calculated by a charge-expansion perturbation theory approach with allowance for mixing of configurations in which a single $2s$ or $2p$ electron is excited to an $n=3$ orbital but with no inclusion of configurations in which an electron occupies the $n=4$ shell. In cases where better wavelength data were available, these transition probabilities were first converted to line strengths, which were then reconverted to $f$- and $A$-values by using the more accurate wavelengths. Transitions involving levels of the $2p^53p$ and $2p^53d$ configurations which are indicated by Jupen and Litzen[4] or by Fawcett[5] to be of low to moderate purity in $LS$ coupling in Ti XIII are excluded here, as are very weak lines. The pattern of levels within the $2s2p^63d$ configuration in the isoelectronic ions Fe XVII and Ni XIX resulting from the scaled Thomas-Fermi calculations of Loulergue and Nussbaumer[6] with extensive allowance for correlation is entirely different from that determined by Vainshtein and Safronova, whose energy levels were apparently used by Pokleba and Safronova in their transition probability calculations. We have thus excluded transitions out of these levels from our tabulation.

## References


[1]L. A. Vainshtein and U. I. Safronova, *Spektroskopicheskie Konstanty Atomov*, 5–122 (Ed. V. B. Belyanin, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Nauch. Sov. Spektrosk., Moscow, 1977).

[2]P. Shorer, Phys. Rev. A **20**, 642 (1979).

[3]A. K. Pokleba and U. I. Safronova, Preprint No. 11, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Inst. Spektrosk. (Moscow, 1981).

[4]C. Jupen and U. Litzen, Phys. Scr. **30**, 112 (1984).

[5]B. C. Fawcett, private communication, as quoted in E. Träbert, Z. Phys. A **319**, 25 (1984).

[6]M. Loulergue and H. Nussbaumer, Astron. Astrophys. **45**, 125 (1975).


Ti XIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5(^2P^\circ_{3/2})3s-2s2p^63s$ | $(^3/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | [120.2] | 3698200 | 4530300 | 5 | 3 | 540 | 0.071 | 0.14 | −0.45 | D | 3 |
| 2. | $2s^22p^5(^2P^\circ_{1/2})3s-2s2p^63s$ | $(^1/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | [128.7] | 3753600 | 4530300 | 3 | 3 | 120 | 0.029 | 0.037 | −1.06 | D | 3 |
| 3. | $2s^22p^53p-2s2p^63p$ | $^3S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [117.1] | 3879300 | 4733300 | 3 | 3 | 130 | 0.028 | 0.032 | −1.08 | E | 3 |
| | | | [117.3] | 3879300 | 4731800 | 3 | 1 | 280 | 0.019 | 0.022 | −1.24 | D | 3 |
| 4. | | $^3D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [120.2] | 3908900 | 4741100 | 7 | 5 | 440 | 0.069 | 0.19 | −0.32 | D | 3 |
| 5. | $2p^6-2p^5(^2P^\circ_{3/2})3s$ | $^1S - (^3/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 26.960 | 0 | 3709200 | 1 | 3 | 3060 | 0.100 | 0.0089 | −1.000 | C− | 1*n* |
| 6. | $2p^6-2p^5(^2P^\circ_{1/2})3s$ | $^1S - (^1/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 26.641 | 0 | 3753600 | 1 | 3 | 4060 | 0.130 | 0.0114 | −0.89 | C− | 1*n* |
| 7. | $2p^6-2p^53d$ | $^1S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | 23.991 | 0 | 4168200 | 1 | 3 | 340 | 0.0088 | 7.0(−4)[a] | −2.06 | E | 1 |
| 8. | | $^1S - {}^3D^\circ$ | | | | | | | | | | | |
| | | | 23.698 | 0 | 4219800 | 1 | 3 | 1.2(+4) | 0.30 | 0.024 | −0.52 | D | 1 |
| 9. | | $^1S - {}^1P^\circ$ | 23.356 | 0 | 4281600 | 1 | 3 | 1.02(+5) | 2.50 | 0.192 | 0.398 | C− | 1 |
| 10. | $2p^5(^2P^\circ_{3/2})3s-2p^53p$ | $(^3/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | 552.115 | 3698200 | 3879300 | 5 | 3 | 18 | 0.048 | 0.44 | −0.62 | D | 3 |
| 11. | | $(^3/_2,^1/_2)^\circ - {}^3D$ | | | | | | | | | | | |
| | | | 474.611 | 3698200 | 3908900 | 5 | 7 | 35 | 0.17 | 1.3 | −0.08 | D | 3 |

Ti XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | $2p^5(^2P^\circ_{1/2})3s-2p^53p$ | $(^1/_2,^1/_2)^\circ$ - $^3S$ | | | | | | | | | | | |
| | | | [745.7] | 3745200 | 3879300 | 1 | 3 | 0.26 | 0.0065 | 0.016 | −2.19 | E | 3 |
| 13. | $2p^53p-2p^53d$ | $^3S$ - $^3P^\circ$ | *341.1* | 3879300 | *4172500* | 3 | 9 | 47 | 0.25 | 0.83 | −0.13 | E | 3 |
| | | | 336.029 | 3879300 | 4176900 | 3 | 5 | 37 | 0.11 | 0.35 | −0.50 | E | 3 |
| | | | 346.163 | 3879300 | 4168200 | 3 | 3 | 55 | 0.099 | 0.34 | −0.53 | D | 3 |
| | | | 351.58 | 3879300 | 4163700 | 3 | 1 | 65 | 0.040 | 0.14 | −0.92 | D | 3 |
| 14. | | $^3D$ - $^3P^\circ$ | | | | | | | | | | | |
| | | | [373.1] | 3908900 | 4176900 | 7 | 5 | 2.7 | 0.0041 | 0.035 | −1.55 | E | 3 |
| 15. | | $^3D$ - $^3F^\circ$ | | | | | | | | | | | |
| | | | 369.531 | 3908900 | 4179500 | 7 | 9 | 67 | 0.18 | 1.5 | 0.09 | D | 3 |
| | | | 362.86 | 3908900 | 4184500 | 7 | 7 | 10 | 0.020 | 0.17 | −0.85 | E | 3 |
| 16. | | $^3P$ - $^3P^\circ$ | | | | | | | | | | | |
| | | | [458.1] | 3949900 | 4168200 | 1 | 3 | 2.0 | 0.019 | 0.028 | −1.73 | D | 3 |
| 17. | | $^3P$ - $^3D^\circ$ | | | | | | | | | | | |
| | | | [370.5] | 3949900 | 4219800 | 1 | 3 | 33 | 0.20 | 0.25 | −0.69 | D | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XIII

## Forbidden Transitions

*A*-values were calculated by Bhatia *et al.*[1] for numerous forbidden transitions within the $2p^53s$, $2p^53p$, and $2p^53d$ configurations, as well as for lines of the $2p^53s-2p^53d$, $2p^6-2p^53s$, and $2p^6-2p^53p$ arrays. Their calculations employed scaled Thomas-Fermi wavefunctions with limited allowance for configuration interaction. A number of these data are quoted here, but the *A*-values were first converted to line strengths, which were then reconverted to transition probabilities by using more accurate wavelengths. Bhatia *et al.* did not indicate which of their results were due to magnetic dipole, and which were due to electric quadrupole, radiation. In those cases where it was impossible to make a definitive determination of the type of radiation solely on the basis of selection rules, the *A*-value could not be converted to a line strength. It appears, however, that the *A*-values quoted for the three transitions within the $2p^53s$ configuration for which the type of transition is not indicated in our tabulation are due to magnetic dipole radiation. Transitions involving levels of the $2p^53p$ and $2p^53d$ configurations which are indicated by Jupen and Litzen[2] or by Fawcett[3] to be of low to moderate purity in *LS* coupling are excluded here, as are very weak lines.

### References

[1]A. K. Bhatia, U. Feldman, and J. F. Seely, At. Data Nucl. Data Tables **32**, 435 (1985).
[2]C. Jupen and U. Litzen, Phys. Scr. **30**, 112 (1984).
[3]B. C. Fawcett, private communication, as quoted in E. Träbert, Z. Phys. A **319**, 25 (1984).

Ti XIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^5(^2P^\circ_{3/2})3s$ - $2p^5(^2P^\circ_{3/2})3s$ | $(^3/_2,^1/_2)^\circ$ - $(^3/_2,^1/_2)^\circ$ | | | | | | | | | | |
| | | | [9090] | 3698200 | 3709200 | 5 | 3 | | 17 | | D+ | 1 |
| 2. | $2p^5(^2P^\circ_{3/2})3s$ - $2p^5(^2P^\circ_{1/2})3s$ | $(^3/_2,^1/_2)^\circ$ - $(^1/_2,^1/_2)^\circ$ | | | | | | | | | | |
| | | | [1810] | 3698200 | 3753600 | 5 | 3 | | 1730 | | C− | 1 |
| | | | [2780] | 3709200 | 3745200 | 3 | 1 | M1 | 1370 | 1.09 | C− | 1 |
| | | | [2250] | 3709200 | 3753600 | 3 | 3 | | 290 | | D+ | 1 |
| 3. | $2p^53d$-$2p^53d$ | $^3P^\circ$ - $^3P^\circ$ | | | | | | | | | | |
| | | | [7570] | 4163700 | 4176900 | 1 | 5 | E2 | 6.5(−4)[a] | 0.048 | E | 1 |
| 4. | | $^3F^\circ$ - $^3D^\circ$ | | | | | | | | | | |
| | | | [2830] | 4184500 | 4219800 | 7 | 3 | E2 | 0.096 | 0.031 | E | 1 |
| 5. | $2p^6$- $2p^5(^2P^\circ_{3/2})3s$ | $^1S$ - $(^3/_2,^1/_2)^\circ$ | | | | | | | | | | |
| | | | [27.040] | 0 | 3698200 | 1 | 5 | M2 | 2.8(+4) | 0.31 | D− | 1 |
| 6. | $2p^5(^2P^\circ_{3/2})3s$ - $2p^53d$ | $(^3/_2,^1/_2)^\circ$ - $^3P^\circ$ | | | | | | | | | | |
| | | | [212.8] | 3698200 | 4168200 | 5 | 3 | | 2.3(+5) | | E | 1 |
| | | | [231.8] | 3709200 | 4176900 | 3 | 5 | | 6.8(+4) | | E | 1 |
| | | | [214.8] | 3698200 | 4163700 | 5 | 1 | E2 | 2.4(+5) | 0.065 | E | 1 |
| 7. | | $(^3/_2,^1/_2)^\circ$ - $^3F^\circ$ | | | | | | | | | | |
| | | | [207.8] | 3698200 | 4179500 | 5 | 9 | E2 | 2.7(+5) | 0.57 | D− | 1 |
| | | | [210.4] | 3709200 | 4184500 | 3 | 7 | E2 | 1.5(+5) | 0.25 | D− | 1 |
| | | | [205.6] | 3698200 | 4184500 | 5 | 7 | | 1.3(+5) | | E | 1 |
| 8. | $2p^5(^2P^\circ_{1/2})3s$ - $2p^53d$ | $(^1/_2,^1/_2)^\circ$ - $^3P^\circ$ | | | | | | | | | | |
| | | | [231.6] | 3745200 | 4176900 | 1 | 5 | E2 | 7600 | 0.015 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XIV

F Isoelectronic Sequence

Ground State: $1s^22s^22p^5\ ^2P^\circ_{3/2}$

Ionization Energy: 863.1 eV = 6961000 $cm^{-1}$

## Allowed Transitions

Oscillator strengths for lines of the multiplet $2s^22p^5\ ^2P^\circ - 2s2p^6\ ^2S$ are the results of the Dirac-Fock calculations of Cheng *et al.*,[1] which included a perturbative treatment of the Breit interaction and the Lamb shift.

For lines of the arrays $2p^5$–$2p^43s$ and $2p^5$–$2p^43d$, we quote the $f$-values calculated by Fawcett[2] using Cowan's Hartree-Fock-Relativistic (HFR) method and incorporating scaling of energy parameters on the basis of a least-squares fit to observed energies. Fawcett's calculations included fairly extensive allowance for configuration mixing in both odd- and even-parity states. Transitions involving levels which are indicated by Fawcett to be of low to moderate purity in *LS* coupling in neighboring fluorinelike ions are excluded from this compilation, as are lines characterized by very small *f*-values.

The ratio of *A*-values for the two resonance lines out of the $2s2p^6\,{}^2S_{1/2}$ level as given in Ref. 1 is in reasonably good agreement with the result of Stratton *et al.*[3] derived from relative-intensity measurements.

## References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]B. C. Fawcett, At. Data Nucl. Data Tables **31**, 495 (1984).

[3]B. C. Stratton, H. W. Moos, S. Suckewer, U. Feldman, J. F. Seely, and A. K. Bhatia, Phys. Rev. A **31**, 2534 (1985).


Ti XIV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5$–$2s2p^6$ | $^2P^\circ$ - $^2S$ | *124.37* | *15740* | 819766 | 6 | 2 | 885 | 0.0684 | 0.168 | −0.387 | C+ | 1 |
| | | | 121.986 | 0 | 819766 | 4 | 2 | 627 | 0.0699 | 0.112 | −0.553 | C+ | 1 |
| | | | 129.440 | 47220 | 819766 | 2 | 2 | 259 | 0.0651 | 0.0555 | −0.885 | C+ | 1 |
| 2. | $2p^5$–$2p^4(^3P)3s$ | $^2P^\circ$ - $^4P$ | | | | | | | | | | | |
| | | | 25.025 | 0 | 3996000 | 4 | 6 | 180 | 0.0025 | 8.2(−4)[a] | −2.00 | E | 2 |
| 3. | | $^2P^\circ$ - $^2P$ | | | | | | | | | | | |
| | | | 24.891 | 47220 | 4064700 | 2 | 2 | 7500 | 0.070 | 0.011 | −0.85 | C− | 2 |
| | | | 24.592 | 0 | 4064700 | 4 | 2 | 6100 | 0.0275 | 0.0089 | −0.96 | C− | 2 |
| 4. | $2p^5$–$2p^4(^1D)3s$ | $^2P^\circ$ - $^2D$ | | | | | | | | | | | |
| | | | 24.315 | 0 | 4112700 | 4 | 6 | 5000 | 0.067 | 0.021 | −0.57 | D | 2 |
| | | | 24.592 | 47220 | 4113600 | 2 | 4 | 5500 | 0.10 | 0.016 | −0.70 | D | 2 |
| 5. | $2p^5$–$2p^4(^1S)3s$ | $^2P^\circ$ - $^2S$ | *23.778* | *15740* | 4221200 | 6 | 2 | 5900 | 0.017 | 0.0078 | −1.00 | E | 2 |
| | | | 23.690 | 0 | 4221200 | 4 | 2 | 2100 | 0.0090 | 0.0028 | −1.44 | E | 2 |
| | | | 23.960 | 47220 | 4221200 | 2 | 2 | 3700 | 0.032 | 0.0050 | −1.19 | D | 2 |
| 6. | $2p^5$–$2p^4(^3P)3d$ | $^2P^\circ$ - $^4P$ | | | | | | | | | | | |
| | | | 22.328 | 0 | 4478700 | 4 | 2 | 5900 | 0.022 | 0.0065 | −1.06 | E | 2 |
| 7. | $2p^5$–$2p^4(^1D)3d$ | $^2P^\circ$ - $^2S$ | *21.90* | *15740* | 4583000 | 6 | 2 | 7.8(+4) | 0.19 | 0.081 | 0.05 | D | 2 |
| | | | 21.82 | 0 | 4583000 | 4 | 2 | 6.4(+4) | 0.23 | 0.066 | −0.04 | D | 2 |
| | | | [22.05] | 47220 | 4583000 | 2 | 2 | 1.4(+4) | 0.10 | 0.015 | −0.70 | D | 2 |
| 8. | | $^2P^\circ$ - $^2F$ | | | | | | | | | | | |
| | | | [21.816] | 0 | 4583700 | 4 | 6 | 4500 | 0.048 | 0.014 | −0.72 | E | 2 |
| 9. | | $^2P^\circ$ - $^2P$ | | | | | | | | | | | |
| | | | [21.733] | 0 | 4601300 | 4 | 4 | 8.8(+4) | 0.62 | 0.18 | 0.39 | D | 2 |
| | | | 21.958 | 47220 | 4601300 | 2 | 4 | 1.2(+4) | 0.18 | 0.026 | −0.44 | D | 2 |
| 10. | | $^2P^\circ$ - $^2D$ | | | | | | | | | | | |
| | | | 21.883 | 47220 | 4617400 | 2 | 4 | 7.0(+4) | 1.0 | 0.14 | 0.30 | D | 2 |
| | | | 21.657 | 0 | 4617400 | 4 | 4 | 1.3(+4) | 0.088 | 0.025 | −0.45 | D | 2 |

Ti XIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11. | $2p^5$–$2p^4(^1S)3d$ | $^2P°$ – $^2D$ | *21.398* | *15740* | *4689100* | 6 | 10 | 2.5(+4) | 0.28 | 0.12 | 0.23 | E | 2 |
| | | | 21.341 | 0 | 4685800 | 4 | 6 | 9800 | 0.10 | 0.028 | −0.40 | D | 2 |
| | | | 21.522 | 47220 | 4694000 | 2 | 4 | 4.5(+4) | 0.62 | 0.088 | 0.09 | D | 2 |
| | | | 21.304 | 0 | 4694000 | 4 | 4 | 960 | 0.0065 | 0.0018 | −1.59 | E | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XIV

## Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $2p^5$ configuration are the results of the Dirac-Fock calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

Ti XIV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^5$–$2p^5$ | $^2P°$ – $^2P°$ | | | | | | | | | | |
| | | | 2117.07 | 0 | 47220 | 4 | 2 | M1 | 1890 | 1.33 | B | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 2 | E2 | 0.091 | 0.0046 | D | 1 |

# Ti XV

O Isoelectronic Sequence

Ground State: $1s^22s^22p^4\ ^3P_2$

Ionization Energy: 941.9 eV = 7597000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 19.970 | 32 | 20.29 | 30 | 20.476 | 23 | 20.60 | 19 |
| 20.074 | 31 | 20.30 | 30 | 20.538 | 22 | 20.63 | 19 |
| 20.19 | 29 | 20.313 | 23 | 20.54 | 22 | 20.65 | 33 |
| 20.234 | 24,31 | 20.36 | 29 | 20.551 | 22 | 20.689 | 28 |
| 20.246 | 31 | 20.374 | 22 | 20.56 | 20 | 20.698 | 38 |
| 20.250 | 35 | 20.418 | 21 | 20.58 | 34 | 20.771 | 27 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 20.80 | 19 | 22.21 | 14 | 22.739 | 11 | 131.146 | 6 |
| 20.882 | 26 | 22.30 | 14 | 22.936 | 13 | 134.609 | 1 |
| 20.893 | 18 | 22.32 | 14 | 22.966 | 10 | 138.357 | 1 |
| 20.897 | 18 | 22.33 | 14 | 23.034 | 17 | 140.395 | 1 |
| 20.928 | 18 | 22.378 | 12 | 23.177 | 10 | 142.130 | 1 |
| 20.982 | 37 | 22.464 | 11 | 23.193 | 10 | 142.750 | 1 |
| 21.03 | 25 | 22.482 | 16 | 23.20 | 9 | 147.436 | 8 |
| 21.04 | 36 | 22.518 | 11 | 102.247 | 2 | 148.588 | 1 |
| 21.065 | 18 | 22.56 | 15 | 106.53 | 2 | 165.690 | 3 |
| 21.079 | 18 | 22.576 | 12 | 106.874 | 2 | 189.62 | 5 |
| 21.102 | 18 | 22.66 | 15 | 109.48 | 7 | | |
| 22.02 | 14 | 22.724 | 11 | 115.031 | 4 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^4$–$2s2p^5$ and $2s2p^5$–$2p^6$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. The results should be quite accurate, except in the case of weak lines. (The $2s^22p^4\ {}^1D_2 - 2s2p^5\ {}^3P^\circ_1$ transition has been omitted from this tabulation, because its $f$-value as reported in Ref. 1 is extremely small, and thus very uncertain.)

Transition probabilities for lines of the $2s^22p^4$–$2s2p^5$ array were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis set included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these two sources are in reasonably good agreement, particularly for the stronger transitions.

The $A$-value for the $2p^4\ {}^3P_2 - 2p^3\,({}^4S^\circ)3s\ {}^5S^\circ_2$ transition is taken from the scaled Thomas-Fermi approach of Kastner *et al.*[3] with configuration interaction and relativistic effects. For all other lines of the $2p^4$–$2p^33s$ array, and for lines of the $2p^4$–$2p^33d$ array, we quote the $f$-values calculated by Fawcett[4] using Cowan's Hartree-Fock-Relativistic (HFR) method and incorporating scaling of energy parameters on the basis of a least-squares fit to observed energies. Fawcett's calculations included fairly extensive allowance for configuration mixing in both odd- and even-parity states. The weakest lines were not reported, and thus are not tabulated here. Transitions involving levels which are indicated by Fawcett to be of low to moderate purity in $LS$ coupling in neighboring oxygenlike ions are excluded from this compilation.

## References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, J. Phys. B **17**, 943 (1984).

[3]S. O. Kastner, A. K. Bhatia, and L. Cohen, Phys. Scr. **15**, 259 (1977).

[4]B. C. Fawcett, At. Data Nucl. Data Tables **34**, 215 (1986).


Ti XV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^4$–$2s2p^5$ | ${}^3P - {}^3P^\circ$ | *140.80* | *17802* | *728015* | 9 | 9 | 380 | 0.11 | 0.47 | 0.01 | C | 1 |
| | | | 140.395 | 0 | 712285 | 5 | 5 | 280 | 0.082 | 0.19 | −0.39 | C | 1 |
| | | | 142.130 | 39292 | 742882 | 3 | 3 | 93 | 0.0282 | 0.0396 | −1.073 | C | 1 |
| | | | 134.609 | 0 | 742882 | 5 | 3 | 191 | 0.0311 | 0.069 | −0.81 | C | 1 |
| | | | 138.357 | 39292 | 762060 | 3 | 1 | 410 | 0.0392 | 0.054 | −0.93 | C | 1 |
| | | | 148.588 | 39292 | 712285 | 3 | 5 | 82 | 0.0452 | 0.066 | −0.87 | C | 1 |
| | | | 142.750 | 42345 | 742882 | 1 | 3 | 118 | 0.108 | 0.051 | −0.97 | C | 1 |
| 2. | | ${}^3P - {}^1P^\circ$ | | | | | | | | | | | |
| | | | 102.247 | 0 | 978030 | 5 | 3 | 51 | 0.0048 | 0.0081 | −1.62 | E | 1 |
| | | | [106.53] | 39292 | 978030 | 3 | 3 | 2.2 | 3.8(−4)[a] | 4.0(−4) | −2.94 | E | 1 |
| | | | 106.874 | 42345 | 978030 | 1 | 3 | 5.1 | 0.0026 | 9.1(−4) | −2.59 | E | 1 |

Ti XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | | $^1$D - $^3$P° | | | | | | | | | | | |
| | | | 165.690 | 108720 | 712285 | 5 | 5 | 8.5 | 0.0035 | 0.0095 | −1.76 | E | 1 |
| 4. | | $^1$D - $^1$P° | 115.031 | 108720 | 978030 | 5 | 3 | 1150 | 0.137 | 0.259 | −0.164 | C | 1 |
| 5. | | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [189.62] | 215521 | 742882 | 1 | 3 | 2.7 | 0.0043 | 0.0027 | −2.37 | E | 1 |
| 6. | | $^1$S - $^1$P° | 131.146 | 215521 | 978030 | 1 | 3 | 84 | 0.065 | 0.028 | −1.19 | C | 1 |
| 7. | $2s2p^5$–$2p^6$ | $^3$P° - $^1$S | | | | | | | | | | | |
| | | | [109.48] | 742882 | 1656290 | 3 | 1 | 27 | 0.0016 | 0.0017 | −2.32 | E | 1 |
| 8. | | $^1$P° - $^1$S | 147.436 | 978030 | 1656290 | 3 | 1 | 1200 | 0.130 | 0.189 | −0.409 | C | 1 |
| 9. | $2p^4$–$2p^3$($^4$S°)$3s$ | $^3$P - $^5$S° | | | | | | | | | | | |
| | | | [23.20] | | | 5 | 5 | 48 | 3.9(−4) | 1.5(−4) | −2.71 | E | 3 |
| 10. | $2p^4$–$2p^3$($^2$D°)$3s$ | $^3$P - $^3$D° | *23.060* | *17802* | 4354300 | 9 | 3 | 1.8(+4) | 0.047 | 0.032 | −0.38 | C− | 4 |
| | | | 22.966 | 0 | 4354300 | 5 | 3 | 1.1(+4) | 0.054 | 0.020 | −0.57 | C− | 4 |
| | | | 23.177 | 39292 | 4354300 | 3 | 3 | 4680 | 0.0377 | 0.0086 | −0.95 | C− | 4 |
| | | | 23.193 | 42345 | 4354300 | 1 | 3 | 2000 | 0.049 | 0.0037 | −1.31 | C− | 4 |
| 11. | $2p^4$ – $2p^3$($^2$D°)$3s$ | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 22.464 | 0 | 4451600 | 5 | 7 | 5200 | 0.055 | 0.020 | −0.56 | C− | 4 |
| | | | 22.724 | 39292 | 4440900 | 3 | 5 | 1800 | 0.023 | 0.0052 | −1.16 | D | 4 |
| | | | 22.739 | 42345 | 4440000 | 1 | 3 | 1500 | 0.034 | 0.0025 | −1.47 | C− | 4 |
| | | | 22.518 | 0 | 4440900 | 5 | 5 | 3700 | 0.028 | 0.010 | −0.85 | D | 4 |
| | | | [22.724] | 39292 | 4440000 | 3 | 3 | 3900 | 0.030 | 0.0067 | −1.05 | C− | 4 |
| 12. | | $^3$P - $^1$D° | | | | | | | | | | | |
| | | | [22.378] | 0 | 4468700 | 5 | 5 | 640 | 0.0048 | 0.0018 | −1.62 | E | 4 |
| | | | [22.576] | 39292 | 4468700 | 3 | 5 | 860 | 0.011 | 0.0025 | −1.48 | E | 4 |
| 13. | | $^1$D - $^1$D° | 22.936 | 108720 | 4468700 | 5 | 5 | 1.1(+4) | 0.090 | 0.034 | −0.35 | C− | 4 |
| 14. | $2p^4$ - $2p^3$($^2$P°)$3s$ | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | [22.02] | | | 5 | 5 | 1200 | 0.0090 | 0.0033 | −1.35 | D− | 4 |
| | | | [22.30] | | | 3 | 3 | 980 | 0.0073 | 0.0016 | −1.66 | D | 4 |
| | | | [22.33] | | | 3 | 1 | 5200 | 0.013 | 0.0029 | −1.41 | C | 4 |
| | | | [22.21] | | | 3 | 5 | 2800 | 0.034 | 0.0075 | −0.99 | D | 4 |
| | | | [22.32] | | | 1 | 3 | 3100 | 0.070 | 0.0051 | −1.15 | C | 4 |
| 15. | | $^1$D - $^3$P° | | | | | | | | | | | |
| | | | [22.56] | | | 5 | 5 | 2500 | 0.019 | 0.0071 | −1.02 | E | 4 |
| | | | [22.66] | | | 5 | 3 | 1300 | 0.0058 | 0.0022 | −1.54 | E | 4 |
| 16. | | $^1$D - $^1$P° | 22.482 | 108720 | 4556900 | 5 | 3 | 6400 | 0.029 | 0.011 | −0.84 | D | 4 |
| 17. | | $^1$S - $^1$P° | 23.034 | 215521 | 4556900 | 1 | 3 | 6300 | 0.15 | 0.011 | −0.82 | D | 4 |

Ti XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18. | $2p^4 - 2p^3(^4S°)3d$ | $^3P - ^3D°$ | *20.985* | *17802* | *4783200* | 9 | 15 | 2.6(+4) | 0.29 | 0.18 | 0.42 | D | 4 |
| | | | 20.897 | 0 | 4785400 | 5 | 7 | 2.85(+4) | 0.261 | 0.090 | 0.116 | C− | 4 |
| | | | 21.102 | 39292 | 4778200 | 3 | 5 | 1.3(+4) | 0.15 | 0.031 | −0.35 | D | 4 |
| | | | 21.079 | 42345 | 4786400 | 1 | 3 | 1.58(+4) | 0.316 | 0.0291 | −0.50 | C− | 4 |
| | | | [20.928] | 0 | 4778200 | 5 | 5 | 8400 | 0.055 | 0.019 | −0.56 | D | 4 |
| | | | [21.065] | 39292 | 4786400 | 3 | 3 | 1.1(+4) | 0.072 | 0.015 | −0.67 | C− | 4 |
| | | | [20.893] | 0 | 4786400 | 5 | 3 | 1100 | 0.0042 | 0.0014 | −1.68 | D | 4 |
| 19. | $2p^4 - 2p^3(^2D°)3d$ | $^3P - ^3F°$ | | | | | | | | | | | |
| | | | [20.60] | | | 5 | 7 | 4400 | 0.039 | 0.013 | −0.71 | E | 4 |
| | | | [20.80] | | | 3 | 5 | 1900 | 0.020 | 0.0041 | −1.22 | E | 4 |
| | | | [20.63] | | | 5 | 5 | 1900 | 0.012 | 0.0041 | −1.22 | E | 4 |
| 20. | | $^3P - ^3G°$ | | | | | | | | | | | |
| | | | [20.56] | | | 5 | 7 | 1800 | 0.016 | 0.0054 | −1.10 | E | 4 |
| 21. | $2p^4 - 2p^3(^2D°)3d$ | $^3P - ^3D°$ | | | | | | | | | | | |
| | | | 20.418 | 0 | 4897600 | 5 | 7 | 8.0(+4) | 0.70 | 0.24 | 0.54 | C− | 4 |
| 22. | | $^3P - ^3P°$ | | | | | | | | | | | |
| | | | 20.538 | 39292 | 4908300 | 3 | 3 | 3.8(+4) | 0.24 | 0.049 | −0.14 | D | 4 |
| | | | [20.374] | 0 | 4908300 | 5 | 3 | 2400 | 0.0088 | 0.0030 | −1.36 | D− | 4 |
| | | | [20.54] | | | 3 | 1 | 4.1(+4) | 0.086 | 0.017 | −0.59 | C− | 4 |
| | | | [20.551] | 42345 | 4908300 | 1 | 3 | 1.3(+4) | 0.24 | 0.0016 | −0.62 | D | 4 |
| 23. | | $^3P - ^3S°$ | | | | | | | | | | | |
| | | | 20.313 | 0 | 492300 | 5 | 3 | 7.5(+4) | 0287 | 0.094 | 0.15 | D | 4 |
| | | | [20.476] | 39292 | 492300 | 3 | 3 | 2700 | 0.017 | 0.0034 | −1.29 | D | 4 |
| 24. | | $^3P - ^1F°$ | | | | | | | | | | | |
| | | | [20.234] | 0 | 4942200 | 5 | 7 | 1.9(+4) | 0.16 | 0.053 | −0.10 | E | 4 |
| 25. | $2p^4 - 2p^3(^2D°)3d$ | $^1D - ^3G°$ | | | | | | | | | | | |
| | | | [21.03] | | | 5 | 7 | 900 | 0.0084 | 0.0029 | −1.38 | E | 4 |
| 26. | | $^1D - ^3D°$ | | | | | | | | | | | |
| | | | [20.882] | 108720 | 4897600 | 5 | 7 | 960 | 0.0088 | 0.0030 | −1.36 | E | 4 |
| 27. | | $^1P - ^1F°$ | [20.771] | 108720 | 4923000 | 5 | 3 | 1.1(+4) | 0.041 | 0.014 | −0.69 | E | 4 |
| 28. | | $^1D - ^1F°$ | 20.689 | 108720 | 4942200 | 5 | 7 | 4.3(+4) | 0.39 | 0.13 | 0.29 | D | 4 |
| 29. | $2p^4 - 2p^3(^2P°)3d$ | | | | | | | | | | | | |
| | | | [20.19] | | | 5 | 7 | 6900 | 0.059 | 0.020 | −0.53 | E | 4 |
| | | | [20.36] | | | 3 | 5 | 2800 | 0.029 | 0.0058 | −1.06 | E | 4 |
| 30. | | $^3P - ^3P°$ | | | | | | | | | | | |
| | | | [20.29] | | | 3 | 3 | 1.1(+4) | 0.068 | 0.014 | −0.69 | D | 4 |
| | | | [20.30] | | | 1 | 1 | 5.8(+4) | 0.119 | 0.0239 | −0.447 | C− | 4 |
| | | | [20.30] | | | 1 | 3 | 3.4(+4) | 0.63 | 0.042 | −0.20 | D | 4 |

Ti XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31. | $2p^4 - 2p^3(^2D^\circ)3d$ | $^3P - {}^3D^\circ$ | | | | | | | | | | | |
| | | | [20.246] | 42345 | 4981500 | 1 | 3 | 4.2(+4) | 0.78 | 0.052 | −0.11 | C− | 4 |
| | | | 20.234 | 39292 | 4981500 | 3 | 3 | 4.90+4) | 0.301 | 0.060 | −0.044 | C− | 4 |
| | | | [20.074] | 0 | 4981500 | 5 | 3 | 1200 | 0.0042 | 0.0014 | −1.68 | D | 4 |
| 32. | | $^3P - {}^1P^\circ$ | | | | | | | | | | | |
| | | | [19.970] | 39292 | 5046900 | 3 | 3 | 1300 | 0.0080 | 0.0016 | −1.62 | E | 4 |
| 33. | | $^1D - {}^3F^\circ$ | | | | | | | | | | | |
| | | | [20.65] | | | 5 | 5 | 4800 | 0.031 | 0.011 | −0.81 | E | 4 |
| 34. | | $^1D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [20.58] | | | 5 | 3 | 2900 | 0.011 | 0.0037 | −1.26 | E | 4 |
| 35. | | $^1S - {}^3D^\circ$ | [20.250] | 108720 | 5046900 | 5 | 3 | 6500 | 0.024 | 0.0080 | −0.92 | D | 4 |
| 36. | $2p^4 - 2p^3(^2P^\circ)3d$ | $^1S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [21.04] | | | 1 | 3 | 1300 | 0.025 | 0.0017 | −1.60 | E | 4 |
| 37. | | $^1S - {}^3D^\circ$ | | | | | | | | | | | |
| | | | [20.982] | 215521 | 4981500 | 1 | 3 | 1600 | 0.032 | 0.0022 | −1.49 | E | 4 |
| 38. | | $^1S - {}^1P^\circ$ | 20.698 | 215521 | 5046900 | 1 | 3 | 1.1(+5) | 2.2 | 0.15 | 0.34 | D | 4 |

[a]The number in parenthesis following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Ti XV

### Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^4$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

Transition probabilities for these same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these data are in quite good agreement with the data of Cheng *et al.* For this ion of the oxygen isoelectronic sequence, correlation effects due to mixing with configurations outside the complex were found by Froese Fischer and Saha to be rather small, as shown by a comparison of the results of their calculations employing an extensive basis to those derived by the same technique but limited to configurations within the $n=2$ complex.

*A*-values for forbidden transitions within the $2s2p^5$ configuration, and for transitions of the $2s^22p^4$–$2p^6$ array, were calculated by Bhatia *et al.*[3] using scaled Thomas-Fermi wavefunctions with allowance for configuration interaction and relativistic effects. We utilized their M1 and E2 line strength data, which were communicated to us by Bhatia,[4] and we converted these to *A*-values with wavelengths derived from experimental data. This approach normally yields transition probabilities that are more accurate than those based on calculated wavelengths (as published in Ref. 3).

The weakest lines are excluded from this compilation, as their transition probabilities are considered to be very uncertain. (This applies to all lines of the $2s^22p^4$–$2p^6$ array.)

## References

[1]K. T. Cheng, Y.-K Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).
[3]A. K. Bhatia, U. Feldman, and G. A. Doschek, J. Appl. Phys. **51**, 1464 (1980).
[4]A. K. Bhatia, private communication (1986).


Ti XV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^4$–$2p^4$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | 2545.08 | 0 | 39292 | 5 | 3 | M1 | 1290 | 2.37 | C+ | 1 |
| | | | " | " | " | 5 | 3 | E2 | 0.024 | 0.0045 | E | 1 |
| | | | [32750] | 39292 | 42345 | 3 | 1 | M1 | 1.40 | 1.82 | C+ | 1 |
| | | | [2360.8] | 0 | 42345 | 5 | 1 | E2 | 0.055 | 0.0024 | E | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | 919.73 | 0 | 108720 | 5 | 5 | M1 | 2400 | 0.35 | D | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.77 | 0.0015 | E | 1 |
| | | | 1440.2 | 39292 | 108720 | 3 | 5 | M1 | 220 | 0.12 | D | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [567.44] | 39292 | 215521 | 3 | 1 | M1 | 2.5(+4)[a] | 0.17 | D | 1 |
| 4. | | $^1$D - $^1$S | [936.32] | 108720 | 215521 | 5 | 1 | E2 | 18 | 0.0078 | E | 1 |
| 5. | $2s2p^5$–$2s2p^5$ | $^3$P° - $^3$P° | | | | | | | | | | |
| | | | [3267.4] | 712285 | 742882 | 5 | 3 | M1 | 640 | 2.48 | C | 3,4 |
| | | | [5212.9] | 742882 | 762060 | 3 | 1 | M1 | 377 | 1.98 | C | 3,4 |
| | | | [2008.4] | 712285 | 762060 | 5 | 1 | E2 | 0.11 | 0.0022 | E | 3,4 |
| 6. | | $^3$P° - $^1$P° | | | | | | | | | | |
| | | | [376.30] | 712285 | 978030 | 5 | 3 | M1 | 3700 | 0.022 | D− | 3,4 |
| | | | [425.26] | 742882 | 978030 | 3 | 3 | M1 | 1500 | 0.013 | D− | 3,4 |
| | | | [463.03] | 762060 | 978030 | 1 | 3 | M1 | 1600 | 0.018 | D− | 3,4 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XVI

N Isoelectronic Sequence

Ground State: $1s^22s^22p^3\ ^4S^\circ_{3/2}$

Ionization Energy: 1044 eV = 8420000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 97.991 | 4 | 121.538 | 12 | 143.459 | 6 | 169.740 | 1 |
| 102.393 | 4 | 122.99 | 2 | 145.665 | 6 | 176.267 | 16 |
| 104.80 | 13 | 124.805 | 12 | 146.55 | 6 | 178.240 | 16 |
| 105.43 | 13 | 128.373 | 12 | 154.34 | 15 | 193.19 | 5 |
| 106.39 | 3 | 129.075 | 14 | 157.812 | 1 | 193.36 | 16 |
| 109.03 | 13 | 132.022 | 12 | 161.168 | 1 | 211.37 | 5 |
| 110.561 | 8 | 134.724 | 11 | 162.503 | 10 | 218.14 | 5 |
| 110.62 | 13 | 138.020 | 14 | 163.610 | 16 | 229.38 | 9 |
| 116.198 | 8 | 138.760 | 11 | 167.242 | 10 | 249.24 | 9 |
| 118.215 | 8 | 138.800 | 14 | 167.297 | 15 | 270.35 | 9 |
| 121.382 | 7 | 142.62 | 6 | 168.40 | 10 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^3$–$2s2p^4$ and $2s2p^4$–$2p^5$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

## Reference

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

Ti XVI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^3$–$2s2p^4$ | $^4$S° - $^4$P | *164.74* | 0 | *607000* | 4 | 12 | 110 | 0.14 | 0.30 | −0.26 | C | 1 |
| | | | 169.740 | 0 | 589140 | 4 | 6 | 100 | 0.066 | 0.15 | −0.58 | C | 1 |
| | | | 161.168 | 0 | 620470 | 4 | 4 | 120 | 0.0469 | 0.100 | −0.73 | C | 1 |
| | | | 157.812 | 0 | 633660 | 4 | 2 | 132 | 0.0246 | 0.051 | −1.007 | C | 1 |
| 2. | | $^4$S° - $^2$D | | | | | | | | | | | |
| | | | [122.99] | 0 | 813080 | 4 | 4 | 1.7 | 3.8(−4)[a] | 6.2(−4) | −2.82 | E | 1 |
| 3. | | $^4$S° - $^2$S | | | | | | | | | | | |
| | | | [106.39] | 0 | 939920 | 4 | 2 | 4.1 | 3.5(−4) | 4.9(−4) | −2.85 | E | 1 |
| 4. | | $^4$S° - $^2$P | | | | | | | | | | | |
| | | | 102.393 | 0 | 976650 | 4 | 4 | 12 | 0.0019 | 0.0026 | −2.12 | E | 1 |
| | | | [97.991] | 0 | 1020500 | 4 | 2 | 1.5 | 1.1(−4) | 1.4(−4) | −3.36 | E | 1 |
| 5. | | $^2$D° - $^4$P | | | | | | | | | | | |
| | | | [218.14] | 130720 | 589140 | 6 | 6 | 0.73 | 5.2(−4) | 0.0022 | −2.51 | E | 1 |
| | | | [193.19] | 116030 | 633660 | 4 | 2 | 0.43 | 1.2(−4) | 3.1(−4) | −3.32 | E | 1 |
| | | | [211.37] | 116030 | 589140 | 4 | 6 | 0.96 | 9.6(−4) | 0.0027 | −2.42 | E | 1 |
| 6. | | $^2$D° - $^2$D | *144.78* | *124840* | *815560* | 10 | 10 | 250 | 0.078 | 0.37 | −0.11 | C− | 1 |
| | | | 145.665 | 130720 | 817210 | 6 | 6 | 230 | 0.074 | 0.21 | −0.35 | C | 1 |
| | | | 143.459 | 116030 | 813080 | 4 | 4 | 280 | 0.085 | 0.16 | −0.47 | C | 1 |
| | | | [146.55] | 130720 | 813080 | 6 | 4 | 6.1 | 0.0013 | 0.0038 | −2.11 | D | 1 |
| | | | [142.62] | 116030 | 817210 | 4 | 6 | 0.26 | 1.2(−4) | 2.3(−4) | −3.32 | E | 1 |
| 7. | | $^2$D° - $^2$S | | | | | | | | | | | |
| | | | 121.382 | 116030 | 939920 | 4 | 2 | 240 | 0.026 | 0.042 | −0.98 | E | 1 |
| 8. | | $^2$D° - $^2$P | *115.42* | *124840* | *991270* | 10 | 6 | 730 | 0.088 | 0.333 | −0.057 | C | 1 |
| | | | 118.215 | 130720 | 976650 | 6 | 4 | 740 | 0.104 | 0.243 | −0.205 | C | 1 |
| | | | 110.561 | 116030 | 1020500 | 4 | 2 | 336 | 0.0308 | 0.0448 | −0.91 | C | 1 |
| | | | 116.198 | 116030 | 976650 | 4 | 4 | 145 | 0.0294 | 0.0450 | −0.93 | C | 1 |
| 9. | | $^2$P° - $^4$P | | | | | | | | | | | |
| | | | [270.35] | 219250 | 589140 | 4 | 6 | 0.17 | 2.8(−4) | 0.0010 | −2.95 | E | 1 |
| | | | [249.24] | 219250 | 620470 | 4 | 4 | 0.63 | 5.9(−4) | 0.0019 | −2.63 | E | 1 |
| | | | [229.38] | 197700 | 633660 | 2 | 2 | 0.41 | 3.2(−4) | 4.8(−4) | −3.19 | E | 1 |
| 10. | | $^2$P° - $^2$D | *165.70* | *212070* | *815560* | 6 | 10 | 40 | 0.027 | 0.090 | −0.78 | C− | 1 |
| | | | 167.242 | 219250 | 817210 | 4 | 6 | 46.4 | 0.0292 | 0.064 | −0.93 | C | 1 |
| | | | 162.503 | 197700 | 813080 | 2 | 4 | 26.1 | 0.0207 | 0.0221 | −1.383 | C | 1 |
| | | | [168.40] | 219250 | 813080 | 4 | 4 | 4.2 | 0.0018 | 0.0040 | −2.14 | D | 1 |

Ti XVI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11. | | $^2P^o - ^2S$ | *137.39* | *212070* | 939920 | 6 | 2 | 330 | 0.031 | 0.085 | −0.73 | C | 1 |
| | | | 138.760 | 219250 | 939920 | 4 | 2 | 84 | 0.0121 | 0.0221 | −1.315 | C | 1 |
| | | | 134.724 | 197700 | 939920 | 2 | 2 | 260 | 0.071 | 0.063 | −0.85 | C | 1 |
| 12. | | $^2P^o - ^2P$ | *128.34* | *212070* | *991270* | 6 | 6 | 300 | 0.075 | 0.19 | −0.35 | C | 1 |
| | | | 132.022 | 219250 | 976650 | 4 | 4 | 87 | 0.0228 | 0.0396 | −1.040 | C | 1 |
| | | | 121.538 | 197700 | 1020500 | 2 | 2 | 56 | 0.0123 | 0.0098 | −1.61 | C | 1 |
| | | | 124.805 | 219250 | 1020500 | 4 | 2 | 610 | 0.071 | 0.12 | −0.55 | C | 1 |
| | | | 128.373 | 197700 | 976650 | 2 | 4 | 54 | 0.0269 | 0.0227 | −1.269 | C | 1 |
| 13. | $2s2p^4-2p^5$ | $^4P - ^2P^o$ | | | | | | | | | | | |
| | | | [105.43] | 589140 | 1537660 | 6 | 4 | 8.7 | 9.7(−4) | 0.0020 | −2.24 | E | 1 |
| | | | [109.03] | 620470 | 1537660 | 4 | 4 | 3.3 | 5.8(−4) | 8.3(−4) | −2.63 | E | 1 |
| | | | [104.80] | 633660 | 1587830 | 2 | 2 | 2.9 | 4.8(−4) | 3.3(−4) | −3.02 | E | 1 |
| | | | [110.62] | 633660 | 1537660 | 2 | 4 | 1.1 | 3.9(−4) | 2.8(−4) | −3.11 | E | 1 |
| 14. | | $^2D - ^2P^o$ | *135.35* | *815560* | *1554380* | 10 | 6 | 420 | 0.070 | 0.31 | −0.16 | C | 1 |
| | | | 138.800 | 817210 | 1537660 | 6 | 4 | 350 | 0.067 | 0.18 | −0.40 | C | 1 |
| | | | 129.075 | 813080 | 1587830 | 4 | 2 | 381 | 0.0476 | 0.081 | −0.72 | C | 1 |
| | | | 138.020 | 813080 | 1537660 | 4 | 4 | 88 | 0.0251 | 0.0456 | −1.000 | C | 1 |
| 15. | | $^2S - ^2P^o$ | *162.74* | 939920 | *1554380* | 2 | 6 | 41 | 0.049 | 0.052 | −1.01 | D− | 1 |
| | | | 167.297 | 939920 | 1537660 | 2 | 4 | 55 | 0.0460 | 0.051 | −1.036 | C | 1 |
| | | | [154.34] | 939920 | 1587830 | 2 | 2 | 1.8 | 6.6(−4) | 6.7(−4) | −2.88 | E | 1 |
| 16. | | $^2P - ^2P^o$ | *177.59* | *991270* | *1554380* | 6 | 6 | 320 | 0.15 | 0.53 | −0.04 | C | 1 |
| | | | 178.240 | 976650 | 1537660 | 4 | 4 | 252 | 0.120 | 0.282 | −0.319 | C | 1 |
| | | | 176.267 | 1020500 | 1587830 | 2 | 2 | 245 | 0.114 | 0.132 | −0.64 | C | 1 |
| | | | 163.610 | 976650 | 1587830 | 4 | 2 | 192 | 0.0386 | 0.083 | −0.81 | C | 1 |
| | | | [193.36] | 1020500 | 1537660 | 2 | 4 | 22.7 | 0.0255 | 0.0325 | −1.292 | C | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XVI

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 313.04 | 8 | 519.18 | 7 | 1129.2 | 4 | 2722 | 12 |
| 438.46 | 7 | 557.35 | 7 | 1224.1 | 4 | 3191 | 6 |
| 456.10 | 2 | 611.36 | 11 | 1241 | 12 | 4639 | 5 |
| 482.11 | 11 | 627.20 | 11 | 1493 | 4 | 6805 | 3 |
| 491.91 | 11 | 814.93 | 10 | 1993 | 14 | 7579 | 6 |
| 505.82 | 2 | 861.85 | 1 | 2245 | 6 | 24200 | 9 |
| 508.29 | 7 | 968.80 | 4 | 2280 | 13 | | |

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^3$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in

Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. The weakest lines are excluded from this compilation, as their strengths are considered to be very uncertain.

$A$-values for forbidden transitions within the $2s2p^4$ configuration, for transitions of the $2s^22p^3$–$2p^5$ array, and for the M1 component of the single transition within the $2p^5$ configuration were calculated by Bhatia *et al.*[2] using scaled Thomas-Fermi wavefunctions with allowance for configuration interaction and relativistic effects. We utilized their M1 and E2 line strength data, which were communicated to us by Bhatia,[3] and we converted these to $A$-values with wavelengths derived from experimental data. This approach normally yields transition probabilities that are more accurate than those based on calculated wavelengths (as published in Ref. 2). The weakest lines are excluded from the compilation. (This applies to all lines of the $2s^22p^3$–$2p^5$ array.)

The $A$-value quoted here for the E2 component of the transition within the $2p^5$ configuration was obtained by applying a $Z$-expansion formula published by Oboladze and Safronova.[4] Their value for the magnetic dipole contribution to this line is in very good agreement with the result of Ref. 2. It is not clear whether Oboladze and Safronova incorporated configuration interaction into their calculations. Thus the $A$-value of the E2 contribution should be considered rather uncertain.

## References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]A. K. Bhatia, U. Feldman, and G. A. Doschek, J. Appl. Phys. **51**, 1464 (1980).
[3]A. K. Bhatia, private communication (1986).
[4]N. S. Obladze and U. I. Safronova, Opt. Spectrosc. (USSR) **48**, 469 (1980).

Ti XVI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^3$–$2p^3$ | $^4S°$ - $^2D°$ | | | | | | | | | | |
| | | | [861.85] | 0 | 116030 | 4 | 4 | M1 | 2000 | 0.19 | D | 1 |
| 2. | | $^4S°$ - $^2P°$ | | | | | | | | | | |
| | | | [456.10] | 0 | 219250 | 4 | 4 | M1 | 7800 | 0.11 | D | 1 |
| | | | [505.82] | 0 | 197700 | 4 | 2 | M1 | 4900 | 0.047 | D− | 1 |
| 3. | | $^2D°$ - $^2D°$ | | | | | | | | | | |
| | | | [6805] | 116030 | 130720 | 4 | 6 | M1 | 28.1 | 1.97 | C | 1 |
| | | | " | " | " | 4 | 6 | E2 | 5.0(−5)[a] | 0.0026 | E | 1 |
| 4. | | $^2D°$ - $^2P°$ | | | | | | | | | | |
| | | | [1493] | 130720 | 197700 | 6 | 2 | E2 | 0.52 | 0.0046 | E | 1 |
| | | | 1129.2 | 130720 | 219250 | 6 | 4 | M1 | 2000 | 0.43 | D | 1 |
| | | | " | " | " | 6 | 4 | E2 | 3.0 | 0.013 | E | 1 |
| | | | 1224.1 | 116030 | 197700 | 4 | 2 | M1 | 1600 | 0.22 | D | 1 |
| | | | " | " | " | 4 | 2 | E2 | 1.7 | 0.0057 | E | 1 |
| | | | 968.9 | 116030 | 219250 | 4 | 4 | M1 | 5200 | 0.70 | D | 1 |
| | | | " | " | " | 4 | 4 | E2 | 1.4 | 0.0028 | E | 1 |
| 5. | | $^2P°$ - $^2P°$ | | | | | | | | | | |
| | | | 4635.6 | 197700 | 219250 | 2 | 4 | M1 | 72 | 1.06 | C | 1 |
| | | | " | " | " | 2 | 4 | E2 | 2.2(−4) | 0.0011 | E | 1 |
| 6. | $2s2p^4$–$2s2p^4$ | $^4P$ - $^4P$ | | | | | | | | | | |
| | | | [3191] | 589140 | 620470 | 6 | 4 | M1 | 740 | 3.58 | C | 2,3 |
| | | | [7579] | 620470 | 633660 | 4 | 2 | M1 | 101 | 3.27 | C | 2,3 |
| | | | [2245] | 589140 | 633660 | 6 | 2 | E2 | 0.054 | 0.0037 | E | 2,3 |
| 7. | | $^4P$ - $^2D$ | | | | | | | | | | |
| | | | [438.46] | 589140 | 817210 | 6 | 6 | M1 | 4700 | 0.088 | D | 2,3 |
| | | | [519.18] | 620470 | 813080 | 4 | 4 | M1 | 1800 | 0.038 | D | 2,3 |
| | | | [508.29] | 620470 | 817210 | 4 | 6 | M1 | 440 | 0.013 | D | 2,3 |
| | | | [557.35] | 633660 | 813080 | 2 | 4 | M1 | 340 | 0.010 | D− | 2,3 |

Ti XVI: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^4P - {}^2S$ | | | | | | | | | | |
| | | | [313.04] | 620470 | 939920 | 4 | 2 | M1 | 2.1(+4) | 0.047 | D | 2,3 |
| 9. | | $^2D - {}^2D$ | | | | | | | | | | |
| | | | [24200] | 813080 | 817210 | 4 | 6 | M1 | 0.76 | 2.4 | D | 2,3 |
| 10. | | $^2D - {}^2S$ | | | | | | | | | | |
| | | | [814.93] | 817210 | 939920 | 6 | 2 | E2 | 20 | 0.0084 | E | 2,3 |
| 11. | | $^2D - {}^2P$ | | | | | | | | | | |
| | | | [491.91] | 817210 | 1020500 | 6 | 2 | E2 | 35 | 0.0012 | D− | 2,3 |
| | | | [627.20] | 817210 | 976650 | 6 | 4 | M1 | 1000 | 0.037 | D− | 2,3 |
| | | | [482.11] | 813080 | 1020500 | 4 | 2 | M1 | 2500 | 0.021 | D− | 2,3 |
| | | | [611.36] | 813080 | 976650 | 4 | 4 | M1 | 2100 | 0.072 | D− | 2,3 |
| 12. | | $^2S - {}^2P$ | | | | | | | | | | |
| | | | [2722] | 939920 | 976650 | 2 | 4 | M1 | 53 | 0.16 | D | 2,3 |
| | | | [1241] | 939920 | 1020500 | 2 | 2 | M1 | 2000 | 0.29 | D | 2,3 |
| 13. | | $^2P - {}^2P$ | | | | | | | | | | |
| | | | [2280] | 976650 | 1020500 | 4 | 2 | M1 | 1400 | 1.2 | C | 2,3 |
| 14. | $2p^5–2p^5$ | $^2P° - {}^2P°$ | | | | | | | | | | |
| | | | [1993] | 1537660 | 1587830 | 4 | 2 | M1 | 2270 | 1.33 | C | 2,3 |
| | | | " | " | " | 4 | 2 | E2 | 0.11 | 0.0041 | E | 4 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XVII

C Isoelectronic Sequence

Ground State: $1s^22s^22p^2\ {}^3P_0$

Ionization Energy: 1131 eV = 9120000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 18.05 | 29 | 123.654 | 4 | 139.18 | 22 | 152.174 | 3 |
| 18.13 | 28,29 | 124.553 | 10 | 141.948 | 9 | 153.554 | 3 |
| 18.176 | 28 | 124.77 | 17 | 142.589 | 14 | 154.133 | 3 |
| 102 | 15 | 126.004 | 17 | 142.98 | 19 | 156.54 | 18 |
| 107 | 15 | 126.676 | 5 | 144.19 | 19 | 157.52 | 18 |
| 109.432 | 6 | 127.782 | 4 | 144.405 | 16 | 158.14 | 18 |
| 114.17 | 20 | 135.202 | 16 | 144.66 | 16 | 158.469 | 3 |
| 119.284 | 4 | 136.160 | 16 | 146.067 | 16 | 159.62 | 18 |
| 122.62 | 5 | 136.393 | 16 | 146.856 | 3 | 159.955 | 3 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 163.049 | 27 | 183.11 | 8 | 210.55 | 21 | 230.93 | 21 |
| 167.74 | 13 | 185.11 | 8 | 213.62 | 23 | 234.63 | 23 |
| 169.36 | 18 | 186.863 | 24 | 224.16 | 7 | 270.43 | 25 |
| 171.06 | 18 | 188.312 | 2 | 227.57 | 7 | 295.94 | 11 |
| 172.380 | 2 | 190.71 | 2 | 227.93 | 12 | 305.00 | 25 |
| 181.67 | 2 | 191.16 | 2 | 228.21 | 7 | 328 | 1 |
| 182.072 | 2 | 207.73 | 21 | 228.93 | 26 | 359 | 1 |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^2$–$2s2p^3$ and $2s2p^3$–$2p^4$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

Transition probabilities for lines of the $2s^22p^2$–$2s2p^3$ array were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these two sources are in reasonably good agreement, particularly for the stronger transitions.

Stratton *et al.*[3] measured the ratio of $A$-values for two lines out of the $2s2p^3\ ^3S^\circ_1$ level. Their result agrees fairly well with the theoretical data of Cheng *et al.*

Data for a few lines of the $2p^2$–$2p3d$ array were interpolated from the HX (Hartree-Fock with statistical allowance for exchange) $f$-values of Bromage and Fawcett[4] for the isoelectronic ions Ca XV and Fe XXI.

## References


[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2] C. Froese Fischer and H. P. Saha, Phys. Scr. **32**, 181 (1985).

[3] B. C. Stratton, H. W. Moos, S. Suckewer, U. Feldman, J. F. Seely, and A. K. Bhatia, Phys. Rev. A **31**, 2534 (1985).

[4] G. E. Bromage and B. C. Fawcett, Mon. Not. R. Astron. Soc. **178**, 605 (1977).


Ti XVII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^2$–$2s2p^3$ | $^3$P - $^5$S° | | | | | | | | | | | |
| | | | [359] | | | 5 | 5 | 0.083 | 1.6(−4)[a] | 9.5(−4) | −3.10 | E | 1 |
| | | | [328] | | | 3 | 5 | 0.060 | 1.6(−4) | 5.2(−4) | −3.32 | E | 1 |
| 2. | | $^3$P - $^3$D° | *184.52* | *40866* | *582820* | 9 | 15 | 60 | 0.051 | 0.28 | −0.34 | D | 1 |
| | | | 188.312 | 55761 | 586795 | 5 | 7 | 52 | 0.0390 | 0.121 | −0.71 | C | 1 |
| | | | 182.072 | 29664 | 578878 | 3 | 5 | 66 | 0.055 | 0.099 | −0.78 | C | 1 |
| | | | 172.380 | 0 | 580114 | 1 | 3 | 64 | 0.086 | 0.049 | −1.07 | C | 1 |
| | | | [191.16] | 55761 | 578878 | 5 | 5 | 0.88 | 4.8(−4) | 0.0015 | −2.62 | E | 1 |
| | | | [181.67] | 29664 | 580114 | 3 | 3 | 13 | 0.0063 | 0.011 | −1.72 | D | 1 |
| | | | [190.71] | 55761 | 580114 | 5 | 3 | 0.15 | 5.0(−5) | 1.6(−4) | −3.60 | E | 1 |
| 3. | | $^3$P - $^3$P° | *155.51* | *40866* | *683916* | 9 | 9 | 150 | 0.054 | 0.25 | −0.31 | C− | 1 |
| | | | 158.469 | 55761 | 686803 | 5 | 5 | 140 | 0.051 | 0.13 | −0.59 | C | 1 |
| | | | 153.554 | 29664 | 680926 | 3 | 3 | 85 | 0.0300 | 0.0455 | −1.046 | C | 1 |
| | | | 159.955 | 55761 | 680926 | 5 | 3 | 37 | 0.0085 | 0.022 | −1.37 | D | 1 |
| | | | 154.133 | 29664 | 678454 | 3 | 1 | 163 | 0.0194 | 0.0295 | −1.235 | C | 1 |
| | | | 152.174 | 29664 | 686803 | 3 | 5 | 10 | 0.0060 | 0.0090 | −1.74 | D | 1 |
| | | | 146.856 | 0 | 680926 | 1 | 3 | 37.9 | 0.0368 | 0.0178 | −1.434 | C | 1 |

Ti XVII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^3$P - $^3$S° | *125.39* | *40866* | 838350 | 9 | 3 | 750 | 0.059 | 0.22 | −0.27 | C | 1 |
| | | | 127.782 | 55761 | 838350 | 5 | 3 | 460 | 0.068 | 0.14 | −0.47 | C | 1 |
| | | | 123.654 | 29664 | 838350 | 3 | 3 | 230 | 0.052 | 0.064 | −0.81 | C | 1 |
| | | | 119.284 | 0 | 838350 | 1 | 3 | 80 | 0.051 | 0.020 | −1.29 | C | 1 |
| 5. | | $^3$P - $^1$D° | | | | | | | | | | | |
| | | | 126.676 | 55761 | 845180 | 5 | 5 | 30 | 0.0072 | 0.015 | −1.44 | E | 1 |
| | | | [122.62] | 29664 | 845180 | 3 | 5 | 1.3 | 4.9(−4) | 5.9(−4) | −2.83 | E | 1 |
| 6. | | $^3$P - $^1$P° | | | | | | | | | | | |
| | | | 109.432 | 29664 | 943520 | 3 | 3 | 22 | 0.0039 | 0.0042 | −1.93 | E | 1 |
| 7. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [224.16] | 140693 | 586795 | 5 | 7 | 3.2 | 0.0034 | 0.013 | −1.77 | E | 1 |
| | | | [228.21] | 140693 | 578878 | 5 | 5 | 0.26 | 2.0(−4) | 7.5(−4) | −3.00 | E | 1 |
| | | | [227.57] | 140693 | 580114 | 5 | 3 | 0.62 | 2.9(−4) | 0.0011 | −2.84 | E | 1 |
| 8. | | $^1$D - $^3$P° | | | | | | | | | | | |
| | | | [183.11] | 140693 | 686803 | 5 | 5 | 1.1 | 5.6(−4) | 0.0017 | −2.55 | E | 1 |
| | | | [185.11] | 140693 | 680926 | 5 | 3 | 1.9 | 6.0(−4) | 0.0018 | −2.52 | E | 1 |
| 9. | | $^1$D - $^1$D° | 141.948 | 140693 | 845180 | 5 | 5 | 387 | 0.117 | 0.273 | −0.233 | C | 1 |
| 10. | | $^1$D - $^1$P° | 124.553 | 140693 | 943520 | 5 | 3 | 520 | 0.072 | 0.15 | −0.44 | C | 1 |
| 11. | | $^1$S - $^3$D° | | | | | | | | | | | |
| | | | [295.94] | 242204 | 580114 | 1 | 3 | 0.22 | 8.8(−4) | 8.6(−4) | −3.06 | E | 1 |
| 12. | | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [227.93] | 242204 | 680926 | 1 | 3 | 0.68 | 0.0016 | 0.0012 | −2.80 | E | 1 |
| 13. | | $^1$S - $^3$S° | [167.74] | 242204 | 838350 | 1 | 3 | 2.2 | 0.0028 | 0.0015 | −2.55 | E | 1 |
| 14. | | $^1$S - $^1$P° | 142.589 | 242204 | 943520 | 1 | 3 | 135 | 0.123 | 0.058 | −0.91 | C | 1 |
| 15. | $2s2p^3$–$2p^4$ | $^5$S° - $^3$P | | | | | | | | | | | |
| | | | [107] | | | 5 | 5 | 3.4 | 5.8(−4) | 0.0010 | −2.54 | E | 1 |
| | | | [102] | | | 5 | 3 | 1.1 | 1.0(−4) | 1.7(−4) | −3.30 | E | 1 |
| 16. | | $^3$D° - $^3$P | *141.26* | *582820* | *1290730* | 15 | 9 | 340 | 0.062 | 0.43 | −0.03 | C− | 1 |
| | | | 146.067 | 586795 | 1271390 | 7 | 5 | 260 | 0.059 | 0.20 | −0.38 | C | 1 |
| | | | 136.160 | 578878 | 1313300 | 5 | 3 | 195 | 0.0326 | 0.073 | −0.79 | C | 1 |
| | | | 135.202 | 580114 | 1319750 | 3 | 1 | 293 | 0.0268 | 0.0358 | −1.095 | C | 1 |
| | | | 144.405 | 578878 | 1271390 | 5 | 5 | 94 | 0.0295 | 0.070 | −0.83 | C | 1 |
| | | | 136.393 | 580114 | 1313300 | 3 | 3 | 114 | 0.0317 | 0.0427 | −1.022 | C | 1 |
| | | | [144.66] | 580114 | 1271390 | 3 | 5 | 15 | 0.0076 | 0.011 | −1.64 | D | 1 |
| 17. | | $^3$D° - $^1$D | | | | | | | | | | | |
| | | | 126.004 | 586795 | 1380330 | 7 | 5 | 21 | 0.0036 | 0.010 | −1.60 | E | 1 |
| | | | [124.77] | 578878 | 1380330 | 5 | 5 | 3.5 | 8.1(−4) | 0.0017 | −2.39 | E | 1 |

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [1177.4] | 55761 | 140693 | 5 | 5 | M1 | 2200 | 0.68 | D | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.36 | 0.0024 | E | 1 |
| | | | [900.67] | 29664 | 140693 | 3 | 5 | M1 | 1800 | 0.25 | D | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [470.50] | 29664 | 242204 | 3 | 1 | M1 | 2.6(+4)[a] | 0.10 | D | 1 |
| 4. | | $^1$D - $^1$S | [985.11] | 140693 | 242204 | 5 | 1 | E2 | 12 | 0.0065 | E | 1 |
| 5. | $2s2p^3$–$2s2p^3$ | $^5$S° - $^3$D° | | | | | | | | | | |
| | | | [407.8] | | | 5 | 5 | M1 | 1500 | 0.019 | E | 3,4 |
| 6. | | $^5$S° - $^3$P° | | | | | | | | | | |
| | | | [283.2] | | | 5 | 5 | M1 | 1.5(+4) | 0.063 | D− | 3,4 |
| | | | [288.0] | | | 5 | 3 | M1 | 8700 | 0.023 | D− | 3,4 |
| 7. | | $^3$D° - $^3$D° | | | | | | | | | | |
| | | | [80880] | 578878 | 580114 | 5 | 3 | M1 | 0.073 | 4.3 | D | 3,4 |
| | | | [12630] | 578878 | 586795 | 5 | 7 | M1 | 8.0 | 4.2 | D | 3,4 |
| 8. | | $^3$D° - $^3$P° | | | | | | | | | | |
| | | | [1062.3] | 586795 | 680926 | 7 | 3 | E2 | 3.0 | 0.0072 | E | 3,4 |
| | | | [1004.3] | 578878 | 678454 | 5 | 1 | E2 | 8.2 | 0.0050 | E | 3,4 |
| | | | [999.92] | 586795 | 686803 | 7 | 5 | M1 | 2300 | 0.43 | D | 3,4 |
| | | | [1016.9] | 580114 | 678454 | 3 | 1 | M1 | 3100 | 0.12 | D | 3,4 |
| | | | [926.57] | 578878 | 686803 | 5 | 5 | M1 | 1900 | 0.28 | D | 3,4 |
| | | | [991.95] | 580114 | 680926 | 3 | 3 | M1 | 3000 | 0.33 | D | 3,4 |
| | | | [937.30] | 580114 | 686803 | 3 | 5 | M1 | 450 | 0.069 | D− | 3,4 |
| | | | " | " | " | 3 | 5 | E2 | 1.1 | 0.0024 | E | 4 |
| 9. | | $^3$D° - $^3$S° | | | | | | | | | | |
| | | | [385.40] | 578878 | 838350 | 5 | 3 | M1 | 1900 | 0.012 | E | 3,4 |
| 10. | | $^3$D° - $^1$D° | | | | | | | | | | |
| | | | [375.52] | 578878 | 845180 | 5 | 5 | M1 | 1100 | 0.011 | D− | 3,4 |
| 11. | | $^3$D° - $^1$P° | | | | | | | | | | |
| | | | [274.24] | 578878 | 943520 | 5 | 3 | M1 | 1.2(+4) | 0.027 | D− | 3,4 |
| 12. | | $^3$P° - $^3$P° | | | | | | | | | | |
| | | | [17010] | 680926 | 686803 | 3 | 5 | M1 | 2.7 | 2.5 | D | 3,4 |
| | | | [40440] | 678454 | 680926 | 1 | 3 | M1 | 0.26 | 1.9 | D | 3,4 |
| 13. | | $^3$P° - $^3$S° | | | | | | | | | | |
| | | | [659.85] | 686803 | 838350 | 5 | 3 | M1 | 690 | 0.022 | D− | 3,4 |
| | | | [635.24] | 680926 | 838350 | 3 | 3 | M1 | 530 | 0.015 | D− | 3,4 |
| | | | [625.39] | 678454 | 838350 | 1 | 3 | M1 | 920 | 0.025 | D− | 3,4 |

Ti XVII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14. | | $^3P^\circ - {}^1D^\circ$ | | | | | | | | | | |
| | | | [631.39] | 686803 | 845180 | 5 | 5 | M1 | 3200 | 0.15 | D | 3,4 |
| | | | [608.83] | 680926 | 845180 | 3 | 5 | M1 | 1300 | 0.053 | D− | 3,4 |
| 15. | | $^3P^\circ - {}^1P^\circ$ | | | | | | | | | | |
| | | | [389.53] | 686803 | 943520 | 5 | 3 | M1 | 1500 | 0.010 | D− | 3,4 |
| 16. | | $^3S^\circ - {}^1P^\circ$ | [950.84] | 838350 | 943520 | 3 | 3 | M1 | 4900 | 0.47 | D | 3,4 |
| 17. | $2p^4$–$2p^4$ | $^3P - {}^3P$ | | | | | | | | | | |
| | | | [2385] | 1271390 | 1313300 | 5 | 3 | M1 | 1610 | 2.43 | C | 3,4 |
| | | | 〃 | 〃 | 〃 | 5 | 3 | E2 | 1.3 | 0.18 | D | 4 |
| | | | [15500] | 1313300 | 1319750 | 3 | 1 | M1 | 14 | 1.9 | C− | 3,4 |
| | | | [2067] | 1271390 | 1319750 | 5 | 1 | E2 | 0.085 | 0.019 | D− | 3,4 |
| 18. | | $^3P - {}^1D$ | | | | | | | | | | |
| | | | [917.94] | 1271390 | 1380330 | 5 | 5 | M1 | 2400 | 0.35 | D | 3,4 |
| | | | [1492] | 1313300 | 1380330 | 3 | 5 | M1 | 190 | 0.12 | D− | 3,4 |
| 19. | | $^3P - {}^1S$ | | | | | | | | | | |
| | | | [410.63] | 1313300 | 1556830 | 3 | 1 | M1 | 3.5(+4) | 0.090 | D− | 3,4 |
| 20. | | $^1D - {}^1S$ | [566.57] | 1380330 | 1556830 | 5 | 1 | E2 | 200 | 0.0069 | E | 3,4 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XVIII

B Isoelectronic Sequence

Ground State: $1s^22s^22p\ ^2P^\circ_{1/2}$

Ionization Energy: 1221 eV = 9850000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 17.22 | 14 | 144.759 | 3 | 187.55 | 8 | 246 | 7 |
| 17.365 | 14 | 148.83 | 9 | 189.663 | 8 | 292.44 | 11 |
| 17.39 | 14 | 150.15 | 9 | 191.23 | 8 | 301.49 | 11 |
| 111 | 6 | 153.15 | 9 | 193.41 | 8 | 322 | 1 |
| 112 | 6 | 153.23 | 4 | 197.838 | 2 | 328 | 1 |
| 133.852 | 3 | 159.00 | 4 | 200.18 | 2 | 462 | 10 |
| 134 | 5 | 166.225 | 4 | 208.07 | 12 | | |
| 137 | 5 | 179.902 | 2 | 216.59 | 12 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^2 2p-2s2p^2$ and $2s2p^2-2p^3$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

According to several sources (see, e.g., introduction to Fe XXII), the two levels $2s2p^2\,{}^2P_{1/2}$ and ${}^2S_{1/2}$ "cross" at about V XIX or Cr XX. Transitions to these levels in this neighboring ion, Ti XVIII, have been omitted from this compilation, since the precise location of the level crossing, and thus the correct designations of the levels, are uncertain.

The Hartree-Fock results of Shamey[2] for the isoelectronic ions Ar XIV and Fe XXII, which allowed for limited configuration interaction, were interpolated to provide $f$-values for the $2p-3s$, $2p-3d$, and $2p-4d$ transitions.

## References


[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2] L. J. Shamey, J. Opt. Soc. Am. **61**, 942 (1971).


Ti XVIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^2 2p-2s2p^2$ | $^2P^\circ - {}^4P$ | | | | | | | | | | | |
| | | | [328] | | | 4 | 6 | 0.14 | 3.5(−4)[a] | 0.0015 | −2.85 | E | 1 |
| | | | [322] | | | 2 | 2 | 0.19 | 3.0(−4) | 6.4(−4) | −3.22 | E | 1 |
| 2. | | $^2P^\circ - {}^2D$ | *191.62* | *37530* | *559400* | 6 | 10 | 52 | 0.0473 | 0.179 | −0.55 | C− | 1 |
| | | | 197.838 | 56300 | 561760 | 4 | 6 | 45.6 | 0.0401 | 0.104 | −0.79 | C | 1 |
| | | | 179.902 | 0 | 555860 | 2 | 4 | 63 | 0.061 | 0.072 | −0.91 | C | 1 |
| | | | [200.18] | 56300 | 555860 | 4 | 4 | 2.0 | 0.0012 | 0.0032 | −2.32 | D | 1 |
| 3. | | $^2P^\circ - {}^2P$ | | | | | | | | | | | |
| | | | 144.759 | 56300 | 747100 | 4 | 4 | 320 | 0.099 | 0.19 | −0.40 | C | 1 |
| | | | 133.852 | 0 | 747100 | 2 | 4 | 52 | 0.0277 | 0.0244 | −1.256 | C | 1 |
| 4. | $2s2p^2-2p^3$ | $^4P - {}^4S^\circ$ | *161.50* | | | 12 | 4 | 335 | 0.0437 | 0.279 | −0.280 | C | 1 |
| | | | 166.225 | | | 6 | 4 | 154 | 0.0426 | 0.140 | −0.59 | C | 1 |
| | | | 159.00 | | | 4 | 4 | 116 | 0.0441 | 0.092 | −0.75 | C | 1 |
| | | | 153.23 | | | 2 | 4 | 67 | 0.0470 | 0.0474 | −1.027 | C | 1 |
| 5. | | $^4P - {}^2D^\circ$ | | | | | | | | | | | |
| | | | [137] | | | 6 | 6 | 4.6 | 0.0013 | 0.0035 | −2.11 | E | 1 |
| | | | [134] | | | 4 | 4 | 3.7 | 0.0010 | 0.0018 | −2.40 | E | 1 |
| 6. | | $^4P - {}^2P^\circ$ | | | | | | | | | | | |
| | | | [112] | | | 4 | 4 | 1.2 | 2.3(−4) | 3.4(−4) | −3.04 | E | 1 |
| | | | [111] | | | 2 | 2 | 0.87 | 1.6(−4) | 1.2(−4) | −3.49 | E | 1 |
| 7. | | $^2D - {}^4S^\circ$ | | | | | | | | | | | |
| | | | [246] | | | 4 | 4 | 0.12 | 1.1(−4) | 3.6(−4) | −3.36 | E | 1 |
| 8. | | $^2D - {}^2D^\circ$ | *190.28* | *559400* | *1084950* | 10 | 10 | 110 | 0.057 | 0.36 | −0.24 | C | 1 |
| | | | 189.663 | 561760 | 1089050 | 6 | 6 | 96 | 0.052 | 0.19 | −0.51 | C | 1 |
| | | | 191.23 | 555860 | 1078790 | 4 | 4 | 66 | 0.0362 | 0.091 | −0.84 | C | 1 |
| | | | [193.41] | 561760 | 1078790 | 6 | 4 | 30.5 | 0.0114 | 0.0436 | −1.165 | C | 1 |
| | | | 187.55 | 555860 | 1089050 | 4 | 6 | 16.4 | 0.0130 | 0.0321 | −1.284 | C | 1 |

Ti XVIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9. | | $^2D - ^2P^\circ$ | *151.05* | *559400* | *1221440* | 10 | 6 | 166 | 0.0340 | 0.169 | −0.469 | C | 1 |
| | | | 150.15 | 561760 | 1227760 | 6 | 4 | 115 | 0.0259 | 0.077 | −0.81 | C | 1 |
| | | | 153.15 | 555860 | 1208810 | 4 | 2 | 197 | 0.0346 | 0.070 | −0.86 | C | 1 |
| | | | 148.83 | 555860 | 1227760 | 4 | 4 | 34.0 | 0.0113 | 0.0221 | −1.345 | C | 1 |
| 10. | | $^2P - ^4S^\circ$ | | | | | | | | | | | |
| | | | [462] | | | 4 | 4 | 0.11 | 3.4(−4) | 0.0021 | −2.87 | E | 1 |
| 11. | | $^2P - ^2D^\circ$ | | | | | | | | | | | |
| | | | [292.44] | 747100 | 1089050 | 4 | 6 | 26 | 0.050 | 0.19 | −0.70 | C | 1 |
| | | | [301.49] | 747100 | 1078790 | 4 | 4 | 0.81 | 0.0011 | 0.0044 | −2.36 | D | 1 |
| 12. | | $^2P - ^2P^\circ$ | | | | | | | | | | | |
| | | | 208.07 | 747100 | 1227760 | 4 | 4 | 120 | 0.079 | 0.22 | −0.50 | C | 1 |
| | | | [216.59] | 747100 | 1208810 | 4 | 2 | 23 | 0.0082 | 0.023 | −1.48 | D | 1 |
| 13. | $2p$–$3s$ | $^2P^\circ - ^2S$ | | | | | | | | | | | |
| | | | | | | 4 | 2 | | 0.020 | | −1.10 | E | *interp.* |
| | | | | | | 2 | 2 | | 0.020 | | −1.40 | E | *interp.* |
| 14. | $2p$–$3d$ | $^2P^\circ - ^2D$ | *17.32* | *37530* | *5812000* | 6 | 10 | 8.6(+4) | 0.64 | 0.22 | 0.59 | D | *interp.* |
| | | | 17.365 | 56300 | 5815000 | 4 | 6 | 8.6(+4) | 0.58 | 0.13 | 0.37 | D | *interp.* |
| | | | 17.22 | 0 | 5807000 | 2 | 4 | 7.3(+4) | 0.65 | 0.074 | 0.11 | D | *interp.* |
| | | | [17.39] | 56300 | 5807000 | 4 | 4 | 1.4(+4) | 0.064 | 0.015 | −0.59 | D | *interp.* |
| 15. | $2p$–$4d$ | $^2P^\circ - ^2D$ | | | | | | | | | | | |
| | | | | | | 4 | 6 | | 0.11 | | −0.36 | D | *interp.* |
| | | | | | | 2 | 4 | | 0.12 | | −0.62 | E | *interp.* |
| | | | | | | 4 | 4 | | 0.012 | | −1.32 | D | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Ti XVIII

### Forbidden Transitions

The line strengths tabulated for the single magnetic dipole and single electric quadrupole transition within the $2s^2 2p$ ground state configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing is limited to the $n=2$ complex. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 in order to bring this value into conformance with the definition of the quadrupole strength used in the NBS tables.

Transition probabilities for the same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their orbital basis includes many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. The line strengths for both the M1 and E2 transitions, derived from these data by interpolation between appropriately spaced ions of the B sequence, are in very good agreement with the data of Cheng *et al.*[1]

$A$-values for forbidden transitions within the $2s2p^2$ and $2p^3$ configurations, and for transitions of the $2s^2 2p$–$2p^3$ array, were calculated by Bhatia *et al.*[3] using scaled Thomas-Fermi wavefunctions with allowance for configuration interaction and relativistic effects. We utilized their M1 and E2 line strength data, which were communicated to us by Bhatia,[4] and converted these to $A$-values with wavelengths derived from experimental data. This approach should normally yield transition probabilities that are more accurate than those based on theoretically determined wavelengths. The weakest lines determined by Bhatia *et al.*—for example, all lines of the $2s^22p$–$2p^3$ array—were excluded from this compilation.

## References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).
[3]A. K. Bhatia, U. Feldman, and G. H. Doschek, J. Appl. Phys. **51**, 1464 (1980).
[4]A. K. Bhatia, private communication (1986).


Ti XVIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p$–$2p$ | $^2P^\circ$ - $^2P^\circ$ | | | | | | | | | | |
| | | | 1778.1 | 0 | 56240 | 2 | 4 | M1 | 1600 | 1.33 | B | 1 |
| | | | " | " | " | 2 | 4 | E2 | 0.071 | 0.0030 | C | 1 |
| 2. | $2s2p^2$–$2s2p^2$ | $^4P$ - $^4P$ | | | | | | | | | | |
| | | | [3598.4] | 333170 | 360960 | 4 | 6 | M1 | 343 | 3.56 | C | 3,4 |
| | | | " | " | " | 4 | 6 | E2 | 0.0019 | 0.0041 | D | 4 |
| | | | [4312.2] | 309980 | 333170 | 2 | 4 | M1 | 276 | 3.28 | C | 3,4 |
| 3. | | $^2D$ - $^2D$ | | | | | | | | | | |
| | | | [17123] | 555860 | 561700 | 4 | 6 | M1 | 2.10 | 2.35 | C | 3,4 |
| 4. | | $^2S$ - $^2P$ | | | | | | | | | | |
| | | | [1362.6] | 673680 | 747070 | 2 | 4 | M1 | 1400 | 0.51 | C− | 3,4 |
| | | | [1664.7] | 673680 | 733750 | 2 | 2 | M1 | 1900 | 0.64 | C− | 3,4 |
| 5. | | $^2P$ - $^2P$ | | | | | | | | | | |
| | | | [7507.5] | 733750 | 747070 | 2 | 4 | M1 | 13 | 0.80 | C− | 3,4 |
| 6. | $2p^3$–$2p^3$ | $^2D^\circ$ - $^2D^\circ$ | | | | | | | | | | |
| | | | [9901] | 1078800 | 1088900 | 4 | 6 | M1 | 10.2 | 2.20 | C | 3,4 |
| 7. | | $^2D^\circ$ - $^2P^\circ$ | | | | | | | | | | |
| | | | [720.5] | 1088900 | 1227700 | 6 | 4 | M1 | 3600 | 0.20 | D | 3,4 |
| | | | " | " | " | 6 | 4 | E2 | 26 | 0.012 | D− | 4 |
| | | | [769.2] | 1078800 | 1208800 | 4 | 2 | M1 | 3000 | 0.10 | D | 3,4 |
| | | | [671.6] | 1078800 | 1227700 | 4 | 4 | M1 | 7800 | 0.35 | D | 3,4 |
| 8. | | $^2P^\circ$ - $^2P^\circ$ | | | | | | | | | | |
| | | | [5291.0] | 1208800 | 1227700 | 2 | 4 | M1 | 55 | 1.20 | C | 3,4 |

# Ti XIX

Be Isoelectronic Sequence

Ground State: $1s^2 2s^2\ ^1S_0$

Ionization Energy: 1346 eV = 10860000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 15.57 | 11 | 16.55 | 24 | 16.93 | 28 | 169.58 | 2 |
| 15.67 | 11 | 16.56 | 29 | 16.96 | 32 | 175.33 | 4 |
| 15.68 | 11 | 16.57 | 24 | 17.03 | 19 | 189.46 | 3 |
| 15.70 | 10 | 16.58 | 12 | 17.08 | 19,25 | 193.54 | 3 |
| 15.74 | 10 | 16.61 | 29 | 17.14 | 30 | 194.37 | 7 |
| 15.75 | 10 | 16.64 | 29 | 17.18 | 31 | 199.88 | 3 |
| 15.83 | 9 | 16.69 | 27 | 17.20 | 19 | 206.11 | 3 |
| 15.86 | 8,10 | 16.71 | 27 | 17.28 | 21 | 212.22 | 3 |
| 16.02 | 16 | 16.72 | 29 | 17.33 | 21 | 218.51 | 3 |
| 16.18 | 15 | 16.74 | 27 | 17.36 | 21,35 | 304.98 | 6 |
| 16.30 | 14 | 16.77 | 27 | 17.42 | 21 | 328.30 | 1 |
| 16.31 | 14 | 16.79 | 27 | 17.45 | 21 | 412.00 | 5 |
| 16.41 | 24 | 16.80 | 34 | 17.50 | 22 | 464.69 | 5 |
| 16.43 | 24 | 16.81 | 33 | 17.51 | 21 | 537.29 | 5 |
| 16.46 | 24 | 16.84 | 27 | 17.77 | 20 | | |
| 16.48 | 13 | 16.85 | 28 | 18.09 | 23 | | |
| 16.51 | 24 | 16.92 | 26 | 163.14 | 4 | | |

Oscillator strengths for transitions of the arrays $2s^2$–$2s2p$ and $2s2p$–$2p^2$ are taken from the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include the configuration interaction most relevant for the states of these configurations, as well as a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except for the weakest intercombination lines. (The $^3P_1^\circ$ - $^1S_0$ transition of the $2s2p$–$2p^2$ array has been omitted here, since the $f$-value is considerably smaller than those of the other lines of this array.)

A number of sources of reliable data, from other relativistic calculations, are available for the $2s$–$2p$ transitions. However, with the exception of some of the weaker lines, they all agree well with the results of Cheng *et al.*[1] The latter are quoted exclusively here since they provide data from a single set of comprehensive calculations, all done at a uniform and reasonably accurate level of approximation, for the valence shell $2s$–$2p$ transitions for all ions of the isoelectronic sequence.

The $f$-values for the $2s^2$–$2s3p$, $2s2p$–$2p3p$, $2s2p$–$2s3s$, $2p^2$–$2p3s$, $2s2p$–$2s3d$, and $2p^2$–$2p3d$ arrays of transitions are taken from the work of Fawcett,[2] who used Cowan's version of the relativistic Hartree-Fock method with intermediate coupling and configuration interaction. This work provides a comprehensive set of data for the entire isoelectronic sequence, calculated at a uniform level of approximation. Some of these transitions, for some ions of this sequence, have also been calculated by Bhatia *et al.*[3] using the program SUPERSTRUCTURE, which includes configuration interaction and intermediate coupling. Where they overlap, these two sets of calculations agree to within the uncertainties assigned here. Transitions involving the $J=1$ levels of $2p3p\ ^3S$ and $^3P$ have been omitted because of erratic behavior of the $f$-values along the sequence.

The oscillator strength for the $2s^2\ ^1S$ - $2s4p\ ^1P^\circ$ transition is the result of the relativistic random phase approximation (RRPA) calculations of Lin and Johnson.[4] The $f$-value for the intercombination line of this array was interpolated from the results of Ref. 4 for neighboring Be-like ions.

A few multiplet $f$-values for transitions involving the outer electron alone, $2s3s$–$2s3p$ and $2s3p$–$2s3d$, have been interpolated along the isoelectronic sequence and assigned a low accuracy.

### References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]B. C. Fawcett, At. Data Nucl. Data Tables **30**, 1 (1984); **33**, 479 (1985).

[3]A. K. Bhatia, U. Feldman, and J. F. Seely, At. Data Nucl. Data Tables **35**, 449 (1986).

[4]C. D. Lin and W. R. Johnson, Phys. Rev. A **15**, 1046 (1977).

Ti XIX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^2$–$2s2p$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [328.30] | 0 | 304600 | 1 | 3 | 0.14 | 6.6(−4)[a] | 7.1(−4) | −3.18 | D | 1 |
| 2. | | $^1$S - $^1$P° | [169.58] | 0 | 589692 | 1 | 3 | 135 | 0.175 | 0.0977 | −0.757 | B | 1 |
| 3. | $2s2p$–$2p^2$ | $^3$P° - $^3$P | *203.88* | *326470* | *816950* | 9 | 9 | 103 | 0.0641 | 0.387 | −0.239 | B | 1 |
| | | | [206.11] | 347240 | 832410 | 5 | 5 | 69.4 | 0.0442 | 0.150 | −0.656 | B | 1 |
| | | | [199.88] | 304600 | 804890 | 3 | 3 | 28.2 | 0.0169 | 0.0334 | −1.295 | B | 1 |
| | | | [218.51] | 347240 | 804890 | 5 | 3 | 36.1 | 0.0155 | 0.0558 | −1.111 | B | 1 |
| | | | [212.22] | 304600 | 775810 | 3 | 1 | 96.0 | 0.0216 | 0.0453 | −1.188 | B | 1 |
| | | | [189.46] | 304600 | 832410 | 3 | 5 | 34.1 | 0.0306 | 0.0573 | −1.037 | B | 1 |
| | | | [193.54] | 288190 | 804890 | 1 | 3 | 42.1 | 0.0709 | 0.0452 | −1.149 | B | 1 |
| 4. | | $^3$P° - $^1$D | | | | | | | | | | | |
| | | | [175.33] | 347240 | 917580 | 5 | 5 | 15 | 0.0068 | 0.020 | −1.47 | C | 1 |
| | | | [163.14] | 304600 | 917580 | 3 | 5 | 1.2 | 7.7(−4) | 0.0012 | −2.64 | D | 1 |
| 5. | | $^1$P° - $^3$P | | | | | | | | | | | |
| | | | [412.00] | 589692 | 832410 | 3 | 5 | 1.0 | 0.0043 | 0.017 | −1.89 | D | 1 |
| | | | [464.69] | 589692 | 804890 | 3 | 3 | 0.020 | 6.6(−5) | 3.0(−4) | −3.70 | E | 1 |
| | | | [537.29] | 589692 | 775810 | 3 | 1 | 0.13 | 1.9(−4) | 0.0010 | −3.24 | E | 1 |
| 6. | | $^1$P° - $^1$D | [304.98] | 589692 | 917580 | 3 | 5 | 29.2 | 0.0678 | 0.204 | −0.692 | B | 1 |
| 7. | | $^1$P° - $^1$S | [194.37] | 589692 | 1104170 | 3 | 1 | 227 | 0.0428 | 0.0822 | −0.891 | B | 1 |
| 8. | $2s^2$–$2s3p$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [15.86] | 0 | 6303200 | 1 | 3 | 2.9(+4) | 0.33 | 0.017 | −0.48 | C− | 2 |
| 9. | | $^1$S - $^1$P° | [15.83] | 0 | [6319000] | 1 | 3 | 3.2(+4) | 0.36 | 0.019 | −0.44 | C− | 2 |
| 10. | $2s2p$–$2p3p$ | $^3$P° - $^3$D | | | | | | | | | | | |
| | | | [15.74] | 347240 | 6699700 | 5 | 7 | 2.7(+4) | 0.14 | 0.036 | −0.15 | C− | 2 |
| | | | [15.75] | 304600 | [6654000] | 3 | 5 | 2.4(+4) | 0.15 | 0.023 | −0.35 | C− | 2 |
| | | | [15.70] | 288190 | [6656000] | 1 | 3 | 7000 | 0.078 | 0.0040 | −1.11 | D | 2 |
| | | | [15.86] | 347240 | [6654000] | 5 | 5 | 2000 | 0.0074 | 0.0019 | −1.43 | D | 2 |
| | | | [15.74] | 304600 | [6656000] | 3 | 3 | 1.2(+4) | 0.043 | 0.0067 | −0.89 | D | 2 |
| 11. | | $^3$P° - $^3$P | | | | | | | | | | | |
| | | | [15.68] | 347240 | [6726000] | 5 | 5 | 2.7(+4) | 0.10 | 0.026 | −0.30 | C− | 2 |
| | | | [15.67] | 304600 | 6685800 | 3 | 1 | 3.3(+4) | 0.040 | 0.0062 | −0.92 | D | 2 |
| | | | [15.57] | 304600 | [6726000] | 3 | 5 | 2800 | 0.017 | 0.0026 | −1.29 | D | 2 |
| 12. | | $^1$P° - $^1$P | [16.58] | 589692 | [6620000] | 3 | 3 | 1.4(+4) | 0.057 | 0.0093 | −0.77 | D | 2 |
| 13. | | $^1$P° - $^3$D | | | | | | | | | | | |
| | | | [16.48] | 589692 | [6656000] | 3 | 3 | 1.1(+4) | 0.043 | 0.0070 | −0.89 | D | 2 |
| 14. | | $^1$P° - $^3$P | | | | | | | | | | | |
| | | | [16.30] | 589692 | [6726000] | 3 | 5 | 5600 | 0.037 | 0.0060 | −0.95 | D | 2 |
| | | | [16.31] | 589692 | [6720000] | 3 | 3 | 250 | 0.0010 | 1.6(−4) | −2.52 | C− | 2 |
| 15. | | $^1$P° - $^1$D | [16.18] | 589692 | 6770900 | 3 | 5 | 3.8(+4) | 0.25 | 0.040 | −0.12 | C− | 2 |

Ti XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16. | | $^1P^o - {}^1S$ | [16.02] | 589692 | [6830000] | 3 | 1 | 3.1(+4) | 0.040 | 0.0063 | −0.92 | D | 2 |
| 17. | $2s^2$–$2s4p$ | $^1S - {}^3P^o$ | | | | | | | | | | | |
| | | | | | | 1 | 3 | | 0.016 | | −1.80 | D | *interp.* |
| 18. | | $^1S - {}^1P^o$ | | | | 1 | 3 | | 0.16 | | −0.80 | D | 4 |
| 19. | $2s2p$–$2s3s$ | $^3P^o - {}^3S$ | *17.14* | *326470* | 6160800 | 9 | 3 | 1.9(+4) | 0.028 | 0.014 | −0.61 | D | 2 |
| | | | [17.20] | 347240 | 6160800 | 5 | 3 | 1.1(+4) | 0.028 | 0.0079 | −0.85 | D | 2 |
| | | | [17.08] | 304600 | 6160800 | 3 | 3 | 6400 | 0.028 | 0.0047 | −1.08 | D | 2 |
| | | | [17.03] | 288190 | 6160800 | 1 | 3 | 2100 | 0.028 | 0.0016 | −1.55 | D | 2 |
| 20. | | $^1P^o - {}^1S$ | [17.77] | 589692 | [6216000] | 3 | 1 | 6300 | 0.010 | 0.0018 | −1.52 | D | 2 |
| 21. | $2p^2$–$2p3s$ | $^3P - {}^3P^o$ | *17.38* | *816950* | *[6571000]* | 9 | 9 | 1.2(+4) | 0.056 | 0.029 | −0.30 | D | 2 |
| | | | [17.36] | 832410 | [6593000] | 5 | 5 | 8900 | 0.040 | 0.011 | −0.70 | D | 2 |
| | | | [17.42] | 804890 | [6545000] | 3 | 3 | 2600 | 0.012 | 0.0021 | −1.44 | D | 2 |
| | | | [17.51] | 832410 | [6545000] | 5 | 3 | 5400 | 0.015 | 0.0043 | −1.12 | D | 2 |
| | | | [17.45] | 804890 | [6535000] | 3 | 1 | 1.2(+4) | 0.018 | 0.0031 | −1.27 | D | 2 |
| | | | [17.28] | 804890 | [6593000] | 3 | 5 | 4000 | 0.030 | 0.0051 | −1.05 | D | 2 |
| | | | [17.33] | 775810 | [6545000] | 1 | 3 | 4200 | 0.057 | 0.0033 | −1.24 | D | 2 |
| 22. | | $^1D - {}^1P^o$ | [17.50] | 917580 | [6633000] | 5 | 3 | 1.1(+4) | 0.030 | 0.0086 | −0.82 | D | 2 |
| 23. | | $^1S - {}^1P^o$ | [18.09] | 1104170 | [6633000] | 1 | 3 | 3900 | 0.058 | 0.0035 | −1.24 | D | 2 |
| 24. | $2s2p$–$2s3d$ | $^3P^o - {}^3D$ | *16.48* | *326470* | *6393800* | 9 | 15 | 1.1(+5) | 0.72 | 0.35 | 0.81 | C− | 2 |
| | | | [16.51] | 347240 | 6402700 | 5 | 7 | 1.0(+5) | 0.60 | 0.16 | 0.48 | C− | 2 |
| | | | [16.43] | 304600 | 6389200 | 3 | 5 | 8.2(+4) | 0.55 | 0.089 | 0.22 | C− | 2 |
| | | | [16.41] | 288190 | 6380600 | 1 | 3 | 6.1(+4) | 0.74 | 0.040 | −0.13 | C− | 2 |
| | | | [16.55] | 347240 | 6389200 | 5 | 5 | 2.7(+4) | 0.11 | 0.030 | −0.26 | C− | 2 |
| | | | [16.46] | 304600 | 6380600 | 3 | 3 | 4.4(+4) | 0.18 | 0.029 | −0.27 | C− | 2 |
| | | | [16.57] | 347240 | 6380600 | 5 | 3 | 2900 | 0.0072 | 0.0020 | −1.44 | C− | 2 |
| 25. | | $^1P^o - {}^1D$ | [17.08] | 589692 | 6445900 | 3 | 5 | 8.3(+4) | 0.61 | 0.10 | 0.26 | C− | 2 |
| 26. | $2p^2$–$2p3d$ | $^3P - {}^3F^o$ | | | | | | | | | | | |
| | | | [16.92] | 832410 | [6743000] | 5 | 7 | 2.0(+4) | 0.12 | 0.033 | −0.22 | C− | 2 |
| 27. | | $^3P - {}^3D^o$ | *16.73* | *816950* | *[6794000]* | 9 | 15 | 1.1(+5) | 0.77 | 0.38 | 0.84 | C− | 2 |
| | | | [16.74] | 832410 | 6807600 | 5 | 7 | 1.2(+5) | 0.72 | 0.20 | 0.56 | C− | 2 |
| | | | [16.71] | 804890 | 6789100 | 3 | 5 | 7.3(+4) | 0.51 | 0.084 | 0.18 | C− | 2 |
| | | | [16.69] | 775810 | [6769000] | 1 | 3 | 1.02(+5) | 1.28 | 0.070 | 0.107 | C− | 2 |
| | | | [16.79] | 832410 | 6789100 | 5 | 5 | 5200 | 0.022 | 0.0061 | −0.96 | D | 2 |
| | | | [16.77] | 804890 | [6769000] | 3 | 3 | 2.6(+4) | 0.11 | 0.018 | −0.48 | C− | 2 |
| | | | [16.84] | 832410 | [6769000] | 5 | 3 | 340 | 8.8(−4) | 2.4(−4) | −2.36 | D | 2 |
| 28. | | $^3P - {}^1D^o$ | | | | | | | | | | | |
| | | | [16.93] | 832410 | 6738000 | 5 | 5 | 4200 | 0.018 | 0.0050 | −1.05 | C− | 2 |
| | | | [16.85] | 804890 | 6738000 | 3 | 5 | 4.4(+4) | 0.31 | 0.052 | −0.03 | D | 2 |

Ti XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | | $^3P$ - $^3P^\circ$ | *16.67* | *816950* | *[6815000]* | 9 | 9 | 8.2(+4) | 0.342 | 0.169 | 0.488 | C− | 2 |
| | | | [16.72] | 832410 | 6813700 | 5 | 5 | 7.3(+4) | 0.304 | 0.084 | 0.182 | C− | 2 |
| | | | [16.64] | 804890 | 6813700 | 3 | 3 | 5.3(+4) | 0.22 | 0.036 | −0.18 | C− | 2 |
| | | | [16.72] | 832410 | 6813700 | 5 | 3 | 3.3(+4) | 0.082 | 0.023 | −0.39 | C− | 2 |
| | | | [16.61] | 804890 | [6826000] | 3 | 1 | 8.0(+4) | 0.11 | 0.018 | −0.48 | C− | 2 |
| | | | [16.64] | 804890 | 6813700 | 3 | 5 | 6200 | 0.043 | 0.0071 | −0.89 | D | 2 |
| | | | [16.56] | 775810 | 6813700 | 1 | 3 | 890 | 0.011 | 6.0(−4) | −1.96 | D | 2 |
| 30. | | $^1D$ - $^3F^\circ$ | | | | | | | | | | | |
| | | | [17.14] | 917580 | [6752000] | 5 | 5 | 6400 | 0.028 | 0.0079 | −0.85 | D | 2 |
| 31. | | $^1D$ - $^1D^\circ$ | [17.18] | 917580 | 6738000 | 5 | 5 | 1.7(+4) | 0.074 | 0.021 | −0.43 | C− | 2 |
| 32. | | $^1D$ - $^3P^\circ$ | | | | | | | | | | | |
| | | | [16.96] | 917580 | 6813700 | 5 | 5 | 1.7(+4) | 0.074 | 0.021 | −0.43 | C− | 2 |
| 33. | | $^1D$ - $^1P^\circ$ | [16.81] | 917580 | 6866000 | 5 | 3 | 6300 | 0.016 | 0.0044 | −1.10 | D | 2 |
| 34. | | $^1D$ - $^1F^\circ$ | [16.80] | 917580 | 6871700 | 5 | 7 | 1.81(+5) | 1.07 | 0.296 | 0.73 | C− | 2 |
| 35. | | $^1S$ - $^1P^\circ$ | [17.36] | 1104170 | 6866000 | 1 | 3 | 9.5(+4) | 1.29 | 0.074 | 0.111 | C− | 2 |
| 36. | $2s3s$–$2s3p$ | $^3S$ - $^3P^\circ$ | | | | 3 | 9 | | 0.15 | | −0.35 | D | *interp.* |
| 37. | | $^1S$ - $^1P^\circ$ | | | | 1 | 3 | | 0.062 | | −1.21 | E | *interp.* |
| 38. | $2s3p$–$2s3d$ | $^3P^\circ$ - $^3D$ | | | | 9 | 15 | | 0.033 | | −0.53 | E | *interp.* |
| 39. | | $^1P^\circ$ - $^1D$ | | | | 3 | 5 | | 0.058 | | −0.76 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XIX

## Forbidden Transitions

Transition probabilities for magnetic dipole and electric quadrupole transitions within the $2s2p$ and $2p^2$ configurations and for lines of the $2s^2$–$2p^2$ transition array, as well as for magnetic quadrupole transitions of the arrays $2s^2$–$2s2p$ and $2s2p$–$2p^2$, were calculated by Glass[1] using relativistic intermediate-coupling wavefunctions. He makes extensive allowance for configuration interaction and has achieved better than 1% agreement between calculated and experimental transition energies.

Of his results for electric quadrupole transitions, we have tabulated data for only the strongest lines. The calculated $A$-values for the M2 transitions and for the remaining E2 transitions are extremely small, and are therefore not listed.

### Reference

[1]R. Glass, Z. Phys. A **320**, 545 (1985).

Ti XIX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^2$–$2p^2$ | $^1S$ – $^3P$ | | | | | | | | | | |
| | | | [120.13] | 0 | 832410 | 1 | 5 | E2 | 480 | 3.6(−5)[a] | E | 1 |
| | | | [124.24] | 0 | 804890 | 1 | 3 | M1 | 2200 | 4.7(−4) | E | 1 |
| 2. | $2s2p$–$2s2p$ | $^3P°$ – $^3P°$ | | | | | | | | | | |
| | | | 2344.6 | 304600 | 347240 | 3 | 5 | M1 | 1040 | 2.49 | C+ | 1 |
| | | | [6092.2] | 288190 | 304600 | 1 | 3 | M1 | 78.1 | 1.96 | C+ | 1 |
| 3. | | $^3P°$ – $^1P°$ | | | | | | | | | | |
| | | | [412.45] | 347240 | 589692 | 5 | 3 | M1 | 2900 | 0.023 | D− | 1 |
| | | | [350.76] | 304600 | 589692 | 3 | 3 | M1 | 2800 | 0.013 | D− | 1 |
| | | | " | " | " | 3 | 3 | E2 | 9.9 | 9.4(−5) | E | 1 |
| | | | [331.67] | 288190 | 589692 | 1 | 3 | M1 | 4500 | 0.018 | D− | 1 |
| 4. | $2p^2$–$2p^2$ | $^3P$ – $^3P$ | | | | | | | | | | |
| | | | [3632.7] | 804890 | 832410 | 3 | 5 | M1 | 277 | 2.46 | C | 1 |
| | | | [3437.8] | 775810 | 804890 | 1 | 3 | M1 | 419 | 1.89 | C | 1 |
| 5. | | $^3P$ – $^1D$ | | | | | | | | | | |
| | | | [1174.1] | 832410 | 917580 | 5 | 5 | M1 | 2500 | 0.72 | D+ | 1 |
| | | | [887.4] | 804890 | 917580 | 3 | 5 | M1 | 2100 | 0.27 | D | 1 |
| 6. | | $^3P$ – $^1S$ | | | | | | | | | | |
| | | | [334.14] | 804890 | 1104170 | 3 | 1 | M1 | 3.8(+4) | 0.053 | D | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XX

Li Isoelectronic Sequence

Ground State: $1s^22s\ ^2S_{1/2}$

Ionization Energy: 1425.4 eV = 11497000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2.621 | 4 | 9.591 | 23 | 11.958 | 15 | 24.2 | 27 |
| 2.629 | 1 | 9.733 | 9,21 | 15.211 | 6 | 24.8 | 35 |
| 2.6295 | 3 | 9.788 | 21 | 15.253 | 6 | 24.9 | 35 |
| 2.631 | 1 | 10.046 | 19 | 15.907 | 13 | 25.1 | 44 |
| 2.6319 | 2 | 10.109 | 19 | 16.049 | 13 | 26.2 | 26 |
| 2.632 | 3 | 10.278 | 8 | 16.067 | 13 | 26.870 | 33 |
| 2.6355 | 2 | 10.620 | 17 | 22.9 | 28 | 27.000 | 33 |
| 9.246 | 11 | 10.690 | 17 | 23.5 | 37 | 27.001 | 33 |
| 9.434 | 10 | 11.452 | 7 | 23.6 | 37 | 27.3 | 42 |
| 9.534 | 23 | 11.872 | 15 | 23.8 | 46 | 27.4 | 42 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 30.614 | 25 | 45.650 | 29 | 48.3 | 65 | 99.197 | 52 |
| 31.411 | 31 | 45.996 | 29 | 53.2 | 56 | 99.246 | 52 |
| 31.586 | 31 | 46.030 | 29 | 53.8 | 56 | 101.8 | 59 |
| 31.591 | 31 | 47.123 | 38 | 54.1 | 63 | 101.9 | 59 |
| 32.056 | 40 | 47.270 | 38 | 64.691 | 54 | 259.30 | 5 |
| 32.124 | 40 | 47.8 | 58 | 64.700 | 54 | 309.15 | 5 |
| 44.070 | 24 | 48.1 | 58 | 65.8 | 61 | | |

Transition probabilities for the strongest inner-shell transitions to doubly excited $n = 2$ states are taken from the multiconfiguration Dirac-Fock (MCDF) calculations of Hata and Grant.[1] Their results are in good agreement with the $Z$-expansion perturbation calculations of Vainshtein and Safronova,[2] who included relativistic corrections at the level of the Pauli approximation.

Oscillator strengths for lines of the principal ($2s$–$2p$) resonance multiplet are the results of the MCDF calculations of Cheng *et al.*,[3] which include a perturbative treatment of the Breit interaction and the Lamb shift. The results of the MCDF calculations of Armstrong *et al.*[4] were interpolated to provide $f$-values for the $2p$–$3d$ transitions.

The $f$-value for the $3d$–$4f$ transition was taken from a study of systematic trends along isoelectronic sequences by Smith and Wiese.[5] The tabulated data for many additional transitions were taken from the theoretical analysis of Martin and Wiese,[6] which was based on a generalized study of systematic trends for several spectral series of the lithium isoelectronic sequence.

Results of the relativistic Hartree-Fock calculations of Kim and Desclaux[7] for several ions of the Li sequence were incorporated into the data of Ref. 6 for the $2s$–$3p$ transitions. For all other transitions for which the results of Ref. 6 are quoted here, no relativistic calculations were available. However, the relativistic calculations of Younger and Weiss[8] for the hydrogen isoelectronic sequence provide a means of assessing the magnitude of relativistic corrections since the Li sequence is very similar in structure to the H sequence. For those transitions for which relativistic effects were estimated to be significant (specifically, whenever the ratio of the weighted relativistic hydrogenic $f$-values $g_i f_{ik}$ of any two lines within a multiplet was found to deviate from the corresponding $LS$-coupling linestrength ratio by more than 5% for the appropriate value of the nuclear charge $Z$), the $f$-values were excluded from the compilation. A more detailed discussion of this comparison is given in Ref. 6.

Although the $2p$–$3s$ multiplet did not satisfy the criterion described in the paragraph above, we have nevertheless quoted the multiplet $f$-value obtained by Onello[9] using a $Z$-expansion technique based on a variational calculation for O VI that allowed for large-scale configuration interaction. The resulting multiplet oscillator strengths for Fe XXIV and Ni XXVI are in very good agreement with data derived from the results of calculations that included relativistic effects.[10,11] We thus felt that the results of Ref. 9 should be sufficiently accurate for inclusion in this compilation.

Biemont[12] has calculated $f$-values in the single-configuration Hartree-Fock approximation for numerous multiplets. His results have been used here to supplement the data taken from the above mentioned sources. Only transitions in which the principal quantum number of the lower state is less than 5 have been tabulated here.

Transition probability data are available for numerous transitions involving doubly excited states with the spectator electron occupying the $n=3$ shell, or higher.[13,14] These have not been tabulated, however, since they belong to, or are very close to belonging to, the unresolved satellites of the helium-like ion.

## References


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Ti xx: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^22s$–$1s(^2S)2s2p(^3P°)$ | $^2S$ - $^2P°$ | *2.628* | | | 2 | 6 | 2.4(+5)[a] | 0.075 | 0.0013 | −0.82 | D | 1 |
| | | | [2.629] | | | 2 | 4 | 4.9(+4) | 0.010 | 1.8(−4) | −1.69 | D | 1 |
| | | | [2.631] | | | 2 | 2 | 6.1(+5) | 0.063 | 0.0011 | −0.90 | C | 1 |
| 2. | $1s^22p$–$1s2p^2$ | $^2P°$ - $^2D$ | | | | | | | | | | | |
| | | | 2.6355 | 385650 | 38329000 | 4 | 6 | 1.2(+6) | 0.19 | 0.0065 | −0.13 | C | 1 |
| | | | 2.6319 | 323470 | 38318000 | 2 | 4 | 1.5(+6) | 0.31 | 0.0054 | −0.21 | C | 1 |
| 3. | | $^2P°$ - $^2P$ | | | | | | | | | | | |
| | | | 2.6295 | 385650 | 38416000 | 4 | 4 | 3.2(+6) | 0.33 | 0.011 | 0.12 | C | 1 |
| | | | [2.632] | | | 2 | 2 | 2.7(+6) | 0.28 | 0.0048 | −0.25 | C | 1 |
| 4. | | $^2P°$ - $^2S$ | | | | | | | | | | | |
| | | | [8.621] | | | 4 | 2 | 1.1(+6) | 0.61 | 0.070 | 0.39 | C | 1 |
| 5. | $2s$–$2p$ | $^2S$ - $^2P°$ | *274.03* | 0 | *364920* | 2 | 6 | 21.3 | 0.0721 | 0.130 | −0.841 | B+ | 3 |
| | | | 259.30 | 0 | 385650 | 2 | 4 | 25.2 | 0.0509 | 0.0869 | −0.992 | B+ | 3 |
| | | | 309.15 | 0 | 323470 | 2 | 2 | 14.8 | 0.0212 | 0.0432 | −1.373 | B+ | 3 |
| 6. | $2s$–$3p$ | $^2S$ - $^2P°$ | *15.225* | 0 | *6568200* | 2 | 6 | 3.53(+4) | 0.368 | 0.0369 | −0.133 | B | 6 |
| | | | 15.211 | 0 | 6574200 | 2 | 4 | 3.50(+4) | 0.243 | 0.0243 | −0.313 | B | 6 |
| | | | 15.253 | 0 | 6556100 | 2 | 2 | 3.58(+4) | 0.125 | 0.0126 | −0.602 | B | 6 |
| 7. | $2s$–$4p$ | $^2S$ - $^2P°$ | 11.452 | 0 | 8732100 | 2 | 6 | 1.7(+4) | 0.099 | 0.0075 | −0.70 | C+ | 6 |
| 8. | $2s$–$5p$ | $^2S$ - $^2P°$ | 10.278 | 0 | 9729500 | 2 | 6 | 8400 | 0.040 | 0.0027 | −1.10 | C+ | 6 |
| 9. | $2s$–$6p$ | $^2S$ - $^2P°$ | 9.733 | 0 | 10270000 | 2 | 6 | 4950 | 0.0211 | 0.00135 | −1.375 | C+ | 6 |
| 10. | $2s$–$7p$ | $^2S$ - $^2P°$ | 9.434 | 0 | 10600000 | 2 | 6 | 3100 | 0.0124 | 7.70(−4) | −1.606 | C+ | 6 |
| 11. | $2s$–$8p$ | $^2S$ - $^2P°$ | 9.246 | 0 | 10820000 | 2 | 6 | 2000 | 0.0077 | 4.7(−4) | −1.81 | D | 12 |
| 12. | $2p$–$3s$ | $^2P°$ - $^2S$ | *16.399* | *364920* | 6463000 | 6 | 2 | 1.3(+4) | 0.018 | 0.0058 | −0.97 | D | 9 |
| 13. | $2p$–$3d$ | $^2P°$ - $^2D$ | *16.002* | *364920* | *6614000* | 6 | 10 | 1.05(+5) | 0.674 | 0.213 | 0.607 | B | *interp.* |
| | | | 16.049 | 385650 | 6616600 | 4 | 6 | 1.05(+5) | 0.610 | 0.129 | 0.387 | B | *interp.* |
| | | | 15.907 | 323470 | 6610000 | 2 | 4 | 8.84(+4) | 0.671 | 0.0703 | 0.128 | B | *interp.* |
| | | | 16.067 | 385650 | 6610000 | 4 | 4 | 1.8(+4) | 0.068 | 0.014 | −0.57 | B | *interp.* |
| 14. | $2p$–$4s$ | $^2P°$ - $^2S$ | | | | 6 | 2 | | 0.0037 | | −1.65 | D+ | 6 |
| 15. | $2p$–$4d$ | $^2P°$ - $^2D$ | *11.929* | *364920* | *8747700* | 6 | 10 | 3.4(+4) | 0.12 | 0.028 | −0.14 | B | 6 |
| | | | 11.958 | 385650 | 8748300 | 4 | 6 | 3.4(+4) | 0.11 | 0.017 | −0.36 | B | *ls* |
| | | | 11.872 | 323470 | 8746700 | 2 | 4 | 2.8(+4) | 0.12 | 0.0093 | −0.62 | B | *ls* |
| | | | 11.958 | 385650 | 8746700 | 4 | 4 | 5600 | 0.012 | 0.0019 | −1.32 | C+ | *ls* |
| 16. | $2p$–$5s$ | $^2P°$ - $^2S$ | | | | 6 | 2 | | 0.0017 | | −1.99 | D+ | 6 |
| 17. | $2p$–$5d$ | $^2P°$ - $^2D$ | *10.667* | *364920* | *9740000* | 6 | 10 | 1.59(+4) | 0.0451 | 0.00950 | −0.568 | C+ | 6 |
| | | | 10.690 | 385650 | 9740200 | 4 | 6 | 1.58(+4) | 0.0405 | 0.00570 | −0.791 | C+ | *ls* |
| | | | 10.620 | 323470 | 9739700 | 2 | 4 | 1.34(+4) | 0.0453 | 0.00317 | −1.043 | C+ | *ls* |
| | | | 10.690 | 385650 | 9739700 | 4 | 4 | 2600 | 0.0045 | 6.3(−4) | −1.75 | D | *ls* |

Ti xx: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18. | 2p–6s | $^2P^\circ$ - $^2S$ | | | | 6 | 2 | | 8.5(−4) | | −2.29 | D | 6 |
| 19. | 2p–6d | $^2P^\circ$ - $^2D$ | *10.088* | *364920* | *10277800* | 6 | 10 | 8650 | 0.0220 | 0.00438 | −0.879 | C+ | 6 |
| | | | 10.109 | 385650 | 10277900 | 4 | 6 | 8600 | 0.0198 | 0.00263 | −1.102 | C+ | ls |
| | | | 10.046 | 323470 | 10277700 | 2 | 4 | 7290 | 0.0221 | 0.00146 | −1.355 | C+ | ls |
| | | | 10.109 | 385650 | 10277700 | 4 | 4 | 1400 | 0.0022 | 2.9(−4) | −2.06 | D | ls |
| 20. | 2p–7s | $^2P^\circ$ - $^2S$ | | | | 6 | 2 | | 4.9(−4) | | −2.53 | D | 6 |
| 21. | 2p–7d | $^2P^\circ$ - $^2D$ | *9.766* | *364920* | *10600000* | 6 | 10 | 5290 | 0.0126 | 0.00243 | −1.121 | C+ | 6 |
| | | | 9.788 | 385650 | 10610000 | 4 | 6 | 5260 | 0.0113 | 0.00146 | −1.344 | C+ | ls |
| | | | 9.733 | 323470 | 10590000 | 2 | 4 | 4450 | 0.0126 | 8.10(−4) | −1.597 | C+ | ls |
| | | | 9.788 | 385650 | 10590000 | 4 | 4 | 860 | 0.0012 | 1.6(−4) | −2.30 | D | ls |
| 22. | 2p–8s | $^2P^\circ$ - $^2S$ | | | | 6 | 2 | | 2.8(−4) | | −2.77 | D | 12 |
| 23. | 2p–8d | $^2P^\circ$ - $^2D$ | *9.560* | *364920* | *10820000* | 6 | 10 | 3500 | 0.0079 | 0.0015 | −1.32 | D | 12 |
| | | | 9.591 | 385650 | 10820000 | 4 | 6 | 3400 | 0.0071 | 9.0(−4) | −1.55 | D | ls |
| | | | 9.534 | 323470 | 10810000 | 2 | 4 | 2900 | 0.0080 | 5.0(−4) | −1.80 | D | ls |
| | | | 9.591 | 385650 | 10810000 | 4 | 4 | 570 | 7.9(−4) | 1.0(−4) | −2.50 | E | ls |
| 24. | 3s–4p | $^2S$ - $^2P^\circ$ | [44.070] | 6463000 | 8732100 | 2 | 6 | 4800 | 0.42 | 0.12 | −0.08 | C | 6 |
| 25. | 3s–5p | $^2S$ - $^2P^\circ$ | [30.614] | 6463000 | 9729500 | 2 | 6 | 2540 | 0.107 | 0.0216 | −0.67 | C | 6 |
| 26. | 3s–6p | $^2S$ - $^2P^\circ$ | [26.2] | 6463000 | 10270000 | 2 | 6 | 1500 | 0.047 | 0.0081 | −1.03 | C | 6 |
| 27. | 3s–7p | $^2S$ - $^2P^\circ$ | [24.2] | 6463000 | 10600000 | 2 | 6 | 940 | 0.0248 | 0.00395 | −1.305 | C | 6 |
| 28. | 3s–8p | $^2S$ - $^2P^\circ$ | [22.9] | 6463000 | 10820000 | 2 | 6 | 650 | 0.0154 | 0.00232 | −1.51 | C | 12 |
| 29. | 3p–4d | $^2P^\circ$ - $^2D$ | *45.882* | *6568200* | *8747700* | 6 | 10 | 1.1(+4) | 0.59 | 0.53 | 0.55 | B | 6 |
| | | | [45.996] | 6574200 | 8748300 | 4 | 6 | 1.1(+4) | 0.53 | 0.32 | 0.32 | B | ls |
| | | | [45.650] | 6556100 | 8746700 | 2 | 4 | 9600 | 0.60 | 0.18 | 0.08 | B | ls |
| | | | [46.030] | 6574200 | 8746700 | 4 | 4 | 1800 | 0.058 | 0.035 | −0.64 | C+ | ls |
| 30. | 3p–5s | $^2P^\circ$ - $^2S$ | | | | 6 | 2 | | 0.0090 | | −1.27 | D+ | 6 |
| 31. | 3p–5d | $^2P^\circ$ - $^2D$ | *31.528* | *6568200* | *9740000* | 6 | 10 | 5520 | 0.137 | 0.0853 | −0.085 | C+ | 6 |
| | | | [31.586] | 6574200 | 9740200 | 4 | 6 | 5490 | 0.123 | 0.0512 | −0.308 | C+ | ls |
| | | | [31.411] | 6556100 | 9739700 | 2 | 4 | 4640 | 0.137 | 0.0284 | −0.561 | C+ | ls |
| | | | [31.591] | 6574200 | 9739700 | 4 | 4 | 920 | 0.014 | 0.0057 | −1.26 | D | ls |
| 32. | 3p–6s | $^2P^\circ$ - $^2S$ | | | | 6 | 2 | | 0.0038 | | −1.64 | C− | 6 |
| 33. | 3p–6d | $^2P^\circ$ - $^2D$ | *26.957* | *6568200* | *10277800* | 6 | 10 | 3070 | 0.0557 | 0.0297 | −0.476 | C+ | 6 |
| | | | [27.000] | 6574200 | 10277900 | 4 | 6 | 3050 | 0.0501 | 0.0178 | −0.698 | C+ | ls |
| | | | [26.870] | 6556100 | 10277700 | 2 | 4 | 2580 | 0.0560 | 0.00990 | −0.951 | C+ | ls |
| | | | [27.001] | 6574200 | 10277700 | 4 | 4 | 510 | 0.0056 | 0.0020 | −1.65 | D | ls |
| 34. | 3p–7s | $^2P^\circ$ - $^2S$ | | | | 6 | 2 | | 0.0019 | | −1.94 | C− | 6 |

Ti XX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ (10$^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35. | 3p–7d | $^2$P° – $^2$D | *24.8* | *6568200* | *10600000* | 6 | 10 | 1880 | 0.0289 | 0.0142 | −0.761 | C+ | 6 |
| | | | [24.8] | 6574200 | 10610000 | 4 | 6 | 1890 | 0.0261 | 0.00852 | −0.981 | C+ | *ls* |
| | | | [24.8] | 6556100 | 10590000 | 2 | 4 | 1570 | 0.0290 | 0.00473 | −1.237 | C+ | *ls* |
| | | | [24.9] | 6574200 | 10590000 | 4 | 4 | 310 | 0.0029 | 9.5(−4) | −1.94 | D | *ls* |
| 36. | 3p–8s | $^2$P° – $^2$S | | | | 6 | 2 | | 0.0011 | | −2.18 | D | 12 |
| 37. | 3p–8d | $^2$P° – $^2$D | *23.5* | *6568200* | *10820000* | 6 | 10 | 1250 | 0.0173 | 0.0080 | −0.98 | C | 12 |
| | | | [23.5] | 6574200 | 10820000 | 4 | 6 | 1200 | 0.016 | 0.0048 | −1.21 | C | *ls* |
| | | | [23.5] | 6556100 | 10810000 | 2 | 4 | 1100 | 0.017 | 0.0027 | −1.46 | C | *ls* |
| | | | [23.6] | 6574200 | 10810000 | 4 | 4 | 200 | 0.0017 | 5.3(−4) | −2.17 | D | *ls* |
| 38. | 3d–4p | $^2$D – $^2$P° | *47.212* | *6614000* | 8732100 | 10 | 6 | 620 | 0.0125 | 0.0194 | −0.90 | C | 12 |
| | | | [47.270] | 6616600 | 8732100 | 6 | 4 | 560 | 0.0124 | 0.0116 | −1.128 | C | *ls* |
| | | | [47.123] | 6610000 | 8732100 | 4 | 2 | 630 | 0.010 | 0.0065 | −1.38 | C | *ls* |
| | | | [47.123] | 6610000 | 8732100 | 4 | 4 | 63 | 0.0021 | 0.0013 | −2.08 | D | *ls* |
| 39. | 3d–4f | $^2$D – $^2$F° | | | | 10 | 14 | | 1.00 | | 1.000 | B | 5 |
| 40. | 3d–5p | $^2$D – $^2$P° | *32.098* | *6614000* | 9729500 | 10 | 6 | 270 | 0.0025 | 0.0026 | −1.60 | D | 12 |
| | | | [32.124] | 6616600 | 9729500 | 6 | 4 | 240 | 0.0025 | 0.0016 | −1.82 | D | *ls* |
| | | | [32.056] | 6610000 | 9729500 | 4 | 2 | 270 | 0.0021 | 8.7(−4) | −2.08 | D | *ls* |
| | | | [32.056] | 6610000 | 9729500 | 4 | 4 | 26 | 4.0(−4) | 1.7(−4) | −2.79 | E | *ls* |
| 41. | 3d–5f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.157 | | 0.196 | C | 12 |
| 42. | 3d–6p | $^2$D – $^2$P° | *27.3* | *6614000* | 10270000 | 10 | 6 | 140 | 9.4(−4) | 8.4(−4) | −2.03 | D | 12 |
| | | | [27.4] | 6616600 | 10270000 | 6 | 4 | 120 | 9.2(−4) | 5.0(−4) | −2.26 | D | *ls* |
| | | | [27.3] | 6610000 | 10270000 | 4 | 2 | 140 | 7.8(−4) | 2.8(−4) | −2.51 | D | *ls* |
| | | | [27.3] | 6610000 | 10270000 | 4 | 4 | 14 | 1.6(−4) | 5.6(−5) | −3.21 | E | *ls* |
| 43. | 3d–6f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.054 | | −0.27 | C | 12 |
| 44. | 3d–7p | $^2$D – $^2$P° | [25.1] | *6614000* | 10600000 | 10 | 6 | 83 | 4.7(−4) | 3.9(−4) | −2.33 | D | 12 |
| 45. | 3d–7f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.0256 | | −0.59 | C | 12 |
| 46. | 3d–8p | $^2$D – $^2$P° | [23.8] | *6614000* | 10820000 | 10 | 6 | 53 | 2.7(−4) | 2.1(−4) | −2.57 | D | 12 |
| 47. | 3d–8f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.0144 | | −0.84 | C | 12 |
| 48. | 4s–5p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.467 | | −0.030 | C | 6 |
| 49. | 4s–6p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.127 | | −0.60 | C | 6 |
| 50. | 4s–7p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.055 | | −0.96 | C | 6 |
| 51. | 4s–8p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.0296 | | −1.228 | C | 12 |
| 52. | 4p–5d | $^2$P° – $^2$D | *99.216* | 8732100 | *9740000* | 6 | 10 | 2360 | 0.581 | 1.14 | 0.542 | C+ | 6 |
| | | | [99.197] | 8732100 | 9740200 | 4 | 6 | 2370 | 0.524 | 0.684 | 0.321 | C+ | *ls* |
| | | | [99.246] | 8732100 | 9739700 | 2 | 4 | 1970 | 0.582 | 0.380 | 0.066 | C+ | *ls* |
| | | | [99.246] | 8732100 | 9739700 | 4 | 4 | 390 | 0.058 | 0.076 | −0.63 | D | *ls* |
| 53. | 4p–6s | $^2$P° – $^2$S | | | | 6 | 2 | | 0.0147 | | −1.055 | C− | 6 |

Ti XX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 54. | 4p–6d | $^2$P° - $^2$D | *64.696* | 8732100 | *10277800* | 6 | 10 | 1350 | 0.141 | 0.180 | −0.073 | C+ | 6 |
| | | | [64.691] | 8732100 | 10277900 | 4 | 6 | 1350 | 0.127 | 0.108 | −0.295 | C+ | *ls* |
| | | | [64.700] | 8732100 | 10277700 | 2 | 4 | 1120 | 0.141 | 0.0600 | −0.550 | C+ | *ls* |
| | | | [64.700] | 8732100 | 10277700 | 4 | 4 | 220 | 0.014 | 0.012 | −1.25 | D | *ls* |
| 55. | 4p–7s | $^2$P° - $^2$S | | | | 6 | 2 | | 0.0060 | | −1.44 | C− | 6 |
| 56. | 4p–7d | $^2$P° - $^2$D | *53.5* | 8732100 | *10600000* | 6 | 10 | 860 | 0.0615 | 0.0650 | −0.433 | C+ | 6 |
| | | | [53.2] | 8732100 | 10610000 | 4 | 6 | 875 | 0.0557 | 0.0390 | −0.652 | C+ | *ls* |
| | | | [53.8] | 8732100 | 10590000 | 2 | 4 | 706 | 0.0613 | 0.0217 | −0.912 | C+ | *ls* |
| | | | [53.8] | 8732100 | 10590000 | 4 | 4 | 140 | 0.0061 | 0.0043 | −1.61 | D | *ls* |
| 57. | 4p–8s | $^2$P° - $^2$S | | | | 6 | 2 | | 0.0032 | | −1.72 | D | 12 |
| 58. | 4p–8d | $^2$P° - $^2$D | *47.8* | 8732100 | *10820000* | 6 | 10 | 580 | 0.0330 | 0.0312 | −0.70 | C | 12 |
| | | | [47.8] | 8732100 | 10820000 | 4 | 6 | 580 | 0.0297 | 0.0187 | −0.93 | C | *ls* |
| | | | [48.1] | 8732100 | 10810000 | 2 | 4 | 473 | 0.0328 | 0.0104 | −1.183 | C | *ls* |
| | | | [48.1] | 8732100 | 10810000 | 4 | 4 | 96 | 0.0033 | 0.0021 | −1.88 | D | *ls* |
| 59. | 4d–5p | $^2$D - $^2$P° | *101.9* | *8747700* | 9729500 | 10 | 6 | 334 | 0.0312 | 0.105 | −0.51 | C | 12 |
| | | | [101.9] | 8748300 | 9729500 | 6 | 4 | 300 | 0.031 | 0.063 | −0.73 | C | *ls* |
| | | | [101.8] | 8746700 | 9729500 | 4 | 2 | 336 | 0.0261 | 0.0350 | −0.98 | C | *ls* |
| | | | [101.8] | 8746700 | 9729500 | 4 | 4 | 34 | 0.0052 | 0.0070 | −1.68 | D | *ls* |
| 60. | 4d–5f | $^2$D - $^2$F° | | | | 10 | 14 | | 0.889 | | 0.949 | B | 12 |
| 61. | 4d–6p | $^2$D - $^2$P° | [65.8] | *8747700* | 10270000 | 10 | 6 | 170 | 0.0065 | 0.014 | −1.19 | D | 12 |
| 62. | 4d–6f | $^2$D - $^2$F° | | | | 10 | 14 | | 0.186 | | 0.270 | C | 12 |
| 63. | 4d–7p | $^2$D - $^2$P° | [54.1] | *8747700* | 10600000 | 10 | 6 | 95 | 0.0025 | 0.0045 | −1.60 | D | 12 |
| 64. | 4d–7f | $^2$D - $^2$F° | | | | 10 | 14 | | 0.072 | | −0.14 | C | 12 |
| 65. | 4d–8p | $^2$D - $^2$P° | [48.3] | *8747700* | 10820000 | 10 | 6 | 62 | 0.0013 | 0.0021 | −1.89 | D | 12 |
| 66. | 4d–8f | $^2$D - $^2$F° | | | | 10 | 14 | | 0.0366 | | −0.437 | C | 12 |
| 67. | 4f–5d | $^2$F° - $^2$D | | | | 14 | 10 | | 0.0089 | | −0.90 | D | 12 |
| 68. | 4f–6d | $^2$F° - $^2$D | | | | 14 | 10 | | 0.0016 | | −1.65 | D | 12 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Ti XX

### Forbidden Transitions

The single magnetic dipole transition within the $1s^22p$ configuration has the line strength of 1.33 in the absence of relativistic effects in the wavefunctions.[1] It is estimated that these effects are negligible, since comprehensive relativistic calculations by Cheng *et al.*[2] for the analogous transition in the $1s^22s^22p$ configuration of the boron sequence show that such relativistic corrections are negligible until much more highly charged ions.

The listed transition probability data are also expected to be quite accurate since the energy levels are derived from experimental data.

An electric quadrupole transition at the same wavelength is estimated to be of negligible strength, as calculated by Bhatia[3] for this transition in the case of Mn XXIII. (He obtains a ratio of about $10^{-3}$ for the ratio of E2 to M1 line strengths).

### References

[1]W. L. Wiese, M. W. Smith, and B. M. Miles, "Atomic Transition Probabilities", Vol. II, NSRDS-NBS 22, U.S. Govt. Print. Office, Washington, DC 1969.
[2]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[3]A. K. Bhatia, private communication (1986).

Ti XX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p$–$2p$ | $^2P^\circ$ – $^2P^\circ$ | | | | | | | | | | |
| | | | [1609.11] | 323549 | 385695 | 2 | 4 | M1 | 2150 | 1.33 | B | *interp.* |

# Ti XXI

He Isoelectronic Sequence

Ground State: $1s^2\ ^1S_0$

Ionization Energy: 6249.0 eV = 50401000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2.0633 | 17 | 2.513 | 7,10 | 10.866 | 31 | 42.876 | 45 |
| 2.0637 | 16 | 2.514 | 7 | 11.059 | 32 | 88.984 | 55 |
| 2.1108 | 15 | 2.520 | 9 | 14.198 | 21 | 89.904 | 56 |
| 2.1117 | 14 | 2.527 | 5 | 14.520 | 22 | 91.836 | 58 |
| 2.2211 | 13 | 2.539 | 6 | 14.736 | 27 | 92.678 | 59 |
| 2.2237 | 12 | 2.6102 | 2 | 15.019 | 28 | 260.3 | 19 |
| 2.497 | 11 | 2.6227 | 1 | 28.243 | 41 | 390.5 | 18 |
| 2.505 | 4,8 | 9.4982 | 25 | 28.599 | 42 | 495.8 | 18 |
| 2.507 | 3 | 9.6791 | 26 | 28.791 | 48 | 523.0 | 18 |
| 2.508 | 7 | 9.6947 | 35 | 29.126 | 49 | 566.3 | 20 |
| 2.510 | 7 | 9.8584 | 36 | 40.982 | 39 | | |
| 2.511 | 3 | 10.607 | 23 | 41.558 | 40 | | |
| 2.512 | 3,7 | 10.821 | 24 | 42.351 | 44 | | |

Oscillator strengths for transitions of the $1s^2$–$1s2p$ array are taken from the results of Drake,[1] who incorporated accurate nonrelativistic matrix elements and Dirac hydrogenic matrix elements into a $Z$-expansion technique in order to provide $f$-values which would accurately reflect correlation effects for low-$Z$ ions and relativistic effects for high-$Z$ ions of the helium isoelectronic sequence. The $f$-values for the $1s^2\ ^1S$ – $1snp\ ^3P^\circ$ ($n$ = 3–5) transitions were interpolated from results of the relativistic random phase approximation (RRPA) calculations of Johnson and Lin.[2] Data for other $s$–$p$ and $p$–$s$ transitions were interpolated from the RRPA results of Lin *et al.*,[3] with the exception of the $2s$–$2p$ transitions, where we tabulate the actual published RRPA $A$-values of these same authors.[4]

The charge expansion results of Laughlin[5] are given for various $p$–$d$ and $d$–$p$ transitions, as well as transitions between $4d$ and $4f$ levels. For those multiplets involving no change in principal quantum number ($3p$–$3d$, $4p$–$4d$, $4d$–$4f$) the $f$-values should be considered rather uncertain, since they are sensitive to energy differences. Oscillator strengths for the $2p$–$3d$ transitions, and for $1s3p\ ^3P^\circ$ – $1s3d\ ^3D$, were interpolated from the variational calculations of Weiss.[6] Both of these calculations indicate that, unlike the triplets, the *nd* $^1$D energy levels ($n=3,4$) lie below the *np* $^1$P° levels, and the 4*f* $^1$F° lies below the 4*d* $^1$D.

Brown and Cortez[7] have provided *f*-values for numerous *d*–*f* and *f*–*d* transitions for the isoelectronic sequence by fitting *Z*-expansion formulas to the results of variational calculations for the low-*Z* ions. Their results for transitions between the lower-lying D and F° terms are tabulated here.

Transition probabilities for the stronger transitions involving the doubly excited $n=2$ states are taken from the papers by Bitter *et al.*,[8] which reports theoretical results from both the *Z*-expansion method and SUPERSTRUCTURE, and Vainshtein and Safronova,[9] which is based on the *Z*-expansion method. These sets of data agree well for the stronger transitions, and we report here the average of the two when both are available. Numerous data are also available for transitions involving doubly excited states where the spectator electron has principal quantum number $n=3$ or higher.[8,10] However, these data are not tabulated here since most of the transitions are very close to belonging to the unresolved satellites of the H-like ions, if they do not in fact do so.

## References


[1] G. W. F. Drake, Phys. Rev. A **19**, 1387 (1979).
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[4] C. D. Lin, W. R. Johnson, and A. Dalgarno, Phys. Rev. A **15**, 154 (1977).
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[7] R. T. Brown and J.-L. M. Cortez, Astrophys. J. **176**, 267 (1972).
[8] M. Bitter, S. von Goeler, S. Cohen, K. W. Hill, S. Sesnic, F. Tenney, J. Timberlake, U. I. Safronova, L. A. Vainshtein, J. Dubau, M. Loulergue, F. Bely-Dubau, and L. Steenman-Clark, Phys. Rev. A **29**, 661 (1984).
[9] L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **21**, 49 (1978).
[10] L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **25**, 311 (1980).


Ti XXI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2$–$1s2p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [2.6227] | 0 | [38129200] | 1 | 3 | 1.12(+5)[a] | 0.0346 | 2.99(−4) | −1.461 | B | 1 |
| 2. | | $^1$S – $^1$P° | [2.6102] | 0 | [38311600] | 1 | 3 | 2.40(+6) | 0.735 | 0.00632 | −0.134 | B | 1 |
| 3. | $1s2s$–$2s2p$ | $^3$S – $^3$P° | *2.509* | [37927500] | [*77790000*] | 3 | 9 | 1.4(+6) | 0.40 | 0.0098 | 0.07 | C | 8,9 |
| | | | [2.507] | [37927500] | [77820000] | 3 | 5 | 1.4(+6) | 0.22 | 0.0054 | −0.18 | C | 8,9 |
| | | | [2.511] | [37927500] | [77750000] | 3 | 3 | 1.4(+6) | 0.13 | 0.0033 | −0.40 | C | 8,9 |
| | | | [2.512] | [37927500] | [77740000] | 3 | 1 | 1.4(+6) | 0.044 | 0.0011 | −0.88 | C | 8,9 |
| 4. | | $^1$S – $^1$P° | [2.505] | [38135000] | [78060000] | 1 | 3 | 1.4(+6) | 0.40 | 0.0033 | −0.40 | C | 8,9 |
| 5. | $1s2p$–$2s^2$ | $^3$P° – $^1$S | | | | | | | | | | | |
| | | | [2.527] | [38129200] | [77700000] | 3 | 1 | 1.2(+5) | 0.0038 | 9.6(−5) | −1.94 | D | 8,9 |
| 6. | | $^1$P° – $^1$S | [2.539] | [38311600] | [77700000] | 3 | 1 | 4.1(+5) | 0.013 | 3.3(−4) | −1.40 | D | 8,9 |
| 7. | $1s2p$–$2p^2$ | $^3$P° – $^3$P | *2.511* | [*38158300*] | [*77980000*] | 9 | 9 | 2.7(+6) | 0.26 | 0.019 | 0.36 | D+ | 8,9 |
| | | | [2.512] | [38183600] | [78000000] | 5 | 5 | 1.8(+6) | 0.17 | 0.0070 | −0.07 | C | 8,9 |
| | | | [2.510] | [38129200] | [77970000] | 3 | 3 | 6.9(+5) | 0.065 | 0.0016 | −0.71 | D | 9 |
| | | | [2.514] | [38183600] | [77970000] | 5 | 3 | 1.2(+6) | 0.068 | 0.0028 | −0.47 | C | 9 |
| | | | [2.513] | [38129200] | [77920000] | 3 | 1 | 2.7(+6) | 0.085 | 0.0021 | −0.59 | C | 8,9 |
| | | | [2.508] | [38129200] | [78000000] | 3 | 5 | 7.9(+5) | 0.12 | 0.0031 | −0.43 | D | 8,9 |
| | | | [2.510] | [38118700] | [77970000] | 1 | 3 | 9.6(+5) | 0.27 | 0.0022 | −0.57 | D | 9 |
| 8. | | $^3$P° – $^1$D | | | | | | | | | | | |
| | | | [2.505] | [38183600] | [78100000] | 5 | 5 | 3.5(+5) | 0.033 | 0.0014 | −0.78 | D | 8,9 |
| 9. | | $^1$P° – $^3$P | | | | | | | | | | | |
| | | | [2.520] | [38311600] | [78000000] | 3 | 5 | 2.6(+5) | 0.041 | 0.0010 | −0.91 | D | 8,9 |

Ti XXI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | | $^1P^o - ^1D$ | [2.513] | [38311600] | [78100000] | 3 | 5 | 2.4(+6) | 0.38 | 0.0094 | 0.06 | C | 8,9 |
| 11. | | $^1P^o - ^1S$ | [2.497] | [38311600] | [78360000] | 3 | 1 | 2.4(+6) | 0.075 | 0.0018 | −0.65 | C | 8,9 |
| 12. | $1s^2$–$1s3p$ | $^1S - ^3P^o$ | | | | | | | | | | | |
| | | | [2.2237] | 0 | [44970800] | 1 | 3 | 3.8(+4) | 0.0084 | 6.1(−5) | −2.08 | E | *interp.* |
| 13. | | $^1S - ^1P^o$ | [2.2211] | 0 | [45021900] | 1 | 3 | 6.35(+5) | 0.141 | 0.00103 | −0.851 | C+ | *interp.* |
| 14. | $1s^2$–$1s4p$ | $^1S - ^3P^o$ | | | | | | | | | | | |
| | | | [2.1117] | 0 | [47355200] | 1 | 3 | 1.5(+4) | 0.0031 | 2.2(−5) | −2.51 | E | *interp.* |
| 15. | | $^1S - ^1P^o$ | [2.1108] | 0 | [47376200] | 1 | 3 | 2.60(+5) | 0.0522 | 3.63(−4) | −1.282 | C+ | *interp.* |
| 16. | $1s^2$–$1s5p$ | $^1S - ^3P^o$ | | | | | | | | | | | |
| | | | [2.0637] | 0 | [48455800] | 1 | 3 | 8400 | 0.0016 | 1.1(−5) | −2.80 | E | *interp.* |
| 17. | | $^1S - ^1P^o$ | [2.0633] | 0 | [48466500] | 1 | 3 | 1.32(+5) | 0.0252 | 1.71(−4) | −1.599 | C+ | *interp.* |
| 18. | $1s2s$–$1s2p$ | $^3S - ^3P^o$ | *433.3* | [37927500] | *[38158300]* | 3 | 9 | 5.09 | 0.0430 | 0.184 | −0.889 | B | 4 |
| | | | [390.5] | [37927500] | [38183600] | 3 | 5 | 7.07 | 0.0269 | 0.104 | −1.093 | B | 4 |
| | | | [495.8] | [37927500] | [38129200] | 3 | 3 | 3.31 | 0.0122 | 0.0597 | −1.437 | B | 4 |
| | | | [523.0] | [37927500] | [38118700] | 3 | 1 | 2.93 | 0.00401 | 0.0207 | −1.920 | B | 4 |
| 19. | | $^3S - ^1P^o$ | | | | | | | | | | | |
| | | | [260.3] | [37927500] | [38311600] | 3 | 3 | 1.02 | 0.00104 | 0.00266 | −2.507 | B | 4 |
| 20. | | $^1S - ^1P^o$ | [566.3] | [38135000] | [38311600] | 1 | 3 | 2.28 | 0.0329 | 0.0613 | −1.483 | B | 4 |
| 21. | $1s2s$–$1s3p$ | $^3S - ^3P^o$ | | | | | | | | | | | |
| | | | [14.198] | [37927500] | [44970800] | 3 | 3 | 4.10(+4) | 0.124 | 0.0174 | −0.429 | C | *interp.* |
| 22. | | $^1S - ^1P^o$ | [14.520] | [38135000] | [45021900] | 1 | 3 | 3.93(+4) | 0.373 | 0.0178 | −0.428 | C | *interp.* |
| 23. | $1s2s$–$1s4p$ | $^3S - ^3P^o$ | | | | | | | | | | | |
| | | | [10.607] | [37927500] | [47355200] | 3 | 3 | 1.8(+4) | 0.030 | 0.0031 | −1.05 | C+ | *interp.* |
| 24. | | $^1S - ^1P^o$ | [10.821] | [38135000] | [47376200] | 1 | 3 | 1.7(+4) | 0.090 | 0.0032 | −1.05 | C+ | *interp.* |
| 25. | $1s2s$–$1s5p$ | $^3S - ^3P^o$ | | | | | | | | | | | |
| | | | [9.4982] | [37927500] | [48455800] | 3 | 3 | 8900 | 0.012 | 0.0011 | −1.44 | C+ | *interp.* |
| 26. | | $^1S - ^1P^o$ | [9.6791] | [38135000] | [48466500] | 1 | 3 | 8800 | 0.037 | 0.0012 | −1.43 | C+ | *interp.* |
| 27. | $1s2p$–$1s3s$ | $^3P^o - ^3S$ | | | | | | | | | | | |
| | | | [14.736] | [38129200] | [44915100] | 3 | 3 | 4600 | 0.015 | 0.0022 | −1.35 | C− | *interp.* |
| 28. | | $^1P^o - ^1S$ | [15.019] | [38311600] | [44969900] | 3 | 1 | 1.3(+4) | 0.015 | 0.0022 | −1.35 | C+ | *interp.* |
| 29. | $1s2p$–$1s3d$ | $^3P^o - ^3D$ | | | | 9 | 15 | | 0.68 | | 0.79 | C+ | *interp.* |
| 30. | | $^1P^o - ^1D$ | | | | 3 | 5 | | 0.70 | | 0.32 | C+ | *interp.* |

Ti XXI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31. | 1s2p–1s4s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [10.866] | [38129200] | [47332000] | 3 | 3 | 1800 | 0.0032 | 3.4(−4) | −2.02 | D | *interp.* |
| 32. | | $^1$P° – $^1$S | [11.059] | [38311600] | [47354200] | 3 | 1 | 5200 | 0.0032 | 3.5(−4) | −2.02 | C | *interp.* |
| 33. | 1s2p–1s4d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.12 | | 0.03 | C | 5 |
| 34. | | $^1$P° – $^1$D | | | | 3 | 5 | | 0.12 | | −0.44 | C | 5 |
| 35. | 1s2p–1s5s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [9.6947] | [38129200] | [48444100] | 3 | 3 | 920 | 0.0013 | 1.2(−4) | −2.41 | D | *interp.* |
| 36. | | $^1$P° – $^1$S | [9.8584] | [38311600] | [48455200] | 3 | 1 | 2700 | 0.0013 | 1.3(−4) | −2.41 | C | *interp.* |
| 37. | 1s3s–1s3p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.019 | | −1.24 | E | *interp.* |
| 38. | | $^1$S – $^1$P° | | | | 1 | 3 | | 0.058 | | −1.24 | D | *interp.* |
| 39. | 1s3s–1s4p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [40.982] | [44915100] | [47355200] | 3 | 3 | 5400 | 0.137 | 0.055 | −0.386 | C | *interp.* |
| 40. | | $^1$S – $^1$P° | [41.558] | [44969900] | [47376200] | 1 | 3 | 5300 | 0.410 | 0.056 | −0.387 | C | *interp.* |
| 41. | 1s3s–1s5p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [28.243] | [44915100] | [48455800] | 3 | 3 | 2900 | 0.035 | 0.0098 | −0.98 | C | *interp.* |
| 42. | | $^1$S – $^1$P° | [28.599] | [44969900] | [48466500] | 1 | 3 | 2880 | 0.106 | 0.0100 | −0.975 | C+ | *interp.* |
| 43. | 1s3p–1s3d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.013 | | −0.93 | D | *interp.* |
| 44. | 1s3p–1s4s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [42.351] | [44970800] | [47332000] | 3 | 3 | 1300 | 0.034 | 0.014 | −0.99 | C− | *interp.* |
| 45. | | $^1$P° – $^1$S | [42.876] | [45021900] | [47354200] | 3 | 1 | 3800 | 0.035 | 0.015 | −0.98 | C | *interp.* |
| 46. | 1s3p–1s4d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.60 | | 0.73 | C | 5 |
| 47. | | $^1$P° – $^1$D | | | | 3 | 5 | | 0.62 | | 0.27 | C | 5 |
| 48. | 1s3p–1s5s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [28.791] | [44970800] | [48444100] | 3 | 3 | 620 | 0.0077 | 0.0022 | −1.64 | D | *interp.* |
| 49. | | $^1$P° – $^1$S | [29.126] | [45021900] | [48455200] | 3 | 1 | 1800 | 0.0077 | 0.0022 | −1.64 | C | *interp.* |
| 50. | 1s3d–1s3p | $^1$D – $^1$P° | | | | 5 | 3 | | 0.0024 | | −1.92 | E | 5 |
| 51. | 1s3d–1s4p | $^3$D – $^3$P° | | | | 15 | 9 | | 0.012 | | −0.74 | C | 5 |
| 52. | | $^1$D – $^1$P° | | | | 5 | 3 | | 0.011 | | −1.26 | C | 5 |
| 53. | 1s4s–1s4p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.027 | | −1.09 | E | *interp.* |

Ti XXI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 54. | | $^1$S – $^1$P° | | | | 1 | 3 | | 0.081 | | −1.09 | E | *interp.* |
| 55. | 1s4s–1s5p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [88.984] | [47332000] | [48455800] | 3 | 3 | 1280 | 0.152 | 0.134 | −0.341 | C | *interp.* |
| 56. | | $^1$S – $^1$P° | [89.904] | [47354200] | [48466500] | 1 | 3 | 1300 | 0.46 | 0.14 | −0.34 | D | *interp.* |
| 57. | 1s4p–1s4d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.023 | | −0.68 | D | 5 |
| 58. | 1s4p–1s5s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [91.836] | [47355200] | [48444100] | 3 | 3 | 440 | 0.056 | 0.051 | −0.77 | D | *interp.* |
| 59. | | $^1$P° – $^1$S | [92.678] | [47376200] | [48455200] | 3 | 1 | 1300 | 0.056 | 0.051 | −0.77 | C | *interp.* |
| 60. | 1s4d–1s4p | $^1$D – $^1$P° | | | | 5 | 3 | | 0.0037 | | −1.73 | E | 5 |
| 61. | 1s4d–1s4f | $^3$D – $^3$F° | | | | 15 | 21 | | 9.3(−4) | | −1.86 | E | 5 |
| 62. | 1s4d–1s5f | $^3$D – $^3$F° | | | | 15 | 21 | | 0.89 | | 1.13 | B | 7 |
| 63. | | $^1$D – $^1$F° | | | | 5 | 7 | | 0.89 | | 0.65 | B | 7 |
| 64. | 1s4f–1s4d | $^1$F° – $^1$D | | | | 7 | 5 | | 4.9(−4) | | −2.46 | E | 5 |
| 65. | 1s4f–1s5d | $^3$F° – $^3$D | | | | 21 | 15 | | 0.0089 | | −0.73 | C | 7 |
| 66. | | $^1$F° – $^1$D | | | | 7 | 5 | | 0.0089 | | −1.21 | C | 7 |
| 67. | 1s5s–1s5p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.034 | | −0.99 | E | *interp.* |
| 68. | | $^1$S – $^1$P° | | | | 1 | 3 | | 0.10 | | −1.00 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XXI

## Forbidden Transitions

The results of multiconfiguration Dirac-Fock calculations by Hata and Grant[1] have been selected for this tabulation. Their work includes both a very detailed consideration of configuration interaction—with configurational wavefunction sets containing as many as 51 interacting states—as well as a fully relativistic treatment based on the Dirac Hamiltonian. Their calculated wavelengths are in very close agreement with experiment, and the agreement between the experimental lifetime data[2-4] and the theoretical result is excellent, with differences not exceeding five percent. A comprehensive comparison table containing all experimental data[2-6] on these He-like ions of Fe-group elements is given in Table 1 and demonstrates the excellent agreement between experimental and theoretical data throughout.

The probabilities of the M1 transitions $1s^2\ ^1S_0 - 1s3s\ ^3S_1$ and $1s^2\ ^1S_0 - 1s4s\ ^3S_1$ have been calculated by Kundu and Mukherjee[7] with a nonrelativistic time-dependent coupled Hartree-Fock approximation. Since they agree, for the $1s^2\ ^1S_0 - 1s2s\ ^3S_1$ M1 line, within 14% with the result of Hata and Grant[1], an accuracy estimate of ± 25% appears to be reasonable.

TABLE 1. Comparison of calculated[1] and observed[2-6] lifetimes (in ns) for the 2s $^3S_1$ state (M1 decay) and the 2p $^3P_2$ state (M2 + E1 decay) for several He-like ions

| Ion | 2s $^3S_1$ state Theory | Experiment | 2p $^3P^\circ_2$ state Theory[a] | Experiment |
|---|---|---|---|---|
| Ti XXI | 26.0 | 25.8±1.3[b] | 0.42 | 0.44±0.03[c]; 0.404±0.040[d] |
| V XXII | 16.5 | 16.9±0.7[e] | 0.307 | |
| Cr XXIII | 10.7 | | 0.225 | 0.215±0.035[d] |
| Fe XXV | 4.72 | 4.8±0.6[e] | 0.124 | 0.11±0.02[c]; 0.121±0.015[f] |

[a]The lifetime for this state is the reciprocal of the sum of the transition rates 2p $^3P^\circ_2 \rightarrow$ 1s $^1S_0$ (M2) and 2p $^3P^\circ_2 \rightarrow$ 2s $^3S_1$ (E1), i.e., $\tau = [A(M2)+A(E1)]^{-1}$. The transition probability for the E1 transition 2s $^3S_1$ - 2p $^3P^\circ_2$ is taken from the MCDF calculations of Hata and Grant.[8]
[a]Ref. 2.
[b]Ref. 3.
[c]Ref. 4.
[d]Ref. 5.
[e]Ref. 6.

## References


[1]J. Hata and I. P. Grant, Mon. Not. R. Astron. Soc. **211**, 549 (1984).
[2]H. Gould, R. Marrus, and R. W. Schmieder, Phys. Rev. Lett. **31**, 504 (1973).
[3]H. Gould (unpublished result).
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[7]B. Kundu and P. K. Mukherjee, Astrophys. J. **298**, 844 (1985).
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Ti XXI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2$–$1s2s$ | $^1S$ - $^3S$ | [2.6369] | 0 | [37923330] | 1 | 3 | M1 | 3.85(+7)[a] | 7.85(−5) | B | 1 |
| 2. | $1s^2$–$1s2p$ | $^1S$ - $^3P^\circ$ | | | | | | | | | | |
| | | | [2.6192] | 0 | [38180210] | 1 | 5 | M2 | 1.69(+9) | 0.157 | B | 1 |
| 3. | $1s^2$–$1s3s$ | $^1S$ - $^3S$ | [2.2266] | 0 | [44911530] | 1 | 3 | M1 | 1.50(+7) | 1.84(−5) | C | 2 |
| 4. | $1s^2$–$1s4s$ | $^1S$ - $^3S$ | [2.1129] | 0 | [47328420] | 1 | 3 | M1 | 6.76(+6) | 7.09(−6) | C | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Ti XXII

H Isoelectronic Sequence

Ground State: 1s $^2S_{1/2}$

Ionization Energy: 6625.87 eV = 53440800 cm$^{-1}$

## Allowed Transitions

Electric dipole transition probability data for this hydrogen-like ion can be obtained directly, in a non-relativistic approximation, from the data for neutral hydrogen.[1] The oscillator strength is independent of $Z$ along the entire isoelectronic sequence and is therefore identical to the value for the hydrogen atom. Line strengths scale as $Z^{-2}$ and transition probabilities scale as $Z^4$, i.e.,

$$S_Z = Z^{-2} S_H, \qquad A_Z = Z^4 A_H.$$

For higher nuclear charges in this sequence, relativistic corrections will cause these values to deviate increasingly from the non-relativistic ones. The first effect of relativity will be to alter the transition energies, or wavelengths, from the non-relativistic, even though the line strength itself is still well approximated by the non-relativistic value. In this case, experimental energies should be used in the standard conversion formulas, given in the general introduction to this volume, to calculate the most accurate values of $f$ and $A$. It should be noted that the relativistic removal of the $j$-degeneracy introduces dipole transitions which do not occur in the non-relativistic theory, e.g., $2s_{1/2}$ - $2p_{3/2}$.

For very high $Z$, it is necessary to use the four-component Dirac spinors rather than two-component Schroedinger functions in theoretical calculations, and this introduces relativistic corrections to the line strengths themselves. Several recent systematic studies of the problem[2,3] indicate that these corrections are not large for stages of ionization in the range 20–30. Corrections for $Z = 30$ are usually no larger than 5–10% and generally substantially less than 5%. If an accuracy greater than this is required, the reader is referred to these papers[2,3] for a more detailed error analysis.

## References


[1]W. L. Wiese, M. W. Smith, and B. M. Glennon, Atomic Transition Probabilities - Hydrogen through Neon (A Critical Data Compilation), Vol. I, 157 pp., Nat. Stand. Ref. Data Ser., Nat. Bur. Stand. (U.S.), 4 (May 1966).

[2]S. M. Younger and A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **79**, 629 (1975).

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# Vanadium

## V I

Ground State: $1s^22s^22p^63s^23p^63d^34s^2\ ^4F_{3/2}$

Ionization Energy: 6.740 eV = 54360 cm$^{-1}$

### Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 3043.12 | 18 | 3284.36 | 68 | 3779.64 | 66 | 3896.15 | 43 |
| 3043.55 | 18 | 3291.68 | 13 | 3784.67 | 11 | 3902.26 | 8 |
| 3044.93 | 18 | 3298.15 | 13 | 3787.18 | 11 | 3909.89 | 8 |
| 3050.39 | 71 | 3299.09 | 55 | 3790.33 | 29 | 3910.78 | 42 |
| 3050.88 | 17 | 3308.25 | 13 | 3790.46 | 66 | 3912.88 | 42 |
| 3052.19 | 16 | 3309.18 | 55 | 3791.33 | 11 | 3920.48 | 42 |
| 3053.65 | 18 | 3329.85 | 55 | 3793.61 | 10 | 3921.86 | 42 |
| 3056.33 | 18 | 3356.35 | 54 | 3794.96 | 10,29 | 3922.43 | 42 |
| 3060.46 | 18 | 3365.55 | 54 | 3799.91 | 29 | 3925.22 | 9 |
| 3060.92 | 16 | 3376.05 | 54 | 3803.47 | 29 | 3930.02 | 62 |
| 3063.72 | 17 | 3377.39 | 54 | 3803.78 | 65 | 3934.01 | 42 |
| 3066.37 | 18 | 3377.62 | 54 | 3803.89 | 11 | 3936.27 | 42 |
| 3066.53 | 18 | 3397.58 | 54 | 3806.79 | 65 | 3941.99 | 62 |
| 3069.65 | 16 | 3400.39 | 46 | 3807.50 | 29 | 3943.66 | 42 |
| 3075.93 | 57 | 3402.57 | 46 | 3808.52 | 10 | 3992.80 | 81 |
| 3080.15 | 16 | 3405.15 | 46 | 3809.60 | 29 | 3998.73 | 81 |
| 3080.33 | 57 | 3406.84 | 46 | 3813.48 | 10 | 4029.89 | 6 |
| 3082.11 | 18 | 3417.06 | 46 | 3815.51 | 29 | 4032.84 | 7 |
| 3083.54 | 57 | 3529.73 | 53 | 3817.84 | 11 | 4048.62 | 7 |
| 3087.06 | 57 | 3533.68 | 53 | 3818.24 | 10 | 4050.96 | 104 |
| 3088.11 | 56 | 3533.76 | 53 | 3819.96 | 29 | 4051.35 | 104 |
| 3089.13 | 57 | 3543.49 | 53 | 3821.48 | 29 | 4052.45 | 7 |
| 3091.43 | 16 | 3545.33 | 53 | 3822.00 | 10 | 4067.9 | 7 |
| 3091.54 | 16 | 3553.27 | 53 | 3822.89 | 29 | 4070.76 | 7 |
| 3093.24 | 16 | 3555.14 | 53 | 3823.21 | 29 | 4090.57 | 41 |
| 3093.79 | 57 | 3583.71 | 45 | 3823.98 | 44 | 4092.39 | 52 |
| 3094.69 | 56 | 3663.60 | 98 | 3826.77 | 44 | 4092.68 | 28 |
| 3112.92 | 56 | 3667.74 | 98 | 3828.56 | 10 | 4093.48 | 52 |
| 3183.41 | 15 | 3671.20 | 67 | 3835.57 | 44 | 4095.48 | 41 |
| 3183.96 | 15 | 3672.41 | 99 | 3836.05 | 44 | 4099.78 | 28 |
| 3183.98 | 15 | 3673.41 | 98 | 3839.00 | 44 | 4102.15 | 41 |
| 3185.38 | 15 | 3675.70 | 30 | 3840.13 | 64 | 4104.77 | 96 |
| 3198.01 | 15 | 3676.70 | 99 | 3840.75 | 10 | 4105.16 | 28 |
| 3202.39 | 15 | 3680.12 | 98 | 3841.89 | 9 | 4109.78 | 28 |
| 3204.19 | 14 | 3683.12 | 30 | 3844.43 | 8 | 4111.78 | 28 |
| 3205.58 | 70 | 3686.26 | 67 | 3847.33 | 8 | 4113.51 | 52 |
| 3207.41 | 15 | 3687.50 | 98 | 3855.36 | 8 | 4115.18 | 28 |
| 3212.43 | 70 | 3688.07 | 30 | 3855.85 | 10 | 4116.47 | 28 |
| 3215.37 | 14 | 3690.28 | 30 | 3859.34 | 44 | 4116.59 | 28 |
| 3217.12 | 15 | 3692.22 | 30 | 3862.22 | 9 | 4116.71 | 28 |
| 3218.87 | 69 | 3695.34 | 98 | 3863.86 | 64 | 4118.62 | 41 |
| 3226.10 | 15 | 3695.86 | 30 | 3864.33 | 63 | 4119.45 | 41 |
| 3230.64 | 14 | 3703.57 | 30 | 3864.86 | 8 | 4120.53 | 41 |
| 3233.19 | 69 | 3704.70 | 30 | 3867.60 | 8 | 4123.50 | 28 |
| 3249.57 | 14 | 3705.04 | 30 | 3871.07 | 64 | 4124.10 | 52 |
| 3254.77 | 14 | 3706.03 | 90 | 3875.07 | 8 | 4128.06 | 28 |
| 3263.24 | 13 | 3708.71 | 90 | 3875.90 | 8 | 4131.16 | 27 |
| 3271.64 | 13 | 3713.96 | 12 | 3876.08 | 9 | 4131.99 | 28 |
| 3273.03 | 68 | 3721.34 | 12 | 3886.58 | 63 | 4134.49 | 28 |
| 3277.94 | 13 | 3777.16 | 11 | 3890.18 | 9 | 4136.40 | 27 |
| 3283.31 | 13 | 3778.67 | 29 | 3892.86 | 8 | 4141.82 | 27 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 4142.63 | 27 | 4429.79 | 24 | 4851.49 | 2 | 6002.29 | 50 |
| 4148.85 | 27 | 4436.13 | 22 | 4864.73 | 2 | 6002.61 | 33 |
| 4153.32 | 27 | 4437.83 | 22 | 4864.83 | 51 | 6008.65 | 50 |
| 4159.68 | 26 | 4441.68 | 22 | 4875.49 | 2 | 6017.89 | 50 |
| 4160.40 | 27 | 4444.19 | 22 | 4880.56 | 51 | 6025.38 | 77 |
| 4176.78 | 5 | 4449.57 | 61 | 4881.56 | 2 | 6039.73 | 33 |
| 4179.41 | 26 | 4452.01 | 79 | 4886.81 | 51 | 6048.66 | 50 |
| 4182.58 | 25 | 4457.47 | 22 | 4904.30 | 51 | 6058.09 | 33 |
| 4189.84 | 25 | 4457.75 | 88 | 4904.43 | 101 | 6063.32 | 77 |
| 4191.55 | 25 | 4459.75 | 22 | 4925.66 | 51 | 6081.44 | 33 |
| 4198.60 | 25 | 4460.33 | 22 | 4932.03 | 51 | 6087.49 | 34 |
| 4200.19 | 26 | 4462.36 | 79 | 5193.00 | 105 | 6090.21 | 33 |
| 4200.89 | 5 | 4468.00 | 79 | 5195.39 | 105 | 6090.54 | 34 |
| 4204.51 | 25 | 4468.76 | 87 | 5234.08 | 108 | 6097.42 | 34 |
| 4209.85 | 25 | 4469.71 | 79 | 5240.87 | 108 | 6106.97 | 60 |
| 4218.70 | 25 | 4474.04 | 94 | 5372.65 | 21 | 6111.65 | 33 |
| 4219.49 | 25 | 4490.81 | 78 | 5398.91 | 21 | 6119.53 | 33 |
| 4232.46 | 95 | 4491.17 | 61 | 5415.25 | 107 | 6128.33 | 34 |
| 4232.95 | 95 | 4496.06 | 94 | 5487.91 | 106 | 6135.07 | 60 |
| 4234.00 | 5 | 4496.86 | 78 | 5507.75 | 106 | 6135.36 | 33 |
| 4234.52 | 5 | 4502.01 | 61 | 5515.32 | 1 | 6150.16 | 20 |
| 4236.62 | 26 | 4514.18 | 94 | 5527.66 | 1 | 6170.37 | 20 |
| 4259.31 | 5 | 4524.21 | 85 | 5535.35 | 1 | 6178.90 | 49 |
| 4268.64 | 80 | 4525.17 | 94 | 5544.87 | 38 | 6189.37 | 20 |
| 4271.55 | 80 | 4529.58 | 85 | 5545.91 | 38 | 6199.19 | 19 |
| 4276.95 | 80 | 4537.66 | 74 | 5547.06 | 38 | 6213.87 | 20 |
| 4284.05 | 80 | 4540.01 | 86 | 5557.45 | 1 | 6216.37 | 19 |
| 4291.82 | 103 | 4545.40 | 93 | 5558.75 | 73 | 6224.51 | 20 |
| 4296.10 | 103 | 4560.72 | 93 | 5560.52 | 1 | 6230.80 | 19 |
| 4297.67 | 103 | 4571.79 | 93 | 5561.68 | 73 | 6233.20 | 20 |
| 4298.03 | 103 | 4577.18 | 3 | 5565.92 | 38 | 6240.14 | 20 |
| 4306.22 | 4 | 4578.73 | 93 | 5584.50 | 37 | 6242.83 | 19 |
| 4307.19 | 4 | 4579.19 | 93 | 5588.46 | 38 | 6243.11 | 19 |
| 4309.80 | 4 | 4580.40 | 3 | 5589.71 | 1 | 6251.82 | 19 |
| 4330.03 | 4 | 4586.37 | 3 | 5592.41 | 37 | 6256.90 | 19 |
| 4332.82 | 4 | 4594.12 | 3 | 5592.96 | 1 | 6258.57 | 19 |
| 4341.01 | 4 | 4606.15 | 3 | 5597.81 | 38 | 6261.23 | 20 |
| 4342.83 | 89 | 4619.78 | 3 | 5604.94 | 37 | 6266.32 | 20 |
| 4350.81 | 23 | 4624.41 | 39 | 5624.60 | 37 | 6274.65 | 19 |
| 4352.87 | 4 | 4626.49 | 39 | 5624.87 | 37 | 6285.16 | 19 |
| 4354.97 | 89 | 4635.17 | 3 | 5626.02 | 37 | 6292.82 | 19 |
| 4355.94 | 4 | 4640.09 | 39 | 5627.63 | 37 | 6296.49 | 19 |
| 4363.52 | 23 | 4640.72 | 39 | 5632.45 | 1 | 6326.85 | 76 |
| 4368.04 | 4 | 4645.97 | 3 | 5646.11 | 37 | 6339.09 | 76 |
| 4379.23 | 24 | 4646.40 | 39 | 5657.44 | 37 | 6349.48 | 76 |
| 4380.97 | 23 | 4669.30 | 3 | 5668.36 | 37 | 6357.30 | 76 |
| 4384.18 | 23 | 4670.45 | 39 | 5670.85 | 36 | 6452.34 | 48 |
| 4384.71 | 24 | 4706.16 | 83 | 5698.53 | 35 | 6469.68 | 59 |
| 4387.20 | 40 | 4706.57 | 102 | 5703.59 | 35 | 6504.16 | 48 |
| 4389.98 | 24 | 4710.55 | 102 | 5707.00 | 35 | 6531.41 | 48 |
| 4392.06 | 23 | 4746.62 | 97 | 5725.64 | 109 | 6543.50 | 48 |
| 4393.83 | 40 | 4748.51 | 97 | 5727.05 | 35 | 6558.02 | 59 |
| 4395.22 | 24 | 4750.98 | 97 | 5727.65 | 35 | 6565.90 | 48 |
| 4400.57 | 24 | 4751.57 | 83 | 5731.25 | 36 | 6605.96 | 48 |
| 4405.02 | 23 | 4753.93 | 97 | 5737.06 | 35 | 6607.83 | 59 |
| 4406.10 | 40 | 4757.47 | 97 | 5743.43 | 35 | 6624.86 | 48 |
| 4406.64 | 24 | 4766.62 | 97 | 5748.89 | 82 | 6633.29 | 58 |
| 4407.63 | 24 | 4776.36 | 97 | 5761.43 | 35 | 6753.00 | 32 |
| 4408.20 | 24 | 4784.47 | 2 | 5772.41 | 82 | 6766.50 | 32 |
| 4412.13 | 23 | 4786.50 | 97 | 5776.66 | 36 | 6785.00 | 32 |
| 4416.47 | 24 | 4796.92 | 97 | 5782.60 | 35 | 6812.41 | 32 |
| 4419.93 | 22 | 4799.76 | 2 | 5850.33 | 82 | 6832.44 | 32 |
| 4421.57 | 24 | 4807.52 | 97 | 5924.55 | 77 | 6841.88 | 32 |
| 4423.22 | 40 | 4827.45 | 2 | 5978.89 | 77 | 7936.95 | 72 |
| 4426.00 | 24 | 4831.64 | 2 | 5980.77 | 50 | 8027.34 | 31 |
| 4428.52 | 22 | 4832.42 | 2 | 5984.60 | 50 | 8093.50 | 31 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 8116.80 | 31 | 8255.90 | 31 | 9085.19 | 47 | 13787.33 | 75 |
| 8144.57 | 31 | 8919.80 | 47 | 9113.71 | 47 | 14040.45 | 75 |
| 8161.06 | 31 | 8932.88 | 47 | 9156.57 | 84 | 14252.89 | 75 |
| 8186.74 | 31 | 8971.61 | 47 | 9202.89 | 47 | 14423.14 | 75 |
| 8198.86 | 31 | 9022.70 | 84 | 9691.57 | 92 | 16406.07 | 100 |
| 8241.54 | 31 | 9037.57 | 47 | 13291.12 | 91 | | |
| 8253.56 | 31 | 9046.64 | 47 | 13467.40 | 91 | | |

For this spectrum, we selected three experiments. The most reliable data are those of Whaling *et al.*,[1] who measured branching ratios with a hollow-cathode discharge. These authors also determined accurate lifetimes by laser-induced fluorescence, thereby enabling them to convert their relative emission data to absolute values. In most cases, the lifetimes and resulting absolute oscillator strengths are accurate to within five and ten percent, respectively.

The other two references that we utilized for this compilation are the anomalous dispersion (hook) measurements of Ostrovskii and Penkin[2] and the absorption measurements of King.[3] Both of these data sources provide relative oscillator strengths, which we normalized to the data of Whaling *et al.* This entailed a subtraction of 3.70 from the given log *gf*-values of King, and 4.67 from the log *gf*-values of Ostrovskii and Penkin. After this normalization, the agreement between Refs. 1 and 2 is quite impressive: for 33 of 34 overlapping lines, the log *gf*-values agree within ±25%. For strong lines (log $gf > -1.00$) the two sources generally agree within ±12%.

The data of King[3] overlap with those of Whaling *et al.* for 118 lines. The agreement between these two references (after normalization of King) is not as good as the comparison mentioned above. For Refs. 1 and 3, 75% of the data agree within ±25 percent, and 82% of the data agree within ±50 percent. However, for several lines of long wavelength ($\lambda > 6000$ Å) arising from lower levels of appreciable excitation potential ($E_i > 9000\ \mathrm{cm}^{-1}$), Refs. 1 and 3 disagree by more than a factor of two. In general, long-wavelength lines exhibit more pronounced scatter than other lines. We have therefore reduced the accuracy ratings of King's data for lines having wavelengths greater than 6000 Å.

In evaluating the data of Ref. 1, we found a few misprints and/or errors which have been subsequently corrected in this compilation. For example, we have omitted the 5075.69 Å line from this compilation. Whaling *et al.* designated this line as the $a\ ^6D_{9/2} - z\ ^4G^\circ_{9/2}$ transition. The line is actually a blend, with the major contribution to the intensity arising from the $a\ ^4G_{11/2} - w\ ^4G^\circ_{11/2}$ transition.[4] We have also renormalized transition probabilities for eight lines (designated by 1*n* in the source column) because of arithmetic errors in converting branching ratio data to *A*-values. Finally, the reader should make note that in the transition probability column found in Ref. 1 for lines emitted from the $x\ ^4G^\circ$ levels, the unit should be $10^7\ \mathrm{s}^{-1}$, and not $10^5\ \mathrm{s}^{-1}$ as listed.[4]

The log *gf*-value tabulated by Ostrovskii and Penkin for the 3675.70 Å line is probably too large by a factor of ten. This probable error (likely a typographical one) was detected by Whaling,[4] who applied the "bowtie" method to some of his unpublished branching-ratios and to the *f*-values of Ref. 2. For this line, we have therefore used King's measurement, which is in better agreement with Whaling's unpublished value than the result of Ref. 2.

King has provided data for a few intercombination lines. As a general rule, we have omitted these, as well as other lines having log *gf*-values less than −3.00, since errors are estimated to be greater than 50 percent for these weak lines. We have also omitted King's data for blended lines, which he indicated as such in his tables.

## References

[1]W. Whaling, P. Hannaford, R. M. Lowe, E. Biemont, and N. Grevesse, Astron. Astrophys. **153**, 109 (1985).
[2]Yu. I. Ostrovskii and N. P. Penkin, Opt. Spektrosk. **5**, 345 (1958).
[3]R. B. King, Astrophys. J. **105**, 376 (1947).
[4]W. Whaling, private communication.

### *Note Added in Proof*

Upon completion of our V I data tables, another paper was published on this spectrum. It is by Doerr, Kock, Kwiatkowski, Werner, and Zimmermann, and appears in J. Quant. Spectrosc. Radiat. Transfer **33**, 55 (1985). These authors determined a set of relative oscillator strengths ranging from $\lambda = 2850$ Å to $\lambda = 6020$ Å, by combining emission measurements on a hollow cathode with absorption (hook) measurements, using a high-temperature furnace. These *f*-values were then normalized to the authors' own lifetime data, obtained via selective dye-laser excitation. This reference provides data for several transitions below 3000 Å not tabulated in this compilation.

We compared these new data to those of Whaling *et al.* For 78% of the 45 overlapping lines, the two sources agree within fifty percent. However, for five transitions, the *f*-values disagree by more than a factor of two. We believe that for the 3925.22 Å line (the case of worst agreement), undetected blending is quite possible.

V I: Allowed transitions

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $a\,^4$F - $z\,^6$D° (1) | | | | | | | | | | | |
| | | 5632.45 | 553.0 | 18302 | 10 | 8 | 1.6(−4)[a] | 6.1(−5) | 0.011 | −3.22 | C+ | 1 |
| | | 5592.96 | 323.5 | 18198 | 8 | 6 | 2.1(−4) | 7.4(−5) | 0.011 | −3.23 | B | 1 |
| | | 5557.45 | 137.4 | 18126 | 6 | 4 | 2.0(−4) | 6.2(−5) | 0.0068 | −3.43 | B | 1 |
| | | 5527.66 | 0.0 | 18086 | 4 | 2 | 1.1(−4) | 2.5(−5) | 0.0018 | −4.00 | C | 1 |
| | | 5589.71 | 553.0 | 18438 | 10 | 10 | 3.0(−5) | 1.4(−5) | 0.0026 | −3.85 | B | 1 |
| | | 5560.52 | 323.5 | 18302 | 8 | 8 | 6.4(−5) | 3.0(−5) | 0.0043 | −3.62 | B | 1 |
| | | 5535.35 | 137.4 | 18198 | 6 | 6 | 8.9(−5) | 4.1(−5) | 0.0045 | −3.61 | B | 1 |
| | | 5515.32 | 0.0 | 18126 | 4 | 4 | 6.5(−5) | 3.0(−5) | 0.0022 | −3.93 | C+ | 1 |
| 2. | $a\,^4$F - $z\,^4$D° (3) | *4867.0* | *319.4* | *20860* | 28 | 20 | 0.0940 | 0.0239 | 10.7 | −0.175 | B+ | 1 |
| | | 4881.56 | 553.0 | 21033 | 10 | 8 | 0.077 | 0.022 | 3.5 | −0.66 | B+ | 1 |
| | | 4875.49 | 323.5 | 20828 | 8 | 6 | 0.073 | 0.020 | 2.5 | −0.81 | B+ | 1 |
| | | 4864.73 | 137.4 | 20688 | 6 | 4 | 0.077 | 0.018 | 1.8 | −0.96 | B+ | 1 |
| | | 4851.49 | 0.0 | 20607 | 4 | 2 | 0.103 | 0.0182 | 1.16 | −1.139 | B+ | 1 |
| | | 4827.45 | 323.5 | 21033 | 8 | 8 | 0.0119 | 0.00416 | 0.529 | −1.478 | B+ | 1 |
| | | 4831.64 | 137.4 | 20828 | 6 | 6 | 0.020 | 0.0070 | 0.67 | −1.38 | B+ | 1 |
| | | 4832.42 | 0.0 | 20688 | 4 | 4 | 0.0223 | 0.00781 | 0.497 | −1.505 | B | 1 |
| | | 4784.47 | 137.4 | 21033 | 6 | 8 | 7.7(−4) | 3.5(−4) | 0.033 | −2.67 | B+ | 1 |
| | | 4799.76 | 0.0 | 20828 | 4 | 6 | 0.00127 | 6.58(−4) | 0.0416 | −2.580 | B+ | 1 |
| 3. | $a\,^4$F - $z\,^4$G° (4) | *4589.1* | *319.4* | *22104* | 28 | 36 | 0.055 | 0.022 | 9.4 | −0.21 | B+ | 1 |
| | | 4594.12 | 553.0 | 22314 | 10 | 12 | 0.056 | 0.021 | 3.2 | −0.67 | B+ | 1 |
| | | 4586.37 | 323.5 | 22121 | 8 | 10 | 0.051 | 0.020 | 2.4 | −0.79 | B+ | 1 |
| | | 4580.40 | 137.4 | 21963 | 6 | 8 | 0.0471 | 0.0198 | 1.79 | −0.926 | B+ | 1 |
| | | 4577.18 | 0.0 | 21841 | 4 | 6 | 0.0475 | 0.0224 | 1.35 | −1.048 | B+ | 1 |
| | | 4635.17 | 553.0 | 22121 | 10 | 10 | 0.0037 | 0.0012 | 0.18 | −1.92 | B | 1 |
| | | 4619.78 | 323.5 | 21963 | 8 | 8 | 0.0062 | 0.0020 | 0.24 | −1.80 | B+ | 1 |
| | | 4606.15 | 137.4 | 21841 | 6 | 6 | 0.0069 | 0.0022 | 0.20 | −1.88 | C | 1 |
| | | 4669.30 | 553.0 | 21963 | 10 | 8 | 1.10(−4) | 2.88(−5) | 0.00442 | −3.541 | B+ | 1 |
| | | 4645.97 | 323.5 | 21841 | 8 | 6 | 2.31(−4) | 5.61(−5) | 0.00686 | −3.348 | B+ | 1 |
| 4. | $a\,^4$F - $z\,^4$F° (5) | | | | | | | | | | | |
| | | 4352.87 | 553.0 | 23520 | 10 | 10 | 0.058 | 0.017 | 2.4 | −0.78 | C | 2*n* |
| | | 4341.01 | 323.5 | 23353 | 8 | 8 | 0.050 | 0.014 | 1.6 | −0.95 | C | 2*n* |
| | | 4332.82 | 137.4 | 23211 | 6 | 6 | 0.046 | 0.013 | 1.1 | −1.11 | B+ | 1 |
| | | 4330.03 | 0.0 | 23088 | 4 | 4 | 0.052 | 0.015 | 0.83 | −1.23 | B+ | 1 |
| | | 4368.04 | 323.5 | 23211 | 8 | 6 | 0.0101 | 0.00217 | 0.249 | −1.761 | B+ | 1 |
| | | 4355.94 | 137.4 | 23088 | 6 | 4 | 0.0105 | 0.00199 | 0.171 | −1.923 | B+ | 1 |
| | | 4309.80 | 323.5 | 23520 | 8 | 10 | 0.0094 | 0.0033 | 0.37 | −1.58 | C | 2*n* |
| | | 4306.22 | 137.4 | 23353 | 6 | 8 | 0.012 | 0.0046 | 0.39 | −1.56 | C | 2*n* |
| | | 4307.19 | 0.0 | 23211 | 4 | 6 | 0.0111 | 0.00463 | 0.263 | −1.732 | B+ | 1 |
| 5. | $a\,^4$F - $z\,^2$D° (6) | | | | | | | | | | | |
| | | 4234.00 | 323.5 | 23935 | 8 | 6 | 0.0048 | 9.7(−4) | 0.11 | −2.11 | C− | 3*n* |
| | | 4259.31 | 137.4 | 23609 | 6 | 4 | 0.0062 | 0.0011 | 0.095 | −2.17 | C− | 3*n* |
| | | 4200.89 | 137.4 | 23935 | 6 | 6 | 7.8(−4) | 2.1(−4) | 0.017 | −2.91 | C− | 3*n* |
| | | 4234.52 | 0.0 | 23609 | 4 | 4 | 0.0069 | 0.0019 | 0.10 | −2.13 | C− | 3*n* |
| | | 4176.78 | 0.0 | 23935 | 4 | 6 | 4.6(−4) | 1.8(−4) | 0.010 | −3.14 | C− | 3*n* |
| 6. | $a\,^4$F - $z\,^4$P° | | | | | | | | | | | |
| | | 4029.89 | 323.5 | 25131 | 8 | 6 | 0.00100 | 1.83(−4) | 0.0194 | −2.835 | B | 1 |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7. | $a\,^4F - y\,^6F^\circ$ | | | | | | | | | | | |
| | | 4070.76 | 553.0 | 25111 | 10 | 10 | 9.7(−4) | 2.4(−4) | 0.032 | −2.62 | C− | 3*n* |
| | | 4052.45 | 323.5 | 24993 | 8 | 8 | 4.8(−4) | 1.2(−4) | 0.013 | −3.02 | C− | 3*n* |
| | | [4067.9] | 323.5 | 24899 | 8 | 6 | 0.0020 | 3.7(−4) | 0.040 | −2.53 | C− | 3*n* |
| | | 4048.62 | 137.4 | 24830 | 6 | 4 | 0.0026 | 4.3(−4) | 0.034 | −2.59 | C− | 3*n* |
| | | 4032.84 | 0.0 | 24789 | 4 | 2 | 0.0029 | 3.5(−4) | 0.019 | −2.85 | C− | 3*n* |
| 8. | $a\,^4F - y\,^4F^\circ$ (7) | *3879.7* | *319.4* | *26087* | 28 | 28 | 0.344 | 0.0777 | 27.8 | 0.338 | B+ | 1 |
| | | 3902.26 | 553.0 | 26172 | 10 | 10 | 0.268 | 0.0612 | 7.86 | −0.213 | B+ | 1 |
| | | 3875.07 | 323.5 | 26122 | 8 | 8 | 0.236 | 0.0531 | 5.42 | −0.372 | B+ | 1 |
| | | 3864.86 | 137.4 | 26004 | 6 | 6 | 0.270 | 0.0605 | 4.62 | −0.440 | B+ | 1 |
| | | 3855.36 | 0.0 | 25931 | 4 | 4 | 0.330 | 0.0735 | 3.73 | −0.531 | B+ | 1*n* |
| | | 3909.89 | 553.0 | 26122 | 10 | 8 | 0.043 | 0.0079 | 1.0 | −1.10 | B+ | 1 |
| | | 3892.86 | 323.5 | 26004 | 8 | 6 | 0.082 | 0.014 | 1.4 | −0.95 | B+ | 1 |
| | | 3875.90 | 137.4 | 25931 | 6 | 4 | 0.083 | 0.012 | 0.95 | −1.13 | B+ | 1*n* |
| | | 3867.60 | 323.5 | 26172 | 8 | 10 | 0.0254 | 0.00712 | 0.725 | −1.244 | B+ | 1 |
| | | 3847.33 | 137.4 | 26122 | 6 | 8 | 0.048 | 0.014 | 1.1 | −1.07 | B+ | 1 |
| | | 3844.43 | 0.0 | 26004 | 4 | 6 | 0.060 | 0.020 | 1.0 | −1.10 | B+ | 1 |
| 9. | $a\,^4F - z\,^2G^\circ$ (8) | | | | | | | | | | | |
| | | 3876.08 | 553.0 | 26345 | 10 | 10 | 0.091 | 0.020 | 2.6 | −0.69 | B | 1 |
| | | 3890.18 | 323.5 | 26022 | 8 | 8 | 0.066 | 0.015 | 1.5 | −0.92 | B+ | 1 |
| | | 3925.22 | 553.0 | 26022 | 10 | 8 | 0.0097 | 0.0018 | 0.23 | −1.75 | B+ | 1 |
| | | 3841.89 | 323.5 | 26345 | 8 | 10 | 0.0096 | 0.0027 | 0.27 | −1.67 | B | 1 |
| | | 3862.22 | 137.4 | 26022 | 6 | 8 | 0.0113 | 0.00337 | 0.257 | −1.694 | B | 1 |
| 10. | $a\,^4F - y\,^4D^\circ$ (9) | *3838.2* | *319.4* | *26366* | 28 | 20 | 0.672 | 0.106 | 37.5 | 0.472 | B | 1 |
| | | 3855.85 | 553.0 | 26480 | 10 | 8 | 0.578 | 0.103 | 13.1 | 0.013 | B+ | 1 |
| | | 3840.75 | 323.5 | 26353 | 8 | 6 | 0.548 | 0.0909 | 9.19 | −0.138 | B | 1 |
| | | 3828.56 | 137.4 | 26249 | 6 | 4 | 0.533 | 0.0781 | 5.91 | −0.329 | B+ | 1 |
| | | 3818.24 | 0.0 | 26183 | 4 | 2 | 0.673 | 0.0735 | 3.70 | −0.531 | B+ | 1 |
| | | 3822.00 | 323.5 | 26480 | 8 | 8 | 0.081 | 0.018 | 1.8 | −0.85 | B | 1 |
| | | 3813.48 | 137.4 | 26353 | 6 | 6 | 0.119 | 0.0259 | 1.95 | −0.81 | C | 1 |
| | | 3808.52 | 0.0 | 26249 | 4 | 4 | 0.148 | 0.0322 | 1.61 | −0.890 | B+ | 1 |
| | | 3794.96 | 137.4 | 26480 | 6 | 8 | 0.0047 | 0.0014 | 0.10 | −2.09 | C+ | 1 |
| | | 3793.61 | 0.0 | 26353 | 4 | 6 | 0.0079 | 0.0026 | 0.13 | −1.99 | B | 1 |
| 11. | $a\,^4F - y\,^6D^\circ$ (10) | | | | | | | | | | | |
| | | 3817.84 | 553.0 | 26738 | 10 | 10 | 0.0117 | ).00256 | 0.321 | −1.592 | B | 1 |
| | | 3803.89 | 323.5 | 26605 | 8 | 8 | 0.0054 | 0.0012 | 0.12 | −2.03 | B | 1 |
| | | 3791.33 | 137.4 | 26506 | 6 | 6 | 0.0014 | 3.0(−4) | 0.022 | −2.75 | C− | 3*n* |
| | | 3787.18 | 0.0 | 26398 | 4 | 2 | 8(−4) | 4(−5) | 0.002 | −3.8 | D | 1 |
| | | 3784.67 | 323.5 | 26738 | 8 | 10 | 0.0034 | 9.1(−4) | 0.091 | −2.14 | B | 1 |
| | | 3777.16 | 137.4 | 26605 | 6 | 8 | 8(−4) | 2(−4) | 0.02 | −2.9 | C | 1 |
| 12. | $a\,^4F - z\,^2F^\circ$ (11) | | | | | | | | | | | |
| | | 3713.96 | 553.0 | 27471 | 10 | 8 | 0.0028 | 4.6(−4) | 0.056 | −2.34 | C− | 3*n* |
| | | 3721.34 | 323.5 | 27188 | 8 | 6 | 0.0012 | 1.9(−4) | 0.019 | −2.81 | C− | 3*n* |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13. | $a\ ^4F - y\ ^4G°$ (12) | | | | | | | | | | | |
| | | 3298.15 | 553.0 | 30864 | 10 | 12 | 0.020 | 0.0039 | 0.42 | −1.41 | C− | 3*n* |
| | | 3283.31 | 323.5 | 30772 | 8 | 10 | 0.037 | 0.0075 | 0.65 | −1.22 | C− | 3*n* |
| | | 3271.64 | 137.4 | 30694 | 6 | 8 | 0.048 | 0.010 | 0.66 | −1.21 | C− | 3*n* |
| | | 3263.24 | 0.0 | 30636 | 4 | 6 | 0.071 | 0.017 | 0.73 | −1.17 | C− | 3*n* |
| | | 3308.25 | 553.0 | 30772 | 10 | 10 | 0.0018 | 3.0(−4) | 0.033 | −2.52 | C− | 3*n* |
| | | 3291.68 | 323.5 | 30694 | 8 | 8 | 0.0039 | 6.4(−4) | 0.056 | −2.29 | C− | 3*n* |
| | | 3277.94 | 137.4 | 30636 | 6 | 6 | 0.0068 | 0.0011 | 0.071 | −2.18 | C− | 3*n* |
| 14. | $a\ ^4F - x\ ^4F°$ (13) | | | | | | | | | | | |
| | | 3249.57 | 553.0 | 31317 | 10 | 10 | 0.0069 | 0.0011 | 0.12 | −1.96 | C− | 3*n* |
| | | 3230.64 | 323.5 | 31268 | 8 | 8 | 0.0062 | 9.7(−4) | 0.083 | −2.11 | C− | 3*n* |
| | | 3215.37 | 137.4 | 31229 | 6 | 6 | 0.0062 | 9.6(−4) | 0.061 | −2.24 | C− | 3*n* |
| | | 3204.19 | 0.0 | 31200 | 4 | 4 | 0.0065 | 0.0010 | 0.042 | −2.40 | C− | 3*n* |
| | | 3254.77 | 553.0 | 31268 | 10 | 8 | 0.0015 | 1.9(−4) | 0.020 | −2.72 | C− | 3*n* |
| 15. | $a\ ^4F - x\ ^4G°$ (14) | *3185.9* | *319.4* | *31699* | 28 | 36 | 2.77 | 0.54 | 159 | 1.181 | C | 1,1*n* |
| | | 3185.38 | 553.0 | 31937 | 10 | 12 | 2.7 | 0.49 | 52 | 0.69 | C | 1 |
| | | 3183.96 | 323.5 | 31722 | 8 | 10 | 2.5 | 0.47 | 40 | 0.58 | C | 1 |
| | | 3183.41 | 137.4 | 31541 | 6 | 8 | 2.4 | 0.49 | 31 | 0.46 | C+ | 1 |
| | | 3183.98 | 0.0 | 31398 | 4 | 6 | 2.4 | 0.55 | 23 | 0.34 | C+ | 1 |
| | | 3207.41 | 553.0 | 31722 | 10 | 10 | 0.26 | 0.040 | 4.2 | −0.40 | C | 1 |
| | | 3202.39 | 323.5 | 31541 | 8 | 8 | 0.40 | 0.061 | 5.2 | −0.31 | C | 1 |
| | | 3198.01 | 137.4 | 31398 | 6 | 6 | 0.39 | 0.059 | 3.7 | −0.45 | C+ | 1 |
| | | 3226.10 | 553.0 | 31541 | 10 | 8 | 0.0070 | 8.7(−4) | 0.093 | −2.06 | C | 1*n* |
| | | 3217.12 | 323.5 | 31398 | 8 | 6 | 0.013 | 0.0015 | 0.13 | −1.92 | C | 1 |
| 16. | $a\ ^4F - x\ ^4D°$ (15) | | | | | | | | | | | |
| | | 3091.43 | 553.0 | 32891 | 10 | 8 | 0.014 | 0.0016 | 0.16 | −1.80 | C− | 3*n* |
| | | 3091.54 | 323.5 | 32660 | 8 | 6 | 0.0086 | 9.3(−4) | 0.075 | −2.13 | C− | 3*n* |
| | | 3093.24 | 137.4 | 32457 | 6 | 4 | 0.0038 | 3.6(−4) | 0.022 | −2.66 | C− | 3*n* |
| | | 3069.65 | 323.5 | 32891 | 8 | 8 | 0.10 | 0.014 | 1.2 | −0.94 | C | 2*n* |
| | | 3080.15 | 0.0 | 32457 | 4 | 4 | 0.0061 | 8.7(−4) | 0.035 | −2.46 | C− | 3*n* |
| | | 3052.19 | 137.4 | 32891 | 6 | 8 | 0.024 | 0.0044 | 0.26 | −1.58 | C− | 3*n* |
| | | 3060.92 | 0.0 | 32660 | 4 | 6 | 0.0039 | 8.3(−4) | 0.033 | −2.48 | C− | 3*n* |
| 17. | $a\ ^4F - z\ ^2P°$ (16) | | | | | | | | | | | |
| | | 3063.72 | 137.4 | 32768 | 6 | 4 | 0.038 | 0.0036 | 0.22 | −1.67 | C− | 3*n* |
| | | 3050.88 | 0.0 | 32768 | 4 | 4 | 0.19 | 0.026 | 1.1 | −0.98 | C− | 3*n* |
| 18. | $a\ ^4F - w\ ^4F°$ (17) | | | | | | | | | | | |
| | | 3066.37 | 553.0 | 33155 | 10 | 10 | 2.1 | 0.30 | 30 | 0.47 | C | 2*n* |
| | | 3060.46 | 323.5 | 32989 | 8 | 8 | 1.4 | 0.20 | 16 | 0.21 | C | 2*n* |
| | | 3056.33 | 137.4 | 32847 | 6 | 6 | 1.3 | 0.19 | 11 | 0.05 | C | 2*n* |
| | | 3053.65 | 0.0 | 32738 | 4 | 4 | 1.3 | 0.18 | 7.3 | −0.14 | C | 2*n* |
| | | 3082.11 | 553.0 | 32989 | 10 | 8 | 0.21 | 0.023 | 2.4 | −0.63 | C− | 3*n* |
| | | 3066.53 | 137.4 | 32738 | 6 | 4 | 0.32 | 0.030 | 1.8 | −0.75 | C− | 3*n* |
| | | 3044.93 | 323.5 | 33155 | 8 | 10 | 0.12 | 0.021 | 1.7 | −0.78 | C | 2*n* |
| | | 3043.12 | 137.4 | 32989 | 6 | 8 | 0.23 | 0.042 | 2.5 | −0.60 | C | 2*n* |
| | | 3043.55 | 0.0 | 32847 | 4 | 6 | 0.18 | 0.037 | 1.5 | −0.83 | C | 2*n* |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19. | $a\,^6D - z\,^6D^\circ$ (19) | | | | | | | | | | | |
| | | 6243.11 | 2425 | 18438 | 10 | 10 | 0.018 | 0.011 | 2.2 | −0.98 | B | 1 |
| | | 6251.82 | 2311 | 18302 | 8 | 8 | 0.0097 | 0.0057 | 0.94 | −1.34 | B | 1 |
| | | 6256.90 | 2220 | 18198 | 6 | 6 | 0.0028 | 0.0016 | 0.20 | −2.01 | B | 1 |
| | | 6258.57 | 2112 | 18086 | 2 | 2 | 0.0077 | 0.0045 | 0.19 | −2.04 | B | 1 |
| | | 6296.49 | 2425 | 18302 | 10 | 8 | 0.0054 | 0.0026 | 0.53 | −1.59 | B | 1 |
| | | 6292.82 | 2311 | 18198 | 8 | 6 | 0.0095 | 0.0042 | 0.70 | −1.47 | B | 1 |
| | | 6285.16 | 2220 | 18126 | 6 | 4 | 0.013 | 0.0051 | 0.64 | −1.51 | B | 1 |
| | | 6274.65 | 2153 | 18086 | 4 | 2 | 0.018 | 0.0053 | 0.44 | −1.67 | B | 1 |
| | | 6199.19 | 2311 | 18438 | 8 | 10 | 0.009 | 0.006 | 1 | −1.3 | C+ | 1 |
| | | 6216.37 | 2220 | 18302 | 6 | 8 | 0.011 | 0.0085 | 1.0 | −1.29 | B | 1 |
| | | 6230.80 | 2153 | 18198 | 4 | 6 | 0.013 | 0.011 | 0.93 | −1.34 | B | 1 |
| | | 6242.83 | 2112 | 18126 | 2 | 4 | 0.012 | 0.014 | 0.58 | −1.55 | B | 1 |
| 20. | $a\,^6D - z\,^6F^\circ$ (20) | | | | | | | | | | | |
| | | 6150.16 | 2425 | 18680 | 10 | 12 | 0.0024 | 0.0017 | 0.34 | −1.78 | D | 3*n* |
| | | 6170.37 | 2311 | 18513 | 8 | 10 | 9.0(−4) | 6.4(−4) | 0.10 | −2.29 | D | 3*n* |
| | | 6189.37 | 2220 | 18372 | 6 | 8 | 2.3(−4) | 1.8(−4) | 0.022 | −2.97 | D | 3*n* |
| | | 6213.87 | 2425 | 18513 | 10 | 10 | 0.0015 | 8.9(−4) | 0.18 | −2.05 | D | 3*n* |
| | | 6224.51 | 2311 | 18372 | 8 | 8 | 0.0021 | 0.0012 | 0.20 | −2.01 | D | 3*n* |
| | | 6233.20 | 2220 | 18259 | 6 | 6 | 0.0024 | 0.0014 | 0.17 | −2.07 | D | 3*n* |
| | | 6240.14 | 2153 | 18174 | 4 | 4 | 0.0011 | 6.4(−4) | 0.053 | −2.59 | D | 3*n* |
| | | 6266.32 | 2220 | 18174 | 6 | 4 | 0.0022 | 8.5(−4) | 0.11 | −2.29 | D | 3*n* |
| | | 6261.23 | 2153 | 18120 | 4 | 2 | 0.0022 | 6.6(−4) | 0.054 | −2.58 | D | 3*n* |
| 21. | $a\,^6D - z\,^4D^\circ$ | | | | | | | | | | | |
| | | 5372.65 | 2425 | 21033 | 10 | 8 | 4(−5) | 1(−5) | 0.002 | −3.9 | E | 1 |
| | | 5398.91 | 2311 | 20828 | 8 | 6 | 3(−5) | 1(−5) | 0.001 | −4.1 | E | 1 |
| 22. | $a\,^6D - z\,^6P^\circ$ (21) | *4450.3* | *2296* | *24760* | 30 | 18 | 3.8 | 0.068 | 30 | 0.31 | C− | 2*n*,3*n* |
| | | 4460.33 | 2425 | 24839 | 10 | 8 | 0.30 | 0.071 | 10 | −0.15 | C− | 3*n* |
| | | 4459.75 | 2311 | 24728 | 8 | 6 | 0.18 | 0.040 | 4.6 | −0.50 | C− | 3*n* |
| | | 4457.47 | 2220 | 24648 | 6 | 4 | 0.11 | 0.021 | 1.8 | −0.90 | C− | 3*n* |
| | | 4437.83 | 2311 | 24839 | 8 | 8 | 0.093 | 0.027 | 3.2 | −0.66 | C | 2*n* |
| | | 4441.68 | 2220 | 24728 | 6 | 6 | 0.13 | 0.037 | 3.3 | −0.65 | C | 2*n* |
| | | 4444.19 | 2153 | 24648 | 4 | 4 | 0.16 | 0.049 | 2.9 | −0.71 | C | 2*n* |
| | | 4419.93 | 2220 | 24839 | 6 | 8 | 0.020 | 0.0076 | 0.67 | −1.34 | C | 2*n* |
| | | 4428.52 | 2153 | 24728 | 4 | 6 | 0.049 | 0.022 | 1.3 | −1.06 | C | 2*n* |
| | | 4436.13 | 2112 | 24648 | 2 | 4 | 0.11 | 0.063 | 1.8 | −0.90 | C | 2*n* |
| 23. | $a\,^6D - z\,^4P^\circ$ (23) | | | | | | | | | | | |
| | | 4380.97 | 2311 | 25131 | 8 | 6 | 0.00166 | 3.58(−4) | 0.0413 | −2.543 | B+ | 1 |
| | | 4405.02 | 2220 | 24915 | 6 | 4 | 0.0034 | 6.6(−4) | 0.058 | −2.40 | C− | 3*n* |
| | | 4363.52 | 2220 | 25131 | 6 | 6 | 0.0056 | 0.0016 | 0.14 | −2.02 | B+ | 1 |
| | | 4392.06 | 2153 | 24915 | 4 | 4 | 0.0101 | 0.00292 | 0.169 | −1.932 | B+ | 1 |
| | | 4412.13 | 2112 | 24771 | 2 | 2 | 0.042 | 0.012 | 0.36 | −1.61 | B+ | 1 |
| | | 4350.81 | 2153 | 25131 | 4 | 6 | 0.0020 | 8.5(−4) | 0.049 | −2.47 | B | 1 |
| | | 4384.18 | 2112 | 24915 | 2 | 4 | 0.0032 | 0.0018 | 0.053 | −2.43 | B | 1 |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33. | $a\,^4D - z\,^4P^\circ$ (34) | *6095.1* | *8597* | *24999* | 20 | 12 | 0.340 | 0.114 | 45.6 | 0.357 | B+ | 1 |
| | | 6090.21 | 8716 | 25131 | 8 | 6 | 0.260 | 0.108 | 17.4 | −0.062 | B | 1 |
| | | 6119.53 | 8579 | 24915 | 6 | 4 | 0.213 | 0.0797 | 9.64 | −0.320 | B+ | 1 |
| | | 6135.36 | 8476 | 24771 | 4 | 2 | 0.159 | 0.0449 | 3.62 | −0.746 | B+ | 1 |
| | | 6039.73 | 8579 | 25131 | 6 | 6 | 0.068 | 0.037 | 4.4 | −0.65 | B+ | 1 |
| | | 6081.44 | 8476 | 24915 | 4 | 4 | 0.119 | 0.0660 | 5.28 | −0.579 | B+ | 1 |
| | | 6111.65 | 8413 | 24771 | 2 | 2 | 0.172 | 0.0963 | 3.88 | −0.715 | B+ | 1 |
| | | 6002.61 | 8476 | 25131 | 4 | 6 | 0.0081 | 0.0066 | 0.52 | −1.58 | B+ | 1 |
| | | 6058.09 | 8413 | 24915 | 2 | 4 | 0.0192 | 0.0211 | 0.843 | −1.374 | B+ | 1 |
| 34. | $a\,^4D - y\,^6F^\circ$ (33) | | | | | | | | | | | |
| | | 6097.42 | 8716 | 25111 | 8 | 10 | 3.7(−4) | 2.6(−4) | 0.042 | −2.68 | D | 3*n* |
| | | 6090.54 | 8579 | 24993 | 6 | 8 | 5.6(−4) | 4.2(−4) | 0.050 | −2.60 | D | 3*n* |
| | | 6087.49 | 8476 | 24899 | 4 | 6 | 4.6(−4) | 3.9(−4) | 0.031 | −2.81 | D | 3*n* |
| | | 6128.33 | 8476 | 24789 | 4 | 2 | 0.0045 | 0.0013 | 0.10 | −2.30 | D | 3*n* |
| 35. | $a\,^4D - y\,^4F^\circ$ (35) | *5716.0* | *8597* | *26087* | 20 | 28 | 0.232 | 0.159 | 59.9 | 0.503 | B+ | 1,1*n*,3*n* |
| | | 5727.05 | 8716 | 26172 | 8 | 10 | 0.198 | 0.122 | 18.4 | −0.012 | B+ | 1 |
| | | 5698.53 | 8579 | 26122 | 6 | 8 | 0.199 | 0.129 | 14.5 | −0.111 | B+ | 1 |
| | | 5703.59 | 8476 | 26004 | 4 | 6 | 0.210 | 0.154 | 11.5 | −0.211 | B+ | 1 |
| | | 5707.00 | 8413 | 25931 | 2 | 4 | 0.180 | 0.176 | 6.61 | −0.454 | B+ | 1*n* |
| | | 5743.43 | 8716 | 26122 | 8 | 8 | 0.027 | 0.013 | 2.0 | −0.97 | B+ | 1 |
| | | 5737.06 | 8579 | 26004 | 6 | 6 | 0.062 | 0.031 | 3.5 | −0.74 | B+ | 1 |
| | | 5727.65 | 8476 | 25931 | 4 | 4 | 0.068 | 0.033 | 2.5 | −0.87 | B+ | 1*n* |
| | | 5782.60 | 8716 | 26004 | 8 | 6 | 0.0024 | 9.1(−4) | 0.14 | −2.14 | C− | 3*n* |
| | | 5761.43 | 8579 | 25931 | 6 | 4 | 0.043 | 0.014 | 1.6 | −1.07 | B+ | 1*n* |
| 36. | $a\,^4D - z\,^2G^\circ$ (36) | | | | | | | | | | | |
| | | 5670.85 | 8716 | 26345 | 8 | 10 | 0.078 | 0.047 | 7.0 | −0.42 | B | 1 |
| | | 5731.25 | 8579 | 26022 | 6 | 8 | 0.047 | 0.031 | 3.5 | −0.73 | B+ | 1 |
| | | 5776.66 | 8716 | 26022 | 8 | 8 | 0.0072 | 0.0036 | 0.55 | −1.54 | B | 1 |
| 37. | $a\,^4D - y\,^4D^\circ$ (37) | *5626.2* | *8597* | *26366* | 20 | 20 | 0.128 | 0.0607 | 22.5 | 0.084 | B | 1 |
| | | 5627.63 | 8716 | 26480 | 8 | 8 | 0.114 | 0.0541 | 8.02 | −0.363 | B | 1 |
| | | 5624.60 | 8579 | 26353 | 6 | 6 | 0.068 | 0.032 | 3.6 | −0.71 | B | 1 |
| | | 5624.87 | 8476 | 26249 | 4 | 4 | 0.046 | 0.022 | 1.6 | −1.06 | B+ | 1 |
| | | 5626.02 | 8413 | 26183 | 2 | 2 | 0.060 | 0.028 | 1.1 | −1.24 | B | 1 |
| | | 5668.36 | 8716 | 26353 | 8 | 6 | 0.032 | 0.012 | 1.7 | −1.03 | B | 1 |
| | | 5657.44 | 8579 | 26249 | 6 | 4 | 0.050 | 0.016 | 1.8 | −1.02 | B | 1 |
| | | 5646.11 | 8476 | 26183 | 4 | 2 | 0.068 | 0.016 | 1.2 | −1.19 | B+ | 1 |
| | | 5584.50 | 8579 | 26480 | 6 | 8 | 0.0168 | 0.0105 | 1.16 | −1.202 | B | 1 |
| | | 5592.41 | 8476 | 26353 | 4 | 6 | 0.026 | 0.018 | 1.3 | −1.14 | B | 1 |
| | | 5604.94 | 8413 | 26249 | 2 | 4 | 0.028 | 0.026 | 0.97 | −1.28 | B+ | 1 |
| 38. | $a\,^4D - y\,^6D^\circ$ (38) | | | | | | | | | | | |
| | | 5547.06 | 8716 | 26738 | 8 | 10 | 0.0116 | 0.00669 | 0.977 | −1.272 | B | 1 |
| | | 5545.91 | 8579 | 26605 | 6 | 8 | 0.0037 | 0.0023 | 0.25 | −1.86 | B | 1 |
| | | 5544.87 | 8476 | 26506 | 4 | 6 | 0.0014 | 9.5(−4) | 0.069 | −2.42 | C− | 3*n* |
| | | 5588.46 | 8716 | 26605 | 8 | 8 | 0.0014 | 6.6(−4) | 0.096 | −2.28 | C | 1 |
| | | 5565.92 | 8476 | 26438 | 4 | 4 | 0.0014 | 6.5(−4) | 0.048 | −2.58 | C | 1 |
| | | 5597.81 | 8579 | 26438 | 6 | 4 | 0.0017 | 5.3(−4) | 0.059 | −2.50 | C+ | 1 |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39. | $a\ ^4D - y\ ^4P°$ (39) | | | | | | | | | | | |
| | | 4670.45 | 8716 | 30121 | 8 | 6 | 0.14 | 0.034 | 4.1 | −0.57 | C− | 3n |
| | | 4646.40 | 8579 | 30095 | 6 | 4 | 0.10 | 0.021 | 2.0 | −0.89 | C− | 3n |
| | | 4640.09 | 8476 | 30022 | 4 | 2 | 0.078 | 0.013 | 0.77 | −1.30 | C− | 3n |
| | | 4640.72 | 8579 | 30121 | 6 | 6 | 0.019 | 0.0061 | 0.55 | −1.44 | C− | 3n |
| | | 4624.41 | 8476 | 30095 | 4 | 4 | 0.047 | 0.015 | 0.92 | −1.22 | C− | 3n |
| | | 4626.49 | 8413 | 30022 | 2 | 2 | 0.090 | 0.029 | 0.88 | −1.24 | C− | 3n |
| 40. | $a\ ^4D - x\ ^4F°$ (40) | | | | | | | | | | | |
| | | 4423.22 | 8716 | 31317 | 8 | 10 | 0.039 | 0.014 | 1.7 | −0.94 | C− | 3n |
| | | 4406.10 | 8579 | 31268 | 6 | 8 | 0.043 | 0.017 | 1.5 | −1.00 | C− | 3n |
| | | 4393.83 | 8476 | 31229 | 4 | 6 | 0.021 | 0.0091 | 0.53 | −1.44 | C− | 3n |
| | | 4387.20 | 8413 | 31200 | 2 | 4 | 0.019 | 0.011 | 0.31 | −1.67 | C− | 3n |
| 41. | $a\ ^4D - w\ ^4F°$ (41) | | | | | | | | | | | |
| | | 4090.57 | 8716 | 33155 | 8 | 10 | 0.85 | 0.27 | 29 | 0.33 | C | 2n |
| | | 4095.48 | 8579 | 32989 | 6 | 8 | 0.72 | 0.24 | 19 | 0.16 | C | 2n |
| | | 4102.15 | 8476 | 32847 | 4 | 6 | 0.71 | 0.27 | 14 | 0.03 | C | 2n |
| | | 4118.62 | 8716 | 32989 | 8 | 8 | 0.11 | 0.028 | 3.0 | −0.65 | C− | 3n |
| | | 4119.45 | 8579 | 32847 | 6 | 6 | 0.16 | 0.040 | 3.3 | −0.62 | C− | 3n |
| | | 4120.53 | 8476 | 32738 | 4 | 4 | 0.16 | 0.041 | 2.3 | −0.78 | C− | 3n |
| 42. | $a\ ^4D - w\ ^4D°$ (42) | | | | | | | | | | | |
| | | 3934.01 | 8716 | 34128 | 8 | 8 | 0.62 | 0.14 | 15 | 0.06 | C− | 3n |
| | | 3922.43 | 8579 | 34066 | 6 | 6 | 0.26 | 0.059 | 4.6 | −0.45 | C− | 3n |
| | | 3920.48 | 8476 | 33976 | 4 | 4 | 0.082 | 0.019 | 0.98 | −1.12 | C− | 3n |
| | | 3943.66 | 8716 | 34066 | 8 | 6 | 0.077 | 0.013 | 1.4 | −0.97 | C− | 3n |
| | | 3936.27 | 8579 | 33976 | 6 | 4 | 0.096 | 0.015 | 1.2 | −1.05 | C− | 3n |
| | | 3921.86 | 8476 | 33967 | 4 | 2 | 0.27 | 0.031 | 1.6 | −0.90 | C− | 3n |
| | | 3912.88 | 8579 | 34128 | 6 | 8 | 0.033 | 0.010 | 0.78 | −1.22 | C− | 3n |
| | | 3910.78 | 8413 | 33976 | 2 | 4 | 0.099 | 0.046 | 1.2 | −1.04 | C− | 3n |
| 43. | $a\ ^4D - ^4F°$ | | | | | | | | | | | |
| | | 3896.15 | 8716 | 34375 | 8 | 8 | 0.056 | 0.013 | 1.3 | −0.99 | C− | 3n |
| 44. | $a\ ^4D - v\ ^4D°$ (44) | | | | | | | | | | | |
| | | 3839.00 | 8579 | 34620 | 6 | 6 | 0.20 | 0.044 | 3.3 | −0.58 | C− | 3n |
| | | 3836.05 | 8476 | 34537 | 4 | 4 | 0.12 | 0.026 | 1.3 | −0.99 | C− | 3n |
| | | 3835.57 | 8413 | 34477 | 2 | 2 | 0.17 | 0.037 | 0.94 | −1.13 | C− | 3n |
| | | 3859.34 | 8716 | 34620 | 8 | 6 | 0.088 | 0.015 | 1.5 | −0.93 | C− | 3n |
| | | 3823.98 | 8476 | 34620 | 4 | 6 | 0.087 | 0.029 | 1.4 | −0.94 | C− | 3n |
| | | 3826.77 | 8413 | 34537 | 2 | 4 | 0.079 | 0.035 | 0.87 | −1.16 | C− | 3n |
| 45. | $a\ ^4D - x\ ^4P°$ (45) | | | | | | | | | | | |
| | | 3583.71 | 8716 | 36612 | 8 | 6 | 0.056 | 0.0081 | 0.76 | −1.19 | C− | 3n |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46. | $a\ ^4D - t\ ^4D°$ (46) | | | | | | | | | | | |
| | | 3400.39 | 8716 | 38116 | 8 | 8 | 0.25 | 0.043 | 3.9 | −0.46 | C− | 3n |
| | | 3402.57 | 8579 | 37960 | 6 | 6 | 0.18 | 0.032 | 2.1 | −0.72 | C− | 3n |
| | | 3405.15 | 8476 | 37835 | 4 | 4 | 0.13 | 0.023 | 1.0 | −1.03 | C− | 3n |
| | | 3406.84 | 8413 | 37757 | 2 | 2 | 0.19 | 0.032 | 0.72 | −1.19 | C− | 3n |
| | | 3417.06 | 8579 | 37835 | 6 | 4 | 0.13 | 0.016 | 1.0 | −1.03 | C− | 3n |
| 47. | $a\ ^4P - z\ ^4D°$ | | | | | | | | | | | |
| | | 8919.80 | 9825 | 21033 | 6 | 8 | 0.0053 | 0.0084 | 1.5 | −1.30 | B | 1 |
| | | 8932.88 | 9637 | 20828 | 4 | 6 | 0.0038 | 0.0068 | 0.80 | −1.56 | C+ | 1 |
| | | 8971.61 | 9545 | 20688 | 2 | 4 | 0.0023 | 0.0056 | 0.33 | −1.95 | D | 1 |
| | | 9085.19 | 9825 | 20828 | 6 | 6 | 0.0017 | 0.0021 | 0.38 | −1.90 | C+ | 1 |
| | | 9046.64 | 9637 | 20688 | 4 | 4 | 0.0027 | 0.0033 | 0.39 | −1.88 | D | 1 |
| | | 9037.57 | 9545 | 20607 | 2 | 2 | 0.004 | 0.005 | 0.3 | −2.0 | D | 1 |
| | | 9202.89 | 9825 | 20688 | 6 | 4 | 0.002 | 0.002 | 0.3 | −2.0 | D | 1 |
| | | 9113.71 | 9637 | 20607 | 4 | 2 | 8(−4) | 5(−4) | 0.06 | −2.7 | D | 1 |
| 48. | $a\ ^4P - z\ ^4P°$ (48) | *6541.4* | *9716* | *24999* | 12 | 12 | 0.052 | 0.033 | 8.6 | −0.40 | B | 1 |
| | | 6531.41 | 9825 | 25131 | 6 | 6 | 0.038 | 0.024 | 3.1 | −0.84 | B | 1 |
| | | 6543.50 | 9637 | 24915 | 4 | 4 | 0.0085 | 0.0055 | 0.47 | −1.66 | B+ | 1 |
| | | 6565.90 | 9545 | 24771 | 2 | 2 | 0.0066 | 0.0043 | 0.18 | −2.07 | B+ | 1 |
| | | 6624.86 | 9825 | 24915 | 6 | 4 | 0.0205 | 0.00899 | 1.18 | −1.268 | B+ | 1 |
| | | 6605.96 | 9637 | 24771 | 4 | 2 | 0.037 | 0.012 | 1.1 | −1.32 | B | 1 |
| | | 6452.34 | 9637 | 25131 | 4 | 6 | 0.0166 | 0.0155 | 1.32 | −1.206 | B+ | 1 |
| | | 6504.16 | 9545 | 24915 | 2 | 4 | 0.023 | 0.029 | 1.2 | −1.23 | B+ | 1 |
| 49. | $a\ ^4P - y\ ^4F°$ | | | | | | | | | | | |
| | | 6178.90 | 9825 | 26004 | 6 | 6 | 1.6(−4) | 9.2(−5) | 0.011 | −3.26 | D | 1 |
| 50. | $a\ ^4P - y\ ^4D°$ (49) | | | | | | | | | | | |
| | | 6002.29 | 9825 | 26480 | 6 | 8 | 0.0038 | 0.0027 | 0.32 | −1.78 | B | 1 |
| | | 5980.77 | 9637 | 26353 | 4 | 6 | 0.0031 | 0.0025 | 0.20 | −2.00 | B | 1 |
| | | 5984.60 | 9545 | 26249 | 2 | 4 | 0.0017 | 0.0018 | 0.072 | −2.44 | B | 1 |
| | | 6048.66 | 9825 | 26353 | 6 | 6 | 7.7(−4) | 4.2(−4) | 0.050 | −2.60 | C+ | 1 |
| | | 6017.89 | 9637 | 26249 | 4 | 4 | 0.0020 | 0.0011 | 0.086 | −2.36 | B | 1 |
| | | 6008.65 | 9545 | 26183 | 2 | 2 | 0.0042 | 0.0023 | 0.090 | −2.34 | C | 1 |
| 51. | $a\ ^4P - y\ ^4P°$ (50) | | | | | | | | | | | |
| | | 4925.66 | 9825 | 30121 | 6 | 6 | 0.073 | 0.026 | 2.6 | −0.80 | C− | 3n |
| | | 4886.81 | 9637 | 30095 | 4 | 4 | 0.018 | 0.0063 | 0.40 | −1.60 | C− | 3n |
| | | 4932.03 | 9825 | 30095 | 6 | 4 | 0.046 | 0.011 | 1.1 | −1.17 | C− | 3n |
| | | 4904.30 | 9637 | 30022 | 4 | 2 | 0.074 | 0.013 | 0.87 | −1.27 | C− | 3n |
| | | 4880.56 | 9637 | 30121 | 4 | 6 | 0.032 | 0.017 | 1.1 | −1.16 | C− | 3n |
| | | 4864.83 | 9545 | 30095 | 2 | 4 | 0.041 | 0.029 | 0.92 | −1.24 | C− | 3n |
| 52. | $a\ ^4P - w\ ^4D°$ (52) | | | | | | | | | | | |
| | | 4113.51 | 9825 | 34128 | 6 | 8 | 0.17 | 0.058 | 4.7 | −0.46 | C− | 3n |
| | | 4092.39 | 9637 | 34066 | 4 | 6 | 0.14 | 0.053 | 2.9 | −0.67 | C− | 3n |
| | | 4124.10 | 9825 | 34066 | 6 | 6 | 0.061 | 0.016 | 1.3 | −1.03 | C− | 3n |
| | | 4093.48 | 9545 | 33967 | 2 | 2 | 0.19 | 0.049 | 1.3 | −1.01 | C− | 3n |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53. | $a\ ^4P - t\ ^4D^\circ$ (53) | | | | | | | | | | | |
| | | 3533.68 | 9825 | 38116 | 6 | 8 | 0.52 | 0.13 | 9.0 | −0.11 | C− | 3*n* |
| | | 3529.73 | 9637 | 37960 | 4 | 6 | 0.41 | 0.11 | 5.3 | −0.34 | C− | 3*n* |
| | | 3533.76 | 9545 | 37835 | 2 | 4 | 0.37 | 0.14 | 3.2 | −0.56 | C− | 3*n* |
| | | 3553.27 | 9825 | 37960 | 6 | 6 | 0.22 | 0.042 | 2.9 | −0.60 | C− | 3*n* |
| | | 3545.33 | 9637 | 37835 | 4 | 4 | 0.37 | 0.070 | 3.3 | −0.55 | C− | 3*n* |
| | | 3543.49 | 9545 | 37757 | 2 | 2 | 0.67 | 0.13 | 2.9 | −0.60 | C− | 3*n* |
| | | 3555.14 | 9637 | 37757 | 4 | 2 | 0.26 | 0.024 | 1.1 | −1.01 | C− | 3*n* |
| 54. | $a\ ^4P - w\ ^4P^\circ$ (54) | | | | | | | | | | | |
| | | 3377.62 | 9825 | 39423 | 6 | 6 | 0.60 | 0.10 | 6.9 | −0.21 | C− | 3*n* |
| | | 3376.05 | 9637 | 39249 | 4 | 4 | 0.32 | 0.055 | 2.4 | −0.66 | C− | 3*n* |
| | | 3397.58 | 9825 | 39249 | 6 | 4 | 0.23 | 0.027 | 1.8 | −0.79 | C− | 3*n* |
| | | 3377.39 | 9637 | 39237 | 4 | 2 | 0.90 | 0.077 | 3.4 | −0.51 | C− | 3*n* |
| | | 3356.35 | 9637 | 39423 | 4 | 6 | 0.31 | 0.079 | 3.5 | −0.50 | C− | 3*n* |
| | | 3365.55 | 9545 | 39249 | 2 | 4 | 0.48 | 0.16 | 3.6 | −0.49 | C− | 3*n* |
| 55. | $a\ ^4P - x\ ^4S^\circ$ (55) | *3317.9* | *9716* | 39847 | 12 | 4 | 1.2 | 0.069 | 9.0 | −0.08 | C− | 3*n* |
| | | 3329.85 | 9825 | 39847 | 6 | 4 | 0.77 | 0.085 | 5.6 | −0.29 | C− | 3*n* |
| | | 3309.18 | 9637 | 39847 | 4 | 4 | 0.32 | 0.052 | 2.3 | −0.68 | C− | 3*n* |
| | | 3299.09 | 9545 | 39847 | 2 | 4 | 0.15 | 0.050 | 1.1 | −1.00 | C− | 3*n* |
| 56. | $a\ ^4P - v\ ^4P^\circ$ (56) | | | | | | | | | | | |
| | | 3112.92 | 9637 | 41752 | 4 | 2 | 0.50 | 0.036 | 1.5 | −0.84 | C− | 3*n* |
| | | 3088.11 | 9637 | 42010 | 4 | 6 | 0.49 | 0.10 | 4.2 | −0.38 | C− | 3*n* |
| | | 3094.69 | 9545 | 41849 | 2 | 4 | 0.43 | 0.12 | 2.5 | −0.61 | C− | 3*n* |
| 57. | $a\ ^4P - r\ ^4D^\circ$ (57) | | | | | | | | | | | |
| | | 3083.54 | 9825 | 42245 | 6 | 8 | 0.25 | 0.047 | 2.9 | −0.55 | C− | 3*n* |
| | | 3075.93 | 9637 | 42138 | 4 | 6 | 0.28 | 0.060 | 2.4 | −0.62 | C− | 3*n* |
| | | 3080.33 | 9545 | 41999 | 2 | 4 | 0.27 | 0.076 | 1.5 | −0.82 | C− | 3*n* |
| | | 3093.79 | 9825 | 42138 | 6 | 6 | 0.41 | 0.059 | 3.6 | −0.45 | C− | 3*n* |
| | | 3089.13 | 9637 | 41999 | 4 | 4 | 0.53 | 0.075 | 3.1 | −0.52 | C− | 3*n* |
| | | 3087.06 | 9545 | 41928 | 2 | 2 | 0.92 | 0.13 | 2.7 | −0.58 | C− | 3*n* |
| 58. | $a\ ^2G - y\ ^4F^\circ$ | | | | | | | | | | | |
| | | 6633.29 | 11101 | 26172 | 10 | 10 | 7.5(−4) | 4.9(−4) | 0.11 | −2.31 | C+ | 1 |
| 59. | $a\ ^2G - z\ ^2G^\circ$ (59) | | | | | | | | | | | |
| | | 6558.02 | 11101 | 26345 | 10 | 10 | 0.0020 | 0.0013 | 0.28 | −1.89 | B | 1 |
| | | 6607.83 | 10893 | 26022 | 8 | 8 | 0.0021 | 0.0014 | 0.24 | −1.96 | B+ | 1 |
| | | 6469.68 | 10893 | 26345 | 8 | 10 | 2(−4) | 2(−4) | 0.03 | −2.9 | D | 1 |
| 60. | $a\ ^2G - z\ ^2F^\circ$ (60) | | | | | | | | | | | |
| | | 6106.97 | 11101 | 27471 | 10 | 8 | 0.0039 | 0.0017 | 0.35 | −1.76 | D | 3*n* |
| | | 6135.07 | 10893 | 27188 | 8 | 6 | 0.0048 | 0.0020 | 0.33 | −1.79 | D | 3*n* |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 61. | $a\ ^2G - y\ ^2G°$ (62) | | | | | | | | | | | |
| | | 4502.01 | 11101 | 33307 | 10 | 10 | 0.055 | 0.017 | 2.5 | −0.78 | C− | 3*n* |
| | | 4449.57 | 10893 | 33360 | 8 | 8 | 0.038 | 0.011 | 1.3 | −1.05 | C− | 3*n* |
| | | 4491.17 | 11101 | 33360 | 10 | 8 | 0.015 | 0.0035 | 0.52 | −1.45 | C− | 3*n* |
| 62. | $a\ ^2G - x\ ^2G°$ (63) | | | | | | | | | | | |
| | | 3930.02 | 11101 | 36539 | 10 | 10 | 0.33 | 0.076 | 9.8 | −0.12 | C− | 3*n* |
| | | 3941.99 | 11101 | 36461 | 10 | 8 | 0.10 | 0.019 | 2.5 | −0.72 | C− | 3*n* |
| 63. | $a\ ^2G - w\ ^4G°$ (64) | | | | | | | | | | | |
| | | 3886.58 | 11101 | 36823 | 10 | 8 | 0.16 | 0.030 | 3.8 | −0.53 | C− | 3*n* |
| | | 3864.33 | 10893 | 36763 | 8 | 6 | 0.19 | 0.032 | 3.3 | −0.59 | C− | 3*n* |
| 64. | $a\ ^2G - x\ ^2F°$ (66) | *3867.7* | *11009* | *36857* | 18 | 14 | 0.410 | 0.072 | 16.4 | 0.110 | C− | 3*n* |
| | | 3871.07 | 11101 | 36926 | 10 | 8 | 0.28 | 0.050 | 6.4 | −0.30 | C− | 3*n* |
| | | 3863.86 | 10893 | 36766 | 8 | 6 | 0.31 | 0.052 | 5.3 | −0.38 | C− | 3*n* |
| | | 3840.13 | 10893 | 36926 | 8 | 8 | 0.21 | 0.046 | 4.7 | −0.43 | C− | 3*n* |
| 65. | $a\ ^2G - v\ ^2G°$ (68) | | | | | | | | | | | |
| | | 3806.79 | 11101 | 37362 | 10 | 10 | 0.25 | 0.054 | 6.7 | −0.27 | C− | 3*n* |
| | | 3803.78 | 10893 | 37175 | 8 | 8 | 0.14 | 0.031 | 3.1 | −0.60 | C− | 3*n* |
| 66. | $a\ ^2G - w\ ^2F°$ (69) | | | | | | | | | | | |
| | | 3790.46 | 11101 | 37475 | 10 | 8 | 0.23 | 0.039 | 4.9 | −0.41 | C− | 3*n* |
| | | 3779.64 | 10893 | 37343 | 8 | 6 | 0.11 | 0.018 | 1.8 | −0.84 | C− | 3*n* |
| 67. | $a\ ^2G - x\ ^2H°$ (70) | | | | | | | | | | | |
| | | 3686.26 | 11101 | 38221 | 10 | 12 | 0.23 | 0.056 | 6.8 | −0.25 | C− | 3*n* |
| | | 3671.20 | 10893 | 38124 | 8 | 10 | 0.21 | 0.052 | 5.0 | −0.38 | C− | 3*n* |
| 68. | $a\ ^2G - t\ ^2G°$ (71) | | | | | | | | | | | |
| | | 3284.36 | 11101 | 41539 | 10 | 10 | 0.28 | 0.045 | 4.8 | −0.35 | C− | 3*n* |
| | | 3273.03 | 10893 | 41437 | 8 | 8 | 0.27 | 0.043 | 3.7 | −0.46 | C− | 3*n* |
| 69. | $a\ ^2G - u\ ^2F°$ (72) | | | | | | | | | | | |
| | | 3233.19 | 11101 | 42021 | 10 | 8 | 0.32 | 0.041 | 4.3 | −0.39 | C− | 3*n* |
| | | 3218.87 | 10893 | 41950 | 8 | 6 | 0.35 | 0.040 | 3.4 | −0.49 | C− | 3*n* |
| 70. | $a\ ^2G - u\ ^2H°$ (73) | | | | | | | | | | | |
| | | 3212.43 | 11101 | 42221 | 10 | 12 | 1.4 | 0.26 | 27 | 0.41 | C− | 3*n* |
| | | 3205.58 | 10893 | 42079 | 8 | 10 | 1.3 | 0.25 | 21 | 0.30 | C− | 3*n* |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71. | $a\ ^2G - t\ ^2F^\circ$ (74) | | | | | | | | | | | |
| | | 3050.39 | 11101 | 43874 | 10 | 8 | 0.53 | 0.059 | 5.9 | −0.23 | C− | 3*n* |
| 72. | $a\ ^2P - y\ ^6D^\circ$ | | | | | | | | | | | |
| | | 7936.95 | 13802 | 26398 | 4 | 2 | 0.0079 | 0.0037 | 0.39 | −1.83 | C+ | 1 |
| 73. | $a\ ^2P - ^4P^\circ$ | | | | | | | | | | | |
| | | 5558.75 | 13802 | 31786 | 4 | 2 | 0.094 | 0.022 | 1.6 | −1.06 | C− | 3*n* |
| | | 5561.68 | 13811 | 31786 | 2 | 2 | 0.062 | 0.029 | 1.1 | −1.24 | C− | 3*n* |
| 74. | $a\ ^2D2 - y\ ^2P^\circ$ (82) | | | | | | | | | | | |
| | | 4537.66 | 14549 | 36580 | 6 | 4 | 0.16 | 0.032 | 2.9 | −0.71 | C− | 3*n* |
| 75. | $a\ ^4H - z\ ^4G^\circ$ | | | | | | | | | | | |
| | | 14040.45 | 15001 | 22121 | 12 | 10 | 0.0025 | 0.0062 | 3.4 | −1.13 | E | 1 |
| | | 14252.89 | 14949 | 21963 | 10 | 8 | 0.0024 | 0.0058 | 2.7 | −1.23 | D | 1 |
| | | 14423.14 | 14910 | 21841 | 8 | 6 | 0.004 | 0.009 | 4 | −1.1 | D | 1 |
| | | 13787.33 | 15001 | 22314 | 12 | 12 | 0.0033 | 0.0094 | 5.1 | −0.95 | E | 1 |
| 76. | $a\ ^4H - y\ ^4G^\circ$ (84) | | | | | | | | | | | |
| | | 6326.85 | 15063 | 30864 | 14 | 12 | 0.022 | 0.011 | 3.2 | −0.81 | D | 3*n* |
| | | 6339.09 | 15001 | 30772 | 12 | 10 | 0.028 | 0.014 | 3.5 | −0.77 | D | 3*n* |
| | | 6349.48 | 14949 | 30694 | 10 | 8 | 0.027 | 0.013 | 2.7 | −0.89 | D | 3*n* |
| | | 6357.30 | 14910 | 30636 | 8 | 6 | 0.034 | 0.015 | 2.6 | −0.91 | D | 3*n* |
| 77. | $a\ ^4H - x\ ^4G^\circ$ | | | | | | | | | | | |
| | | 5924.55 | 15063 | 31937 | 14 | 12 | 0.005 | 0.002 | 0.6 | −1.5 | E | 1 |
| | | 5978.89 | 15001 | 31722 | 12 | 10 | 0.008 | 0.004 | 0.8 | −1.4 | D | 1 |
| | | 6025.38 | 14949 | 31541 | 10 | 8 | 0.0050 | 0.0022 | 0.43 | −1.66 | C | 1*n* |
| | | 6063.32 | 14910 | 31398 | 8 | 6 | 0.0056 | 0.0023 | 0.37 | −1.73 | C | 1 |
| 78. | $a\ ^4H - y\ ^2H^\circ$ (86) | | | | | | | | | | | |
| | | 4496.86 | 14949 | 37181 | 10 | 10 | 0.081 | 0.025 | 3.6 | −0.61 | C− | 3*n* |
| | | 4490.81 | 14949 | 37211 | 10 | 12 | 0.11 | 0.042 | 6.2 | −0.38 | C− | 3*n* |
| 79. | $a\ ^4H - z\ ^4I^\circ$ (87) | | | | | | | | | | | |
| | | 4452.01 | 15063 | 37518 | 14 | 16 | 0.92 | 0.31 | 64 | 0.64 | C− | 3*n* |
| | | 4462.36 | 15001 | 37404 | 12 | 14 | 0.76 | 0.26 | 46 | 0.50 | C− | 3*n* |
| | | 4469.71 | 14949 | 37316 | 10 | 12 | 0.62 | 0.22 | 33 | 0.35 | C− | 3*n* |
| | | 4468.00 | 14910 | 37285 | 8 | 10 | 0.23 | 0.085 | 9.9 | −0.17 | C− | 3*n* |
| 80. | $a\ ^4H - x\ ^4H^\circ$ (88) | | | | | | | | | | | |
| | | 4268.64 | 15063 | 38483 | 14 | 14 | 1.2 | 0.32 | 63 | 0.65 | C− | 3*n* |
| | | 4271.55 | 15001 | 38405 | 12 | 12 | 0.96 | 0.26 | 44 | 0.50 | C− | 3*n* |
| | | 4276.95 | 14949 | 38324 | 10 | 10 | 0.94 | 0.26 | 36 | 0.41 | C− | 3*n* |
| | | 4284.05 | 14910 | 38246 | 8 | 8 | 1.2 | 0.32 | 36 | 0.41 | C− | 3*n* |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 81. | $a\,^4H - u\,^4G°$ (89) | | | | | | | | | | | |
| | | 3998.73 | 15063 | 40064 | 14 | 12 | 1.0 | 0.22 | 40 | 0.48 | C− | 3*n* |
| | | 3992.80 | 15001 | 40039 | 12 | 10 | 1.2 | 0.24 | 38 | 0.46 | C− | 3*n* |
| 82. | $b\,^4P - x\,^4D°$ (92) | | | | | | | | | | | |
| | | 5772.41 | 15572 | 32891 | 6 | 8 | 0.067 | 0.045 | 5.1 | −0.57 | C− | 3*n* |
| | | 5748.89 | 15271 | 32660 | 4 | 6 | 0.048 | 0.035 | 2.7 | −0.85 | C− | 3*n* |
| | | 5850.33 | 15572 | 32660 | 6 | 6 | 0.040 | 0.021 | 2.4 | −0.91 | C− | 3*n* |
| 83. | $b\,^4P - x\,^4P°$ (94) | | | | | | | | | | | |
| | | 4751.57 | 15572 | 36612 | 6 | 6 | 0.11 | 0.037 | 3.5 | −0.65 | C− | 3*n* |
| | | 4706.16 | 15572 | 36815 | 6 | 4 | 0.24 | 0.054 | 5.0 | −0.49 | C− | 3*n* |
| 84. | $a\,^2H - z\,^2G°$ | | | | | | | | | | | |
| | | 9022.70 | 15265 | 26345 | 12 | 10 | 0.0020 | 0.0020 | 0.73 | −1.61 | B | 1 |
| | | 9156.57 | 15104 | 26022 | 10 | 8 | 0.0028 | 0.0028 | 0.85 | −1.55 | C+ | 1 |
| 85. | $a\,^2H - v\,^2G°$ (99) | | | | | | | | | | | |
| | | 4524.21 | 15265 | 37362 | 12 | 10 | 0.30 | 0.076 | 14 | −0.04 | C− | 3*n* |
| | | 4529.58 | 15104 | 37175 | 10 | 8 | 0.24 | 0.060 | 9.0 | −0.22 | C− | 3*n* |
| 86. | $a\,^2H - z\,^4I°$ (100) | | | | | | | | | | | |
| | | 4540.01 | 15265 | 37285 | 12 | 10 | 0.085 | 0.022 | 3.9 | −0.58 | C− | 3*n* |
| 87. | $a\,^2H - w\,^2F°$ (102) | | | | | | | | | | | |
| | | 4468.76 | 15104 | 37475 | 10 | 8 | 0.11 | 0.026 | 3.8 | −0.59 | C− | 3*n* |
| 88. | $a\,^2H - z\,^2I°$ (101) | | | | | | | | | | | |
| | | 4457.75 | 15104 | 37530 | 10 | 12 | 0.27 | 0.098 | 14 | −0.01 | C− | 3*n* |
| 89. | $a\,^2H - x\,^2H°$ (103) | | | | | | | | | | | |
| | | 4354.97 | 15265 | 38221 | 12 | 12 | 0.13 | 0.036 | 6.3 | −0.36 | C− | 3*n* |
| | | 4342.83 | 15104 | 38124 | 10 | 10 | 0.14 | 0.041 | 5.8 | −0.39 | C− | 3*n* |
| 90. | $a\,^2H - u\,^2H°$ (104) | | | | | | | | | | | |
| | | 3708.71 | 15265 | 42221 | 12 | 12 | 0.44 | 0.091 | 13 | 0.04 | C− | 3*n* |
| | | 3706.03 | 15104 | 42079 | 10 | 10 | 0.52 | 0.11 | 13 | 0.03 | C− | 3*n* |
| 91. | $b\,^4F - z\,^4F°$ | | | | | | | | | | | |
| | | 13467.40 | 15665 | 23088 | 4 | 4 | 0.002 | 0.005 | 1 | −1.7 | D | 1 |
| | | 13291.12 | 15665 | 23211 | 4 | 6 | 0.0017 | 0.0068 | 1.2 | −1.57 | D | 1 |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92. | $b\,^4$F – $y\,^4$F° (106) | | | | | | | | | | | |
| | | 9691.57 | 15689 | 26004 | 6 | 6 | 0.004 | 0.006 | 1 | −1.5 | D | 1 |
| 93. | $b\,^4$F – $v\,^4$G° (109) | | | | | | | | | | | |
| | | 4545.40 | 15771 | 37765 | 10 | 12 | 0.76 | 0.28 | 42 | 0.45 | C− | 3*n* |
| | | 4560.72 | 15724 | 37644 | 8 | 10 | 0.70 | 0.27 | 33 | 0.34 | C− | 3*n* |
| | | 4571.79 | 15689 | 37556 | 6 | 8 | 0.60 | 0.25 | 23 | 0.18 | C− | 3*n* |
| | | 4578.73 | 15665 | 37499 | 4 | 6 | 0.68 | 0.32 | 19 | 0.11 | C− | 3*n* |
| | | 4579.19 | 15724 | 37556 | 8 | 8 | 0.15 | 0.046 | 5.6 | −0.43 | C− | 3*n* |
| 94. | $b\,^4$F – $t\,^4$D° (110) | | | | | | | | | | | |
| | | 4474.04 | 15771 | 38116 | 10 | 8 | 0.47 | 0.11 | 17 | 0.05 | C− | 3*n* |
| | | 4496.06 | 15724 | 37960 | 8 | 6 | 0.40 | 0.091 | 11 | −0.14 | C− | 3*n* |
| | | 4514.18 | 15689 | 37835 | 6 | 4 | 0.33 | 0.068 | 6.1 | −0.39 | C− | 3*n* |
| | | 4525.17 | 15665 | 37757 | 4 | 2 | 0.41 | 0.063 | 3.7 | −0.60 | C− | 3*n* |
| 95. | $b\,^4$F – $u\,^4$F° (111) | | | | | | | | | | | |
| | | 4232.46 | 15771 | 39391 | 10 | 10 | 0.98 | 0.26 | 37 | 0.42 | C− | 3*n* |
| | | 4232.95 | 15724 | 39342 | 8 | 8 | 0.77 | 0.21 | 23 | 0.22 | C− | 3*n* |
| 96. | $b\,^4$F – $s\,^4$D° (112) | | | | | | | | | | | |
| | | 4104.77 | 15771 | 40126 | 10 | 8 | 2.1 | 0.43 | 58 | 0.63 | C− | 3*n* |
| 97. | $z\,^6$G° – $e\,^6$F (113) | | | | | | | | | | | |
| | | 4807.52 | 17137 | 37931 | 14 | 12 | 0.58 | 0.17 | 38 | 0.38 | C− | 3*n* |
| | | 4796.92 | 16917 | 37758 | 12 | 10 | 0.48 | 0.14 | 26 | 0.22 | C− | 3*n* |
| | | 4786.50 | 16729 | 37615 | 10 | 8 | 0.47 | 0.13 | 20 | 0.11 | C− | 3*n* |
| | | 4776.36 | 16573 | 37503 | 8 | 6 | 0.51 | 0.13 | 16 | 0.02 | C− | 3*n* |
| | | 4766.62 | 16450 | 37423 | 6 | 4 | 0.56 | 0.13 | 12 | −0.12 | C− | 3*n* |
| | | 4757.47 | 16362 | 37375 | 4 | 2 | 0.76 | 0.13 | 8.0 | −0.29 | C− | 3*n* |
| | | 4753.93 | 16729 | 37758 | 10 | 10 | 0.15 | 0.051 | 8.0 | −0.29 | C− | 3*n* |
| | | 4750.98 | 16573 | 37615 | 8 | 8 | 0.17 | 0.057 | 7.1 | −0.34 | C− | 3*n* |
| | | 4748.51 | 16450 | 37503 | 6 | 6 | 0.12 | 0.040 | 3.7 | −0.62 | C− | 3*n* |
| | | 4746.62 | 16362 | 37423 | 4 | 4 | 0.19 | 0.064 | 4.0 | −0.59 | C− | 3*n* |
| 98. | $z\,^6$G° – $e\,^6$H (114) | | | | | | | | | | | |
| | | 3695.34 | 17137 | 44190 | 14 | 16 | 2.8 | 0.67 | 110 | 0.97 | C− | 3*n* |
| | | 3687.50 | 16917 | 44028 | 12 | 14 | 2.9 | 0.69 | 100 | 0.92 | C− | 3*n* |
| | | 3680.12 | 16729 | 43894 | 10 | 12 | 2.2 | 0.54 | 65 | 0.73 | C− | 3*n* |
| | | 3673.41 | 16573 | 43788 | 8 | 10 | 2.7 | 0.67 | 65 | 0.73 | C− | 3*n* |
| | | 3667.74 | 16450 | 43707 | 6 | 8 | 2.7 | 0.73 | 53 | 0.64 | C− | 3*n* |
| | | 3663.60 | 16362 | 43649 | 4 | 6 | 3.1 | 0.93 | 45 | 0.57 | C− | 3*n* |
| 99. | $z\,^6$G° – $f\,^6$G (115) | | | | | | | | | | | |
| | | 3676.70 | 17137 | 44327 | 14 | 14 | 1.3 | 0.27 | 45 | 0.57 | C− | 3*n* |
| | | 3672.41 | 16917 | 44140 | 12 | 12 | 0.92 | 0.19 | 27 | 0.35 | C− | 3*n* |

V I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100. | $a\ ^4G - z\ ^4F°$ | | | | | | | | | | | |
| | | 16406.07 | 17117 | 23211 | 8 | 6 | 0.0016 | 0.0048 | 2.1 | −1.41 | D | 1 |
| 101. | $a\ ^4G - y\ ^4H°$ (118) | | | | | | | | | | | |
| | | 4904.43 | 17242 | 37626 | 12 | 14 | 0.099 | 0.042 | 8.1 | −0.30 | C− | 3*n* |
| 102. | $a\ ^4G - x\ ^4H°$ (119) | | | | | | | | | | | |
| | | 4706.57 | 17242 | 38483 | 12 | 14 | 0.17 | 0.065 | 12 | −0.11 | C− | 3*n* |
| | | 4710.55 | 17182 | 38405 | 10 | 12 | 0.19 | 0.076 | 12 | −0.12 | C− | 3*n* |
| 103. | $a\ ^4G - w\ ^4H°$ (120) | | | | | | | | | | | |
| | | 4291.82 | 17242 | 40536 | 12 | 14 | 0.88 | 0.28 | 48 | 0.53 | C− | 3*n* |
| | | 4296.10 | 17182 | 40452 | 10 | 12 | 0.77 | 0.26 | 36 | 0.41 | C− | 3*n* |
| | | 4297.67 | 17117 | 40379 | 8 | 10 | 0.70 | 0.24 | 28 | 0.29 | C− | 3*n* |
| | | 4298.03 | 17055 | 40315 | 6 | 8 | 0.78 | 0.29 | 25 | 0.24 | C− | 3*n* |
| 104. | $a\ ^4G - t\ ^4G°$ (121) | | | | | | | | | | | |
| | | 4051.35 | 17242 | 41918 | 12 | 12 | 1.3 | 0.33 | 53 | 0.60 | C− | 3*n* |
| | | 4050.96 | 17182 | 41861 | 10 | 10 | 1.4 | 0.35 | 46 | 0.54 | C− | 3*n* |
| 105. | $z\ ^6F° - e\ ^6F$ (125) | | | | | | | | | | | |
| | | 5193.00 | 18680 | 37931 | 12 | 12 | 0.40 | 0.16 | 33 | 0.29 | C− | 3*n* |
| | | 5195.39 | 18372 | 37615 | 8 | 8 | 0.23 | 0.095 | 13 | −0.12 | C− | 3*n* |
| 106. | $b\ ^2H - v\ ^2G°$ (129) | | | | | | | | | | | |
| | | 5487.91 | 19145 | 37362 | 12 | 10 | 0.29 | 0.11 | 23 | 0.11 | C− | 3*n* |
| | | 5507.75 | 19024 | 37175 | 10 | 8 | 0.35 | 0.13 | 23 | 0.11 | C− | 3*n* |
| 107. | $b\ ^2H - z\ ^2I°$ (130) | | | | | | | | | | | |
| | | 5415.25 | 19145 | 37606 | 12 | 14 | 0.31 | 0.16 | 34 | 0.28 | C− | 3*n* |
| 108. | $b\ ^2H - x\ ^2H°$ (131) | | | | | | | | | | | |
| | | 5240.87 | 19145 | 38221 | 12 | 12 | 0.43 | 0.18 | 37 | 0.33 | C− | 3*n* |
| | | 5234.08 | 19024 | 38124 | 10 | 10 | 0.49 | 0.20 | 34 | 0.30 | C− | 3*n* |
| 109. | $a\ ^2F - x\ ^2G°$ (135) | | | | | | | | | | | |
| | | 5725.64 | 19078 | 36539 | 8 | 10 | 0.21 | 0.13 | 19 | 0.01 | C− | 3*n* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V II

Ti Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4\ {}^5D_0$

Ionization Energy: $14.66\ eV = 118200\ cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2527.90 | 17 | 2784.20 | 51 | 2944.57 | 5 | 3530.77 | 8 |
| 2528.47 | 17 | 2787.91 | 47 | 2948.08 | 42 | 3531.48 | 8 |
| 2528.83 | 17 | 2825.86 | 48 | 2952.07 | 5 | 3538.24 | 8 |
| 2554.20 | 50 | 2843.82 | 48 | 2955.58 | 42 | 3545.19 | 7 |
| 2589.10 | 49 | 2847.57 | 34 | 2968.37 | 20 | 3556.80 | 7 |
| 2640.86 | 46 | 2854.34 | 34 | 2972.26 | 27 | 3560.59 | 8 |
| 2672.01 | 3 | 2862.31 | 34 | 2973.98 | 44 | 3563.71 | 8 |
| 2677.80 | 3 | 2868.11 | 54 | 2985.18 | 44 | 3566.18 | 8 |
| 2678.57 | 3 | 2869.13 | 34 | 3001.20 | 21 | 3592.01 | 8 |
| 2679.33 | 3 | 2869.96 | 6 | 3014.82 | 21 | 3593.32 | 8 |
| 2682.88 | 3 | 2875.69 | 6 | 3016.78 | 21 | 3618.92 | 36 |
| 2683.09 | 3 | 2879.16 | 6 | 3020.21 | 53 | 3669.41 | 31 |
| 2685.69 | 3 | 2880.03 | 6 | 3048.21 | 33 | 3715.48 | 16 |
| 2687.96 | 3 | 2882.49 | 6 | 3063.25 | 33 | 3727.35 | 18 |
| 2688.72 | 3 | 2884.78 | 6 | 3100.94 | 25 | 3732.76 | 16 |
| 2689.88 | 3 | 2889.61 | 6 | 3113.56 | 40 | 3815.38 | 37 |
| 2690.25 | 3 | 2891.64 | 6 | 3122.89 | 39 | 3850.41 | 14 |
| 2690.79 | 3 | 2892.43 | 6 | 3134.93 | 32 | 3866.74 | 14 |
| 2694.74 | 1 | 2892.65 | 6 | 3136.50 | 32 | 3903.27 | 14 |
| 2700.94 | 2 | 2893.31 | 6 | 3139.73 | 32 | 3916.42 | 12 |
| 2701.54 | 1 | 2896.20 | 4 | 3151.32 | 35 | 3926.50 | 14 |
| 2702.19 | 1 | 2903.07 | 4 | 3190.69 | 11 | 3929.73 | 13 |
| 2705.22 | 2 | 2906.45 | 4 | 3216.00 | 10 | 3951.97 | 12 |
| 2706.17 | 2 | 2907.46 | 5 | 3237.88 | 24 | 3973.64 | 13 |
| 2706.70 | 1 | 2908.81 | 6 | 3250.78 | 38 | 3977.73 | 12 |
| 2707.86 | 2 | 2910.01 | 4 | 3251.87 | 30 | 3997.13 | 13 |
| 2711.74 | 1 | 2910.38 | 5 | 3271.12 | 10 | 4005.71 | 23 |
| 2713.05 | 2 | 2911.05 | 5 | 3279.84 | 26 | 4036.78 | 13 |
| 2714.21 | 1 | 2912.46 | 45 | 3287.71 | 10 | 4056.27 | 15 |
| 2715.66 | 2 | 2915.88 | 43 | 3337.85 | 41 | 4178.39 | 19 |
| 2715.75 | 2 | 2917.37 | 5 | 3461.58 | 9 | 4202.35 | 19 |
| 2723.22 | 2 | 2919.99 | 4 | 3485.92 | 9 | 4204.20 | 19 |
| 2728.64 | 2 | 2920.38 | 4,5 | 3493.16 | 9 | 4220.05 | 19 |
| 2732.92 | 2 | 2924.02 | 5 | 3499.82 | 7 | 4224.51 | 19 |
| 2733.91 | 2 | 2924.63 | 5 | 3504.43 | 9 | 4404.68 | 22 |
| 2734.22 | 52 | 2930.80 | 5 | 3516.00 | 9 | 4424.62 | 22 |
| 2741.56 | 2 | 2934.39 | 5 | 3517.30 | 9 | | |
| 2753.41 | 29 | 2941.37 | 5 | 3520.02 | 7 | | |
| 2760.71 | 28 | 2941.49 | 5 | 3524.71 | 7 | | |

For this ion, we selected three data sources. First, we utilized the work of Karamatskos *et al.*,[1] who measured numerous branching ratios by using a hollow-cathode discharge as a source and a Fourier transform spectrometer for the spectral recordings. Absolute $f$-values were obtained by normalizing these branching ratios to radiative lifetimes which they measured by the technique of selective laser excitation. Of all the published data sources on this spectrum, the $f$-values of Ref. 1 are estimated to be the most reliable. They should be generally accurate to within 15 percent. Another reference we used is the work of Roberts *et al.*,[2] who determined absolute oscillator strengths by a combination of arc-emission measurements and beam-foil lifetimes. Finally, we included some data of Wujec and Musielok,[3] who measured $f$-values in emission with a wall-stabilized arc.

A comparison between the data of Refs. 1 and 2 shows that the oscillator strengths of Roberts *et al.* are consistently too small—by about 60 percent. Probably, the principal reason for this disagreement is that Roberts *et al*. based their data on beam-foil lifetimes, which have since been often shown to be too long, due to cascade effects. We have therefore included the $f$-values of Ref. 2 only if they could be directly renormalized to the more accurate lifetime data of Ref. 1.

There are a few other recent experiments which provide oscillator strengths for V II. These are the emission measurements of Wujec and Musielok,[3] and of Goly and Weniger.[4,5] In all three experiments, wall-stabilized arcs were used in conjunction with photographic detection systems. The most recent reference (also covering the most lines) is by Wujec and Musielok.[3] Here, the authors determined oscillator strengths for 211 spectral lines. They stated that the data in the earlier papers (Refs. 4 and 5) were normalized to incorrect absolute scales and should not be trusted. Therefore, in our data evaluation procedure, we disregarded Refs. 4 and 5, and compared the log $gf$-values of Ref. 3 to those of Ref. 1. The data of these two references overlap for 39 lines.

This comparison showed significant scatter. The $f$-values of Refs. 1 and 3 agreed within 50 percent for only 19 lines (49% of the lines in common). Quite a few lines disagreed by more than a factor of two. We also found a wavelength-dependent trend. The $f$-values of Wujec and Musielok appear to be too small for short wavelengths and too large for longer wavelengths.

As a further consistency check, we compared the log $gf$-values of Refs. 1 and 3 to those calculated with a semiempirical approach by Kurucz and Peytremann.[6] Past experience has shown that for the first and second spectra of the iron-group elements, the data of Ref. 6 are fairly reliable (within 50%) for stronger lines and typically scatter around absolute scales that are closely confirmed by accurate experiments. We also found this typical behavior when we compared Refs. 1 and 6 for V II. On the other hand, the data of Ref. 3 show more pronounced scatter when compared to those of Ref. 6. But for strong lines, in most cases, we found agreement within 50%, if the absolute scale of Wujec and Musielok is reduced by log $gf$ = 0.2. We have therefore utilized the data of Ref. 3 only for strong lines with log $gf$-values larger than −0.3, have reduced these values by 0.2, and have assigned accuracy ratings of "D."

## References


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[4] A. Goly and S. Weniger, J. Quant. Spectrosc. Radiat. Transfer **32**, 61 (1984).

[5] A. Goly and S. Weniger, J. Quant. Spectrosc. Radiat. Transfer **25**, 381 (1981).

[6] R. L. Kurucz and E. Peytremann, Smithsonian Astrophysical Observatory Special Report 362 (1975).


V II: Allowed transitions

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $a\ ^5D - z\ ^3D°$ | | | | | | | | | | | |
| | | 2711.74 | 339.2 | 37205 | 9 | 7 | 0.084 | 0.0072 | 0.58 | −1.19 | B | 1 |
| | | 2714.21 | 208.9 | 37041 | 7 | 5 | 0.097 | 0.0077 | 0.48 | −1.27 | B | 1 |
| | | 2702.19 | 208.9 | 37205 | 7 | 7 | 0.29 | 0.031 | 2.0 | −0.66 | C | 1 |
| | | 2706.70 | 106.6 | 37041 | 5 | 5 | 0.21 | 0.023 | 1.0 | −0.94 | C | 1 |
| | | 2694.74 | 106.6 | 37205 | 5 | 7 | 0.0019 | 2.8(−4)[a] | 0.013 | −2.85 | B | 1 |
| | | 2701.54 | 36.1 | 37041 | 3 | 5 | 0.020 | 0.0036 | 0.095 | −1.97 | B | 1 |
| 2. | $a\ ^5D - z\ ^5F°$ | *2710.9* | *206.3* | *37083* | 25 | 35 | 0.323 | 0.0498 | 11.1 | 0.095 | B | 1 |
| | | 2700.94 | 339.2 | 37352 | 9 | 11 | 0.35 | 0.046 | 3.7 | −0.38 | B | 1 |
| | | 2706.17 | 208.9 | 37151 | 7 | 9 | 0.34 | 0.047 | 3.0 | −0.48 | B | 1 |
| | | 2715.66 | 106.6 | 36919 | 5 | 7 | 0.31 | 0.048 | 2.1 | −0.62 | B | 1 |
| | | 2728.64 | 36.1 | 36673 | 3 | 5 | 0.22 | 0.040 | 1.1 | −0.92 | B | 1 |
| | | 2705.22 | 0.0 | 36955 | 1 | 3 | 0.043 | 0.014 | 0.13 | −1.85 | C+ | 1 |
| | | 2715.75 | 339.2 | 37151 | 9 | 9 | 0.021 | 0.0023 | 0.18 | −1.69 | B | 1 |
| | | 2723.22 | 208.9 | 36919 | 7 | 7 | 0.015 | 0.0017 | 0.11 | −1.92 | C+ | 1 |
| | | 2733.91 | 106.6 | 36673 | 5 | 5 | 0.028 | 0.0032 | 0.14 | −1.80 | B | 1 |
| | | 2707.86 | 36.1 | 36955 | 3 | 3 | 0.13 | 0.015 | 0.39 | −1.36 | C+ | 1 |
| | | 2732.92 | 339.2 | 36919 | 9 | 7 | 0.0029 | 2.5(−4) | 0.020 | −2.65 | C+ | 1 |
| | | 2741.56 | 208.9 | 36673 | 7 | 5 | 0.0032 | 2.6(−4) | 0.016 | −2.74 | B | 1 |
| | | 2713.05 | 106.6 | 36955 | 5 | 3 | 0.068 | 0.0045 | 0.20 | −1.65 | C+ | 1 |

V II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | $a\ ^5D - z\ ^5D°$ (uv 3) | *2684.2* | *206.3* | *37450* | 25 | 25 | 0.847 | 0.0914 | 20.2 | 0.359 | B | 1 |
| | | 2687.96 | 339.2 | 37531 | 9 | 9 | 0.76 | 0.082 | 6.6 | −0.13 | B | 1 |
| | | 2679.33 | 208.9 | 37521 | 7 | 7 | 0.34 | 0.037 | 2.3 | −0.59 | C+ | 1 |
| | | 2682.88 | 106.6 | 37369 | 5 | 5 | 0.20 | 0.021 | 0.95 | −0.97 | B | 1 |
| | | 2685.69 | 36.1 | 37259 | 3 | 3 | 0.067 | 0.0073 | 0.19 | −1.66 | B | 1 |
| | | 2688.72 | 339.2 | 37521 | 9 | 7 | 0.15 | 0.013 | 0.99 | −0.95 | C+ | 1 |
| | | 2690.25 | 208.9 | 37369 | 7 | 5 | 0.34 | 0.027 | 1.7 | −0.73 | B | 1 |
| | | 2690.79 | 106.6 | 37259 | 5 | 3 | 0.52 | 0.034 | 1.5 | −0.77 | B | 1 |
| | | 2689.88 | 36.1 | 37201 | 3 | 1 | 0.92 | 0.033 | 0.89 | −1.00 | B | 1 |
| | | 2678.57 | 208.9 | 37531 | 7 | 9 | 0.12 | 0.016 | 0.99 | −0.95 | C+ | 1 |
| | | 2672.01 | 106.6 | 37521 | 5 | 7 | 0.23 | 0.035 | 1.5 | −0.76 | C+ | 1 |
| | | 2677.80 | 36.1 | 37369 | 3 | 5 | 0.34 | 0.061 | 1.6 | −0.74 | B | 1 |
| | | 2683.09 | 0.0 | 37259 | 1 | 3 | 0.34 | 0.11 | 0.97 | −0.96 | B | 1 |
| 4. | $a\ ^5F - z\ ^3D°$ | | | | | | | | | | | |
| | | 2919.99 | 2968 | 37205 | 9 | 7 | 0.13 | 0.013 | 1.1 | −0.95 | B | 1 |
| | | 2920.38 | 2809 | 37041 | 7 | 5 | 0.044 | 0.0040 | 0.27 | −1.55 | C | 1 |
| | | 2906.45 | 2809 | 37205 | 7 | 7 | 0.78 | 0.099 | 6.6 | −0.16 | B | 1 |
| | | 2910.01 | 2687 | 37041 | 5 | 5 | 1.1 | 0.14 | 6.5 | −0.17 | B | 1 |
| | | 2896.20 | 2687 | 37205 | 5 | 7 | 0.21 | 0.036 | 1.7 | −0.74 | B | 1 |
| | | 2903.07 | 2605 | 37041 | 3 | 5 | 0.34 | 0.071 | 2.0 | −0.67 | B | 1 |
| 5. | $a\ ^5F - z\ ^5F°$ | *2926.8* | *2926* | *37083* | 35 | 35 | 1.75 | 0.224 | 75.6 | 0.895 | B | 1 |
| | | 2924.02 | 3163 | 37352 | 11 | 11 | 1.7 | 0.22 | 24 | 0.39 | B | 1 |
| | | 2924.63 | 2968 | 37151 | 9 | 9 | 1.2 | 0.16 | 14 | 0.15 | B | 1 |
| | | 2930.80 | 2809 | 36919 | 7 | 7 | 0.58 | 0.075 | 5.1 | −0.28 | B | 1 |
| | | 2941.49 | 2687 | 36673 | 5 | 5 | 0.32 | 0.042 | 2.0 | −0.68 | C | 1 |
| | | 2910.38 | 2605 | 36955 | 3 | 3 | 1.2 | 0.16 | 4.5 | −0.33 | B | 1 |
| | | 2941.37 | 3163 | 37151 | 11 | 9 | 0.35 | 0.037 | 3.9 | −0.39 | C | 1 |
| | | 2944.57 | 2968 | 36919 | 9 | 7 | 0.76 | 0.077 | 6.7 | −0.16 | B | 1 |
| | | 2952.07 | 2809 | 36673 | 7 | 5 | 0.72 | 0.067 | 4.6 | −0.33 | B | 1 |
| | | 2917.37 | 2687 | 36955 | 5 | 3 | 0.18 | 0.014 | 0.65 | −1.17 | B | 1 |
| | | 2907.46 | 2968 | 37352 | 9 | 11 | 0.23 | 0.035 | 3.0 | −0.50 | B | 1 |
| | | 2911.05 | 2809 | 37151 | 7 | 9 | 0.37 | 0.061 | 4.1 | −0.37 | B | 1 |
| | | 2920.38 | 2687 | 36919 | 5 | 7 | 0.32 | 0.056 | 2.7 | −0.55 | C | 1 |
| | | 2934.39 | 2605 | 36673 | 3 | 5 | 0.18 | 0.038 | 1.1 | −0.94 | B | 1 |
| 6. | $a\ ^5F - z\ ^5D°$ (uv 12) | *2895.7* | *2926* | *37450* | 35 | 25 | 1.80 | 0.162 | 54.0 | 0.753 | B | 1 |
| | | 2908.81 | 3163 | 37531 | 11 | 9 | 1.6 | 0.17 | 17 | 0.26 | B | 1 |
| | | 2893.31 | 2968 | 37521 | 9 | 7 | 1.2 | 0.12 | 10 | 0.03 | B | 1 |
| | | 2892.65 | 2809 | 37369 | 7 | 5 | 1.3 | 0.12 | 7.9 | −0.08 | B | 1 |
| | | 2891.64 | 2687 | 37259 | 5 | 3 | 1.4 | 0.10 | 4.9 | −0.29 | B | 1 |
| | | 2889.61 | 2605 | 37201 | 3 | 1 | 1.9 | 0.080 | 2.3 | −0.62 | B | 1 |
| | | 2892.43 | 2968 | 37531 | 9 | 9 | 0.36 | 0.045 | 3.9 | −0.39 | B | 1 |
| | | 2880.03 | 2809 | 37521 | 7 | 7 | 0.26 | 0.032 | 2.1 | −0.65 | B | 1 |
| | | 2882.49 | 2687 | 37369 | 5 | 5 | 0.42 | 0.053 | 2.5 | −0.58 | B | 1 |
| | | 2884.78 | 2605 | 37259 | 3 | 3 | 0.56 | 0.070 | 2.0 | −0.68 | C | 1 |
| | | 2879.16 | 2809 | 37531 | 7 | 9 | 0.037 | 0.0060 | 0.40 | −1.38 | B | 1 |
| | | 2869.96 | 2687 | 37521 | 5 | 7 | 0.022 | 0.0037 | 0.18 | −1.73 | C+ | 1 |
| | | 2875.69 | 2605 | 37369 | 3 | 5 | 0.034 | 0.0070 | 0.20 | −1.68 | B | 1 |

V II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7. | $a\,^3F - z\,^3D°$ | | | | | | | | | | | |
| | | 3556.80 | 9098 | 37205 | 9 | 7 | 0.51 | 0.075 | 7.9 | −0.17 | B | 1 |
| | | 3545.19 | 8842 | 37041 | 7 | 5 | 0.43 | 0.058 | 4.8 | −0.39 | B | 1 |
| | | 3524.71 | 8842 | 37205 | 7 | 7 | 0.067 | 0.012 | 1.0 | −1.06 | B | 1 |
| | | 3520.02 | 8640 | 37041 | 5 | 5 | 0.073 | 0.014 | 0.78 | −1.17 | B | 1 |
| | | 3499.82 | 8640 | 37205 | 5 | 7 | 0.0032 | 8.2(−4) | 0.047 | −2.39 | D | 2*n* |
| 8. | $a\,^3F - z\,^5F°$ | | | | | | | | | | | |
| | | 3538.24 | 9098 | 37352 | 9 | 11 | 0.011 | 0.0024 | 0.26 | −1.66 | B | 1 |
| | | 3531.48 | 8842 | 37151 | 7 | 9 | 0.0041 | 9.7(−4) | 0.080 | −2.16 | C | 1 |
| | | 3563.71 | 9098 | 37151 | 9 | 9 | 0.0049 | 9.3(−4) | 0.098 | −2.08 | D | 2*n* |
| | | 3560.59 | 8842 | 36919 | 7 | 7 | 0.023 | 0.0044 | 0.36 | −1.51 | B | 1 |
| | | 3566.18 | 8640 | 36673 | 5 | 5 | 0.076 | 0.015 | 0.85 | −1.14 | B | 1 |
| | | 3593.32 | 9098 | 36919 | 9 | 7 | 0.17 | 0.026 | 2.8 | −0.63 | B | 1 |
| | | 3592.01 | 8842 | 36673 | 7 | 5 | 0.44 | 0.061 | 5.0 | −0.37 | B | 1 |
| | | 3530.77 | 8842 | 36955 | 5 | 3 | 0.45 | 0.050 | 2.9 | −0.60 | C+ | 1 |
| 9. | $a\,^3F - z\,^5D°$ (6) | | | | | | | | | | | |
| | | 3516.00 | 9098 | 37531 | 9 | 9 | 0.0020 | 3.7(−4) | 0.038 | −2.48 | B | 1 |
| | | 3485.92 | 8842 | 37521 | 7 | 7 | 0.036 | 0.0065 | 0.53 | −1.34 | C+ | 1 |
| | | 3517.30 | 9098 | 37521 | 9 | 7 | 0.38 | 0.054 | 5.7 | −0.31 | B | 1 |
| | | 3504.43 | 8842 | 37369 | 7 | 5 | 0.16 | 0.021 | 1.7 | −0.84 | B | 1 |
| | | 3493.16 | 8842 | 37259 | 5 | 3 | 0.060 | 0.0066 | 0.38 | −1.48 | D | 2*n* |
| | | 3461.58 | 8842 | 37521 | 5 | 7 | 0.0053 | 0.0013 | 0.075 | −2.18 | D | 2*n* |
| 10. | $a\,^3F - z\,^3G°$ (7) | | | | | | | | | | | |
| | | 3276.12 | 9098 | 39613 | 9 | 11 | 0.52 | 0.10 | 9.8 | −0.04 | D | 3*n* |
| | | 3271.12 | 8842 | 39404 | 7 | 9 | 0.69 | 0.14 | 11 | 0.00 | D | 3*n* |
| | | 3287.71 | 8640 | 39234 | 5 | 7 | 0.75 | 0.17 | 9.2 | −0.07 | D | 3*n* |
| 11. | $a\,^3F - z\,^3F°$ (8) | | | | | | | | | | | |
| | | 3190.69 | 9098 | 40430 | 9 | 9 | 0.33 | 0.050 | 4.7 | −0.35 | D | 3*n* |
| 12. | $a\,^3P - z\,^3D°$ | | | | | | | | | | | |
| | | 3951.97 | 11908 | 37205 | 5 | 7 | 0.11 | 0.036 | 2.4 | −0.74 | B | 1 |
| | | 3916.42 | 11515 | 37041 | 3 | 5 | 0.076 | 0.029 | 1.12 | −1.06 | B | 1 |
| | | 3977.73 | 11908 | 37041 | 5 | 5 | 0.024 | 0.0056 | 0.37 | −1.55 | B | 1 |
| 13. | $a\,^3P - z\,^5F°$ | | | | | | | | | | | |
| | | 3997.13 | 11908 | 36919 | 5 | 7 | 0.038 | 0.013 | 0.83 | −1.20 | C | 1 |
| | | 3973.64 | 11515 | 36673 | 3 | 5 | 0.075 | 0.030 | 1.2 | −1.05 | B | 1 |
| | | 4036.78 | 11908 | 36673 | 5 | 5 | 0.024 | 0.0058 | 0.38 | −1.54 | B | 1 |
| | | 3929.73 | 11515 | 36955 | 3 | 3 | 0.037 | 0.0086 | 0.33 | −1.59 | B | 1 |
| 14. | $a\,^3P - z\,^5D°$ (11) | | | | | | | | | | | |
| | | 3903.27 | 11908 | 37521 | 5 | 7 | 0.081 | 0.026 | 1.7 | −0.89 | B | 1 |
| | | 3866.74 | 11515 | 37369 | 3 | 5 | 0.027 | 0.010 | 0.38 | −1.52 | B | 1 |
| | | 3850.41 | 11296 | 37259 | 1 | 3 | 0.0074 | 0.0049 | 0.062 | −2.31 | D | 2*n* |
| | | 3926.50 | 11908 | 37369 | 5 | 5 | 0.0095 | 0.0022 | 0.14 | −1.96 | B | 1 |

V II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | $a\ ^3H - z\ ^5F^\circ$ | | | | | | | | | | | |
| | | 4056.27 | 12706 | 37352 | 13 | 11 | 7.4(−4) | 1.5(−4) | 0.027 | −2.70 | D | 2*n* |
| 16. | $a\ ^3H - z\ ^3G^\circ$ (15) | | | | | | | | | | | |
| | | 3715.48 | 12706 | 39613 | 13 | 11 | 0.18 | 0.032 | 5.1 | −0.38 | D | 3*n* |
| | | 3732.76 | 12622 | 39404 | 11 | 9 | 0.19 | 0.032 | 4.4 | −0.45 | D | 3*n* |
| 17. | $a\ ^3H - y\ ^3H^\circ$ (uv 50) | | | | | | | | | | | |
| | | 2527.90 | 12706 | 52253 | 13 | 13 | 0.61 | 0.058 | 6.3 | −0.12 | D | 3*n* |
| | | 2528.83 | 12622 | 52153 | 11 | 11 | 0.53 | 0.051 | 4.7 | −0.25 | D | 3*n* |
| | | 2528.47 | 12545 | 52083 | 9 | 9 | 0.52 | 0.050 | 3.7 | −0.35 | D | 3*n* |
| 18. | $b\ ^3F - z\ ^3F^\circ$ (21) | | | | | | | | | | | |
| | | 3727.35 | 13609 | 40430 | 9 | 9 | 0.21 | 0.044 | 4.9 | −0.40 | D | 3*n* |
| 19. | $a\ ^5P - z\ ^5D^\circ$ (25) | | | | | | | | | | | |
| | | 4202.35 | 13742 | 37531 | 7 | 9 | 0.0075 | 0.0025 | 0.25 | −1.75 | D | 2*n* |
| | | 4178.39 | 13595 | 37521 | 5 | 7 | 0.012 | 0.0044 | 0.30 | −1.66 | D | 2*n* |
| | | 4204.20 | 13742 | 37521 | 7 | 7 | 0.0019 | 5.1(−4) | 0.049 | −2.45 | D | 2*n* |
| | | 4224.51 | 13595 | 37259 | 5 | 3 | 0.0028 | 4.5(−4) | 0.031 | −2.65 | D | 2*n* |
| | | 4220.05 | 13512 | 37201 | 3 | 1 | 0.0080 | 7.1(−4) | 0.030 | −2.67 | D | 2*n* |
| 20. | $a\ ^5P - y\ ^5D^\circ$ | | | | | | | | | | | |
| | | 2968.37 | 13742 | 47420 | 7 | 9 | 0.70 | 0.12 | 8.1 | −0.08 | D | 3*n* |
| 21. | $a\ ^5P - z\ ^5P^\circ$ (27) | | | | | | | | | | | |
| | | 3001.20 | 13742 | 47052 | 7 | 7 | 0.75 | 0.10 | 7.0 | −0.15 | D | 3*n* |
| | | 3016.78 | 13742 | 46880 | 7 | 5 | 0.50 | 0.048 | 3.4 | −0.47 | D | 3*n* |
| | | 3014.82 | 13595 | 46755 | 5 | 3 | 0.89 | 0.073 | 3.6 | −0.44 | D | 3*n* |
| 22. | $a\ ^3G - z\ ^5F^\circ$ | | | | | | | | | | | |
| | | 4404.68 | 14656 | 37352 | 11 | 11 | 0.0021 | 6.2(−4) | 0.098 | −2.17 | D | 2*n* |
| | | 4424.62 | 14556 | 37151 | 9 | 9 | 0.0018 | 5.3(−4) | 0.070 | −2.32 | D | 2*n* |
| 23. | $a\ ^3G - z\ ^3G^\circ$ (32) | | | | | | | | | | | |
| | | 4005.71 | 14656 | 39613 | 11 | 11 | 0.13 | 0.032 | 4.6 | −0.46 | D | 3*n* |
| 24. | $b\ ^3G - z\ ^3H^\circ$ (38) | | | | | | | | | | | |
| | | 3237.88 | 16422 | 47297 | 9 | 11 | 0.26 | 0.050 | 4.8 | −0.35 | D | 3*n* |
| 25. | $b\ ^3G - y\ ^3G^\circ$ (39) | | | | | | | | | | | |
| | | 3100.94 | 16341 | 48580 | 7 | 7 | 0.58 | 0.084 | 6.0 | −0.23 | D | 3*n* |

V II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26. | $b\,^1G - z\,^1H°$ (73) | 3279.84 | 19113 | 49593 | 9 | 11 | 0.58 | 0.11 | 11 | 0.01 | D | 3*n* |
| 27. | $b\,^3P - x\,^3D°$ (87) | | | | | | | | | | | |
| | | 2972.26 | 19133 | 52767 | 5 | 7 | 0.52 | 0.096 | 4.7 | −0.32 | D | 3*n* |
| 28. | $a\,^1I - z\,^1I°$ (uv 149) | 2760.71 | 19191 | 55403 | 13 | 13 | 0.25 | 0.029 | 3.4 | −0.43 | D | 3*n* |
| 29. | $a\,^1I - y\,^1H°$ (uv 150) | 2753.41 | 19191 | 55499 | 13 | 11 | 0.42 | 0.040 | 4.8 | −0.28 | D | 3*n* |
| 30. | $c\,^3P - y\,^3D°$ (108) | | | | | | | | | | | |
| | | 3251.87 | 20343 | 51086 | 5 | 7 | 0.35 | 0.078 | 4.2 | −0.41 | D | 3*n* |
| 31. | $b\,^3H - z\,^3H°$ (116) | | | | | | | | | | | |
| | | 3669.41 | 20363 | 47608 | 13 | 13 | 0.13 | 0.027 | 4.2 | −0.46 | D | 3*n* |
| 32. | $b\,^3H - y\,^3H°$ (122) | | | | | | | | | | | |
| | | 3134.93 | 20363 | 52253 | 13 | 13 | 0.59 | 0.086 | 12 | 0.05 | D | 3*n* |
| | | 3136.50 | 20280 | 52153 | 11 | 11 | 0.53 | 0.077 | 8.8 | −0.07 | D | 3*n* |
| | | 3139.73 | 20242 | 52083 | 9 | 9 | 0.52 | 0.077 | 7.2 | −0.16 | D | 3*n* |
| 33. | $b\,^3H - z\,^3I°$ (123) | | | | | | | | | | | |
| | | 3048.21 | 20280 | 53077 | 11 | 13 | 0.70 | 0.11 | 13 | 0.10 | D | 3*n* |
| | | 3063.25 | 20242 | 52878 | 9 | 11 | 1.0 | 0.17 | 16 | 0.19 | D | 3*n* |
| 34. | $b\,^3H - x\,^3G°$ (uv 159) | | | | | | | | | | | |
| | | 2869.13 | 20363 | 55207 | 13 | 11 | 0.48 | 0.050 | 6.1 | −0.19 | D | 3*n* |
| | | 2854.34 | 20280 | 55304 | 11 | 9 | 0.50 | 0.050 | 5.2 | −0.26 | D | 3*n* |
| | | 2847.57 | 20242 | 55350 | 9 | 7 | 0.46 | 0.043 | 3.7 | −0.41 | D | 3*n* |
| | | 2862.31 | 20280 | 55207 | 11 | 11 | 0.36 | 0.045 | 4.6 | −0.31 | D | 3*n* |
| 35. | $b\,^3D - x\,^3F°$ (138) | | | | | | | | | | | |
| | | 3151.32 | 20522 | 52246 | 3 | 5 | 0.44 | 0.11 | 3.4 | −0.49 | D | 3*n* |
| 36. | $a\,^1P - z\,^1D°$ (158) | 3618.92 | 22274 | 49898 | 3 | 5 | 0.33 | 0.11 | 3.9 | −0.49 | D | 3*n* |
| 37. | $a\,^1H - z\,^1H°$ (166) | 3815.38 | 23391 | 49593 | 11 | 11 | 0.17 | 0.036 | 5.0 | −0.40 | D | 3*n* |
| 38. | $a\,^1H - y\,^1G°$ (171) | 3250.78 | 23391 | 54144 | 11 | 9 | 0.52 | 0.067 | 7.9 | −0.13 | D | 3*n* |
| 39. | $a\,^1H - z\,^1I°$ (173) | 3122.89 | 23391 | 55403 | 11 | 13 | 0.76 | 0.13 | 15 | 0.16 | D | 3*n* |

V II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40. | *a* $^1$H – *y* $^1$H° (174) | 3113.56 | 23391 | 55499 | 11 | 11 | 0.50 | 0.072 | 8.1 | −0.10 | D | 3*n* |
| 41. | *b* $^1$D – *y* $^1$F° (184) | 3337.85 | 25191 | 55142 | 5 | 7 | 0.53 | 0.12 | 6.8 | −0.21 | D | 3*n* |
| 42. | *c* $^3$F – *w* $^3$G° (uv 196) | | | | | | | | | | | |
| | | 2948.08 | 30319 | 64229 | 9 | 11 | 0.40 | 0.064 | 5.6 | −0.24 | D | 3*n* |
| | | 2955.58 | 30306 | 64131 | 7 | 9 | 0.33 | 0.056 | 3.8 | −0.41 | D | 3*n* |
| 43. | *c* $^3$F – *v* $^3$D° (uv 197) | | | | | | | | | | | |
| | | 2915.88 | 30319 | 64603 | 9 | 7 | 0.49 | 0.049 | 4.2 | −0.36 | D | 3n |
| 44. | *d* $^3$F – *w* $^3$G° (218) | | | | | | | | | | | |
| | | 2973.98 | 30614 | 64229 | 9 | 11 | 0.35 | 0.057 | 5.0 | −0.29 | D | 3*n* |
| | | 2985.18 | 30642 | 64131 | 7 | 9 | 0.44 | 0.075 | 5.2 | −0.28 | D | 3*n* |
| 45. | *z* $^5$G° – $^5$F | | | | | | | | | | | |
| | | 2912.46 | 35193 | 69518 | 11 | 9 | 0.50 | 0.052 | 5.5 | −0.24 | D | 3*n* |
| 46. | *z* $^5$G° – *e* $^5$H (uv 213) | | | | | | | | | | | |
| | | 2640.86 | 34593 | 72448 | 5 | 7 | 1.2 | 0.17 | 7.6 | −0.06 | D | 3*n* |
| 47. | *z* $^3$D° – $^5$G | | | | | | | | | | | |
| | | 2787.91 | 37205 | 73064 | 7 | 9 | 0.50 | 0.075 | 4.8 | −0.28 | D | 3*n* |
| 48. | *z* $^5$D° – *e* $^5$P (uv 221) | | | | | | | | | | | |
| | | 2825.86 | 37531 | 72909 | 9 | 7 | 1.2 | 0.11 | 9.3 | 0.00 | D | 3*n* |
| | | 2843.82 | 37521 | 72675 | 7 | 5 | 0.99 | 0.086 | 5.6 | −0.22 | D | 3*n* |
| 49. | *z* $^5$D° – $^3$F | | | | | | | | | | | |
| | | 2589.10 | 37531 | 76143 | 9 | 9 | 0.77 | 0.077 | 5.9 | −0.16 | D | 3*n* |
| 50. | *z* $^5$D° – $^5$D | | | | | | | | | | | |
| | | 2554.04 | 37531 | 76673 | 9 | 9 | 0.54 | 0.053 | 4.0 | −0.32 | D | 3*n* |
| 51. | *z* $^3$G° – $^3$H | | | | | | | | | | | |
| | | 2784.20 | 39404 | 75141 | 9 | 9 | 1.3 | 0.15 | 12 | 0.12 | D | 3*n* |
| 52. | *z* $^3$G° – $^3$F | | | | | | | | | | | |
| | | 2734.22 | 39404 | 75966 | 9 | 7 | 0.62 | 0.054 | 4.4 | −0.31 | D | 3*n* |
| 53. | *z* $^3$F° – $^3$D | | | | | | | | | | | |
| | | 3020.21 | 40430 | 73531 | 9 | 7 | 0.50 | 0.053 | 4.8 | −0.32 | D | 3*n* |

V II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 54. | $z\,^5P^\circ - {}^3P$ | | | | | | | | | | | |
| | | 2868.11 | 46880 | 81736 | 5 | 3 | 2.1 | 0.16 | 7.3 | −0.11 | D | 3n |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V III

Sc Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^63d^3\ {}^4F_{3/2}$

Ionization Energy: 29.311 eV = 236410 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2314.18 | 2 | 2337.13 | 2 | 2373.06 | 7 | 2521.16 | 4 |
| 2318.06 | 10 | 2343.10 | 7 | 2382.46 | 1 | 2521.55 | 9 |
| 2319.00 | 2 | 2346.33 | 2 | 2393.58 | 1 | 2548.21 | 4 |
| 2323.82 | 8 | 2347.13 | 2 | 2399.69 | 1 | 2554.22 | 5 |
| 2325.11 | 2 | 2348.25 | 2 | 2404.18 | 1 | 2593.05 | 3 |
| 2330.42 | 2 | 2358.73 | 6 | 2407.17 | 1 | 2595.10 | 3 |
| 2331.75 | 2 | 2366.31 | 6 | 2413.92 | 1 | | |
| 2334.21 | 2 | 2371.06 | 1 | 2516.14 | 9 | | |

For this spectrum, we have selected the experiment by Goly,[1] who measured relative oscillator strengths in emission with a wall-stabilized arc. Goly converted his data to an absolute scale by utilizing the beam-foil lifetime of the $z\,^4G^\circ_{11/2}$ level, which was measured by Andersen *et al.*[2]

At the time of this evaluation, Ref. 1 is the only work that provides directly measured oscillator strengths. To get a rough idea of the scatter in these data, as well as of the reliability of the absolute scale, we compared the data of Ref. 1 to the calculated log *gf*-values of Kurucz and Peytremann.[3] For many neutral and singly ionized members of the iron-group elements,[4] we have found that the majority of the *f*-values tabulated in Ref. 3 agree reasonably well with high-quality experimental data, although there are occasional drastic deviations. As a result of this comparison, we have increased the log *gf*-values of Goly by 0.13. It is quite possible that the beam-foil lifetimes of Ref. 2 are affected by cascading, a condition which would make Goly's published *f*-values too low.

After renormalizing Goly's data, the subsequent agreement between Refs. 1 and 3 is quite satisfactory. For all thirty overlapping lines, the agreement is within fifty percent, and the data for 23 lines agree within twenty percent.

## References

[1]A. Goly, Astron. Astrophys. **68**, 79 (1978).
[2]T. Andersen, P. Petersen, and E. Biemont, J. Quant. Spectrosc. Radiat. Transfer **17**, 389 (1977).
[3]R. L. Kurucz and E. Peytremann, Smithsonian Astrophysical Observatory Special Report 362 (1975).
[4]S. M. Younger, J. R. Fuhr, G. A. Martin, and W. L. Wiese, J. Phys. Chem. Ref. Data **7**, 495 (1978).

V III: Allowed transitions

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $b\ ^4F - z\ ^4G°$ (uv 10) | | | | | | | | | | | |
| | | 2371.06 | 44647 | 86809 | 10 | 12 | 5.2 | 0.52 | 41 | 0.72 | D | 1n |
| | | 2382.46 | 44346 | 86306 | 8 | 10 | 5.0 | 0.53 | 33 | 0.63 | D | 1n |
| | | 2393.58 | 44110 | 85876 | 6 | 8 | 4.3 | 0.49 | 23 | 0.47 | D | 1n |
| | | 2404.18 | 43942 | 85524 | 4 | 6 | 2.5 | 0.33 | 10 | 0.12 | D | 1n |
| | | 2399.69 | 44647 | 86306 | 10 | 10 | 0.37 | 0.032 | 2.6 | −0.49 | D | 1n |
| | | 2407.17 | 44346 | 85876 | 8 | 8 | 0.64 | 0.056 | 3.5 | −0.35 | D | 1n |
| | | 2413.92 | 44110 | 85524 | 6 | 6 | 0.62 | 0.054 | 2.6 | −0.49 | D | 1n |
| 2. | $b\ ^4F - z\ ^4F°$ (uv 11) | *2332.6* | *44345* | *87203* | 28 | 28 | 3.5 | 0.28 | 61 | 0.90 | D | 1n |
| | | 2330.42 | 44647 | 87544 | 10 | 10 | 3.2 | 0.26 | 20 | 0.42 | D | 1n |
| | | 2331.75 | 44346 | 87219 | 8 | 8 | 2.5 | 0.20 | 12 | 0.21 | D | 1n |
| | | 2334.21 | 44110 | 86938 | 6 | 6 | 2.2 | 0.18 | 8.2 | 0.03 | D | 1n |
| | | 2337.13 | 43942 | 86717 | 4 | 4 | 2.7 | 0.22 | 6.7 | −0.06 | D | 1n |
| | | 2348.25 | 44647 | 87219 | 10 | 8 | 0.45 | 0.030 | 2.3 | −0.53 | D | 1n |
| | | 2347.13 | 44346 | 86938 | 8 | 6 | 0.73 | 0.045 | 2.8 | −0.44 | D | 1n |
| | | 2346.33 | 44110 | 86717 | 6 | 4 | 0.82 | 0.045 | 2.1 | −0.57 | D | 1n |
| | | 2314.18 | 44346 | 87544 | 8 | 10 | 0.38 | 0.039 | 2.4 | −0.51 | D | 1n |
| | | 2319.00 | 44110 | 87219 | 6 | 8 | 0.56 | 0.061 | 2.8 | −0.44 | D | 1n |
| | | 2325.11 | 43942 | 86938 | 4 | 6 | 0.50 | 0.061 | 1.9 | −0.61 | D | 1n |
| 3. | $b\ ^2F - z\ ^2F°$ (uv 13) | | | | | | | | | | | |
| | | 2595.10 | 49805 | 88328 | 8 | 8 | 2.8 | 0.29 | 20 | 0.36 | D | 1n |
| | | 2593.05 | 49328 | 87881 | 6 | 6 | 2.8 | 0.28 | 14 | 0.23 | D | 1n |
| 4. | $b\ ^2F - ^2D°$ | | | | | | | | | | | |
| | | 2521.16 | 49805 | 89458 | 8 | 6 | 1.1 | 0.075 | 5.0 | −0.22 | D | 1n |
| | | 2548.21 | 49328 | 88559 | 6 | 4 | 2.0 | 0.13 | 6.5 | −0.11 | D | 1n |
| 5. | $b\ ^2F - ^4D°$ | | | | | | | | | | | |
| | | 2554.22 | 49805 | 88944 | 8 | 6 | 1.2 | 0.088 | 6.0 | −0.15 | D | 1n |
| 6. | $b\ ^2F - z\ ^2G°$ (uv 15) | | | | | | | | | | | |
| | | 2366.31 | 49805 | 92053 | 8 | 10 | 4.2 | 0.44 | 28 | 0.55 | D | 1n |
| | | 2358.73 | 49328 | 91710 | 6 | 8 | 4.2 | 0.47 | 22 | 0.45 | D | 1n |
| 7. | $c\ ^2D - y\ ^2F°$ | | | | | | | | | | | |
| | | 2343.10 | 56160 | 98825 | 6 | 8 | 3.6 | 0.40 | 19 | 0.38 | D | 1n |
| | | 2373.06 | 56257 | 98384 | 4 | 6 | 2.9 | 0.36 | 11 | 0.16 | D | 1n |
| 8. | $b\ ^4P - y\ ^4D°$ | | | | | | | | | | | |
| | | 2323.82 | 56923 | 99941 | 6 | 8 | 3.8 | 0.41 | 19 | 0.39 | D | 1n |
| 9. | $b\ ^2G - y\ ^2G°$ | | | | | | | | | | | |
| | | 2516.14 | 63303 | 103035 | 10 | 10 | 3.7 | 0.35 | 29 | 0.55 | D | 1n |
| | | 2521.55 | 63315 | 102961 | 8 | 8 | 3.5 | 0.34 | 22 | 0.43 | D | 1n |

V III: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | $b\,^2G - z\,^2H°$ | | | | | | | | | | | |
| | | 2318.06 | 63315 | 106441 | 8 | 10 | 4.6 | 0.46 | 28 | 0.57 | D | 1*n* |

# V IV

Ca Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^63d^2\ ^3F_2$

Ionization Energy: 46.709 eV = 376730 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 677.345 | 2 | 1330.36 | 26 | 1809.85 | 10 | 2431.89 | 49 |
| 680.632 | 2 | 1331.67 | 26 | 1810.57 | 10 | 2432.52 | 50 |
| 681.145 | 2 | 1332.46 | 26 | 1813.05 | 10 | 2433.53 | 47 |
| 682.455 | 1 | 1334.49 | 23 | 1817.68 | 10 | 2446.07 | 49 |
| 682.923 | 1 | 1339.34 | 23 | 1825.84 | 10 | 2446.80 | 49 |
| 684.450 | 1 | 1355.13 | 29 | 1861.56 | 12 | 2449.40 | 47 |
| 691.530 | 4 | 1356.53 | 15 | 1939.07 | 9 | 2449.72 | 47 |
| 722.912 | 5 | 1391.11 | 28 | 1951.43 | 9 | 2450.33 | 47 |
| 723.537 | 5 | 1395.00 | 14 | 1963.10 | 9 | 2450.87 | 48 |
| 724.068 | 5 | 1400.42 | 18 | 1966.24 | 9 | 2463.80 | 47 |
| 724.809 | 5 | 1403.62 | 18 | 1982.42 | 8 | 2467.29 | 48 |
| 737.854 | 6 | 1408.64 | 17 | 1997.72 | 8 | 2480.74 | 62 |
| 750.110 | 3 | 1412.69 | 17 | 1999.32 | 8 | 2506.97 | 59 |
| 884.146 | 7 | 1414.41 | 22 | 2002.48 | 8 | 2509.61 | 59 |
| 1071.05 | 33 | 1414.84 | 17 | 2011.18 | 8 | 2512.24 | 59 |
| 1110.72 | 34 | 1418.53 | 17 | 2014.20 | 8 | 2519.80 | 59 |
| 1112.20 | 34 | 1418.92 | 17 | 2060.11 | 38 | 2570.72 | 55 |
| 1112.44 | 34 | 1419:58 | 22 | 2084.43 | 42 | 2584.64 | 52 |
| 1127.84 | 35 | 1423.42 | 17 | 2120.05 | 37 | 2595.86 | 56 |
| 1131.26 | 35 | 1423.72 | 31 | 2136.33 | 41 | 2596.76 | 53 |
| 1194.46 | 36 | 1424.20 | 21 | 2137.74 | 39 | 2599.98 | 53 |
| 1226.52 | 16 | 1424.92 | 22 | 2141.20 | 39 | 2603.21 | 53 |
| 1243.72 | 20 | 1426.65 | 22 | 2146.83 | 46 | 2610.32 | 103 |
| 1247.07 | 20 | 1429.11 | 21 | 2149.85 | 39 | 2620.32 | 60 |
| 1250.92 | 20 | 1434.09 | 22 | 2151.09 | 40 | 2624.21 | 58 |
| 1272.97 | 32 | 1434.84 | 21 | 2155.34 | 46 | 2628.09 | 58 |
| 1304.17 | 19 | 1449.68 | 21 | 2159.06 | 46 | 2636.40 | 58 |
| 1305.42 | 19 | 1451.04 | 25 | 2160.22 | 43 | 2636.94 | 60 |
| 1308.06 | 19 | 1451.50 | 25 | 2167.20 | 46 | 2644.95 | 58 |
| 1309.50 | 19 | 1454.00 | 25 | 2170.38 | 45 | 2645.54 | 60 |
| 1312.72 | 19 | 1520.14 | 24 | 2173.89 | 44 | 2650.61 | 58 |
| 1317.57 | 23 | 1522.49 | 24 | 2186.39 | 44 | 2655.41 | 60 |
| 1321.72 | 23 | 1525.76 | 24 | 2187.56 | 45 | 2656.87 | 60 |
| 1321.92 | 23 | 1527.22 | 24 | 2268.30 | 11 | 2716.59 | 63 |
| 1326.67 | 23 | 1527.72 | 24 | 2378.29 | 51 | 2718.72 | 104 |
| 1326.81 | 26 | 1601.92 | 30 | 2395.45 | 57 | 2727.78 | 104 |
| 1329.29 | 26 | 1611.88 | 27 | 2416.55 | 50 | 2740.55 | 61 |
| 1329.97 | 26 | 1806.18 | 13 | 2421.32 | 50 | 2740.97 | 104 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2743.52 | 63 | 3274.93 | 69 | 3496.42 | 94 | 4855.05 | 83 |
| 2751.53 | 105 | 3284.56 | 100 | 3500.57 | 97 | 4886.36 | 83 |
| 2763.86 | 105 | 3294.26 | 69 | 3504.10 | 68 | 4899.56 | 75 |
| 2764.22 | 105 | 3295.50 | 95 | 3505.70 | 97 | 4906.28 | 83 |
| 2824.13 | 54 | 3298.37 | 95 | 3514.25 | 94 | 4913.08 | 72 |
| 2834.09 | 106 | 3303.72 | 69 | 3525.89 | 94 | 4916.94 | 73 |
| 2850.16 | 107 | 3314.18 | 69 | 3545.98 | 93 | 4954.41 | 76 |
| 2899.58 | 108 | 3318.79 | 69 | 3550.72 | 97 | 4970.35 | 73 |
| 3034.27 | 65 | 3328.53 | 95 | 3681.04 | 96 | 4971.94 | 78 |
| 3052.35 | 88 | 3333.99 | 69 | 3691.24 | 96 | 4985.65 | 85 |
| 3055.86 | 65 | 3334.79 | 70 | 3833.74 | 101 | 5035.46 | 78 |
| 3060.15 | 65 | 3385.34 | 99 | 4136.72 | 71 | 5074.90 | 78 |
| 3067.85 | 92 | 3433.52 | 89 | 4505.17 | 74 | 5130.78 | 82 |
| 3077.48 | 67 | 3448.41 | 87 | 4508.67 | 74 | 5146.50 | 82 |
| 3096.23 | 92 | 3452.74 | 90 | 4518.58 | 77 | 5175.95 | 82 |
| 3110.42 | 64 | 3455.33 | 102 | 4565.63 | 77 | 5222.93 | 82 |
| 3113.02 | 64 | 3459.40 | 89 | 4608.15 | 79 | 5262.16 | 81 |
| 3121.30 | 64 | 3471.99 | 89 | 4616.57 | 79 | 5267.05 | 82 |
| 3227.51 | 91 | 3473.46 | 89 | 4643.99 | 80 | 5310.77 | 81 |
| 3234.25 | 91 | 3487.63 | 66 | 4801.54 | 83 | 5352.32 | 81 |
| 3241.46 | 91 | 3489.51 | 68 | 4841.26 | 86 | 5353.09 | 81 |
| 3268.08 | 98 | 3490.91 | 94 | 4845.21 | 83 | 5940.12 | 84 |

Oscillator strengths for several hundred transitions in V IV have been calculated by Kurucz and Peytremann,[1] who used a scaled Thomas-Fermi-Dirac approach with limited configuration interaction. Of these lines we have chosen only the stronger lines, i.e., with log $gf > -1.0$, and have omitted intercombination (spin-forbidden) lines. An additional criterion for selecting the data was that all lines had to be experimentally observed, i.e., they appear in the line list of Iglesias.[2] In tabulating this material, we have used the most recent energy level data and term designations available.[3]

We estimate that for the stronger lines of this relatively simple spectrum, Kurucz and Peytremann's data should be fairly reliable. There is indirect support for this estimate from the good consistency between similarly calculated values and lifetime measurements for the isoelectronic ion Ti III.

## References


[1]R. L. Kurucz and E. Peytremann, Smithsonian Astrophysical Observatory Special Report 362 (1975).

[2]L. Iglesias, J. Res. Nat. Bur. Stand., Sect. A **72**, 295 (1968).

[3]J. Sugar and C. Corliss, J. Phys. Chem. Ref. Data **14**, Suppl. 2 (1985).


V IV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^2$–$3d4p$ | $^3$F - $^3$D° | | | | | | | | | | | |
| | | | 684.450 | 325.4 | 146429 | 7 | 5 | 7.7 | 0.038 | 0.61 | −0.57 | D | 1 |
| | | | 682.455 | 325.4 | 146855 | 7 | 7 | 6.5 | 0.045 | 0.71 | −0.50 | D | 1 |
| | | | 682.923 | 0.0 | 146429 | 5 | 5 | 6.9 | 0.048 | 0.54 | −0.62 | D | 1 |
| 2. | | $^3$F - $^3$F° | | | | | | | | | | | |
| | | | 677.345 | 734.7 | 148369 | 9 | 9 | 6.7 | 0.046 | 0.93 | −0.38 | D | 1 |
| | | | 680.632 | 734.7 | 147657 | 9 | 7 | 12 | 0.062 | 1.3 | −0.25 | D | 1 |
| | | | 681.145 | 325.4 | 147135 | 7 | 5 | 11 | 0.056 | 0.87 | −0.41 | D | 1 |
| 3. | | $^1$D - $^1$D° | 750.110 | 10959 | 144273 | 5 | 5 | 10 | 0.087 | 1.1 | −0.36 | D | 1 |
| 4. | | $^1$D - $^1$P° | 691.530 | 10959 | 155566 | 5 | 3 | 11 | 0.046 | 0.52 | −0.64 | D | 1 |

V IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 724.068 | 13458 | 151567 | 5 | 5 | 11 | 0.089 | 1.1 | −0.35 | D | 1 |
| | | | 724.809 | 13458 | 151427 | 5 | 3 | 5.6 | 0.026 | 0.31 | −0.88 | D | 1 |
| | | | 723.537 | 13239 | 151449 | 3 | 1 | 15 | 0.038 | 0.27 | −0.94 | D | 1 |
| | | | 722.912 | 13239 | 151567 | 3 | 5 | 3.1 | 0.040 | 0.29 | −0.92 | D | 1 |
| 6. | | $^1$G - $^1$F° | 737.854 | 18391 | 153919 | 9 | 7 | 24 | 0.15 | 3.3 | 0.13 | D | 1 |
| 7. | | $^1$S - $^1$P° | 884.146 | 42462 | 155566 | 1 | 3 | 4.7 | 0.17 | 0.48 | −0.78 | D | 1 |
| 8. | 3*d*4*s*-3*d*4*p* | $^3$D - $^3$D° | | | | | | | | | | | |
| | | | 1997.72 | 96798 | 146855 | 7 | 7 | 4.7 | 0.28 | 13 | 0.29 | D | 1 |
| | | | 1999.32 | 96412 | 146429 | 5 | 5 | 3.6 | 0.21 | 7.1 | 0.03 | D | 1 |
| | | | 2002.48 | 96196 | 146118 | 3 | 3 | 3.6 | 0.22 | 4.3 | −0.19 | D | 1 |
| | | | 2014.20 | 96798 | 146429 | 7 | 5 | 0.97 | 0.042 | 2.0 | −0.53 | D | 1 |
| | | | 2011.18 | 96412 | 146118 | 5 | 3 | 1.7 | 0.060 | 2.0 | −0.52 | D | 1 |
| | | | 1982.42 | 96412 | 146855 | 5 | 7 | 0.65 | 0.054 | 1.8 | −0.57 | D | 1 |
| 9. | | $^3$D - $^3$F° | | | | | | | | | | | |
| | | | 1939.07 | 96798 | 148369 | 7 | 9 | 5.8 | 0.42 | 19 | 0.47 | D | 1 |
| | | | 1951.43 | 96412 | 147657 | 5 | 7 | 5.0 | 0.40 | 13 | 0.30 | D | 1 |
| | | | 1963.10 | 96196 | 147135 | 3 | 5 | 4.8 | 0.46 | 8.9 | 0.14 | D | 1 |
| | | | 1966.24 | 96798 | 147657 | 7 | 7 | 0.69 | 0.040 | 1.8 | −0.55 | D | 1 |
| 10. | | $^3$D - $^3$P° | | | | | | | | | | | |
| | | | 1825.84 | 96798 | 151567 | 7 | 5 | 5.3 | 0.19 | 7.9 | 0.12 | D | 1 |
| | | | 1817.68 | 96412 | 151427 | 5 | 3 | 4.8 | 0.14 | 4.2 | −0.15 | D | 1 |
| | | | 1809.85 | 96196 | 151449 | 3 | 1 | 7.2 | 0.12 | 2.1 | −0.45 | D | 1 |
| | | | 1813.05 | 96412 | 151567 | 5 | 5 | 1.5 | 0.073 | 2.2 | −0.44 | D | 1 |
| | | | 1810.57 | 96196 | 151427 | 3 | 3 | 2.3 | 0.11 | 2.0 | −0.47 | D | 1 |
| 11. | | $^1$D - $^1$D° | 2268.30 | 100201 | 144273 | 5 | 5 | 3.2 | 0.25 | 9.2 | 0.09 | D | 1 |
| 12. | | $^1$D - $^1$F° | 1861.56 | 100201 | 153919 | 5 | 7 | 6.6 | 0.48 | 15 | 0.38 | D | 1 |
| 13. | | $^1$D - $^1$P° | 1806.18 | 100201 | 155566 | 5 | 3 | 7.3 | 0.21 | 6.4 | 0.03 | D | 1 |
| 14. | 3*d*4*p*-3*d*4*d* | $^1$D° - $^1$F | 1395.00 | 144273 | 215958 | 5 | 7 | 14 | 0.59 | 14 | 0.47 | D | 1 |
| 15. | | $^1$D° - $^1$P | 1356.53 | 144273 | 217991 | 5 | 3 | 4.9 | 0.081 | 1.8 | −0.39 | D | 1 |
| 16. | | $^1$D° - $^1$D | 1226.52 | 144273 | 225804 | 5 | 5 | 15 | 0.35 | 7.0 | 0.24 | D | 1 |
| 17. | | $^3$D° - $^3$D | | | | | | | | | | | |
| | | | 1418.53 | 146855 | 217350 | 7 | 7 | 5.2 | 0.16 | 5.1 | 0.04 | D | 1 |
| | | | 1414.84 | 146429 | 217108 | 5 | 5 | 4.6 | 0.14 | 3.2 | −0.16 | D | 1 |
| | | | 1412.69 | 146118 | 216905 | 3 | 3 | 11 | 0.32 | 4.4 | −0.02 | D | 1 |
| | | | 1423.42 | 146855 | 217108 | 7 | 5 | 3.1 | 0.067 | 2.2 | −0.33 | D | 1 |
| | | | 1418.92 | 146429 | 216905 | 5 | 3 | 3.8 | 0.069 | 1.6 | −0.46 | D | 1 |
| | | | 1408.64 | 146118 | 217108 | 3 | 5 | 1.7 | 0.082 | 1.1 | −0.61 | D | 1 |
| 18. | | $^3$D° - $^3$G | | | | | | | | | | | |
| | | | 1403.62 | 146855 | 218100 | 7 | 9 | 8.4 | 0.32 | 10 | 0.35 | D | 1 |
| | | | 1400.42 | 146429 | 217836 | 5 | 7 | 7.5 | 0.31 | 7.1 | 0.19 | D | 1 |

V IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19. | | $^3D^\circ - {}^3F$ | | | | | | | | | | | |
| | | | 1308.06 | 146855 | 223305 | 7 | 9 | 7.9 | 0.26 | 7.8 | 0.26 | D | 1 |
| | | | 1305.42 | 146429 | 223033 | 5 | 7 | 7.0 | 0.25 | 5.4 | 0.10 | D | 1 |
| | | | 1304.17 | 146118 | 222795 | 3 | 5 | 15 | 0.62 | 8.0 | 0.27 | D | 1 |
| | | | 1312.72 | 146855 | 223033 | 7 | 7 | 8.6 | 0.22 | 6.7 | 0.19 | D | 1 |
| | | | 1309.50 | 146429 | 222795 | 5 | 5 | 8.7 | 0.22 | 4.8 | 0.05 | D | 1 |
| 20. | | $^3D^\circ - {}^3P$ | | | | | | | | | | | |
| | | | 1250.92 | 146855 | 226796 | 7 | 5 | 3.3 | 0.056 | 1.6 | −0.41 | D | 1 |
| | | | 1247.07 | 146429 | 226617 | 5 | 3 | 4.7 | 0.066 | 1.4 | −0.48 | D | 1 |
| | | | 1243.72 | 146118 | 226522 | 3 | 1 | 9.4 | 0.073 | 0.90 | −0.66 | D | 1 |
| 21. | | $^3F^\circ - {}^3D$ | | | | | | | | | | | |
| | | | 1449.68 | 148369 | 217350 | 9 | 7 | 1.2 | 0.031 | 1.3 | −0.56 | D | 1 |
| | | | 1434.84 | 147657 | 217350 | 7 | 7 | 5.4 | 0.17 | 5.5 | 0.07 | D | 1 |
| | | | 1429.11 | 147135 | 217108 | 5 | 5 | 5.0 | 0.15 | 3.6 | −0.12 | D | 1 |
| | | | 1424.20 | 147135 | 217350 | 5 | 7 | 0.71 | 0.030 | 0.71 | −0.82 | D | 1 |
| 22. | | $^3F^\circ - {}^3G$ | | | | | | | | | | | |
| | | | 1426.65 | 148369 | 218464 | 9 | 11 | 22 | 0.82 | 35 | 0.87 | D | 1 |
| | | | 1419.58 | 147657 | 218100 | 7 | 9 | 13 | 0.50 | 16 | 0.54 | D | 1 |
| | | | 1414.41 | 147135 | 217836 | 5 | 7 | 12 | 0.51 | 12 | 0.41 | D | 1 |
| | | | 1434.09 | 148369 | 218100 | 9 | 9 | 1.2 | 0.038 | 1.6 | −0.47 | D | 1 |
| | | | 1424.92 | 147657 | 217836 | 7 | 7 | 1.2 | 0.037 | 1.2 | −0.59 | D | 1 |
| 23. | | $^3F^\circ - {}^3F$ | | | | | | | | | | | |
| | | | 1334.49 | 148369 | 223305 | 9 | 9 | 8.3 | 0.22 | 8.8 | 0.30 | D | 1 |
| | | | 1326.67 | 147657 | 223033 | 7 | 7 | 1.2 | 0.033 | 1.0 | −0.64 | D | 1 |
| | | | 1321.72 | 147135 | 222795 | 5 | 5 | 0.94 | 0.025 | 0.54 | −0.91 | D | 1 |
| | | | 1339.34 | 148369 | 223033 | 9 | 7 | 0.75 | 0.016 | 0.62 | −0.85 | D | 1 |
| | | | 1321.92 | 147657 | 223305 | 7 | 9 | 9.9 | 0.33 | 10 | 0.37 | D | 1 |
| | | | 1317.57 | 147135 | 223033 | 5 | 7 | 8.7 | 0.32 | 6.9 | 0.20 | D | 1 |
| 24. | | $^3P^\circ - {}^3D$ | | | | | | | | | | | |
| | | | 1520.14 | 151567 | 217350 | 5 | 7 | 7.2 | 0.35 | 8.7 | 0.24 | D | 1 |
| | | | 1522.49 | 151427 | 217108 | 3 | 5 | 5.5 | 0.32 | 4.8 | −0.02 | D | 1 |
| | | | 1527.72 | 151449 | 216905 | 1 | 3 | 3.5 | 0.36 | 1.8 | −0.44 | D | 1 |
| | | | 1525.76 | 151567 | 217108 | 5 | 5 | 0.93 | 0.032 | 0.81 | −0.79 | D | 1 |
| | | | 1527.22 | 151427 | 216905 | 3 | 3 | 2.2 | 0.076 | 1.2 | −0.64 | D | 1 |
| 25. | | $^3P^\circ - {}^3S$ | *1452.7* | *151507* | 220344 | 9 | 3 | 20 | 0.22 | 9.3 | 0.29 | D | 1 |
| | | | 1454.00 | 151567 | 220344 | 5 | 3 | 11 | 0.21 | 5.0 | 0.02 | D | 1 |
| | | | 1451.04 | 151427 | 220344 | 3 | 3 | 7.0 | 0.22 | 3.2 | −0.18 | D | 1 |
| | | | 1451.50 | 151449 | 220344 | 1 | 3 | 2.5 | 0.24 | 1.1 | −0.62 | D | 1 |
| 26. | | $^3P^\circ - {}^3P$ | *1329.8* | *151507* | *226706* | 9 | 9 | 18 | 0.48 | 19 | 0.64 | D | 1 |
| | | | 1329.29 | 151567 | 226796 | 5 | 5 | 15 | 0.40 | 8.7 | 0.30 | D | 1 |
| | | | 1329.97 | 151427 | 226617 | 3 | 3 | 4.8 | 0.13 | 1.7 | −0.42 | D | 1 |
| | | | 1332.46 | 151567 | 226617 | 5 | 3 | 7.5 | 0.12 | 2.6 | −0.22 | D | 1 |
| | | | 1331.67 | 151427 | 226522 | 3 | 1 | 17 | 0.15 | 2.0 | −0.34 | D | 1 |
| | | | 1326.81 | 151427 | 226796 | 3 | 5 | 4.0 | 0.17 | 2.3 | −0.28 | D | 1 |
| | | | 1330.36 | 151449 | 226617 | 1 | 3 | 6.0 | 0.48 | 2.1 | −0.32 | D | 1 |

V IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27. | | $^1F^\circ - ^1F$ | 1611.88 | 153919 | 215958 | 7 | 7 | 5.2 | 0.20 | 7.5 | 0.15 | D | 1 |
| 28. | | $^1F^\circ - ^1D$ | 1391.11 | 153919 | 225804 | 7 | 5 | 1.4 | 0.029 | 0.91 | −0.70 | D | 1 |
| 29. | | $^1F^\circ - ^1G$ | 1355.13 | 153919 | 227713 | 7 | 9 | 25 | 0.88 | 28 | 0.79 | D | 1 |
| 30. | | $^1P^\circ - ^1P$ | 1601.92 | 155566 | 217991 | 3 | 3 | 12 | 0.46 | 7.3 | 0.14 | D | 1 |
| 31. | | $^1P^\circ - ^1D$ | 1423.72 | 155566 | 225804 | 3 | 5 | 7.1 | 0.36 | 5.0 | 0.03 | D | 1 |
| 32. | | $^1P^\circ - ^1S$ | 1272.97 | 155566 | 234122 | 3 | 1 | 27 | 0.22 | 2.8 | −0.18 | D | 1 |
| 33. | $3d4p-3d5s$ | $^1D^\circ - ^1D$ | 1071.05 | 144273 | 237639 | 5 | 5 | 6.1 | 0.10 | 1.9 | −0.28 | D | 1 |
| 34. | | $^3D^\circ - ^3D$ | | | | | | | | | | | |
| | | | 1112.20 | 146855 | 236767 | 7 | 7 | 6.3 | 0.12 | 3.0 | −0.09 | D | 1 |
| | | | 1112.44 | 146429 | 236322 | 5 | 5 | 5.0 | 0.094 | 1.7 | −0.33 | D | 1 |
| | | | 1110.72 | 146118 | 236149 | 3 | 3 | 5.0 | 0.092 | 1.0 | −0.56 | D | 1 |
| 35. | | $^3F^\circ - ^3D$ | | | | | | | | | | | |
| | | | 1131.26 | 148369 | 236767 | 9 | 7 | 9.4 | 0.14 | 4.7 | 0.10 | D | 1 |
| | | | 1127.84 | 147657 | 236322 | 7 | 5 | 8.9 | 0.12 | 3.2 | −0.07 | D | 1 |
| 36. | | $^1F^\circ - ^1D$ | 1194.46 | 153919 | 237639 | 7 | 5 | 10 | 0.16 | 4.3 | 0.04 | D | 1 |
| 37. | $3d4d-3d4f$ | $^1F - ^1G^\circ$ | 2120.05 | 215958 | 263111 | 7 | 9 | 8.1 | 0.70 | 34 | 0.69 | D | 1 |
| 38. | | $^1F - ^1D^\circ$ | 2060.11 | 215958 | 264483 | 7 | 5 | 0.43 | 0.020 | 0.94 | −0.86 | D | 1 |
| 39. | | $^3D - ^3F^\circ$ | | | | | | | | | | | |
| | | | 2137.74 | 217350 | 264113 | 7 | 9 | 3.0 | 0.27 | 13 | 0.27 | D | 1 |
| | | | 2149.85 | 217108 | 263608 | 5 | 7 | 5.1 | 0.49 | 17 | 0.39 | D | 1 |
| | | | 2141.20 | 216905 | 263593 | 3 | 5 | 7.0 | 0.80 | 17 | 0.38 | D | 1 |
| 40. | | $^3D$ – ( )[a] | | | | | | | | | | | |
| | | | 2151.09 | 217350 | 263822 | 7 | 9 | 4.3 | 0.38 | 19 | 0.43 | D | 1 |
| 41. | | $^3D - ^3G^\circ$ | | | | | | | | | | | |
| | | | 2136.33 | 217108 | 263902 | 5 | 7 | 2.4 | 0.23 | 8.1 | 0.06 | D | 1 |
| 42. | | $^3D - ^3D^\circ$ | | | | | | | | | | | |
| | | | 2084.43 | 217108 | 265067 | 5 | 5 | 4.0 | 0.26 | 8.8 | 0.11 | D | 1 |
| 43. | | $^3G - ^3F^\circ$ | | | | | | | | | | | |
| | | | 2160.22 | 217836 | 264113 | 7 | 9 | 3.1 | 0.28 | 14 | 0.29 | D | 1 |
| 44. | | $^3G$ – ( )[a] | | | | | | | | | | | |
| | | | 2186.39 | 218100 | 263822 | 9 | 9 | 0.23 | 0.016 | 1.1 | −0.83 | D | 1 |
| | | | 2173.89 | 217836 | 263822 | 7 | 9 | 1.2 | 0.11 | 5.7 | −0.10 | D | 1 |
| 45. | | $^3G - ^3G^\circ$ | | | | | | | | | | | |
| | | | 2187.56 | 218464 | 264162 | 11 | 11 | 0.76 | 0.055 | 4.3 | −0.22 | D | 1 |
| | | | 2170.38 | 218100 | 264162 | 9 | 11 | 3.2 | 0.28 | 18 | 0.40 | D | 1 |

V IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46. | | $^3$G - $^3$H° | | | | | | | | | | | |
| | | | 2155.34 | 218464 | 264846 | 11 | 13 | 12 | 0.95 | 74 | 1.02 | D | 1 |
| | | | 2146.83 | 217836 | 264402 | 7 | 9 | 6.6 | 0.58 | 29 | 0.61 | D | 1 |
| | | | 2167.20 | 218464 | 264592 | 11 | 11 | 1.4 | 0.10 | 8.0 | 0.05 | D | 1 |
| | | | 2159.06 | 218100 | 264402 | 9 | 9 | 1.5 | 0.11 | 6.8 | −0.02 | D | 1 |
| 47. | | $^3$F - $^3$F° | | | | | | | | | | | |
| | | | 2449.72 | 223305 | 264113 | 9 | 9 | 2.0 | 0.18 | 13 | 0.20 | D | 1 |
| | | | 2463.80 | 223033 | 263608 | 7 | 7 | 0.51 | 0.046 | 2.6 | −0.49 | D | 1 |
| | | | 2450.33 | 222795 | 263593 | 5 | 5 | 2.2 | 0.20 | 7.9 | −0.01 | D | 1 |
| | | | 2433.53 | 223033 | 264113 | 7 | 9 | 1.6 | 0.18 | 10 | 0.11 | D | 1 |
| | | | 2449.40 | 222795 | 263608 | 5 | 7 | 3.2 | 0.40 | 16 | 0.30 | D | 1 |
| 48. | | $^3$F - ( )[a] | | | | | | | | | | | |
| | | | 2450.87 | 223033 | 263822 | 7 | 9 | 2.4 | 0.28 | 16 | 0.29 | D | 1 |
| | | | 2467.29 | 223305 | 263822 | 9 | 9 | 0.34 | 0.031 | 2.3 | −0.55 | D | 1 |
| 49. | | $^3$F - $^3$G° | | | | | | | | | | | |
| | | | 2446.80 | 223305 | 264162 | 9 | 11 | 5.3 | 0.58 | 42 | 0.72 | D | 1 |
| | | | 2431.89 | 222795 | 263902 | 5 | 7 | 3.2 | 0.40 | 16 | 0.30 | D | 1 |
| | | | 2446.07 | 223033 | 263902 | 7 | 7 | 2.0 | 0.18 | 10 | 0.10 | D | 1 |
| 50. | | $^3$F - $^3$H° | | | | | | | | | | | |
| | | | 2421.32 | 223305 | 264592 | 9 | 11 | 1.6 | 0.18 | 13 | 0.20 | D | 1 |
| | | | 2416.55 | 223033 | 264402 | 7 | 9 | 1.8 | 0.20 | 11 | 0.14 | D | 1 |
| | | | 2432.52 | 223305 | 264402 | 9 | 9 | 0.32 | 0.029 | 2.1 | −0.59 | D | 1 |
| 51. | | $^3$F - $^3$D° | | | | | | | | | | | |
| | | | 2378.29 | 223033 | 265067 | 7 | 5 | 0.41 | 0.025 | 1.4 | −0.76 | D | 1 |
| 52. | | $^1$D - $^1$D° | 2584.64 | 225804 | 264483 | 5 | 5 | 2.6 | 0.26 | 11 | 0.11 | D | 1 |
| 53. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 2599.98 | 226617 | 265067 | 3 | 5 | 3.4 | 0.57 | 15 | 0.23 | D | 1 |
| | | | 2596.76 | 226522 | 265020 | 1 | 3 | 2.7 | 0.83 | 7.1 | −0.08 | D | 1 |
| | | | 2603.21 | 226617 | 265020 | 3 | 3 | 1.2 | 0.12 | 3.1 | −0.44 | D | 1 |
| 54. | | $^1$G - $^1$G° | 2824.13 | 227713 | 263111 | 9 | 9 | 0.64 | 0.077 | 6.4 | −0.16 | D | 1 |
| 55. | | $^1$G - $^1$H° | 2570.72 | 227713 | 266600 | 9 | 11 | 7.6 | 0.92 | 70 | 0.92 | D | 1 |
| 56. | 3*d*4*d*–3*d*5*p* | $^1$F - $^1$D° | 2595.86 | 215958 | 254469 | 7 | 5 | 2.0 | 0.14 | 8.5 | −0.00 | D | 1 |
| 57. | | $^1$F - $^1$F° | 2395.45 | 215958 | 257691 | 7 | 7 | 0.76 | 0.065 | 3.6 | −0.34 | D | 1 |
| 58. | | $^3$D - $^3$D° | | | | | | | | | | | |
| | | | 2624.21 | 217350 | 255446 | 7 | 7 | 1.1 | 0.12 | 7.0 | −0.09 | D | 1 |
| | | | 2628.09 | 217108 | 255147 | 5 | 5 | 0.86 | 0.089 | 3.9 | −0.35 | D | 1 |
| | | | 2636.40 | 216905 | 254824 | 3 | 3 | 1.0 | 0.11 | 2.7 | −0.50 | D | 1 |
| | | | 2644.95 | 217350 | 255147 | 7 | 5 | 0.27 | 0.020 | 1.2 | −0.85 | D | 1 |
| | | | 2650.61 | 217108 | 254824 | 5 | 3 | 0.36 | 0.023 | 1.0 | −0.94 | D | 1 |

V IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59. | | $^3$D - $^3$P° | | | | | | | | | | | |
| | | | 2512.24 | 217350 | 257143 | 7 | 5 | 1.2 | 0.080 | 4.7 | −0.25 | D | 1 |
| | | | 2519.80 | 217108 | 256782 | 5 | 3 | 1.1 | 0.063 | 2.6 | −0.50 | D | 1 |
| | | | 2509.61 | 216905 | 256740 | 3 | 1 | 1.4 | 0.043 | 1.1 | −0.89 | D | 1 |
| | | | 2506.97 | 216905 | 256782 | 3 | 3 | 0.36 | 0.034 | 0.84 | −0.99 | D | 1 |
| 60. | | $^3$G - $^3$F° | | | | | | | | | | | |
| | | | 2645.54 | 218464 | 256252 | 11 | 9 | 2.8 | 0.24 | 23 | 0.42 | D | 1 |
| | | | 2655.41 | 218100 | 255748 | 9 | 7 | 2.7 | 0.22 | 17 | 0.30 | D | 1 |
| | | | 2656.87 | 217836 | 255463 | 7 | 5 | 2.5 | 0.19 | 12 | 0.13 | D | 1 |
| | | | 2620.32 | 218100 | 256252 | 9 | 9 | 0.13 | 0.013 | 1.0 | −0.93 | D | 1 |
| | | | 2636.94 | 217836 | 255748 | 7 | 7 | 0.16 | 0.016 | 1.0 | −0.94 | D | 1 |
| 61. | | $^1$P - $^1$D° | 2740.55 | 217991 | 254469 | 3 | 5 | 0.22 | 0.041 | 1.1 | −0.91 | D | 1 |
| 62. | | $^1$P - $^1$P° | 2480.74 | 217991 | 258289 | 3 | 3 | 1.7 | 0.16 | 3.8 | −0.33 | D | 1 |
| 63. | | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | 2716.59 | 220344 | 257143 | 3 | 5 | 0.69 | 0.13 | 3.4 | −0.42 | D | 1 |
| | | | 2743.52 | 220344 | 256782 | 3 | 3 | 0.69 | 0.078 | 2.1 | −0.63 | D | 1 |
| 64. | | $^3$F - $^3$D° | | | | | | | | | | | |
| | | | 3110.42 | 223305 | 255446 | 9 | 7 | 1.6 | 0.18 | 17 | 0.21 | D | 1 |
| | | | 3113.02 | 223033 | 255147 | 7 | 5 | 1.4 | 0.15 | 11 | 0.02 | D | 1 |
| | | | 3121.30 | 222795 | 254824 | 5 | 3 | 1.7 | 0.14 | 7.4 | −0.14 | D | 1 |
| 65. | | $^3$F - $^3$F° | | | | | | | | | | | |
| | | | 3034.27 | 223305 | 256252 | 9 | 9 | 0.61 | 0.084 | 7.6 | −0.12 | D | 1 |
| | | | 3055.86 | 223033 | 255748 | 7 | 7 | 0.59 | 0.082 | 5.8 | −0.24 | D | 1 |
| | | | 3060.15 | 222795 | 255463 | 5 | 5 | 0.57 | 0.080 | 4.0 | −0.40 | D | 1 |
| 66. | | $^1$D - $^1$D° | 3487.63 | 225804 | 254469 | 5 | 5 | 0.69 | 0.13 | 7.2 | −0.20 | D | 1 |
| 67. | | $^1$D - $^1$P° | 3077.48 | 225804 | 258289 | 5 | 3 | 0.91 | 0.078 | 3.9 | −0.41 | D | 1 |
| 68. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 3489.51 | 226796 | 255446 | 5 | 7 | 0.21 | 0.053 | 3.0 | −0.58 | D | 1 |
| | | | 3504.10 | 226617 | 255147 | 3 | 5 | 0.15 | 0.046 | 1.6 | −0.86 | D | 1 |
| 69. | | $^3$P - $^3$P° | *3302.4* | *226706* | *256978* | 9 | 9 | 1.2 | 0.19 | 19 | 0.24 | D | 1 |
| | | | 3294.26 | 226796 | 257143 | 5 | 5 | 0.93 | 0.15 | 8.2 | −0.12 | D | 1 |
| | | | 3314.18 | 226617 | 256782 | 3 | 3 | 0.29 | 0.047 | 1.5 | −0.85 | D | 1 |
| | | | 3333.99 | 226796 | 256782 | 5 | 3 | 0.39 | 0.039 | 2.1 | −0.71 | D | 1 |
| | | | 3318.79 | 226617 | 256740 | 3 | 1 | 1.2 | 0.064 | 2.1 | −0.72 | D | 1 |
| | | | 3274.93 | 226617 | 257143 | 3 | 5 | 0.33 | 0.090 | 2.9 | −0.57 | D | 1 |
| | | | 3303.72 | 226522 | 256782 | 1 | 3 | 0.39 | 0.19 | 2.1 | −0.72 | D | 1 |
| 70. | | $^1$G - $^1$F° | 3334.79 | 227713 | 257691 | 9 | 7 | 2.1 | 0.27 | 27 | 0.39 | D | 1 |
| 71. | | $^1$S - $^1$P° | 4136.72 | 234122 | 258289 | 1 | 3 | 0.36 | 0.28 | 3.8 | −0.56 | D | 1 |
| 72. | $3d4f-3d5d$ | $^1$G° - $^1$F | 4913.08 | 263111 | 283459 | 9 | 7 | 0.42 | 0.12 | 17 | 0.03 | D | 1 |

V IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73. | | $^3F^\circ - ^3D$ | | | | | | | | | | | |
| | | | 4970.35 | 264113 | 284227 | 9 | 7 | 0.25 | 0.072 | 11 | −0.19 | D | 1 |
| | | | 4916.94 | 263608 | 283940 | 7 | 5 | 0.31 | 0.080 | 9.1 | −0.25 | D | 1 |
| 74. | | $^3F^\circ - ^3F$ | | | | | | | | | | | |
| | | | 4508.67 | 264113 | 286287 | 9 | 9 | 0.13 | 0.039 | 5.1 | −0.46 | D | 1 |
| | | | 4505.17 | 263608 | 285799 | 7 | 5 | 0.26 | 0.056 | 5.8 | −0.41 | D | 1 |
| 75. | | $(\ ^\circ)^a - ^3D$ | | | | | | | | | | | |
| | | | 4899.56 | 263822 | 284227 | 9 | 7 | 0.15 | 0.042 | 6.1 | −0.42 | D | 1 |
| 76. | | $^3G^\circ - ^3G$ | | | | | | | | | | | |
| | | | 4954.41 | 264162 | 284340 | 11 | 9 | 0.19 | 0.056 | 10 | −0.21 | D | 1 |
| 77. | | $^3G^\circ - ^3F$ | | | | | | | | | | | |
| | | | 4518.58 | 264162 | 286287 | 11 | 9 | 0.40 | 0.10 | 16 | 0.04 | D | 1 |
| | | | 4565.63 | 263902 | 285799 | 7 | 5 | 0.31 | 0.068 | 7.2 | −0.32 | D | 1 |
| 78. | | $^3H^\circ - ^3G$ | | | | | | | | | | | |
| | | | 5035.46 | 264846 | 284699 | 13 | 11 | 0.54 | 0.17 | 37 | 0.35 | D | 1 |
| | | | 5074.90 | 264402 | 284101 | 9 | 7 | 0.27 | 0.082 | 12 | −0.13 | D | 1 |
| | | | 4971.94 | 264592 | 284699 | 11 | 11 | 0.059 | 0.022 | 3.9 | −0.62 | D | 1 |
| 79. | | $^3H^\circ - ^3F$ | | | | | | | | | | | |
| | | | 4608.15 | 264592 | 286287 | 11 | 9 | 0.14 | 0.037 | 6.2 | −0.39 | D | 1 |
| | | | 4616.57 | 264402 | 286057 | 9 | 7 | 0.17 | 0.041 | 5.6 | −0.43 | D | 1 |
| 80. | | $^1H^\circ - ^1G$ | 4643.99 | 266600 | 288128 | 11 | 9 | 0.65 | 0.17 | 29 | 0.28 | D | 1 |
| 81. | $3d5s$–$3d5p$ | $^3D - ^3D^\circ$ | | | | | | | | | | | |
| | | | 5352.32 | 236767 | 255446 | 7 | 7 | 0.84 | 0.36 | 44 | 0.40 | D | 1 |
| | | | 5310.77 | 236322 | 255147 | 5 | 5 | 0.38 | 0.16 | 14 | −0.10 | D | 1 |
| | | | 5353.09 | 236149 | 254824 | 3 | 3 | 0.74 | 0.32 | 17 | −0.02 | D | 1 |
| | | | 5262.16 | 236149 | 255147 | 3 | 5 | 0.47 | 0.33 | 17 | −0.01 | D | 1 |
| 82. | | $^3D - ^3F^\circ$ | | | | | | | | | | | |
| | | | 5130.78 | 236767 | 256252 | 7 | 9 | 1.2 | 0.60 | 70 | 0.62 | D | 1 |
| | | | 5146.50 | 236322 | 255748 | 5 | 7 | 0.92 | 0.51 | 44 | 0.41 | D | 1 |
| | | | 5175.95 | 236149 | 255463 | 3 | 5 | 0.61 | 0.41 | 21 | 0.09 | D | 1 |
| | | | 5267.05 | 236767 | 255748 | 7 | 7 | 0.20 | 0.084 | 10 | −0.23 | D | 1 |
| | | | 5222.93 | 236322 | 255463 | 5 | 5 | 0.30 | 0.12 | 11 | −0.21 | D | 1 |
| 83. | | $^3D - ^3P^\circ$ | | | | | | | | | | | |
| | | | 4906.28 | 236767 | 257143 | 7 | 5 | 1.1 | 0.29 | 32 | 0.30 | D | 1 |
| | | | 4886.36 | 236322 | 256782 | 5 | 3 | 0.93 | 0.20 | 16 | 0.00 | D | 1 |
| | | | 4855.05 | 236149 | 256740 | 3 | 1 | 1.4 | 0.16 | 7.7 | −0.32 | D | 1 |
| | | | 4801.54 | 236322 | 257143 | 5 | 5 | 0.21 | 0.073 | 5.7 | −0.44 | D | 1 |
| | | | 4845.21 | 236149 | 256782 | 3 | 3 | 0.36 | 0.13 | 6.1 | −0.42 | D | 1 |
| 84. | | $^1D - ^1D^\circ$ | 5940.12 | 237639 | 254469 | 5 | 5 | 0.59 | 0.31 | 30 | 0.19 | D | 1 |

V IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 85. | | $^1$D - $^1$F° | 4985.65 | 237639 | 257691 | 5 | 7 | 1.3 | 0.66 | 54 | 0.52 | D | 1 |
| 86. | | $^1$D - $^1$P° | 4841.26 | 237639 | 258289 | 5 | 3 | 1.3 | 0.28 | 23 | 0.15 | D | 1 |
| 87. | $3d5p$–$3d5d$ | $^1$D° - $^1$F | 3448.41 | 254469 | 283459 | 5 | 7 | 3.0 | 0.76 | 43 | 0.58 | D | 1 |
| 88. | | $^1$D° - $^1$D | 3052.35 | 254469 | 287221 | 5 | 5 | 2.3 | 0.32 | 16 | 0.21 | D | 1 |
| 89. | | $^3$D° - $^3$D | | | | | | | | | | | |
| | | | 3473.46 | 255446 | 284227 | 7 | 7 | 1.9 | 0.33 | 27 | 0.37 | D | 1 |
| | | | 3471.99 | 255147 | 283940 | 5 | 5 | 1.8 | 0.32 | 18 | 0.20 | D | 1 |
| | | | 3459.40 | 254824 | 283723 | 3 | 3 | 2.0 | 0.37 | 12 | 0.04 | D | 1 |
| | | | 3433.52 | 254824 | 283940 | 3 | 5 | 0.57 | 0.17 | 5.7 | −0.30 | D | 1 |
| 90. | | $^3$D° - $^3$G | | | | | | | | | | | |
| | | | 3452.74 | 255147 | 284101 | 5 | 7 | 0.88 | 0.22 | 12 | 0.04 | D | 1 |
| 91. | | $^3$D° - $^3$F | | | | | | | | | | | |
| | | | 3241.46 | 255446 | 286287 | 7 | 9 | 3.7 | 0.75 | 56 | 0.72 | D | 1 |
| | | | 3234.25 | 255147 | 286057 | 5 | 7 | 2.9 | 0.63 | 34 | 0.50 | D | 1 |
| | | | 3227.51 | 254824 | 285799 | 3 | 5 | 2.9 | 0.76 | 24 | 0.36 | D | 1 |
| 92. | | $^3$D° - $^3$P | | | | | | | | | | | |
| | | | 3096.23 | 255446 | 287733 | 7 | 5 | 0.94 | 0.097 | 6.9 | −0.17 | D | 1 |
| | | | 3067.85 | 255147 | 287733 | 5 | 5 | 0.26 | 0.037 | 1.9 | −0.73 | D | 1 |
| 93. | | $^3$F° - $^3$D | | | | | | | | | | | |
| | | | 3545.98 | 255748 | 283940 | 7 | 5 | 0.31 | 0.041 | 3.4 | −0.54 | D | 1 |
| 94. | | $^3$F° - $^3$G | | | | | | | | | | | |
| | | | 3514.25 | 256252 | 284699 | 9 | 11 | 4.7 | 1.1 | 110 | 0.98 | D | 1 |
| | | | 3496.42 | 255748 | 284340 | 7 | 9 | 4.4 | 1.0 | 83 | 0.86 | D | 1 |
| | | | 3490.91 | 255463 | 284101 | 5 | 7 | 3.2 | 0.81 | 47 | 0.61 | D | 1 |
| | | | 3525.89 | 255748 | 284101 | 7 | 7 | 0.19 | 0.036 | 2.9 | −0.60 | D | 1 |
| 95. | | $^3$F° - $^3$F | | | | | | | | | | | |
| | | | 3328.53 | 256252 | 286287 | 9 | 9 | 1.7 | 0.29 | 28 | 0.41 | D | 1 |
| | | | 3298.37 | 255748 | 286057 | 7 | 7 | 1.7 | 0.28 | 21 | 0.29 | D | 1 |
| | | | 3295.50 | 255463 | 285799 | 5 | 5 | 1.5 | 0.25 | 13 | 0.09 | D | 1 |
| 96. | | $^3$P° - $^3$D | | | | | | | | | | | |
| | | | 3691.24 | 257143 | 284227 | 5 | 7 | 1.3 | 0.37 | 23 | 0.27 | D | 1 |
| | | | 3681.04 | 256782 | 283940 | 3 | 5 | 1.2 | 0.41 | 15 | 0.09 | D | 1 |
| 97. | | $^3$P° - $^3$S | *3529.9* | *256978* | 285299 | 9 | 3 | 4.1 | 0.26 | 27 | 0.37 | D | 1 |
| | | | 3550.72 | 257143 | 285299 | 5 | 3 | 2.1 | 0.24 | 14 | 0.08 | D | 1 |
| | | | 3505.70 | 256782 | 285299 | 3 | 3 | 1.5 | 0.27 | 9.4 | −0.09 | D | 1 |
| | | | 3500.57 | 256740 | 285299 | 1 | 3 | 0.57 | 0.32 | 3.6 | −0.50 | D | 1 |
| 98. | | $^3$P° - $^3$P | | | | | | | | | | | |
| | | | 3268.08 | 257143 | 287733 | 5 | 5 | 2.7 | 0.44 | 24 | 0.34 | D | 1 |

V IV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99. | | $^1F^o - ^1D$ | 3385.34 | 257691 | 287221 | 7 | 5 | 0.22 | 0.027 | 2.1 | −0.72 | D | 1 |
| 100. | | $^1F^o - ^1G$ | 3284.56 | 257691 | 288128 | 7 | 9 | 5.3 | 1.1 | 84 | 0.89 | D | 1 |
| 101. | | $^1P^o - ^1P$ | 3833.74 | 258289 | 284366 | 3 | 3 | 2.4 | 0.53 | 20 | 0.20 | D | 1 |
| 102. | | $^1P^o - ^1D$ | 3455.33 | 258289 | 287221 | 3 | 5 | 1.1 | 0.33 | 11 | 0.00 | D | 1 |
| 103. | $3d5p-3d6s$ | $^1D^o - ^1D$ | 2610.32 | 254469 | 292767 | 5 | 5 | 0.89 | 0.091 | 3.9 | −0.34 | D | 1 |
| 104. | | $^3D^o - ^3D$ | | | | | | | | | | | |
| | | | 2718.72 | 255147 | 291918 | 5 | 5 | 0.51 | 0.056 | 2.5 | −0.55 | D | 1 |
| | | | 2740.97 | 255446 | 291918 | 7 | 5 | 0.57 | 0.046 | 2.9 | −0.49 | D | 1 |
| | | | 2727.78 | 255147 | 291796 | 5 | 3 | 1.6 | 0.10 | 4.7 | −0.28 | D | 1 |
| 105. | | $^3F^o - ^3D$ | | | | | | | | | | | |
| | | | 2764.22 | 256252 | 292418 | 9 | 7 | 2.7 | 0.24 | 19 | 0.33 | D | 1 |
| | | | 2763.86 | 255748 | 291918 | 7 | 5 | 2.2 | 0.18 | 11 | 0.10 | D | 1 |
| | | | 2751.53 | 255463 | 291796 | 5 | 3 | 1.9 | 0.13 | 6.0 | −0.18 | D | 1 |
| 106. | | $^3P^o - ^3D$ | | | | | | | | | | | |
| | | | 2834.09 | 257143 | 292418 | 5 | 7 | 1.2 | 0.21 | 9.8 | 0.02 | D | 1 |
| 107. | | $^1F^o - ^1D$ | 2850.16 | 257691 | 292767 | 7 | 5 | 2.7 | 0.23 | 15 | 0.21 | D | 1 |
| 108. | | $^1P^o - ^1D$ | 2899.58 | 258289 | 292767 | 3 | 5 | 1.2 | 0.25 | 7.2 | −0.12 | D | 1 |

[a]The $LS$-coupling designation of the term in question was not provided in the NBS energy level compilation,[3] so we have accordingly omitted it from this work.

# V IV

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 998.00 | 12 | 1152.8 | 16 | 1731.9 | 20 | 7857.3 | 3 |
| 1001.2 | 12 | 1165.0 | 13 | 1853.6 | 19 | 9122.2 | 2 |
| 1005.4 | 12 | 1170.2 | 13 | 2354.3 | 5 | 9401.3 | 2 |
| 1033.1 | 11 | 1173.2 | 13 | 3173.4 | 8 | 9777.7 | 2 |
| 1036.6 | 11 | 1196.8 | 15 | 3421.0 | 10 | 13452 | 7 |
| 1037.2 | 11 | 1199.9 | 15 | 3446.8 | 10 | 40005 | 6 |
| 1039.5 | 11 | 1200.6 | 15 | 5435.9 | 4 | 43850 | 6 |
| 1040.7 | 11 | 1202.3 | 15 | 5533.8 | 4 | 244300 | 1 |
| 1041.0 | 11 | 1205.4 | 15 | 5662.1 | 4 | 307200 | 1 |
| 1043.1 | 11 | 1205.5 | 15 | 7428.3 | 3 | 456300 | 9 |
| 1045.2 | 11 | 1208.6 | 15 | 7551.2 | 3 | 858900 | 9 |
| 1120.6 | 14 | 1222.4 | 18 | 7612.4 | 3 | | |
| 1148.4 | 16 | 1275.4 | 17 | 7618.2 | 3 | | |
| 1149.9 | 16 | 1281.7 | 17 | 7741.5 | 3 | | |

For this ion, we selected the work of Warner and Kirkpatrick,[1] who used a single-configuration approximation and calculated radial integrals with scaled Thomas-Fermi wavefunctions. We have tabulated M1 and E2 transition probabilities for 23 lines within the $3d^2$ (ground) configuration and E2 data for 30 lines in the $3d^2$–$3d4s$ transition array. For long-wavelength lines within the $3d^2\ ^3F$ and $3d^2\ ^3P$ terms, we have recalculated Warner and Kirkpatrick's $A$-values by using observed energy-level data instead of theoretically derived values.

## Reference

[1]B. Warner and R. C. Kirkpatrick, Mon. Not. R. Astron. Soc. **144**, 397 (1969).

V IV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^2$–$3d^2$ | $^3F - ^3F$ | | | | | | | | | | |
| | | | [244300] | 325.4 | 734.7 | 7 | 9 | M1 | 0.0014 | 6.9 | C | 1*n* |
| | | | [307200] | 0.0 | 325.4 | 5 | 7 | M1 | 9.6(−4)[a] | 7.2 | C | 1*n* |
| 2. | | $^3F - ^1D$ (1F) | | | | | | | | | | |
| | | | [9777.7] | 734.7 | 10959 | 9 | 5 | E2 | 1.6(−4) | 0.043 | E | 1 |
| | | | [9401.3] | 325.4 | 10959 | 7 | 5 | M1 | 0.035 | 0.0054 | E | 1 |
| | | | " | " | " | 7 | 5 | E2 | 3.6(−5) | 0.0079 | E | 1 |
| | | | [9122.2] | 0.0 | 10959 | 5 | 5 | M1 | 0.019 | 0.0027 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 2.4(−5) | 0.0045 | E | 1 |
| 3. | | $^3F - ^3P$ (2F) | | | | | | | | | | |
| | | | [7857.3] | 734.7 | 13458 | 9 | 5 | E2 | 0.027 | 3.4 | E | 1 |
| | | | [7741.5] | 325.4 | 13239 | 7 | 3 | E2 | 0.026 | 1.3 | E | 1 |
| | | | [7618.2] | 0.0 | 13123 | 5 | 1 | E2 | 0.042 | 0.64 | E | 1 |
| | | | [7612.4] | 325.4 | 13458 | 7 | 5 | M1 | 6.7(−4) | 5.5(−5) | E | 1 |
| | | | " | " | " | 7 | 5 | E2 | 0.0082 | 0.62 | E | 1 |
| | | | [7551.2] | 0.0 | 13239 | 5 | 3 | M1 | 2.1(−5) | 1.0(−6) | E | 1 |
| | | | " | " | " | 5 | 3 | E2 | 0.014 | 0.61 | E | 1 |
| | | | [7428.3] | 0.0 | 13458 | 5 | 5 | M1 | 1.6(−4) | 1.2(−5) | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.0013 | 0.088 | E | 1 |
| 4. | | $^3F - ^1G$ (3F) | | | | | | | | | | |
| | | | [5662.1] | 734.7 | 18391 | 9 | 9 | M1 | 0.025 | 0.0015 | E | 1 |
| | | | " | " | " | 9 | 9 | E2 | 1.9(−5) | 5.9(−4) | E | 1 |
| | | | [5533.8] | 325.4 | 18391 | 7 | 9 | M1 | 0.016 | 9.0(−4) | E | 1 |
| | | | [5435.9] | 0.0 | 18391 | 5 | 9 | E2 | 3.9(−5) | 9.9(−4) | E | 1 |
| 5. | | $^3F - ^1S$ | | | | | | | | | | |
| | | | [2354.3] | 0.0 | 42462 | 5 | 1 | E2 | 0.012 | 5.2(−4) | E | 1 |
| 6. | | $^1D - ^3P$ | | | | | | | | | | |
| | | | [40005] | 10959 | 13458 | 5 | 5 | M1 | 0.0093 | 0.11 | E | 1 |
| | | | [43850] | 10959 | 13239 | 5 | 3 | M1 | 0.0040 | 0.038 | E | 1 |
| 7. | | $^1D - ^1G$ | [13452] | 10959 | 18391 | 5 | 9 | E2 | 4.8(−4) | 1.1 | E | 1 |
| 8. | | $^1D - ^1S$ | [3173.4] | 10959 | 42462 | 5 | 1 | E2 | 8.1 | 1.6 | E | 1 |
| 9. | | $^3P - ^3P$ | | | | | | | | | | |
| | | | [456300] | 13239 | 13458 | 3 | 5 | M1 | 1.05(−4) | 1.85 | C | 1*n* |
| | | | [858900] | 13123 | 13239 | 1 | 3 | M1 | 3.26(−5) | 2.30 | C | 1*n* |

V IV: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | | $^3P - ^1S$ | | | | | | | | | | |
| | | | [3446.8] | 13458 | 42462 | 5 | 1 | E2 | 0.096 | 0.028 | E | 1 |
| | | | [3421.0] | 13239 | 42462 | 3 | 1 | M1 | 0.39 | 5.8(−4) | E | 1 |
| 11. | $3d^2$-$3d4s$ | $^3F - ^3D$ | | | | | | | | | | |
| | | | [1045.2] | 734.7 | 96412 | 9 | 5 | E2 | 370 | 1.4 | E | 1 |
| | | | [1043.1] | 325.4 | 96196 | 7 | 3 | E2 | 580 | 1.3 | E | 1 |
| | | | [1041.0] | 734.7 | 96798 | 9 | 7 | E2 | 1400 | 7.1 | E | 1 |
| | | | [1040.7] | 325.4 | 96412 | 7 | 5 | E2 | 880 | 3.2 | E | 1 |
| | | | [1039.5] | 0.0 | 96196 | 5 | 3 | E2 | 1200 | 2.6 | E | 1 |
| | | | [1036.6] | 325.4 | 96798 | 7 | 7 | E2 | 390 | 1.9 | E | 1 |
| | | | [1037.2] | 0.0 | 96412 | 5 | 5 | E2 | 510 | 1.8 | E | 1 |
| | | | [1033.1] | 0.0 | 96798 | 5 | 7 | E2 | 37 | 0.18 | E | 1 |
| 12. | | $^3F - ^1D$ | | | | | | | | | | |
| | | | [1005.4] | 734.7 | 100201 | 9 | 5 | E2 | 1.1 | 0.0034 | E | 1 |
| | | | [1001.2] | 325.4 | 100201 | 7 | 5 | E2 | 6.5 | 0.019 | E | 1 |
| | | | [998.00] | 0.0 | 100201 | 5 | 5 | E2 | 0.68 | 0.0020 | E | 1 |
| 13. | | $^1D - ^3D$ | | | | | | | | | | |
| | | | [1165.0] | 10959 | 96798 | 5 | 7 | E2 | 4.9 | 0.044 | E | 1 |
| | | | [1170.2] | 10959 | 96412 | 5 | 5 | E2 | 12 | 0.078 | E | 1 |
| | | | [1173.2] | 10959 | 96196 | 5 | 3 | E2 | 3.9 | 0.015 | E | 1 |
| 14. | | $^1D - ^1D$ | [1120.6] | 10959 | 100201 | 5 | 5 | E2 | 850 | 4.5 | E | 1 |
| 15. | | $^3P - ^3D$ | | | | | | | | | | |
| | | | [1196.8] | 13239 | 96798 | 3 | 7 | E2 | 130 | 1.3 | E | 1 |
| | | | [1200.6] | 13123 | 96412 | 1 | 5 | E2 | 120 | 0.89 | E | 1 |
| | | | [1199.9] | 13458 | 96798 | 5 | 7 | E2 | 240 | 2.5 | E | 1 |
| | | | [1202.3] | 13239 | 96412 | 3 | 5 | E2 | 31 | 0.23 | E | 1 |
| | | | [1205.5] | 13458 | 96412 | 5 | 5 | E2 | 200 | 1.5 | E | 1 |
| | | | [1205.4] | 13239 | 96196 | 3 | 3 | E2 | 270 | 1.2 | E | 1 |
| | | | [1208.6] | 13458 | 96196 | 5 | 3 | E2 | 87 | 0.40 | E | 1 |
| 16. | | $^3P - ^1D$ | | | | | | | | | | |
| | | | [1152.8] | 13458 | 100201 | 5 | 5 | E2 | 21 | 0.13 | E | 1 |
| | | | [1149.9] | 13239 | 100201 | 3 | 5 | E2 | 0.23 | 0.0014 | E | 1 |
| | | | [1148.4] | 13123 | 100201 | 1 | 5 | E2 | 0.58 | 0.0034 | E | 1 |
| 17. | | $^1G - ^3D$ | | | | | | | | | | |
| | | | [1281.7] | 18391 | 96412 | 9 | 5 | E2 | 4.3 | 0.044 | E | 1 |
| | | | [1275.4] | 18391 | 96798 | 9 | 7 | E2 | 0.065 | 9.1(−4) | E | 1 |
| 18. | | $^1G - ^1D$ | [1222.4] | 18391 | 100201 | 9 | 5 | E2 | 1000 | 8.1 | E | 1 |
| 19. | | $^1S - ^3D$ | | | | | | | | | | |
| | | | [1853.6] | 42462 | 96412 | 1 | 5 | E2 | 0.053 | 0.0035 | E | 1 |
| 20. | | $^1S - ^1D$ | [1731.9] | 42462 | 100201 | 1 | 5 | E2 | 20 | 0.93 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

few cases the *LS* designations given in Ref. 2 differed from those of Huang *et al*. The level designations used in this compilation are in accord with the theoretical results of Refs. 1 and 2 for Fe X. Percentage compositions published by Bromage[3] for the levels of the $3p^43d$ configuration in V VII and Ni XII indicate that the designations for the iron ion are appropriate for the neighboring ions of the chlorine isoelectronic sequence. Transitions involving highly mixed levels have been excluded, as have the very weak transitions.

The calculated wavelengths of Huang *et al*. differ appreciably from the observed ones found in the literature. Thus the available experimentally determined wavelengths were used in making the conversion from line strengths to *f*- and *A*-values. (Otherwise, the calculated wavelengths of Huang *et al*. were used, but they provide only a rough idea of the spectral-line positions.) Bromage *et al*. indicate that it was necessary to scale down some configuration-interaction parameters by a greater amount than usual in order to fit their calculated energy levels for Fe X to the experimental data. This could be an indication that neglecting to take configuration interaction into account on a larger scale yields significant errors in the energy levels and/or *f*-values.

## References


[1]K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables **28**, 355 (1983).

[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Phys. Scr. **15**, 177 (1977).

[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).


V VII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^5–3s3p^6$ | $^2P^\circ – ^2S$ | *461.67* | *2556* | 219162 | 6 | 2 | 33.3 | 0.0354 | 0.323 | −0.67 | C− | 1 |
| | | | 456.284 | 0 | 219162 | 4 | 2 | 22.9 | 0.0358 | 0.215 | −0.84 | C− | 1 |
| | | | 472.828 | 7669 | 219162 | 2 | 2 | 10.4 | 0.0347 | 0.108 | −1.159 | C− | 1 |
| 2. | $3p^5–3p^4(^3P)3d$ | $^2P^\circ – ^4F$ | | | | | | | | | | | |
| | | | [297] | | | 2 | 4 | 0.070 | 1.8(−4)[a] | 3.6(−4) | −3.43 | E | 1 |
| 3. | | $^2P^\circ – ^4P$ | | | | | | | | | | | |
| | | | [290] | | | 2 | 4 | 0.50 | 0.0013 | 0.0024 | −2.60 | E | 1 |
| | | | [285] | | | 4 | 4 | 0.39 | 4.8(−4) | 0.0018 | −2.72 | E | 1 |
| | | | [293] | | | 2 | 2 | 0.18 | 2.3(−4) | 4.4(−4) | −3.34 | E | 1 |
| | | | [287] | | | 4 | 2 | 0.47 | 2.9(−4) | 0.0011 | −2.93 | E | 1 |
| 4. | | $^2P^\circ – ^2D$ | *225.15* | *2556* | *446700* | 6 | 10 | 1400 | 1.7 | 7.7 | 1.02 | C− | 1 |
| | | | 225.16 | 0 | 444130 | 4 | 6 | 1370 | 1.56 | 4.63 | 0.80 | C | 1 |
| | | | 225.79 | 7669 | 450550 | 2 | 4 | 1290 | 1.97 | 2.93 | 0.60 | C | 1 |
| | | | 221.95 | 0 | 450550 | 4 | 4 | 69 | 0.051 | 0.15 | −0.69 | D | 1 |
| 5. | $3p^5–3p^4(^1D)3d$ | $^2P^\circ – ^2F$ | | | | | | | | | | | |
| | | | [256] | | | 4 | 6 | 0.36 | 5.3(−4) | 0.0018 | −2.67 | E | 1 |
| 6. | | $^2P^\circ – ^2S$ | *238.95* | *2556* | 421050 | 6 | 2 | 1170 | 0.335 | 1.58 | 0.303 | C− | 1 |
| | | | 237.50 | 0 | 421050 | 4 | 2 | 840 | 0.355 | 1.11 | 0.152 | C− | 1 |
| | | | 241.91 | 7669 | 421050 | 2 | 2 | 338 | 0.296 | 0.472 | −0.227 | C− | 1 |
| 7. | $3p^5–3p^4(^1S)3d$ | $^2P^\circ – ^2D$ | *240* | | | 6 | 10 | 2.2 | 0.0032 | 0.015 | −1.72 | E | 1 |
| | | | [238] | | | 4 | 6 | 0.53 | 6.7(−4) | 0.0021 | −2.57 | E | 1 |
| | | | [243] | | | 2 | 4 | 4.2 | 0.0075 | 0.012 | −1.82 | E | 1 |
| | | | [239] | | | 4 | 4 | 0.24 | 2.1(−4) | 6.5(−4) | −3.08 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## V VII

### Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $3p^5$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for mixing among odd-parity configurations was limited to the set $3s^23p^5$, $3s3p^53d$, $3p^53d^2$, and $3s^23p^33d^2$. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

#### Reference

[1] K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables **28**, 355 (1983).

V VII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^5$–$3p^5$ | $^2$P° – $^2$P° | | | | | | | | | | |
| | | | [13040] | 0 | 7669 | 4 | 2 | M1 | 8.09 | 1.33 | B | 1 |
| | | | " | " | " | 4 | 2 | E2 | 0.0010 | 0.47 | D– | 1 |

## V VIII

S Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^4\ ^3P_2$

Ionization Energy: 173.4 eV = 1399000 cm$^{-1}$

### Allowed Transitions

Oscillator strengths are tabulated for a few transitions of the arrays $3s^23p^4$–$3s3p^5$ and $3p^4$–$3p^33d$. These are the results of the Hartree-XR (Hartree-Fock with relativistic effects and statistical allowance for exchange) calculations of Bromage.[1] The percentage compositions are in good agreement with those of Bromage *et al.*[2] for Fe XI. The term designations used here are in accord with the results of these two sources. Transitions involving levels of low purity in *LS* coupling are omitted, as are very weak transitions.

#### References

[1] G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).
[2] G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Phys. Scr. **15**, 177 (1977).

V VIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^4$–$3s3p^5$ | $^3$P – $^3$P° | | | | | | | | | | | |
| | | | 459.799 | 0 | 217486 | 5 | 5 | 13 | 0.040 | 0.30 | −0.70 | D | 1 |
| 2. | | $^1$D – $^1$P° | 398.204 | 27072 | 278200 | 5 | 3 | 49 | 0.070 | 0.46 | −0.46 | D | 1 |

V VIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | $3p^4$–$3p^3(^2D^\circ)3d$ | $^3P$ - $^3P^\circ$ | | | | | | | | | | | |
| | | | 240.22 | 0 | 416290 | 5 | 5 | 830 | 0.72 | 2.8 | 0.56 | D | 1 |
| | | | [240.9] | | | 3 | 1 | 1100 | 0.31 | 0.74 | −0.03 | D | 1 |
| | | | 243.69 | 6008 | 416290 | 3 | 5 | 200 | 0.29 | 0.70 | −0.06 | D | 1 |
| 4. | | $^3P$ - $^1D^\circ$ | | | | | | | | | | | |
| | | | [224.84] | 6008 | 450780 | 3 | 5 | 26 | 0.033 | 0.073 | −1.00 | D | 1 |
| 5. | | $^1D$ - $^1D^\circ$ | 236.01 | 27072 | 450780 | 5 | 5 | 980 | 0.82 | 3.2 | 0.61 | C | 1 |
| 6. | | $^1D$ - $^1F^\circ$ | 228.67 | 27072 | 464380 | 5 | 7 | 1300 | 1.43 | 5.4 | 0.85 | C | 1 |
| 7. | $3p^4$–$3p^3(^2P^\circ)3d$ | $^3P$ - $^3P^\circ$ | | | | | | | | | | | |
| | | | [262.8] | | | 5 | 5 | 19 | 0.020 | 0.087 | −1.00 | D | 1 |
| 8. | | $^1S$ - $^1P^\circ$ | [233.5] | | | 1 | 3 | 1140 | 2.79 | 2.14 | 0.446 | C | 1 |

# V VIII

## Forbidden Transitions

Transition probabilities for magnetic dipole and electric quadrupole lines within the $3p^4$ configuration are the results of the scaled Thomas-Fermi calculations of Mendoza and Zeippen.[1] They included a number of correlation configurations in their basis set and introduced Breit-Pauli relativistic corrections as a perturbation to the nonrelativistic Hamiltonian.

### Reference

[1]C. Mendoza and C. J. Zeippen, Mon. Not. R. Astron. Soc. **202**, 981 (1983).

V VIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^4$–$3p^4$ | $^3P$ - $^3P$ | | | | | | | | | | |
| | | | [16640] | 0 | 6008 | 5 | 3 | M1 | 4.77 | 2.44 | C+ | 1 |
| | | | ″ | ″ | ″ | 5 | 3 | E2 | 1.9(−4)[a] | 0.43 | D− | 1 |
| | | | [63600] | 6008 | 7580 | 3 | 1 | M1 | 0.205 | 1.96 | C+ | 1 |
| | | | [13190] | 0 | 7580 | 5 | 1 | E2 | 8.8(−4) | 0.21 | D− | 1 |
| 2. | | $^3P$ - $^1D$ | | | | | | | | | | |
| | | | [3692.8] | 0 | 27072 | 5 | 5 | M1 | 16 | 0.15 | D− | 1 |
| | | | ″ | ″ | ″ | 5 | 5 | E2 | 0.030 | 0.061 | E | 1 |
| | | | [4746.1] | 6008 | 27072 | 3 | 5 | M1 | 2.6 | 0.052 | E | 1 |
| | | | ″ | ″ | ″ | 3 | 5 | E2 | 0.0013 | 0.0093 | E | 1 |
| | | | [5128.9] | 7580 | 27072 | 1 | 5 | E2 | 3.9(−4) | 0.0041 | E | 1 |
| 3. | | $^3P$ - $^1S$ | | | | | | | | | | |
| | | | [1649.0] | 0 | 60642 | 5 | 1 | E2 | 0.59 | 0.0043 | E | 1 |
| | | | [1830.4] | 6008 | 60642 | 3 | 1 | M1 | 190 | 0.043 | E | 1 |

V VIII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^1$D - $^1$S | [2978.0] | 27072 | 60642 | 5 | 1 | E2 | 5.6 | 0.78 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V IX

P Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s^2 3p^3\ {}^4S^\circ_{3/2}$

Ionization Energy: 205.8 eV = 1660000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 219 | 8 | 244.89 | 5 | 261 | 6 | 452.132 | 1 |
| 227 | 10 | 247.70 | 9 | 262 | 6 | 457.010 | 1 |
| 228 | 10 | 248.91 | 9 | 277 | 4 | 467.143 | 1 |
| 235.72 | 7 | 251.82 | 12 | 430 | 2 | 485.110 | 3 |
| 240 | 9 | 253.21 | 12 | 433.930 | 2 | 488.735 | 3 |
| 243.58 | 5 | 254 | 11 | 435.699 | 2 | | |
| 244.46 | 5 | 256 | 11 | 437.005 | 2 | | |

Line strengths for transitions of the arrays $3s^2 3p^3$–$3s3p^4$ and $3p^3$–$3p^2 3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to configurations within the $n=3$ complex having no more than two electrons in the 3$d$ subshell.

Huang published neither an energy-level diagram nor percentage compositions for levels of the $3s^2 3p^3$, $3s3p^4$, and $3s^2 3p^2 3d$ configurations in V IX. We have used the percentages given by Bromage *et al.*[2] for Fe XII, and by Bromage[3] for V IX and Ni XIV, as a guide to naming the levels; their values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to a few configurations within the $n=3$ complex. Whenever a term designation of a level in Fe XII, as given in Ref. 1, is different from that indicated in Ref. 2, all transitions involving the corresponding level in V IX are omitted from this compilation.

Transitions involving levels which are indicated to be of low purity in *LS* coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded.

### References


[1]K.-N. Huang, At. Data Nucl. Data Tables **30**, 313 (1984).
[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).
[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).

V IX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^3$–$3s3p^4$ | $^4S°$ – $^4P$ | *461.18* | 0 | *216834* | 4 | 12 | 10 | 0.099 | 0.60 | −0.40 | D | 1 |
| | | | 467.143 | 0 | 214067 | 4 | 6 | 9.9 | 0.049 | 0.30 | −0.71 | D | 1 |
| | | | 457.010 | 0 | 218814 | 4 | 4 | 11 | 0.033 | 0.20 | −0.88 | D | 1 |
| | | | 452.132 | 0 | 221174 | 4 | 2 | 11 | 0.017 | 0.099 | −1.18 | D | 1 |
| 2. | | $^2D°$ – $^2D$ | *434.99* | | | 10 | 10 | 19 | 0.055 | 0.79 | −0.26 | E | 1 |
| | | | 435.699 | | | 6 | 6 | 18 | 0.051 | 0.44 | −0.51 | D | 1 |
| | | | 433.930 | | | 4 | 4 | 20 | 0.058 | 0.33 | −0.64 | D | 1 |
| | | | 437.005 | | | 6 | 4 | 0.73 | 0.0014 | 0.012 | −2.08 | E | 1 |
| | | | [430] | | | 4 | 6 | 0.38 | 0.0016 | 0.0090 | −2.20 | E | 1 |
| 3. | | $^2P°$ – $^2D$ | | | | | | | | | | | |
| | | | 488.735 | | | 4 | 6 | 3.5 | 0.019 | 0.12 | −1.13 | D | 1 |
| | | | 485.110 | | | 2 | 4 | 2.0 | 0.014 | 0.046 | −1.54 | D | 1 |
| 4. | $3p^3$–$3p^2(^3P)3d$ | $^4S°$ – $^4D$ | | | | | | | | | | | |
| | | | [277] | | | 4 | 6 | 0.60 | 0.0010 | 0.0038 | −2.38 | E | 1 |
| 5. | | $^4S°$ – $^4P$ | *244.53* | 0 | *408950* | 4 | 12 | 680 | 1.8 | 5.9 | 0.87 | D | 1 |
| | | | 244.89 | 0 | 408350 | 4 | 6 | 670 | 0.90 | 2.9 | 0.56 | D | 1 |
| | | | 244.46 | 0 | 409060 | 4 | 4 | 690 | 0.62 | 2.0 | 0.40 | D | 1 |
| | | | 243.58 | 0 | 410540 | 4 | 2 | 690 | 0.31 | 0.99 | 0.09 | D | 1 |
| 6. | | $^2D°$ – $^4P$ | | | | | | | | | | | |
| | | | [262] | | | 6 | 6 | 4.5 | 0.0046 | 0.024 | −1.56 | E | 1 |
| | | | [261] | | | 4 | 6 | 1.1 | 0.0016 | 0.0056 | −2.19 | E | 1 |
| 7. | | $^2D°$ – $^2F$ | | | | | | | | | | | |
| | | | 235.72 | | | 6 | 8 | 830 | 0.92 | 4.3 | 0.74 | E | 1 |
| 8. | $3p^3$–$3p^2(^1D)3d$ | $^4S°$ – $^2D$ | | | | | | | | | | | |
| | | | [219] | | | 4 | 6 | 0.93 | 0.0010 | 0.0029 | −2.40 | E | 1 |
| 9. | | $^2D°$ – $^2D$ | *248.42* | | | 10 | 10 | 490 | 0.45 | 3.7 | 0.66 | D | 1 |
| | | | 248.91 | | | 6 | 6 | 440 | 0.41 | 2.0 | 0.39 | D | 1 |
| | | | 247.70 | | | 4 | 4 | 470 | 0.43 | 1.4 | 0.23 | D | 1 |
| | | | [240] | | | 6 | 4 | 77 | 0.044 | 0.21 | −0.58 | D | 1 |
| | | | [240] | | | 4 | 6 | 21 | 0.028 | 0.087 | −0.96 | D | 1 |
| 10. | | $^2D°$ – $^2P$ | | | | | | | | | | | |
| | | | [228] | | | 6 | 4 | 11 | 0.0058 | 0.026 | −1.46 | E | 1 |
| | | | [227] | | | 4 | 4 | 5.2 | 0.0040 | 0.012 | −1.79 | E | 1 |
| 11. | | $^2P°$ – $^2D$ | *255* | | | 6 | 10 | 54 | 0.087 | 0.44 | −0.28 | D− | 1 |
| | | | [256] | | | 4 | 6 | 58 | 0.086 | 0.29 | −0.46 | D | 1 |
| | | | [254] | | | 2 | 4 | 46 | 0.090 | 0.15 | −0.75 | D | 1 |
| | | | [256] | | | 4 | 4 | 0.36 | 3.6(−4)[a] | 0.0012 | −2.85 | E | 1 |
| 12. | | $^2P°$ – $^2P$ | | | | | | | | | | | |
| | | | 253.21 | | | 4 | 4 | 410 | 0.39 | 1.3 | 0.19 | E | 1 |
| | | | 251.82 | | | 2 | 4 | 110 | 0.21 | 0.34 | −0.39 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V IX

## Forbidden Transitions

Line strengths for magnetic dipole and electric quadrupole transitions within the $3p^3$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to configurations within the $n=3$ complex having no more than two electrons in the $3d$ subshell. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor $2/3$ which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. We have excluded from this compilation the electric quadrupole contributions to the $^4S^\circ_{3/2} - {}^2P^\circ_{3/2}$ and $^4S^\circ_{3/2} - {}^2P^\circ_{1/2}$ transitions, since their strengths are very small and thus subject to considerable uncertainty.

Data for these same transitions calculated by Mendoza and Zeippen[2] with the scaled Thomas-Fermi approach with allowance for correlation are generally in very good agreement with the results of Ref. 1. These latter calculations treated relativistic effects by introducing Breit-Pauli corrections as a perturbation to the nonrelativistic Hamiltonian.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **30**, 313 (1984).
[2]C. Mendoza and C. J. Zeippen, Mon. Not. R. Astron. Soc. **198**, 127 (1982).

V IX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^3$-$3p^3$ | $^4S^\circ - {}^2D^\circ$ | | | | | | | | | | |
| | | | [2752] | | | 4 | 6 | M1 | 0.12 | 5.6(−4)[a] | E | 1 |
| | | | " | | | 4 | 6 | E2 | 0.025 | 0.014 | E | 1 |
| | | | [2880] | | | 4 | 4 | M1 | 5.1 | 0.018 | D | 1 |
| | | | " | | | 4 | 4 | E2 | 0.013 | 0.0061 | E | 1 |
| 2. | | $^4S^\circ - {}^2P^\circ$ | | | | | | | | | | |
| | | | [1633] | | | 4 | 4 | M1 | 71 | 0.046 | D | 1 |
| | | | [1694] | | | 4 | 2 | M1 | 33 | 0.012 | D | 1 |
| 3. | | $^2D^\circ - {}^2D^\circ$ | | | | | | | | | | |
| | | | [62060] | | | 4 | 6 | M1 | 0.0423 | 2.25 | C+ | 1 |
| | | | " | | | 4 | 6 | E2 | 2.9(−8) | 0.095 | E | 1 |
| 4. | | $^2D^\circ - {}^2P^\circ$ | | | | | | | | | | |
| | | | [4401.7] | | | 6 | 2 | E2 | 0.23 | 0.45 | D− | 1 |
| | | | [4014.0] | | | 6 | 4 | M1 | 16 | 0.15 | C | 1 |
| | | | " | | | 6 | 4 | E2 | 0.60 | 1.5 | D− | 1 |
| | | | [4110.2] | | | 4 | 2 | M1 | 16 | 0.082 | D | 1 |
| | | | " | | | 4 | 2 | E2 | 0.46 | 0.64 | D− | 1 |
| | | | [3770.4] | | | 4 | 4 | M1 | 34 | 0.27 | C | 1 |
| | | | " | | | 4 | 4 | E2 | 0.28 | 0.50 | D− | 1 |
| 5. | | $^2P^\circ - {}^2P^\circ$ | | | | | | | | | | |
| | | | [45480] | | | 2 | 4 | M1 | 0.089 | 1.24 | C+ | 1 |
| | | | " | | | 2 | 4 | E2 | 7.3(−8) | 0.034 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V x

Si Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^2\ {}^3P_0$

Ionization Energy: 230.5 eV = 1859000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 215 | 8 | 271.22 | 10 | 400.390 | 2 | 470.183 | 1 |
| 232.20 | 7 | 296 | 4 | 408.304 | 2 | 472.48 | 1 |
| 245.35 | 11 | 324 | 9 | 408.630 | 2 | 472.68 | 1 |
| 252 | 5 | 393.469 | 2 | 452.522 | 1 | 527.439 | 3 |
| 254 | 12 | 399.719 | 2 | 461.059 | 1 | | |
| 255.24 | 6 | 400.056 | 2 | 461.245 | 1 | | |

Line strengths for transitions of the arrays $3s^23p^2$–$3s3p^3$ and $3p^2$–$3p3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published neither an energy-level diagram nor percentage compositions for levels of the $3s^23p^2$, $3s3p^3$, and $3s^23p3d$ configurations in V X. We have used the percentages given by Bromage *et al.*[2] for Fe XIII, and by Bromage[3] for V X and Ni XV, as a guide to naming the levels; their values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to a partial set of configurations within the $n=3$ complex. Whenever the term designation of a level in Fe XIII, as given in Ref. 1, is different from that indicated in Ref. 2, all transitions involving the corresponding level in V X are omitted from this compilation.

Transitions involving levels which are indicated to be of low purity in *LS* coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded.

### References


[1]K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985).
[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).
[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).


V x: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^2$–$3s3p^3$ | $^3$P - $^3$D° | *465.32* | *6629* | *221537* | 9 | 15 | 8.7 | 0.047 | 0.65 | −0.37 | D− | 1 |
| | | | 470.183 | 9424 | 222107 | 5 | 7 | 8.4 | 0.039 | 0.30 | −0.71 | D | 1 |
| | | | 461.059 | 4179 | 221071 | 3 | 5 | 8.3 | 0.044 | 0.20 | −0.88 | D | 1 |
| | | | 452.522 | 0 | 220984 | 1 | 3 | 6.6 | 0.061 | 0.091 | −1.21 | D | 1 |
| | | | [472.48] | 9424 | 221071 | 5 | 5 | 0.77 | 0.0026 | 0.020 | −1.89 | D− | 1 |
| | | | 461.245 | 4179 | 220984 | 3 | 3 | 2.7 | 0.0086 | 0.039 | −1.59 | D− | 1 |
| | | | [472.68] | 9424 | 220984 | 5 | 3 | 0.077 | 1.5(−4)[a] | 0.0012 | −3.11 | E | 1 |

V x: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | | $^3P - ^3P°$ | *403.87* | *6629* | *254232* | 9 | 9 | 24 | 0.059 | 0.71 | −0.27 | D | 1 |
| | | | 408.304 | 9424 | 254340 | 5 | 5 | 20 | 0.049 | 0.33 | −0.61 | D | 1 |
| | | | 400.056 | 4179 | 254150 | 3 | 3 | 9.6 | 0.023 | 0.091 | −1.16 | D | 1 |
| | | | 408.630 | 9424 | 254150 | 5 | 3 | 7.4 | 0.011 | 0.075 | −1.25 | D | 1 |
| | | | 400.390 | 4179 | 253935 | 3 | 1 | 26 | 0.020 | 0.081 | −1.21 | C− | 1 |
| | | | 399.719 | 4179 | 254340 | 3 | 5 | 3.9 | 0.016 | 0.062 | −1.33 | D | 1 |
| | | | 393.469 | 0 | 254150 | 1 | 3 | 8.2 | 0.057 | 0.074 | −1.24 | D | 1 |
| 3. | | $^1D - ^3D°$ | | | | | | | | | | | |
| | | | 527.439 | 32512 | 222107 | 5 | 7 | 0.19 | 0.0011 | 0.0094 | −2.27 | E | 1 |
| 4. | $3p^2$–$3p3d$ | $^3P - ^3F°$ | | | | | | | | | | | |
| | | | [296] | | | 5 | 7 | 0.81 | 0.0015 | 0.0073 | −2.13 | E | 1 |
| 5. | | $^3P - ^3P°$ | | | | | | | | | | | |
| | | | [252] | | | 3 | 1 | 370 | 0.12 | 0.29 | −0.46 | D | 1 |
| 6. | | $^3P - ^3D°$ | | | | | | | | | | | |
| | | | 255.24 | 9424 | 401210 | 5 | 7 | 520 | 0.71 | 3.0 | 0.55 | D | 1 |
| 7. | | $^3P - ^1F°$ | | | | | | | | | | | |
| | | | [232.20] | 9424 | 440090 | 5 | 7 | 8.8 | 0.0099 | 0.038 | −1.30 | E | 1 |
| 8. | | $^3P - ^1P°$ | | | | | | | | | | | |
| | | | [215] | | | 1 | 3 | 2.1 | 0.0044 | 0.0031 | −2.36 | E | 1 |
| 9. | | $^1D - ^3F°$ | | | | | | | | | | | |
| | | | [324] | | | 5 | 5 | 1.0 | 0.0016 | 0.0085 | −2.10 | E | 1 |
| 10. | | $^1D - ^3D°$ | | | | | | | | | | | |
| | | | [271.22] | 32512 | 401210 | 5 | 7 | 6.5 | 0.010 | 0.045 | −1.30 | E | 1 |
| 11. | | $^1D - ^1F°$ | 245.35 | 32512 | 440090 | 5 | 7 | 550 | 0.70 | 2.83 | 0.54 | C | 1 |
| 12. | | $^1S - ^1P°$ | [254] | | | 1 | 3 | 490 | 1.4 | 1.2 | 0.16 | D | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V x

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 558.35 | 11 | 1600 | 5 | 3033.9 | 8 | 19060 | 1 |
| 560 | 10 | 1714.4 | 3 | 3042.0 | 8 | 23920 | 1 |
| 770 | 9 | 2836.7 | 4 | 3101.5 | 8 | 89020 | 7 |
| 790 | 9 | 2997.1 | 8 | 3119.9 | 8 | 96500 | 7 |
| 1000 | 6 | 3004.9 | 8 | 3528.4 | 2 | 1100000 | 7 |
| 1500 | 5 | 3014.3 | 8 | 4330.0 | 2 | | |
| 1572.9 | 3 | 3022.2 | 8 | 10610 | 1 | | |

Line strengths for magnetic dipole and electric quadrupole transitions are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration interaction encompassed all configurations within the $n=3$ complex. Huang calculated line strengths for transitions within the $3p^2$ configuration, as well as for transitions between pairs of odd-parity levels whose lower level is one of the four lowest-lying odd-parity levels in the $n=3$ complex. Transitions involving odd-parity levels which are indicated by Bromage *et al.*[2] (for Fe XIII) or Bromage[3] (for V X and Ni XV) to be of low purity in *LS* coupling in Fe-group species are omitted here, as are lines whose strengths are very small. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985) and private communication.

[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).

[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).

V x: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^2$–$3p^2$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | [19060] | 4179 | 9424 | 3 | 5 | M1 | 1.89 | 2.43 | C+ | 1 |
| | | | 〃 | 〃 | 〃 | 3 | 5 | E2 | 4.8(−5)[a] | 0.36 | D− | 1 |
| | | | [23920] | 0 | 4179 | 1 | 3 | M1 | 1.29 | 1.97 | C+ | 1 |
| | | | [10610] | 0 | 9424 | 1 | 5 | E2 | 4.2(−4) | 0.17 | D− | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [4330.0] | 9424 | 32512 | 5 | 5 | M1 | 15 | 0.22 | E | 1 |
| | | | 〃 | 〃 | 〃 | 5 | 5 | E2 | 0.017 | 0.076 | E | 1 |
| | | | [3528.4] | 4179 | 32512 | 3 | 5 | M1 | 9.1 | 0.074 | E | 1 |
| | | | 〃 | 〃 | 〃 | 3 | 5 | E2 | 0.0068 | 0.011 | E | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [1714.4] | 9424 | 67754 | 5 | 1 | E2 | 0.93 | 0.0082 | E | 1 |
| | | | [1572.9] | 4179 | 67754 | 3 | 1 | M1 | 210 | 0.031 | E | 1 |
| 4. | | $^1$D - $^1$S | [2836.7] | 32512 | 67754 | 5 | 1 | E2 | 6.3 | 0.69 | D− | 1 |
| 5. | $3s3p^3$–$3s3p^3$ | $^5$S° - $^3$D° | | | | | | | | | | |
| | | | [1500] | | | 5 | 7 | E2 | 0.16 | 0.0052 | E | 1 |
| | | | [1600] | | | 5 | 5 | M1 | 3.2 | 0.0024 | E | 1 |
| | | | 〃 | 〃 | 〃 | 5 | 5 | E2 | 0.11 | 0.0034 | E | 1 |

V x: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6. | | $^5S^o - ^3P^o$ | | | | | | | | | | |
| | | | [1000] | | | 5 | 5 | M1 | 150 | 0.027 | E | 1 |
| | | | [1000] | | | 5 | 3 | M1 | 80 | 0.0089 | E | 1 |
| 7. | | $^3D^o - ^3D^o$ | | | | | | | | | | |
| | | | [96500] | 221071 | 222107 | 5 | 7 | M1 | 0.020 | 4.6 | D+ | 1 |
| | | | " | " | " | 5 | 7 | E2 | 1.3(−9) | 0.047 | E | 1 |
| | | | [1100000] | 220984 | 221071 | 3 | 5 | M1 | 1.8(−5) | 4.4 | E | 1 |
| | | | [89020] | 220984 | 222107 | 3 | 7 | E2 | 4.7(−10) | 0.011 | E | 1 |
| 8. | | $^3D^o - ^3P^o$ | | | | | | | | | | |
| | | | [3119.9] | 222107 | 254150 | 7 | 3 | E2 | 1.3 | 0.70 | D− | 1 |
| | | | [3042.0] | 221071 | 253935 | 5 | 1 | E2 | 3.1 | 0.48 | D− | 1 |
| | | | [3101.5] | 222107 | 254340 | 7 | 5 | M1 | 18 | 0.10 | E | 1 |
| | | | " | " | " | 7 | 5 | E2 | 1.5 | 1.3 | D− | 1 |
| | | | [3022.2] | 221071 | 254150 | 5 | 3 | E2 | 0.24 | 0.11 | D− | 1 |
| | | | [3033.9] | 220984 | 253935 | 3 | 1 | M1 | 23 | 0.024 | E | 1 |
| | | | [3004.9] | 221071 | 254340 | 5 | 5 | M1 | 14 | 0.070 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 1.1 | 0.81 | D− | 1 |
| | | | [3014.3] | 220984 | 254150 | 3 | 3 | M1 | 23 | 0.071 | E | 1 |
| | | | " | " | " | 3 | 3 | E2 | 1.4 | 0.64 | D− | 1 |
| | | | [2997.1] | 220984 | 254340 | 3 | 5 | M1 | 4.2 | 0.021 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.33 | 0.24 | D− | 1 |
| 9. | $3s3p^3$-$3s^23p3d$ | $^3D^o - ^3F^o$ | | | | | | | | | | |
| | | | [770] | | | 5 | 9 | E2 | 4.6 | 0.0066 | E | 1 |
| | | | [790] | | | 3 | 7 | E2 | 2.3 | 0.0029 | E | 1 |
| | | | [770] | | | 7 | 9 | M1 | 430 | 0.065 | E | 1 |
| 10. | | $^3D^o - ^3P^o$ | | | | | | | | | | |
| | | | [560] | | | 5 | 1 | E2 | 220 | 0.0071 | E | 1 |
| 11. | | $^3D^o - ^3D^o$ | | | | | | | | | | |
| | | | [558.35] | 222107 | 401210 | 7 | 7 | M1 | 35 | 0.0016 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XI

Al Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p\ ^2P^\circ_{1/2}$

Ionization Energy: 255.7 eV = 2062000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 207 | 20 | 272.32 | 15 | 332 | 13 | 447 | 10 |
| 222 | 28 | 273 | 25,32 | 335 | 14 | 447.881 | 1 |
| 231 | 27 | 275 | 25 | 336.580 | 3 | 454 | 6 |
| 232 | 27 | 286 | 30 | 346.123 | 2 | 455 | 6 |
| 234 | 19,24 | 287 | 26 | 347.9 | 4 | 456 | 6 |
| 256 | 29 | 290 | 26 | 352.43 | 4 | 458 | 6 |
| 261 | 17 | 291 | 26 | 355 | 12 | 460 | 8 |
| 262 | 18 | 295 | 26 | 356 | 12 | 461 | 10 |
| 263 | 17,18 | 296 | 5 | 358 | 12 | 462 | 8 |
| 265.31 | 15 | 300 | 5,16 | 358.144 | 2 | 463 | 10 |
| 266 | 18,23 | 302 | 16 | 358.89 | 4 | 503 | 9 |
| 268 | 17 | 308 | 22 | 361 | 7 | 506 | 9 |
| 269 | 32 | 316 | 21 | 362 | 7 | 517 | 9 |
| 270 | 31 | 320.626 | 3 | 368 | 11 | 519 | 9 |
| 271 | 23 | 325.945 | 3 | 370 | 11 | | |
| 271.75 | 15 | 330.913 | 3 | 429.232 | 1 | | |
| 272 | 17,23 | 331 | 13 | 446.265 | 1 | | |

Line strengths for transitions of the arrays $3s^23p$–$3s3p^2$, $3s3p^2$–$3p^3$, $3s^23d$–$3s3p3d$, $3s^23p$–$3s^23d$, and $3s3p^2$–$3s3p3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published neither an energy-level diagram nor percentage compositions for levels of the $3s^23p$, $3s3p^2$, $3s^23d$, $3p^3$, and $3s3p3d$ configurations in V XI. We have used the percentages given by Fawcett[2] for the adjacent Al-like ions as a guide to naming the levels; the latter's values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to all configurations within the $n=3$ complex.

Transitions involving levels which are indicated to be of low purity in *LS* coupling in one or both adjacent Al-like ions are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded. A few wavelengths computed by Huang for transitions in Ti X differ significantly from those which resulted from the fitting and scaling procedure applied by Fawcett[2]; lines for which the wavelengths are in serious disagreement have been omitted in our tabulation for V XI.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986) and private communication.

[2]B. C. Fawcett, At. Data Nucl. Data Tables **28**, 557 (1983).

V XI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p$–$3s3p^2$ | $^2P^\circ$ - $^2D$ | *440.54* | *6467* | *233459* | 6 | 10 | 13 | 0.064 | 0.56 | −0.41 | E | 1 |
| | | | 446.265 | 9700 | 233782 | 4 | 6 | 13 | 0.056 | 0.33 | −0.65 | D | 1 |
| | | | 429.232 | 0 | 232974 | 2 | 4 | 13 | 0.074 | 0.21 | −0.83 | D | 1 |
| | | | 447.881 | 9700 | 232974 | 4 | 4 | 0.96 | 0.0029 | 0.017 | −1.94 | E | 1 |

V XI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | | $^2$P° – $^2$S | *354.05* | *6467* | 288915 | 6 | 2 | 110 | 0.067 | 0.47 | −0.39 | D | 1 |
| | | | 358.144 | 9700 | 288915 | 4 | 2 | 24 | 0.023 | 0.11 | −1.03 | D | 1 |
| | | | 346.123 | 0 | 288915 | 2 | 2 | 88 | 0.16 | 0.36 | −0.50 | D | 1 |
| 3. | | $^2$P° – $^2$P | *329.24* | *6467* | *310193* | 6 | 6 | 290 | 0.48 | 3.1 | 0.46 | D | 1 |
| | | | 330.913 | 9700 | 311890 | 4 | 4 | 247 | 0.406 | 1.77 | 0.211 | C− | 1 |
| | | | 325.945 | 0 | 306800 | 2 | 2 | 140 | 0.22 | 0.48 | −0.35 | D | 1 |
| | | | 336.580 | 9700 | 306800 | 4 | 2 | 140 | 0.12 | 0.52 | −0.33 | D | 1 |
| | | | 320.626 | 0 | 311890 | 2 | 4 | 53 | 0.164 | 0.346 | −0.484 | C− | 1 |
| 4. | $3s3p^2$–$3p^3$ | $^4$P – $^4$S° | *354.8* | | | 12 | 4 | 260 | 0.16 | 2.3 | 0.29 | D | 1 |
| | | | 358.89 | | | 6 | 4 | 120 | 0.16 | 1.1 | −0.03 | D | 1 |
| | | | 352.43 | | | 4 | 4 | 89 | 0.17 | 0.77 | −0.18 | D | 1 |
| | | | 347.9 | | | 2 | 4 | 46 | 0.17 | 0.38 | −0.48 | D | 1 |
| 5. | | $^4$P – $^2$P° | | | | | | | | | | | |
| | | | [300] | | | 4 | 4 | 1.5 | 0.0021 | 0.0081 | −2.09 | E | 1 |
| | | | [296] | | | 2 | 4 | 0.66 | 0.0017 | 0.0034 | −2.46 | E | 1 |
| 6. | | $^2$D – $^2$D° | *455* | | | 10 | 10 | 22 | 0.067 | 1.0 | −0.18 | E | 1 |
| | | | [455] | | | 6 | 6 | 20 | 0.063 | 0.57 | −0.42 | E | 1 |
| | | | [456] | | | 4 | 4 | 17 | 0.052 | 0.31 | −0.69 | E | 1 |
| | | | [458] | | | 6 | 4 | 4.7 | 0.0098 | 0.089 | −1.23 | E | 1 |
| | | | [454] | | | 4 | 6 | 1.8 | 0.0084 | 0.050 | −1.48 | E | 1 |
| 7. | | $^2$D – $^2$P° | *362* | | | 10 | 6 | 85 | 0.10 | 1.2 | 0.00 | D | 1 |
| | | | [362] | | | 6 | 4 | 75 | 0.098 | 0.70 | −0.23 | D | 1 |
| | | | [362] | | | 4 | 2 | 92 | 0.090 | 0.43 | −0.44 | D | 1 |
| | | | [361] | | | 4 | 4 | 9.4 | 0.018 | 0.087 | −1.14 | D | 1 |
| 8. | | $^2$S – $^2$P° | *461* | | | 2 | 6 | 9.3 | 0.089 | 0.27 | −0.75 | D | 1 |
| | | | [460] | | | 2 | 4 | 12 | 0.079 | 0.24 | −0.80 | D | 1 |
| | | | [462] | | | 2 | 2 | 3.5 | 0.011 | 0.034 | −1.65 | D | 1 |
| 9. | | $^2$P – $^2$P° | *513* | | | 6 | 6 | 20 | 0.079 | 0.80 | −0.32 | E | 1 |
| | | | [517] | | | 4 | 4 | 17 | 0.069 | 0.47 | −0.56 | D | 1 |
| | | | [506] | | | 2 | 2 | 20 | 0.075 | 0.25 | −0.82 | D | 1 |
| | | | [519] | | | 4 | 2 | 5.3 | 0.011 | 0.073 | −1.37 | D | 1 |
| | | | [503] | | | 2 | 4 | 0.44 | 0.0033 | 0.011 | −2.18 | E | 1 |
| 10. | $3s^23d$–$3s3p(^3$P°$)3d$ | $^2$D – $^2$F° | *453* | | | 10 | 14 | 15 | 0.063 | 0.94 | −0.20 | E | 1 |
| | | | [447] | | | 6 | 8 | 16 | 0.062 | 0.55 | −0.43 | E | 1 |
| | | | [461] | | | 4 | 6 | 12 | 0.056 | 0.34 | −0.65 | E | 1 |
| | | | [463] | | | 6 | 6 | 1.8 | 0.0059 | 0.054 | −1.45 | E | 1 |
| 11. | | $^2$D – $^2$P° | | | | | | | | | | | |
| | | | [370] | | | 6 | 4 | 1.4 | 0.0019 | 0.014 | −1.94 | E | 1 |
| | | | [368] | | | 4 | 4 | 1.7 | 0.0035 | 0.017 | −1.85 | E | 1 |

V XI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | $3s^23d-3s3p(^1P^\circ)3d$ | $^2D-^2F^\circ$ | *357* | | | 10 | 14 | 190 | 0.52 | 6.1 | 0.72 | E | 2 |
| | | | [358] | | | 6 | 8 | 190 | 0.49 | 3.5 | 0.47 | E | 1 |
| | | | [355] | | | 4 | 6 | 190 | 0.53 | 2.5 | 0.33 | E | 1 |
| | | | [356] | | | 6 | 6 | 9.7 | 0.018 | 0.13 | −0.95 | E | 1 |
| 13. | | $^2D-^2D^\circ$ | | | | | | | | | | | |
| | | | [332] | | | 6 | 6 | 150 | 0.24 | 1.6 | 0.17 | E | 1 |
| | | | [331] | | | 4 | 6 | 5.4 | 0.013 | 0.058 | −1.27 | E | 1 |
| 14. | | $^2D-^2P^\circ$ | | | | | | | | | | | |
| | | | [335] | | | 4 | 2 | 250 | 0.21 | 0.91 | −0.08 | D | 1 |
| 15. | $3p-3d$ | $^2P^\circ-^2D$ | *269.61* | *6467* | *377380* | 6 | 10 | 320 | 0.58 | 3.1 | 0.54 | D | 1 |
| | | | 271.75 | 9700 | 377690 | 4 | 6 | 320 | 0.53 | 1.9 | 0.33 | D | 1 |
| | | | 265.31 | 0 | 376920 | 2 | 4 | 270 | 0.57 | 1.0 | 0.06 | D | 1 |
| | | | [272.32] | 9700 | 376920 | 4 | 4 | 58 | 0.064 | 0.23 | −0.59 | D | 1 |
| 16. | $3s3p^2-3s3p(^3P^\circ)3d$ | $^4P-^4F^\circ$ | | | | | | | | | | | |
| | | | [302] | | | 6 | 8 | 0.84 | 0.0015 | 0.0091 | −2.04 | E | 1 |
| | | | [300] | | | 4 | 6 | 0.50 | 0.0010 | 0.0040 | −2.39 | E | 1 |
| 17. | | $^4P-^4P^\circ$ | | | | | | | | | | | |
| | | | [272] | | | 6 | 6 | 39 | 0.043 | 0.23 | −0.59 | D | 1 |
| | | | [261] | | | 2 | 2 | 27 | 0.028 | 0.048 | −1.25 | E | 1 |
| | | | [263] | | | 4 | 2 | 230 | 0.12 | 0.41 | −0.32 | E | 1 |
| | | | [268] | | | 4 | 6 | 180 | 0.28 | 1.0 | 0.05 | D | 1 |
| 18. | | $^4P-^4D^\circ$ | | | | | | | | | | | |
| | | | [266] | | | 6 | 8 | 339 | 0.480 | 2.52 | 0.459 | C− | 1 |
| | | | [262] | | | 4 | 6 | 120 | 0.18 | 0.62 | −0.14 | D | 1 |
| | | | [266] | | | 6 | 6 | 200 | 0.21 | 1.1 | 0.10 | D | 1 |
| | | | [263] | | | 2 | 2 | 300 | 0.31 | 0.54 | −0.21 | E | 1 |
| 19. | | $^4P-^2F^\circ$ | | | | | | | | | | | |
| | | | [234] | | | 6 | 8 | 1.3 | 0.0015 | 0.0068 | −2.05 | E | 1 |
| 20. | | $^4P-^2P^\circ$ | | | | | | | | | | | |
| | | | [207] | | | 2 | 4 | 1.2 | 0.0015 | 0.0021 | −2.51 | E | 1 |
| 21. | | $^2D-^4P^\circ$ | | | | | | | | | | | |
| | | | [316] | | | 6 | 6 | 3.4 | 0.0051 | 0.032 | −1.51 | E | 1 |
| 22. | | $^2D-^4D^\circ$ | | | | | | | | | | | |
| | | | [308] | | | 6 | 8 | 1.0 | 0.0020 | 0.012 | −1.93 | E | 1 |
| 23. | | $^2D-^2F^\circ$ | *268* | | | 10 | 14 | 130 | 0.19 | 1.7 | 0.28 | E | 1 |
| | | | [266] | | | 6 | 8 | 130 | 0.18 | 0.96 | 0.04 | E | 1 |
| | | | [271] | | | 4 | 6 | 110 | 0.18 | 0.66 | −0.13 | E | 1 |
| | | | [272] | | | 6 | 6 | 15 | 0.016 | 0.088 | −1.01 | E | 1 |

V XI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24. | | $^2D - ^2P^o$ | | | | | | | | | | | |
| | | | [234] | | | 4 | 2 | 0.28 | 1.2(−4)[a] | 3.6(−4) | −3.33 | E | 1 |
| 25. | | $^2S - ^2P^o$ | *274* | | | 2 | 6 | 250 | 0.83 | 1.5 | 0.22 | D | 1 |
| | | | [275] | | | 2 | 4 | 290 | 0.66 | 1.2 | 0.12 | D | 1 |
| | | | [273] | | | 2 | 2 | 160 | 0.18 | 0.33 | −0.44 | D | 1 |
| 26. | | $^2P - ^2P^o$ | *292* | | | 6 | 6 | 150 | 0.19 | 1.1 | 0.06 | D | 1 |
| | | | [295] | | | 4 | 4 | 97 | 0.13 | 0.49 | −0.30 | D | 1 |
| | | | [287] | | | 2 | 2 | 180 | 0.23 | 0.43 | −0.34 | D | 1 |
| | | | [291] | | | 4 | 2 | 41 | 0.026 | 0.10 | −0.98 | D | 1 |
| | | | [290] | | | 2 | 4 | 10 | 0.025 | 0.048 | −1.30 | D | 1 |
| 27. | $3s3p^2$– $3s3p(^1P^o)3d$ | $^2D - ^2F^o$ | *232* | | | 10 | 14 | 240 | 0.27 | 2.1 | 0.44 | E | 1 |
| | | | [232] | | | 6 | 8 | 240 | 0.26 | 1.2 | 0.20 | E | 1 |
| | | | [231] | | | 4 | 6 | 230 | 0.28 | 0.85 | 0.05 | E | 1 |
| | | | [231] | | | 6 | 6 | 15 | 0.012 | 0.053 | −1.16 | E | 1 |
| 28. | | $^2D - ^2P^o$ | | | | | | | | | | | |
| | | | [222] | | | 4 | 2 | 1.9 | 6.8(−4) | 0.0020 | −2.56 | E | 1 |
| 29. | | $^2S - ^2P^o$ | | | | | | | | | | | |
| | | | [256] | | | 2 | 2 | 130 | 0.13 | 0.22 | −0.58 | D | 1 |
| 30. | | $^2P - ^2F^o$ | | | | | | | | | | | |
| | | | [286] | | | 4 | 6 | 0.75 | 0.0014 | 0.0052 | −2.26 | E | 1 |
| 31. | | $^2P - ^2D^o$ | | | | | | | | | | | |
| | | | [270] | | | 4 | 6 | 500 | 0.82 | 2.9 | 0.51 | E | 1 |
| 32. | | $^2P - ^2P^o$ | | | | | | | | | | | |
| | | | [269] | | | 2 | 2 | 73 | 0.079 | 0.14 | −0.80 | D | 1 |
| | | | [273] | | | 4 | 2 | 68 | 0.0378 | 0.136 | −0.82 | C− | 1 |

[a] The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## V XI

### Forbidden Transitions

Line strengths for magnetic dipole and electric quadrupole transitions within the $3s^23p$ $^2P^o$ and $3s3p^2$ $^4P$ terms are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into confor mance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1] K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986).

V XI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p$–$3p$ | $^2$P° - $^2$P° | | | | | | | | | | |
| | | | [10310] | 0 | 9700 | 2 | 4 | M1 | 8.18 | 1.33 | C+ | 1 |
| | | | " | " | " | 2 | 4 | E2 | 0.0011 | 0.31 | D− | 1 |
| 2. | $3s3p^2$–$3s3p^2$ | $^4$P - $^4$P | | | | | | | | | | |
| | | | [19600] | | | 4 | 6 | M1 | 2.14 | 3.58 | C | 1 |
| | | | " | | | 4 | 6 | E2 | 4.6(−5)[a] | 0.48 | D− | 1 |
| | | | [27000] | | | 2 | 4 | M1 | 1.1 | 3.3 | D | 1 |
| | | | " | | | 2 | 4 | E2 | 1.1(−6) | 0.039 | E | 1 |
| | | | [11000] | | | 2 | 6 | E2 | 6.1(−4) | 0.35 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XII

Mg Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^2\ ^1S_0$

Ionization Energy: 308.1 eV = 2485000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 56.655 | 14 | 297.77 | 21 | 393.2 | 3 | 490.2 | 7 |
| 76.303 | 13 | 301.50 | 16 | 396.61 | 4 | 499.41 | 7 |
| 281.11 | 15 | 355.11 | 2 | 398.6 | 9 | 500.8 | 7 |
| 283.28 | 15 | 373.20 | 4 | 399.76 | 9 | 502.5 | 7 |
| 283.7 | 15 | 380.87 | 4 | 404.9 | 3 | 522.4 | 1 |
| 288.67 | 15 | 383.63 | 4 | 411.12 | 6 | 609.24 | 5 |
| 289.21 | 15 | 385.54 | 4 | 476.85 | 7 | | |
| 289.7 | 15 | 392.60 | 4 | 488.53 | 7 | | |

Oscillator strengths were interpolated from the results of theoretical calculations reported by various researchers for the neighboring magnesium-like ions Ti XI and Cr XIII. Data for the three transitions $3s^2\ ^1S_0$ – $3snp\ ^1P_1^\circ$ ($n$ = 3–5) were reported by Shorer *et al.*,[1] who applied the relativistic random phase approximation (RRPA) with allowance for correlation within the context of a frozen core. The source of $f$-values for most transitions of the arrays $3s3p$–$3p^2$, $3s3d$–$3p3d$, $3s3p$–$3s3d$, and $3p^2$–$3p3d$ is the work of Fawcett,[2] who performed Hartree-Fock calculations which included relativistic effects and statistical allowance for exchange (HXR); he incorporated correlation effects due to all configurations within the $n$ = 3 complex. The oscillator strength for the $3p3d\ ^1$F° - $3d^2\ ^1$G transition was interpolated from results of the nonrelativistic multiconfiguration Hartree-Fock (MCHF) calculations of Froese Fischer and Godefroid[3]; their atomic model incorporated large-scale allowance for configuration interaction.

$A$-values for the three intercombination lines tabulated here were calculated for V XII by Kastner and Bhatia[4] using a scaled Thomas-Fermi approach that allowed for correlation due to all configurations in the $n$ = 3 complex.

Transitions involving levels which are indicated in Ref. 2 to be of low purity in $LS$ coupling in neighboring Mg-like ions are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings.

## References

[1]P. Shorer, C. D. Lin, and W. R. Johnson, Phys. Rev. A **16**, 1109 (1977).

[2]B. C. Fawcett, At. Data Nucl. Data Tables **28**, 579 (1983).

[3]C. Froese Fischer and M. Godefroid, Nucl. Instrum. Methods **202**, 307 (1982).

[4]S. O. Kastner and A. K. Bhatia, J. Opt. Soc. Am. **69**, 1391 (1979).


V XII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^2$–$3s3p$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | 522.4 | 0 | 191400 | 1 | 3 | 0.11 | 0.0014 | 0.0023 | −2.87 | E | 4 |
| 2. | | $^1$S - $^1$P° | 355.11 | 0 | 281600 | 1 | 3 | 167 | 0.947 | 1.11 | −0.024 | C+ | *interp.* |
| 3. | $3s3p$–$3p^2$ | $^3$P° - $^1$D | | | | | | | | | | | |
| | | | [404.9] | 198700 | 445740 | 5 | 5 | 9.1 | 0.022 | 0.15 | −0.95 | E | 4 |
| | | | [393.2] | 191400 | 445740 | 3 | 5 | 4.5 | 0.017 | 0.068 | −1.28 | E | 4 |
| 4. | | $^3$P° - $^3$P | *384.6* | *195100* | *455100* | 9 | 9 | 130 | 0.29 | 3.3 | 0.42 | D | *interp.* |
| | | | 383.63 | 198700 | 459400 | 5 | 5 | 95 | 0.21 | 1.3 | 0.02 | D− | *interp.* |
| | | | 385.54 | 191400 | 450800 | 3 | 3 | 36 | 0.080 | 0.30 | −0.62 | C | *interp.* |
| | | | 396.61 | 198700 | 450800 | 5 | 3 | 55 | 0.078 | 0.51 | −0.41 | C− | *interp.* |
| | | | 392.60 | 191400 | 446100 | 3 | 1 | 130 | 0.10 | 0.39 | −0.52 | C | *interp.* |
| | | | 373.20 | 191400 | 459400 | 3 | 5 | 32 | 0.11 | 0.41 | −0.48 | D− | *interp.* |
| | | | 380.87 | 188200 | 450800 | 1 | 3 | 49 | 0.32 | 0.40 | −0.49 | C | *interp.* |
| 5. | | $^1$P° - $^1$D | 609.24 | 281600 | 445740 | 3 | 5 | 12 | 0.11 | 0.66 | −0.48 | E | *interp.* |
| 6. | | $^1$P° - $^1$S | 411.12 | 281600 | 524840 | 3 | 1 | 130 | 0.11 | 0.45 | −0.48 | C | *interp.* |
| 7. | $3s3d$–$3p3d$ | $^3$D - $^3$F° | *485.9* | *544600* | *750400* | 15 | 21 | 38 | 0.19 | 4.5 | 0.45 | D | *interp.* |
| | | | 476.85 | 545100 | 754800 | 7 | 9 | 40.6 | 0.178 | 1.96 | 0.096 | C | *interp.* |
| | | | 488.53 | 544400 | 749100 | 5 | 7 | 32 | 0.16 | 1.3 | −0.10 | C− | *interp.* |
| | | | 499.41 | 543900 | 744100 | 3 | 5 | 26 | 0.16 | 0.79 | −0.32 | D− | *interp.* |
| | | | [490.2] | 545100 | 749100 | 7 | 7 | 5.8 | 0.021 | 0.24 | −0.83 | C | *interp.* |
| | | | [500.8] | 544400 | 744100 | 5 | 5 | 6.1 | 0.023 | 0.19 | −0.94 | D | *interp.* |
| | | | [502.5] | 545100 | 744100 | 7 | 5 | 0.12 | 3.3(−4)[a] | 0.0038 | −2.64 | E | *interp.* |
| 8. | | $^3$D - $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 1 | | 0.063 | | −0.72 | C− | *interp.* |
| 9. | | $^3$D - $^3$D° | | | | | | | | | | | |
| | | | 399.76 | 545100 | 795300 | 7 | 7 | 58 | 0.14 | 1.3 | −0.01 | C− | *interp.* |
| | | | [398.6] | 544400 | 795300 | 5 | 7 | 11 | 0.037 | 0.24 | −0.73 | C− | *interp.* |
| 10. | | $^1$D - $^1$D° | | | | 5 | 5 | | 0.038 | | −0.72 | D− | *interp.* |
| 11. | | $^1$D - $^1$F° | | | | 5 | 7 | | 0.51 | | 0.41 | D− | *interp.* |
| 12. | | $^1$D - $^1$P° | | | | 5 | 3 | | 0.14 | | −0.15 | D− | *interp.* |
| 13. | $3s^2$–$3s4p$ | $^1$S - $^1$P° | 76.303 | 0 | 1310600 | 1 | 3 | 1210 | 0.317 | 0.080 | −0.499 | C− | *interp.* |
| 14. | $3s^2$–$3s5p$ | $^1$S - $^1$P° | 56.655 | 0 | 1765100 | 1 | 3 | 720 | 0.104 | 0.0194 | −0.98 | C | *interp.* |

V XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | $3s3p-3s3d$ | $^3P^\circ - {}^3D$ | *286.1* | *195100* | *544600* | 9 | 15 | 180 | 0.368 | 3.12 | 0.52 | C− | *interp.* |
| | | | 288.67 | 198700 | 545100 | 5 | 7 | 176 | 0.307 | 1.46 | 0.186 | C− | *interp.* |
| | | | 283.28 | 191400 | 544400 | 3 | 5 | 140 | 0.28 | 0.78 | −0.08 | C− | *interp.* |
| | | | 281.11 | 188200 | 543900 | 1 | 3 | 100 | 0.37 | 0.34 | −0.43 | C− | *interp.* |
| | | | 289.21 | 198700 | 544400 | 5 | 5 | 44 | 0.055 | 0.26 | −0.56 | C− | *interp.* |
| | | | [283.7] | 191400 | 543900 | 3 | 3 | 77 | 0.093 | 0.26 | −0.55 | C− | *interp.* |
| | | | [289.7] | 198700 | 543900 | 5 | 3 | 4.9 | 0.0037 | 0.018 | −1.73 | D− | *interp.* |
| 16. | | $^1P^\circ - {}^1D$ | 301.50 | 281600 | 613270 | 3 | 5 | 320 | 0.73 | 2.2 | 0.34 | D− | *interp.* |
| 17. | $3p^2-3p3d$ | $^1D - {}^1D^\circ$ | | | | 5 | 5 | | 0.19 | | −0.02 | E | *interp.* |
| 18. | | $^1D - {}^1F^\circ$ | | | | 5 | 7 | | 0.23 | | 0.06 | E | *interp.* |
| 19. | | $^1D - {}^1P^\circ$ | | | | 5 | 3 | | 0.0014 | | −2.15 | E | *interp.* |
| 20. | | $^3P - {}^3P^\circ$ | | | | | | | | | | | |
| | | | | | | 3 | 1 | | 0.067 | | −0.70 | C− | *interp.* |
| 21. | | $^3P - {}^3D^\circ$ | | | | | | | | | | | |
| | | | 297.77 | 459400 | 795300 | 5 | 7 | 210 | 0.39 | 1.9 | 0.29 | E | *interp.* |
| 22. | | $^1S - {}^1P^\circ$ | | | | 1 | 3 | | 0.79 | | −0.10 | C− | *interp.* |
| 23. | $3p3d-3d^2$ | $^1F^\circ - {}^1G$ | | | | 7 | 9 | | 0.418 | | 0.466 | C− | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XIII

Na Isoelectronic Sequence

Ground State: $1s^22s^22p^63s\ ^2S_{1/2}$

Ionization Energy: 336.279 eV = 2712250 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 41.596 | 6 | 47.890 | 15 | 53.318 | 27 | 58.517 | 11 |
| 43.371 | 5 | 48.441 | 14 | 53.322 | 27 | 60.596 | 23 |
| 45.645 | 17 | 48.701 | 14 | 53.778 | 26 | 60.640 | 23 |
| 45.873 | 17 | 51.091 | 13 | 53.818 | 26 | 60.646 | 23 |
| 45.878 | 17 | 51.376 | 13 | 55.932 | 25 | 61.705 | 10 |
| 46.118 | 16 | 51.382 | 13 | 55.967 | 25 | 62.132 | 10 |
| 46.395 | 16 | 52.590 | 12 | 55.975 | 25 | 62.197 | 22 |
| 46.460 | 4 | 52.887 | 3 | 56.783 | 24 | 62.235 | 22 |
| 46.482 | 4 | 52.899 | 12 | 56.828 | 24 | 62.251 | 22 |
| 47.637 | 15 | 52.924 | 3 | 58.139 | 11 | 70.262 | 21 |
| 47.884 | 15 | 53.281 | 27 | 58.505 | 11 | 70.323 | 21 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 70.333 | 21 | 117.5 | 30 | 190.3 | 65 | 280.0 | 74 |
| 71.794 | 2 | 117.89 | 18 | 199.0 | 64 | 280.1 | 74 |
| 72.019 | 2 | 118.08 | 18 | 199.5 | 64 | 280.2 | 74 |
| 74.283 | 20 | 118.50 | 18 | 210.1 | 72 | 313.37 | 7 |
| 74.313 | 20 | 120.9 | 48 | 210.3 | 72 | 323.20 | 7 |
| 74.355 | 20 | 121.0 | 48 | 216.3 | 44 | 324.60 | 7 |
| 78.132 | 9 | 125.0 | 47 | 216.5 | 44 | 326.5 | 56 |
| 78.773 | 9 | 125.1 | 47 | 216.6 | 44 | 327.5 | 56 |
| 78.807 | 9 | 125.9 | 37 | 217.6 | 57 | 340.9 | 61 |
| 90.613 | 32 | 126.6 | 37 | 218.1 | 71 | 342.2 | 61 |
| 97.295 | 41 | 128.9 | 53 | 218.2 | 71 | 342.5 | 61 |
| 97.694 | 41 | 129.0 | 53 | 218.5 | 34 | 401.0 | 68 |
| 97.714 | 41 | 135.4 | 36 | 220.7 | 34 | 401.3 | 68 |
| 99.483 | 31 | 136.2 | 36 | 222.9 | 75 | 401.6 | 68 |
| 99.523 | 19 | 145.0 | 46 | 223.0 | 75 | 421.1 | 60 |
| 99.625 | 19 | 145.1 | 46 | 229.8 | 63 | 422.71 | 1 |
| 99.651 | 40 | 145.2 | 46 | 230.3 | 63 | 423.4 | 60 |
| 99.661 | 19 | 154.6 | 45 | 230.5 | 63 | 443.40 | 1 |
| 100.1 | 40 | 154.7 | 45 | 249.8 | 62 | 464.7 | 73 |
| 106.8 | 39 | 154.8 | 45 | 250.6 | 62 | 465.1 | 73 |
| 107.3 | 39 | 157.8 | 52 | 252.2 | 51 | 483.3 | 67 |
| 109.2 | 50 | 157.9 | 52 | 252.5 | 51 | 484.3 | 67 |
| 109.3 | 50 | 169.4 | 29 | 258.4 | 70 | 485.7 | 67 |
| 110.9 | 38 | 169.8 | 29 | 258.5 | 70 | 855.4 | 33 |
| 111.3 | 49 | 179.2 | 58 | 258.7 | 70 | 883.4 | 33 |
| 111.4 | 49 | 179.5 | 35 | 259.5 | 43 | 888.9 | 33 |
| 111.5 | 38 | 180.8 | 35 | 259.9 | 43 | | |
| 115.3 | 54 | 181.0 | 35 | 260.3 | 43 | | |
| 115.4 | 54 | 189.8 | 65 | 277.6 | 69 | | |
| 117.4 | 30 | 190.2 | 65 | 277.9 | 69 | | |

Strengths of the lines of the $3s$–$3p$ and $3s$–$4p$ transitions are the results of the relativistic single-configuration Hartree-Fock calculations of Kim and Desclaux,[1] while those for the lines of the $3p$–$3d$ transition were taken from Edlen's interpolation formulae.[2] These formulae were based on the results of Weiss' Hartree-Fock calculations,[3] in which ratios of relativistic Dirac to nonrelativistic line strengths in hydrogenic ions were applied as scaling factors to the nonrelativistic Hartree-Fock line strengths in the corresponding sodiumlike species. Oscillator strengths for the $4p$–$4d$ transitions were derived by Gruzdev and Sherstyuk[4] using the relativistic variant of their effective orbital quantum number method, which utilizes a Coulomb potential in conjunction with a semi-empirical orbital quantum number which is determined from experimental energy levels.

Multiplet $f$-values calculated by Biemont[5] using a fully variational Hartree-Fock approach are quoted for numerous transitions $nl$–$n'l'$ ($3 \leqslant n \leqslant 5$; $4 \leqslant n' \leqslant 8$; $l, l' = s,p,d,f$). Data for additional transitions (namely, those for which $n > 5$, where $n$ is the principal quantum number of the lower state) can be found in Ref. 5. Whenever wavelengths of individual lines within a multiplet either were available directly or could be determined from the energy levels, the multiplet strength was distributed among the lines according to $LS$-coupling rules, except in cases where the wavelengths of all the lines in the multiplet are identical. The strength of the $3p\ ^2P^\circ - 4s\ ^2S$ multiplet was not distributed between the two lines in the multiplet, however, since the relativistic single-configuration Hartree-Fock calculations of Kim and Cheng[6] indicate that in the corresponding transition in sodiumlike iron the ratio of the two line strengths deviates somewhat from the value that would be obtained in the case of pure $LS$ coupling.

Transitions with small $f$-values were generally assigned lower accuracy ratings.

## References


[1] Y.-K. Kim and J.-P. Desclaux, Argonne National Laboratory Report ANL–76–88, Part I (1976).

[2] B. Edlen, Phys. Scr. **17**, 565 (1978).

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[4] P. F. Gruzdev and A. I. Sherstyuk, Opt. Spectrosc. (USSR) **46**, 353 (1979).

[5] E. Biemont, Astron. Astrophys., Suppl. Ser. **31**, 285 (1978).

[6] Y.-K. Kim and K.-T. Cheng, J. Opt. Soc. Am. **68**, 836 (1978).

V XIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm⁻¹) | $E_k$ (cm⁻¹) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s⁻¹) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 3*s*-3*p* | $^2$S - $^2$P° | *429.39* | 0 | *232890* | 2 | 6 | 54.2 | 0.449 | 1.27 | −0.047 | B | 1 |
| | | | 422.71 | 0 | 236570 | 2 | 4 | 56.9 | 0.305 | 0.849 | −0.215 | B | 1 |
| | | | 443.40 | 0 | 225530 | 2 | 2 | 49.0 | 0.145 | 0.422 | −0.539 | B | 1 |
| 2. | 3*s*-4*p* | $^2$S - $^2$P° | *71.870* | 0 | *1391410* | 2 | 6 | 803 | 0.187 | 0.0883 | −0.428 | B | 1 |
| | | | 71.794 | 0 | 1392860 | 2 | 4 | 790 | 0.122 | 0.0577 | −0.612 | B | 1 |
| | | | 72.019 | 0 | 1388520 | 2 | 2 | 830 | 0.0645 | 0.0306 | −0.889 | B | 1 |
| 3. | 3*s*-5*p* | $^2$S - $^2$P° | *52.899* | 0 | *1890400* | 2 | 6 | 480 | 0.061 | 0.021 | −0.91 | C | 5 |
| | | | 52.887 | 0 | 1890800 | 2 | 4 | 480 | 0.040 | 0.014 | −1.09 | C | *ls* |
| | | | 52.924 | 0 | 1889500 | 2 | 2 | 480 | 0.020 | 0.0070 | −1.40 | C | *ls* |
| 4. | 3*s*-6*p* | $^2$S - $^2$P° | *46.466* | 0 | *2152100* | 2 | 6 | 288 | 0.0280 | 0.0086 | −1.252 | C | 5 |
| | | | 46.460 | 0 | 2152400 | 2 | 4 | 290 | 0.019 | 0.0057 | −1.43 | C | *ls* |
| | | | 46.482 | 0 | 2151400 | 2 | 2 | 290 | 0.0095 | 0.0029 | −1.72 | D | *ls* |
| 5. | 3*s*-7*p* | $^2$S - $^2$P° | 43.371 | 0 | 2305700 | 2 | 6 | 183 | 0.0155 | 0.00443 | −1.51 | C | 5 |
| 6. | 3*s*-8*p* | $^2$S - $^2$P° | 41.596 | 0 | 2404100 | 2 | 6 | 120 | 0.0096 | 0.0026 | −1.72 | D | 5 |
| 7. | 3*p*-3*d* | $^2$P° - $^2$D | *319.95* | *232890* | *545440* | 6 | 10 | 134 | 0.343 | 2.17 | 0.314 | B | 2 |
| | | | 323.20 | 236570 | 545980 | 4 | 6 | 130 | 0.305 | 1.30 | 0.087 | B | 2 |
| | | | 313.37 | 225530 | 544640 | 2 | 4 | 119 | 0.350 | 0.723 | −0.154 | B | 2 |
| | | | [324.60] | 236570 | 544640 | 4 | 4 | 21.3 | 0.0337 | 0.144 | −0.870 | B | 2 |
| 8. | 3*p*-4*s* | $^2$P° - $^2$S | *93.668* | *232890* | 1300500 | 6 | 2 | 1600 | 0.068 | 0.13 | −0.39 | C | 5 |
| 9. | 3*p*-4*d* | $^2$P° - $^2$D | *78.561* | *232890* | *1505800* | 6 | 10 | 1680 | 0.259 | 0.402 | 0.191 | C | 5 |
| | | | 78.773 | 236570 | 1506100 | 4 | 6 | 1660 | 0.232 | 0.241 | −0.032 | C | *ls* |
| | | | 78.132 | 225530 | 1505400 | 2 | 4 | 1420 | 0.260 | 0.134 | −0.283 | C | *ls* |
| | | | 78.807 | 236570 | 1505400 | 4 | 4 | 280 | 0.026 | 0.027 | −0.98 | D | *ls* |
| 10. | 3*p*-5*s* | $^2$P° - $^2$S | *61.989* | *232890* | 1846100 | 6 | 2 | 690 | 0.0132 | 0.0162 | −1.101 | C | 5 |
| | | | 62.132 | 236570 | 1846100 | 4 | 2 | 456 | 0.0132 | 0.0108 | −1.277 | C | *ls* |
| | | | 61.705 | 225530 | 1846100 | 2 | 2 | 230 | 0.013 | 0.0054 | −1.58 | C | *ls* |
| 11. | 3*p*-5*d* | $^2$P° - $^2$D | *58.384* | *232890* | *1945700* | 6 | 10 | 1000 | 0.087 | 0.10 | −0.28 | C | 5 |
| | | | 58.505 | 236570 | 1945900 | 4 | 6 | 1000 | 0.078 | 0.060 | −0.51 | C | *ls* |
| | | | 58.139 | 225530 | 1945500 | 2 | 4 | 850 | 0.086 | 0.033 | −0.76 | C | *ls* |
| | | | [58.517] | 236570 | 1945500 | 4 | 4 | 170 | 0.0087 | 0.0067 | −1.46 | D | *ls* |
| 12. | 3*p*-6*s* | $^2$P° - $^2$S | *52.796* | *232890* | 2127000 | 6 | 2 | 370 | 0.0051 | 0.0053 | −1.51 | D | 5 |
| | | | [52.899] | 236570 | 2127000 | 4 | 2 | 240 | 0.0050 | 0.0035 | −1.70 | D | *ls* |
| | | | 52.590 | 225530 | 2127000 | 2 | 2 | 130 | 0.0052 | 0.0018 | −1.98 | D | *ls* |
| 13. | 3*p*-6*d* | $^2$P° - $^2$D | *51.282* | *232890* | *2182900* | 6 | 10 | 620 | 0.0406 | 0.0411 | −0.61 | C | 5 |
| | | | 51.376 | 236570 | 2183000 | 4 | 6 | 620 | 0.0365 | 0.0247 | −0.84 | C | *ls* |
| | | | 51.091 | 225530 | 2182800 | 2 | 4 | 520 | 0.0407 | 0.0137 | −1.089 | C | *ls* |
| | | | [51.382] | 236570 | 2182800 | 4 | 4 | 100 | 0.0040 | 0.0027 | −1.80 | D | *ls* |

V XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14. | 3p–7s | $^2$P° – $^2$S | *48.614* | *232890* | 2289900 | 6 | 2 | 220 | 0.0026 | 0.0025 | −1.81 | D | 5 |
| | | | 48.701 | 236570 | 2289900 | 4 | 2 | 150 | 0.0027 | 0.0017 | −1.97 | D | *ls* |
| | | | 48.441 | 225530 | 2289900 | 2 | 2 | 74 | 0.0026 | 8.3(−4)[a] | −2.28 | D | *ls* |
| 15. | 3p–7d | $^2$P° – $^2$D | *47.801* | *232890* | *2324900* | 6 | 10 | 396 | 0.0226 | 0.0213 | −0.87 | C | 5 |
| | | | 47.884 | 236570 | 2325000 | 4 | 6 | 394 | 0.0203 | 0.0128 | −1.090 | C | *ls* |
| | | | 47.637 | 225530 | 2324700 | 2 | 4 | 330 | 0.023 | 0.0071 | −1.34 | C | *ls* |
| | | | [47.890] | 236570 | 2324700 | 4 | 4 | 65 | 0.0022 | 0.0014 | −2.05 | D | *ls* |
| 16. | 3p–8s | $^2$P° – $^2$S | *46.316* | *232890* | 2392000 | 6 | 2 | 140 | 0.0015 | 0.0014 | −2.05 | D | 5 |
| | | | 46.395 | 236570 | 2392000 | 4 | 2 | 94 | 0.0015 | 9.3(−4) | −2.22 | D | *ls* |
| | | | 46.118 | 225530 | 2392000 | 2 | 2 | 49 | 0.0015 | 4.7(−4) | −2.51 | D | *ls* |
| 17. | 3p–8d | $^2$P° – $^2$D | *45.798* | *232890* | *2416400* | 6 | 10 | 267 | 0.0140 | 0.0127 | −1.076 | C | 5 |
| | | | 45.873 | 236570 | 2416500 | 4 | 6 | 270 | 0.013 | 0.0076 | −1.30 | C | *ls* |
| | | | 45.645 | 225530 | 2416300 | 2 | 4 | 225 | 0.0141 | 0.00423 | −1.55 | C | *ls* |
| | | | [45.878] | 236570 | 2416300 | 4 | 4 | 45 | 0.0014 | 8.5(−4) | −2.25 | D | *ls* |
| 18. | 3d–4p | $^2$D – $^2$P° | *118.21* | *545440* | *1391410* | 10 | 6 | 380 | 0.0478 | 0.186 | −0.321 | C | 5 |
| | | | 118.08 | 545980 | 1392860 | 6 | 4 | 345 | 0.0480 | 0.112 | −0.54 | C | *ls* |
| | | | 118.50 | 544640 | 1388520 | 4 | 2 | 380 | 0.040 | 0.062 | −0.80 | C | *ls* |
| | | | [117.89] | 544640 | 1392860 | 4 | 4 | 37 | 0.0077 | 0.012 | −1.51 | D | *ls* |
| 19. | 3d–4f | $^2$D – $^2$F° | *99.582* | *545440* | *1549600* | 10 | 14 | 4400 | 0.91 | 3.0 | 0.96 | C | 5 |
| | | | 99.625 | 545980 | 1549800 | 6 | 8 | 4400 | 0.86 | 1.7 | 0.71 | C | *ls* |
| | | | 99.523 | 544640 | 1549400 | 4 | 6 | 4100 | 0.92 | 1.2 | 0.56 | C | *ls* |
| | | | [99.661] | 545980 | 1549400 | 6 | 6 | 290 | 0.044 | 0.086 | −0.58 | D | *ls* |
| 20. | 3d–5p | $^2$D – $^2$P° | *74.349* | *545440* | *1890400* | 10 | 6 | 150 | 0.0074 | 0.018 | −1.13 | D | 5 |
| | | | 74.313 | 545980 | 1890800 | 6 | 4 | 140 | 0.0075 | 0.011 | −1.35 | D | *ls* |
| | | | [74.355] | 544640 | 1889500 | 4 | 2 | 150 | 0.0061 | 0.0060 | −1.61 | D | *ls* |
| | | | [74.283] | 544640 | 1890800 | 4 | 4 | 15 | 0.0012 | 0.0012 | −2.31 | E | *ls* |
| 21. | 3d–5f | $^2$D – $^2$F° | *70.299* | *545440* | *1967900* | 10 | 14 | 1650 | 0.171 | 0.396 | 0.233 | C | 5 |
| | | | 70.323 | 545980 | 1968000 | 6 | 8 | 1650 | 0.163 | 0.226 | −0.010 | C | *ls* |
| | | | 70.262 | 544640 | 1967800 | 4 | 6 | 1540 | 0.171 | 0.158 | −0.166 | C | *ls* |
| | | | [70.333] | 545980 | 1967800 | 6 | 6 | 110 | 0.0079 | 0.011 | −1.32 | D | *ls* |
| 22. | 3d–6p | $^2$D – $^2$P° | *62.239* | *545440* | *2152100* | 10 | 6 | 75 | 0.0026 | 0.0053 | −1.59 | D | 5 |
| | | | [62.251] | 545980 | 2152400 | 6 | 4 | 67 | 0.0026 | 0.0032 | −1.81 | D | *ls* |
| | | | [62.235] | 544640 | 2151400 | 4 | 2 | 76 | 0.0022 | 0.0018 | −2.06 | D | *ls* |
| | | | [62.197] | 544640 | 2152400 | 4 | 4 | 7.4 | 4.3(−4) | 3.5(−4) | −2.77 | E | *ls* |
| 23. | 3d–6f | $^2$D – $^2$F° | *60.621* | *545440* | *2195000* | 10 | 14 | 820 | 0.063 | 0.13 | −0.20 | C | 5 |
| | | | 60.640 | 545980 | 2195100 | 6 | 8 | 840 | 0.062 | 0.074 | −0.43 | C | *ls* |
| | | | 60.596 | 544640 | 2194900 | 4 | 6 | 790 | 0.065 | 0.052 | −0.58 | C | *ls* |
| | | | [60.646] | 545980 | 2194900 | 6 | 6 | 56 | 0.0031 | 0.0037 | −1.73 | D | *ls* |
| 24. | 3d–7p | $^2$D – $^2$P° | *56.808* | *545440* | 2305700 | 10 | 6 | 45 | 0.0013 | 0.0024 | −1.89 | D | 5 |
| | | | [56.828] | 545980 | 2305700 | 6 | 4 | 39 | 0.0012 | 0.0014 | −2.13 | D | *ls* |
| | | | [56.783] | 544640 | 2305700 | 4 | 2 | 44 | 0.0011 | 8.0(−4) | −2.37 | D | *ls* |
| | | | [56.783] | 544640 | 2305700 | 4 | 4 | 4.4 | 2.1(−4) | 1.6(−4) | −3.07 | E | *ls* |

V XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25. | 3d–7f | $^2$D – $^2$F° | *55.950* | *545440* | *2332700* | 10 | 14 | 476 | 0.0313 | 0.058 | −0.50 | C | 5 |
| | | | 55.967 | 545980 | 2332800 | 6 | 8 | 480 | 0.030 | 0.033 | −0.75 | C | *ls* |
| | | | 55.932 | 544640 | 2332500 | 4 | 6 | 440 | 0.031 | 0.023 | −0.90 | C | *ls* |
| | | | [55.975] | 545980 | 2332500 | 6 | 6 | 33 | 0.0015 | 0.0017 | −2.04 | D | *ls* |
| 26. | 3d–8p | $^2$D – $^2$P° | *53.801* | *545440* | 2404100 | 10 | 6 | 28 | 7.3(−4) | 0.0013 | −2.14 | E | 5 |
| | | | [53.818] | 545980 | 2404100 | 6 | 4 | 25 | 7.3(−4) | 7.8(−4) | −2.36 | E | *ls* |
| | | | [53.778] | 544640 | 2404100 | 4 | 2 | 28 | 6.1(−4) | 4.3(−4) | −2.61 | E | *ls* |
| | | | [53.778] | 544640 | 2404100 | 4 | 4 | 2.8 | 1.2(−4) | 8.7(−5) | −3.31 | E | *ls* |
| 27. | 3d–8f | $^2$D – $^2$F° | *53.302* | *545440* | *2421500* | 10 | 14 | 304 | 0.0181 | 0.0318 | −0.74 | C | 5 |
| | | | 53.318 | 545980 | 2421500 | 6 | 8 | 304 | 0.0173 | 0.0182 | −0.98 | C | *ls* |
| | | | 53.281 | 544640 | 2421400 | 4 | 6 | 284 | 0.0181 | 0.0127 | −1.140 | C | *ls* |
| | | | [53.322] | 545980 | 2421400 | 6 | 6 | 20 | 8.6(−4) | 9.1(−4) | −2.29 | E | *ls* |
| 28. | 4s–4p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.63 | | 0.10 | C | 5 |
| 29. | 4s–5p | $^2$S – $^2$P° | *169.5* | 1300500 | *1890400* | 2 | 6 | 157 | 0.203 | 0.227 | −0.391 | C | 5 |
| | | | [169.4] | 1300500 | 1890800 | 2 | 4 | 157 | 0.135 | 0.151 | −0.57 | C | *ls* |
| | | | [169.8] | 1300500 | 1889500 | 2 | 2 | 160 | 0.068 | 0.076 | −0.87 | C | *ls* |
| 30. | 4s–6p | $^2$S – $^2$P° | *117.4* | 1300500 | *2152100* | 2 | 6 | 110 | 0.066 | 0.051 | −0.88 | C | 5 |
| | | | [117.4] | 1300500 | 2152400 | 2 | 4 | 110 | 0.044 | 0.034 | −1.06 | C | *ls* |
| | | | [117.5] | 1300500 | 2151400 | 2 | 2 | 110 | 0.022 | 0.017 | −1.36 | C | *ls* |
| 31. | 4s–7p | $^2$S – $^2$P° | [99.483] | 1300500 | 2305700 | 2 | 6 | 70 | 0.0313 | 0.0205 | −1.203 | C | 5 |
| 32. | 4s–8p | $^2$S – $^2$P° | [90.613] | 1300500 | 2404100 | 2 | 6 | 47.9 | 0.0177 | 0.0106 | −1.451 | C | 5 |
| 33. | 4p–4d | $^2$P° – $^2$D | *874.1* | *1391410* | *1505800* | 6 | 10 | 26 | 0.50 | 8.6 | 0.48 | C | 4 |
| | | | [883.4] | 1392860 | 1506100 | 4 | 6 | 25 | 0.44 | 5.1 | 0.25 | C | 4 |
| | | | [855.4] | 1388520 | 1505400 | 2 | 4 | 23 | 0.51 | 2.9 | 0.01 | C | 4 |
| | | | [888.9] | 1392860 | 1505400 | 4 | 4 | 4.1 | 0.049 | 0.57 | −0.71 | C | 4 |
| 34. | 4p–5s | $^2$P° – $^2$S | *219.9* | *1391410* | 1846100 | 6 | 2 | 484 | 0.117 | 0.51 | −0.154 | C | 5 |
| | | | [220.7] | 1392860 | 1846100 | 4 | 2 | 320 | 0.12 | 0.34 | −0.33 | C | *ls* |
| | | | [218.5] | 1388520 | 1846100 | 2 | 2 | 170 | 0.12 | 0.17 | −0.63 | C | *ls* |
| 35. | 4p–5d | $^2$P° – $^2$D | *180.4* | *1391410* | *1945700* | 6 | 10 | 266 | 0.216 | 0.77 | 0.113 | C | 5 |
| | | | [180.8] | 1392860 | 1945900 | 4 | 6 | 260 | 0.19 | 0.46 | −0.11 | C | *ls* |
| | | | [179.5] | 1388520 | 1945500 | 2 | 4 | 230 | 0.22 | 0.26 | −0.36 | C | *ls* |
| | | | [181.0] | 1392860 | 1945500 | 4 | 4 | 44 | 0.021 | 0.051 | −1.07 | D | *ls* |
| 36. | 4p–6s | $^2$P° – $^2$S | *135.9* | *1391410* | 2127000 | 6 | 2 | 245 | 0.0226 | 0.061 | −0.87 | C | 5 |
| | | | [136.2] | 1392860 | 2127000 | 4 | 2 | 160 | 0.023 | 0.041 | −1.04 | C | *ls* |
| | | | [135.4] | 1388520 | 2127000 | 2 | 2 | 82 | 0.022 | 0.020 | −1.35 | C | *ls* |
| 37. | 4p–6d | $^2$P° – $^2$D | *126.3* | *1391410* | *2182900* | 6 | 10 | 200 | 0.078 | 0.19 | −0.33 | C | 5 |
| | | | [126.6] | 1392860 | 2183000 | 4 | 6 | 180 | 0.066 | 0.11 | −0.58 | C | *ls* |
| | | | [125.9] | 1388520 | 2182800 | 2 | 4 | 160 | 0.076 | 0.063 | −0.82 | C | *ls* |
| | | | [126.6] | 1392860 | 2182800 | 4 | 4 | 32 | 0.0078 | 0.013 | −1.51 | D | *ls* |

V XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38. | 4p–7s | $^2$P° – $^2$S | *111.3* | *1391410* | 2289900 | 6 | 2 | 140 | 0.0088 | 0.019 | −1.28 | D | 5 |
| | | | [111.5] | 1392860 | 2289900 | 4 | 2 | 95 | 0.0089 | 0.013 | −1.45 | D | *ls* |
| | | | [110.9] | 1388520 | 2289900 | 2 | 2 | 47 | 0.0086 | 0.0063 | −1.76 | D | *ls* |
| 39. | 4p–7d | $^2$P° – $^2$D | *107.1* | *1391410* | *2324900* | 6 | 10 | 134 | 0.0383 | 0.081 | −0.64 | C | 5 |
| | | | [107.3] | 1392860 | 2325000 | 4 | 6 | 130 | 0.035 | 0.049 | −0.86 | C | *ls* |
| | | | [106.8] | 1388520 | 2324700 | 2 | 4 | 110 | 0.038 | 0.027 | −1.11 | C | *ls* |
| | | | [107.3] | 1392860 | 2324700 | 4 | 4 | 22 | 0.0038 | 0.0054 | −1.82 | D | *ls* |
| 40. | 4p–8s | $^2$P° – $^2$S | *99.940* | *1391410* | 2392000 | 6 | 2 | 90 | 0.0045 | 0.0089 | −1.57 | D | 5 |
| | | | [100.1] | 1392860 | 2392000 | 4 | 2 | 60 | 0.0045 | 0.0059 | −1.75 | D | *ls* |
| | | | [99.651] | 1388520 | 2392000 | 2 | 2 | 31 | 0.0046 | 0.0030 | −2.04 | D | *ls* |
| 41. | 4p–8d | $^2$P° – $^2$D | *97.561* | *1391410* | *2416400* | 6 | 10 | 93 | 0.0220 | 0.0424 | −0.88 | C | 5 |
| | | | [97.694] | 1392860 | 2416500 | 4 | 6 | 92 | 0.0197 | 0.0254 | −1.103 | C | *ls* |
| | | | [97.295] | 1388520 | 2416300 | 2 | 4 | 78 | 0.0220 | 0.0141 | −1.356 | C | *ls* |
| | | | [97.714] | 1392860 | 2416300 | 4 | 4 | 15 | 0.0022 | 0.0028 | −2.06 | D | *ls* |
| 42. | 4d–4f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.126 | | 0.100 | C | 5 |
| 43. | 4d–5p | $^2$D – $^2$P° | *260.0* | *1505800* | *1890400* | 10 | 6 | 173 | 0.105 | 0.90 | 0.021 | C | 5 |
| | | | [259.9] | 1506100 | 1890800 | 6 | 4 | 160 | 0.11 | 0.54 | −0.20 | C | *ls* |
| | | | [260.3] | 1505400 | 1889500 | 4 | 2 | 170 | 0.088 | 0.30 | −0.46 | C | *ls* |
| | | | [259.5] | 1505400 | 1890800 | 4 | 4 | 17 | 0.018 | 0.060 | −1.15 | D | *ls* |
| 44. | 4d–5f | $^2$D – $^2$F° | *216.4* | *1505800* | *1967900* | 10 | 14 | 720 | 0.71 | 5.1 | 0.85 | C | 5 |
| | | | [216.5] | 1506100 | 1968000 | 6 | 8 | 720 | 0.68 | 2.9 | 0.61 | C | *ls* |
| | | | [216.3] | 1505400 | 1967800 | 4 | 6 | 670 | 0.70 | 2.0 | 0.45 | C | *ls* |
| | | | [216.6] | 1506100 | 1967800 | 6 | 6 | 50 | 0.035 | 0.15 | −0.68 | D | *ls* |
| 45. | 4d–6p | $^2$D – $^2$P° | *154.7* | *1505800* | *2152100* | 10 | 6 | 80 | 0.0173 | 0.088 | −0.76 | C | 5 |
| | | | [154.7] | 1506100 | 2152400 | 6 | 4 | 73 | 0.017 | 0.053 | −0.98 | C | *ls* |
| | | | [154.8] | 1505400 | 2151400 | 4 | 2 | 79 | 0.014 | 0.029 | −1.24 | C | *ls* |
| | | | [154.6] | 1505400 | 2152400 | 4 | 4 | 8.1 | 0.0029 | 0.0059 | −1.94 | D | *ls* |
| 46. | 4d–6f | $^2$D – $^2$F° | *145.1* | *1505800* | *2195000* | 10 | 14 | 401 | 0.177 | 0.85 | 0.248 | C | 5 |
| | | | [145.1] | 1506100 | 2195100 | 6 | 8 | 410 | 0.17 | 0.49 | 0.01 | C | *ls* |
| | | | [145.0] | 1505400 | 2194900 | 4 | 6 | 380 | 0.18 | 0.34 | −0.15 | C | *ls* |
| | | | [145.2] | 1506100 | 2194900 | 6 | 6 | 26 | 0.0084 | 0.024 | −1.30 | D | *ls* |
| 47. | 4d–7p | $^2$D – $^2$P° | *125.0* | *1505800* | 2305700 | 10 | 6 | 45 | 0.0063 | 0.026 | −1.20 | D | 5 |
| | | | [125.1] | 1506100 | 2305700 | 6 | 4 | 41 | 0.0065 | 0.016 | −1.41 | D | *ls* |
| | | | [125.0] | 1505400 | 2305700 | 4 | 2 | 45 | 0.0053 | 0.0087 | −1.67 | D | *ls* |
| | | | [125.0] | 1505400 | 2305700 | 4 | 4 | 4.4 | 0.0010 | 0.0017 | −2.38 | E | *ls* |
| 48. | 4d–7f | $^2$D – $^2$F° | *120.9* | *1505800* | *2332700* | 10 | 14 | 240 | 0.074 | 0.29 | −0.13 | C | 5 |
| | | | [121.0] | 1506100 | 2332800 | 6 | 8 | 240 | 0.071 | 0.17 | −0.37 | C | *ls* |
| | | | [120.9] | 1505400 | 2332500 | 4 | 6 | 230 | 0.075 | 0.12 | −0.52 | C | *ls* |
| | | | [121.0] | 1506100 | 2332500 | 6 | 6 | 16 | 0.0035 | 0.0083 | −1.68 | D | *ls* |

V XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49. | $4d$–$8p$ | $^2$D - $^2$P° | *111.3* | *1505800* | 2404100 | 10 | 6 | 28 | 0.0031 | 0.011 | −1.51 | D | 5 |
| | | | [111.4] | 1506100 | 2404100 | 6 | 4 | 24 | 0.0030 | 0.0066 | −1.74 | D | *ls* |
| | | | [111.3] | 1505400 | 2404100 | 4 | 2 | 27 | 0.0025 | 0.0037 | −2.00 | D | *ls* |
| | | | [111.3] | 1505400 | 2404100 | 4 | 4 | 2.7 | 5.0(−4) | 7.3(−4) | −2.70 | E | *ls* |
| 50. | $4d$–$8f$ | $^2$D - $^2$F° | *109.2* | *1505800* | *2421500* | 10 | 14 | 156 | 0.0390 | 0.140 | −0.409 | C | 5 |
| | | | [109.2] | 1506100 | 2421500 | 6 | 8 | 160 | 0.037 | 0.080 | −0.65 | C | *ls* |
| | | | [109.2] | 1505400 | 2421400 | 4 | 6 | 150 | 0.039 | 0.056 | −0.81 | C | *ls* |
| | | | [109.3] | 1506100 | 2421400 | 6 | 6 | 10 | 0.0019 | 0.0040 | −1.95 | D | *ls* |
| 51. | $4f$–$5d$ | $^2$F° - $^2$D | *252.5* | *1549600* | *1945700* | 14 | 10 | 30.2 | 0.0206 | 0.240 | −0.54 | C | 5 |
| | | | [252.5] | 1549800 | 1945900 | 8 | 6 | 28.7 | 0.0206 | 0.137 | −0.78 | C | *ls* |
| | | | [252.5] | 1549400 | 1945500 | 6 | 4 | 30 | 0.019 | 0.096 | −0.94 | C | *ls* |
| | | | [252.2] | 1549400 | 1945900 | 6 | 6 | 1.5 | 0.0014 | 0.0069 | −2.08 | D | *ls* |
| 52. | $4f$–$6d$ | $^2$F° - $^2$D | *157.9* | *1549600* | *2182900* | 14 | 10 | 13 | 0.0034 | 0.025 | −1.32 | D | 5 |
| | | | [157.9] | 1549800 | 2183000 | 8 | 6 | 12 | 0.0034 | 0.014 | −1.57 | D | *ls* |
| | | | [157.9] | 1549400 | 2182800 | 6 | 4 | 13 | 0.0032 | 0.010 | −1.72 | D | *ls* |
| | | | [157.8] | 1549400 | 2183000 | 6 | 6 | 0.61 | 2.3(−4) | 7.1(−4) | −2.86 | E | *ls* |
| 53. | $4f$–$7d$ | $^2$F° - $^2$D | *129.0* | *1549600* | *2324900* | 14 | 10 | 6.7 | 0.0012 | 0.0071 | −1.77 | D | 5 |
| | | | [129.0] | 1549800 | 2325000 | 8 | 6 | 6.4 | 0.0012 | 0.0041 | −2.02 | D | *ls* |
| | | | [129.0] | 1549400 | 2324700 | 6 | 4 | 6.6 | 0.0011 | 0.0028 | −2.18 | D | *ls* |
| | | | [128.9] | 1549400 | 2325000 | 6 | 6 | 0.32 | 7.9(−5) | 2.0(−4) | −3.33 | E | *ls* |
| 54. | $4f$–$8d$ | $^2$F° - $^2$D | *115.4* | *1549600* | *2416400* | 14 | 10 | 4.1 | 5.9(−4) | 0.0031 | −2.08 | E | 5 |
| | | | [115.4] | 1549800 | 2416500 | 8 | 6 | 4.0 | 5.9(−4) | 0.0018 | −2.32 | E | *ls* |
| | | | [115.4] | 1549400 | 2416300 | 6 | 4 | 4.0 | 5.3(−4) | 0.0012 | −2.50 | E | *ls* |
| | | | [115.3] | 1549400 | 2416500 | 6 | 6 | 0.20 | 3.9(−5) | 8.9(−5) | −3.63 | E | *ls* |
| 55. | $5s$–$5p$ | $^2$S - $^2$P° | | | | 2 | 6 | | 0.82 | | 0.21 | C | 5 |
| 56. | $5s$–$6p$ | $^2$S - $^2$P° | *326.8* | 1846100 | *2152100* | 2 | 6 | 45.2 | 0.217 | 0.467 | −0.363 | C | 5 |
| | | | [326.5] | 1846100 | 2152400 | 2 | 4 | 45.3 | 0.145 | 0.311 | −0.54 | C | *ls* |
| | | | [327.5] | 1846100 | 2151400 | 2 | 2 | 45.0 | 0.072 | 0.156 | −0.84 | C | *ls* |
| 57. | $5s$–$7p$ | $^2$S - $^2$P° | [217.6] | 1846100 | 2305700 | 2 | 6 | 34 | 0.072 | 0.10 | −0.84 | C | 5 |
| 58. | $5s$–$8p$ | $^2$S - $^2$P° | [179.2] | 1846100 | 2404100 | 2 | 6 | 23.7 | 0.0342 | 0.0404 | −1.165 | C | 5 |
| 59. | $5p$–$5d$ | $^2$P° - $^2$D | | | | 6 | 10 | | 0.71 | | 0.63 | C | 5 |
| 60. | $5p$–$6s$ | $^2$P° - $^2$S | *422.7* | *1890400* | 2127000 | 6 | 2 | 187 | 0.167 | 1.39 | 0.001 | C | 5 |
| | | | [423.4] | 1890800 | 2127000 | 4 | 2 | 120 | 0.17 | 0.93 | −0.18 | C | *ls* |
| | | | [421.1] | 1889500 | 2127000 | 2 | 2 | 63 | 0.167 | 0.463 | −0.476 | C | *ls* |
| 61. | $5p$–$6d$ | $^2$P° - $^2$D | *341.9* | *1890400* | *2182900* | 6 | 10 | 68 | 0.198 | 1.34 | 0.075 | C | 5 |
| | | | [342.2] | 1890800 | 2183000 | 4 | 6 | 67 | 0.18 | 0.80 | −0.15 | C | *ls* |
| | | | [340.9] | 1889500 | 2182800 | 2 | 4 | 57 | 0.199 | 0.447 | −0.400 | C | *ls* |
| | | | [342.5] | 1890800 | 2182800 | 4 | 4 | 11 | 0.020 | 0.089 | −1.10 | D | *ls* |

V XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 62. | 5p–7s | $^2P^o - {}^2S$ | *250.3* | *1890400* | 2289900 | 6 | 2 | 103 | 0.0321 | 0.159 | −0.72 | C | 5 |
| | | | [250.6] | 1890800 | 2289900 | 4 | 2 | 68 | 0.0321 | 0.106 | −0.89 | C | *ls* |
| | | | [249.8] | 1889500 | 2289900 | 2 | 2 | 34 | 0.032 | 0.053 | −1.19 | C | *ls* |
| 63. | 5p–7d | $^2P^o - {}^2D$ | *230.1* | *1890400* | *2324900* | 6 | 10 | 56 | 0.074 | 0.34 | −0.35 | C | 5 |
| | | | [230.3] | 1890800 | 2325000 | 4 | 6 | 55 | 0.066 | 0.20 | −0.58 | C | *ls* |
| | | | [229.8] | 1889500 | 2324700 | 2 | 4 | 46 | 0.073 | 0.11 | −0.84 | C | *ls* |
| | | | [230.5] | 1890800 | 2324700 | 4 | 4 | 9.5 | 0.0076 | 0.023 | −1.52 | D | *ls* |
| 64. | 5p–8s | $^2P^o - {}^2S$ | *199.4* | *1890400* | 2392000 | 6 | 2 | 63 | 0.0125 | 0.0492 | −1.125 | C | 5 |
| | | | [199.5] | 1890800 | 2392000 | 4 | 2 | 41.8 | 0.0125 | 0.0328 | −1.302 | C | *ls* |
| | | | [199.0] | 1889500 | 2392000 | 2 | 2 | 21.1 | 0.0125 | 0.0164 | −1.60 | C | *ls* |
| 65. | 5p–8d | $^2P^o - {}^2D$ | *190.1* | *1890400* | *2416400* | 6 | 10 | 41.0 | 0.0370 | 0.139 | −0.65 | C | 5 |
| | | | [190.2] | 1890800 | 2416500 | 4 | 6 | 41 | 0.033 | 0.083 | −0.88 | C | *ls* |
| | | | [189.8] | 1889500 | 2416300 | 2 | 4 | 34.3 | 0.0370 | 0.0463 | −1.130 | C | *ls* |
| | | | [190.3] | 1890800 | 2416300 | 4 | 4 | 6.8 | 0.0037 | 0.0093 | −1.83 | D | *ls* |
| 66. | 5d–5f | $^2D - {}^2F^o$ | | | | 10 | 14 | | 0.222 | | 0.346 | C | 5 |
| 67. | 5d–6p | $^2D - {}^2P^o$ | *484.5* | *1945700* | *2152100* | 10 | 6 | 79 | 0.167 | 2.66 | 0.223 | C | 5 |
| | | | [484.3] | 1945900 | 2152400 | 6 | 4 | 71 | 0.167 | 1.60 | 0.002 | C | *ls* |
| | | | [485.7] | 1945500 | 2151400 | 4 | 2 | 79 | 0.14 | 0.89 | −0.25 | C | *ls* |
| | | | [483.3] | 1945500 | 2152400 | 4 | 4 | 8.1 | 0.028 | 0.18 | −0.95 | D | *ls* |
| 68. | 5d–6f | $^2D - {}^2F^o$ | *401.1* | *1945700* | *2195000* | 10 | 14 | 180 | 0.62 | 8.2 | 0.79 | C | 5 |
| | | | [401.3] | 1945900 | 2195100 | 6 | 8 | 180 | 0.59 | 4.7 | 0.55 | C | *ls* |
| | | | [401.0] | 1945500 | 2194900 | 4 | 6 | 170 | 0.62 | 3.3 | 0.40 | C | *ls* |
| | | | [401.6] | 1945900 | 2194900 | 6 | 6 | 12 | 0.029 | 0.23 | −0.76 | D | *ls* |
| 69. | 5d–7p | $^2D - {}^2P^o$ | *277.8* | *1945700* | 2305700 | 10 | 6 | 40.5 | 0.0281 | 0.257 | −0.55 | C | 5 |
| | | | [277.9] | 1945900 | 2305700 | 6 | 4 | 36.3 | 0.0281 | 0.154 | −0.77 | C | *ls* |
| | | | [277.6] | 1945500 | 2305700 | 4 | 2 | 41 | 0.024 | 0.086 | −1.03 | C | *ls* |
| | | | [277.6] | 1945500 | 2305700 | 4 | 4 | 4.0 | 0.0047 | 0.017 | −1.73 | D | *ls* |
| 70. | 5d–7f | $^2D - {}^2F^o$ | *258.4* | *1945700* | *2332700* | 10 | 14 | 123 | 0.173 | 1.47 | 0.238 | C | 5 |
| | | | [258.5] | 1945900 | 2332800 | 6 | 8 | 120 | 0.16 | 0.84 | −0.01 | C | *ls* |
| | | | [258.4] | 1945500 | 2332500 | 4 | 6 | 120 | 0.17 | 0.59 | −0.16 | C | *ls* |
| | | | [258.7] | 1945900 | 2332500 | 6 | 6 | 8.2 | 0.0082 | 0.042 | −1.31 | D | *ls* |
| 71. | 5d–8p | $^2D - {}^2P^o$ | *218.2* | *1945700* | 2404100 | 10 | 6 | 24.3 | 0.0104 | 0.075 | −0.98 | C | 5 |
| | | | [218.2] | 1945900 | 2404100 | 6 | 4 | 22 | 0.010 | 0.045 | −1.20 | C | *ls* |
| | | | [218.1] | 1945500 | 2404100 | 4 | 2 | 24 | 0.0087 | 0.025 | −1.46 | D | *ls* |
| | | | [218.1] | 1945500 | 2404100 | 4 | 4 | 2.4 | 0.0017 | 0.0050 | −2.16 | D | *ls* |
| 72. | 5d–8f | $^2D - {}^2F^o$ | *210.2* | *1945700* | *2421500* | 10 | 14 | 82 | 0.076 | 0.53 | −0.12 | C | 5 |
| | | | [210.3] | 1945900 | 2421500 | 6 | 8 | 82 | 0.072 | 0.30 | −0.36 | C | *ls* |
| | | | [210.1] | 1945500 | 2421400 | 4 | 6 | 76 | 0.076 | 0.21 | −0.52 | C | *ls* |
| | | | [210.3] | 1945900 | 2421400 | 6 | 6 | 5.4 | 0.0036 | 0.015 | −1.66 | D | *ls* |

V XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73. | $5f$–$6d$ | $^2$F° - $^2$D | *465.1* | *1967900* | *2182900* | 14 | 10 | 22 | 0.050 | 1.1 | −0.15 | C | 5 |
| | | | [465.1] | 1968000 | 2183000 | 8 | 6 | 21 | 0.051 | 0.63 | −0.39 | C | *ls* |
| | | | [465.1] | 1967800 | 2182800 | 6 | 4 | 22 | 0.048 | 0.44 | −0.54 | C | *ls* |
| | | | [464.7] | 1967800 | 2183000 | 6 | 6 | 1.0 | 0.0034 | 0.031 | −1.69 | D | *ls* |
| 74. | $5f$–$7d$ | $^2$F° - $^2$D | *280.1* | *1967900* | *2324900* | 14 | 10 | 10 | 0.0088 | 0.11 | −0.91 | D | 5 |
| | | | [280.1] | 1968000 | 2325000 | 8 | 6 | 9.7 | 0.0085 | 0.063 | −1.17 | D | *ls* |
| | | | [280.2] | 1967800 | 2324700 | 6 | 4 | 10 | 0.0079 | 0.044 | −1.32 | D | *ls* |
| | | | [280.0] | 1967800 | 2325000 | 6 | 6 | 0.48 | 5.6(−4) | 0.0031 | −2.47 | E | *ls* |
| 75. | $5f$–$8d$ | $^2$F° - $^2$D | *223.0* | *1967900* | *2416400* | 14 | 10 | 6.0 | 0.0032 | 0.033 | −1.35 | D | 5 |
| | | | [223.0] | 1968000 | 2416500 | 8 | 6 | 5.8 | 0.0032 | 0.019 | −1.59 | D | *ls* |
| | | | [223.0] | 1967800 | 2416300 | 6 | 4 | 5.9 | 0.0030 | 0.013 | −1.75 | D | *ls* |
| | | | [222.9] | 1967800 | 2416500 | 6 | 6 | 0.29 | 2.1(−4) | 9.4(−4) | −2.89 | E | *ls* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XIII

## Forbidden Transitions

The electric quadrupole $gf$-values for the $3s$–$3d$ multiplet in this sodiumlike ion was reported by Godefroid *et al.*;[1] it was calculated earlier by Biemont and Godefroid[2] using a fully variational Hartree-Fock approach. This $f$-value was converted to a multiplet strength, which was then distributed between the two lines of the multiplet according to $LS$-coupling rules.

### References


[1]M. Godefroid, C. E. Magnusson, P. O. Zetterberg, and I. Joelsson, Phys. Scr. **32**, 125 (1985).

[2]E. Biemont and M. Godefroid, Phys. Scr. **18**, 323 (1978).


V XIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s$–$3d$ | $^2$S - $^2$D | | | | | | | | | | |
| | | | [183.16] | 0 | 545980 | 2 | 6 | E2 | 4.89(+5)[a] | 0.360 | C | 1,*ls* |
| | | | [183.61] | 0 | 544640 | 2 | 4 | E2 | 4.83(+5) | 0.240 | C | 1,*ls* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XIV

Ne Isoelectronic Sequence

Ground State: $1s^22s^22p^6\ ^1S_0$

Ionization Energy: 896.0 eV = 7227000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 20.716 | 9 | 109 | 3 | 315 | 13 | 351 | 14 |
| 21.018 | 8 | 110 | 3 | 326 | 13 | 437.539 | 11 |
| 21.294 | 7 | 112 | 4 | 331 | 13 | 441 | 16 |
| 23.490 | 6 | 116 | 1 | 343.727 | 15 | 506 | 10 |
| 23.794 | 5 | 126 | 2 | 347 | 17 | 719 | 12 |

For resonance transitions to $J = 1$ levels of the $2p^53s$ and $2p^53d$ configurations, we quote $A$-values which were calculated by Vainshtein and Safronova[1] using a charge-expansion perturbation theory approach with allowance for mixing of the $2p^53s$, $2p^53d$, and $2s2p^63p$ configurations. Their results for the $2p^6$–$2p^53d$ transitions in the isoelectronic ions Ar IX and Fe XVII are in rather good agreement with those of Shorer,[2] who used the relativistic random phase approximation (RRPA) with allowance for mixing between configurations of type $2p^5ns$ and $2p^5nd$, as well as correlation effects due to configurations having a vacancy in the 1s or 2s subshell. But the data of Ref. 1 for the two $2p^6$–$2p^53s$ transitions are approximately a factor of two smaller than those of Shorer for the abovementioned neonlike species, so we have increased the transition probabilities of Ref. 1 for these two lines by a factor of two.

$A$-values quoted here for a number of transitions involving an electron jump of the type $2s$–$2p$, $3s$–$3p$, or $3p$–$3d$ were taken from the work of Pokleba and Safronova,[3] who used wavefunctions calculated by a charge-expansion perturbation theory approach with allowance for mixing of configurations in which a single 2s or 2p electron is excited to an $n = 3$ orbital but with no inclusion of configurations in which an electron occupies the $n = 4$ shell. In cases where better wavelength data were available, these transition probabilities were first converted to line strengths, which were then reconverted to $f$- and $A$-values by using the more accurate wavelengths. Transitions involving levels of the $2p^53p$ and $2p^53d$ configurations which are indicated by Fawcett[4] (in Ti XII) or by Jupen and Litzen[5] (in Ti XII or Fe XVII) to be of low to moderate purity in $LS$ coupling are excluded here, as are very weak lines. The pattern of levels within the $2s2p^63d$ configuration in the isoelectronic ions Fe XVII and Ni XIX resulting from the scaled Thomas-Fermi calculations of Loulergue and Nussbaumer[6] with extensive allowance for correlation is entirely different from that determined by Vainshtein and Safronova, whose energy levels were apparently used by Pokleba and Safronova in their transition probability calculations. We have thus excluded transitions out of these levels from our tabulation.

### References


[1] L. A. Vainshtein and U. I. Safronova, *Spektroskopicheskie Konstanty Atomov*, 5-122 (Ed. V. B. Belyanin, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Nauch. Sov. Spektrosk., Moscow, 1977).

[2] P. Shorer, Phys. Rev. A **20**, 642 (1979).

[3] A. K. Pokleba and U. I. Safronova, Preprint No. 11, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Inst. Spektrosk. (Moscow, 1981).

[4] B. C. Fawcett, private communication, as quoted in E. Träbert, Z. Phys. A **319**, 25 (1984).

[5] C. Jupen and U. Litzen, Phys. Scr. **30**, 112 (1984).

[6] M. Loulergue and H. Nussbaumer, Astron. Astrophys. **45**, 125 (1975).

V XIV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5(^2P^\circ_{3/2})3s-2s2p^63s$ | $(^3/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | [116] | | | 5 | 3 | 550 | 0.067 | 0.13 | −0.48 | E | 3 |
| 2. | $2s^22p^5(^2P^\circ_{1/2})3s-2s2p^63s$ | $(^1/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | [126] | | | 3 | 3 | 120 | 0.029 | 0.036 | −1.07 | D− | 3 |
| 3. | $2s^22p^53p-2s2p^63p$ | $^3S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [109] | | | 3 | 3 | 150 | 0.027 | 0.029 | −1.10 | E | 3 |
| | | | [110] | | | 3 | 1 | 320 | 0.019 | 0.021 | −1.24 | D | 3 |
| 4. | | $^3D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [112] | | | 7 | 5 | 480 | 0.064 | 0.17 | −0.35 | D | 3 |
| 5. | $2p^6-2p^5(^2P^\circ_{3/2})3s$ | $^1S - (^3/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 23.794 | 0 | 4202700 | 1 | 3 | 4200 | 0.107 | 0.0084 | −0.97 | C− | 1*n* |
| 6. | $2p^6-2p^5(^2P^\circ_{1/2})3s$ | $^1S - (^1/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 23.490 | 0 | 4257100 | 1 | 3 | 4960 | 0.123 | 0.0095 | −0.91 | C− | 1*n* |
| 7. | $2p^6-2p^53d$ | $^1S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | 21.294 | 0 | 4696200 | 1 | 3 | 470 | 0.0096 | 6.7(−4)[a] | −2.02 | E | 1 |
| 8. | | $^1S - {}^3D^\circ$ | | | | | | | | | | | |
| | | | 21.018 | 0 | 4757800 | 1 | 3 | 1.9(+4) | 0.38 | 0.026 | −0.42 | D | 1 |
| 9. | | $^1S - {}^1P^\circ$ | 20.716 | 0 | 4827200 | 1 | 3 | 1.30(+5) | 2.51 | 0.171 | 0.400 | C− | 1 |
| 10. | $2p^5(^2P^\circ_{3/2})3s-2p^53p$ | $(^3/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | [506] | | | 5 | 3 | 21 | 0.048 | 0.40 | −0.62 | D | 3 |
| 11. | | $(^3/_2,^1/_2)^\circ - {}^3D$ | | | | | | | | | | | |
| | | | 437.539 | | | 5 | 7 | 38 | 0.15 | 1.1 | −0.12 | D | 3 |
| 12. | $2p^5(^2P^\circ_{1/2})3s-2p^53p$ | $(^1/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | [719] | | | 1 | 3 | 0.23 | 0.0053 | 0.013 | −2.27 | E | 3 |
| 13. | $2p^53p-2p^53d$ | $^3S - {}^3P^\circ$ | *320* | | | 3 | 9 | 51 | 0.23 | 0.74 | −0.15 | E | 3 |
| | | | [315] | | | 3 | 5 | 39 | 0.097 | 0.30 | −0.54 | E | 3 |
| | | | [326] | | | 3 | 3 | 60 | 0.096 | 0.31 | −0.54 | D | 3 |
| | | | [331] | | | 3 | 1 | 70 | 0.038 | 0.13 | −0.94 | D | 3 |
| 14. | | $^3D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [351] | | | 7 | 5 | 3.0 | 0.0040 | 0.032 | −1.56 | E | 3 |

V XIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | | $^3D - ^3F^\circ$ | | | | | | | | | | | |
| | | | 343.727 | | | 7 | 9 | 72 | 0.16 | 1.3 | 0.06 | D | 3 |
| 16. | | $^3P - ^3P^\circ$ | | | | | | | | | | | |
| | | | [441] | | | 1 | 3 | 1.8 | 0.016 | 0.023 | −1.80 | D− | 3 |
| 17. | | $^3P - ^3D^\circ$ | | | | | | | | | | | |
| | | | [347] | | | 1 | 3 | 36 | 0.19 | 0.22 | −0.71 | D | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XV

F Isoelectronic Sequence

Ground State: $1s^22s^22p^5\ ^2P^\circ_{3/2}$

Ionization Energy: 976 eV = 7870000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 18.991 | 11 | 19.443 | 7 | 19.888 | 6 | 21.832 | 4 |
| 19.028 | 11 | 19.45 | 8 | 21.019 | 5 | 22.083 | 3 |
| 19.203 | 11 | 19.518 | 10 | 21.285 | 5 | 22.192 | 2 |
| 19.298 | 10 | 19.589 | 9 | 21.568 | 4 | 113.930 | 1 |
| 19.368 | 9 | 19.671 | 7 | 21.800 | 3 | 122.005 | 1 |

Oscillator strengths for lines of the multiplet $2s^22p^5\ ^2P^\circ - 2s2p^6\ ^2S$ are the results of the Dirac-Fock calculations of Cheng *et al.*,[1] which included a perturbative treatment of the Breit interaction and the Lamb shift. calculations of Cheng *et al.*,[1] which included a perturbative treatment of the Breit interaction and the Lamb shift.

For lines of the arrays $2p^5$–$2p^43s$ and $2p^5$–$2p^43d$, we quote the $f$-values calculated by Fawcett[2] using Cowan's Hartree-Fock-Relativistic (HFR) method and incorporating scaling of energy parameters on the basis of a least-squares fit to observed energies. Fawcett's calculations included fairly extensive allowance for configuration mixing in both odd- and even-parity states. Transitions involving levels which are indicated by Fawcett to be of low to moderate purity in *LS* coupling are excluded from this compilation, as are lines characterized by very small $f$-values.

### References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]B. C. Fawcett, At. Data Nucl. Data Tables **31**, 495 (1984).

V xv: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5$–$2s2p^6$ | $^2P^\circ$ – $^2S$ | *116.50* | *19387* | 877732 | 6 | 2 | 967 | 0.0656 | 0.151 | −0.405 | C+ | 1 |
| | | | 113.930 | 0 | 877732 | 4 | 2 | 690 | 0.0671 | 0.101 | −0.571 | C+ | 1 |
| | | | 122.005 | 58160 | 877732 | 2 | 2 | 277 | 0.0618 | 0.0496 | −0.908 | C+ | 1 |
| 2. | $2p^5$–$2p^4(^3P)3s$ | $^2P^\circ$ – $^4P$ | | | | | | | | | | | |
| | | | 22.192 | 0 | 4506100 | 4 | 6 | 300 | 0.0033 | 9.6(−4)[a] | −1.88 | E | 2 |
| 3. | | $^2P^\circ$ – $^2P$ | | | | | | | | | | | |
| | | | 22.083 | 58160 | 4587200 | 2 | 2 | 9000 | 0.066 | 0.0096 | −0.88 | C− | 2 |
| | | | 21.800 | 0 | 4587200 | 4 | 2 | 7900 | 0.0280 | 0.0080 | −0.95 | C− | 2 |
| 4. | $2p^5$–$2p^4(^1D)3s$ | $^2P^\circ$ – $^2D$ | | | | | | | | | | | |
| | | | 21.568 | 0 | 4636500 | 4 | 6 | 6200 | 0.065 | 0.018 | −0.59 | D | 2 |
| | | | 21.832 | 58160 | 4638600 | 2 | 4 | 7000 | 0.10 | 0.014 | −0.70 | D | 2 |
| 5. | $2p^5$–$2p^4(^1S)3s$ | $^2P^\circ$ – $^2S$ | *21.111* | *19387* | 4756300 | 6 | 2 | 7400 | 0.017 | 0.0069 | −1.00 | E | 2 |
| | | | 21.019 | 0 | 4756300 | 4 | 2 | 2300 | 0.0075 | 0.0021 | −1.52 | E | 2 |
| | | | 21.285 | 58160 | 4756300 | 2 | 2 | 5000 | 0.034 | 0.0048 | −1.17 | D | 2 |
| 6. | $2p^5$–$2p^4(^3P)3d$ | $^2P^\circ$ – $^4P$ | | | | | | | | | | | |
| | | | 19.888 | 0 | 5028200 | 4 | 2 | 9800 | 0.029 | 0.0076 | −0.94 | E | 2 |
| 7. | $2p^5$–$2p^4(^1D)3d$ | $^2P^\circ$ – $^2S$ | *19.517* | *19387* | 5143200 | 6 | 2 | 1.0(+5) | 0.19 | 0.074 | 0.06 | D | 2 |
| | | | 19.443 | 0 | 5143200 | 4 | 2 | 8.5(+4) | 0.24 | 0.061 | −0.02 | D | 2 |
| | | | 19.671 | 58160 | 5143200 | 2 | 2 | 1.7(+4) | 0.099 | 0.013 | −0.70 | D | 2 |
| 8. | | $^2P^\circ$ – $^2F$ | | | | | | | | | | | |
| | | | [19.45] | | | 4 | 6 | 6100 | 0.052 | 0.013 | −0.68 | E | 2 |
| 9. | | $^2P^\circ$ – $^2P$ | | | | | | | | | | | |
| | | | [19.368] | 0 | 5163100 | 4 | 4 | 1.1(+5) | 0.62 | 0.16 | 0.39 | D | 2 |
| | | | 19.589 | 58160 | 5163100 | 2 | 4 | 1.6(+4) | 0.18 | 0.023 | −0.44 | D | 2 |
| 10. | | $^2P^\circ$ – $^2D$ | | | | | | | | | | | |
| | | | 19.518 | 58160 | 5181900 | 2 | 4 | 8.8(+4) | 1.0 | 0.13 | 0.30 | D | 2 |
| | | | 19.298 | 0 | 5181900 | 4 | 4 | 1.8(+4) | 0.098 | 0.025 | −0.41 | D | 2 |
| 11. | $2p^5$–$2p^4(^1S)3d$ | $^2P^\circ$ – $^2D$ | *19.084* | *19387* | *5259500* | 6 | 10 | 3.2(+4) | 0.29 | 0.11 | 0.24 | E | 2 |
| | | | 19.028 | 0 | 5255400 | 4 | 6 | 1.1(+4) | 0.091 | 0.023 | −0.44 | D | 2 |
| | | | 19.203 | 58160 | 5265700 | 2 | 4 | 6.3(+4) | 0.70 | 0.089 | 0.15 | D | 2 |
| | | | [18.991] | 0 | 5265700 | 4 | 4 | 1000 | 0.0055 | 0.0014 | −1.66 | E | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V xv

## Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $2p^5$ configuration are the results of the Dirac-Fock calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

V xv: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^5$–$2p^5$ | $^2P^\circ$ - $^2P^\circ$ | | | | | | | | | | |
| | | | 1719.4 | 0 | 58160 | 4 | 2 | M1 | 3530 | 1.33 | B | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 2 | E2 | 0.21 | 0.0037 | D | 1 |

# V xvi

O Isoelectronic Sequence

Ground State: $1s^22s^22p^4\ ^3P_2$

Ionization Energy: 1060 eV = 8549000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 17.868 | 32 | 18.48 | 33 | 19.62 | 13 | 95.640 | 2 |
| 18.07 | 29 | 18.49 | 33 | 19.81 | 13 | 100.34 | 2 |
| 18.102 | 35 | 18.492 | 38 | 19.91 | 13 | 100.440 | 2 |
| 18.119 | 23 | 18.525 | 27 | 19.93 | 13 | 103.043 | 7 |
| 18.12 | 31 | 18.590 | 26 | 19.951 | 11 | 108.160 | 4 |
| 18.18 | 30 | 18.63 | 18 | 20.017 | 10 | 123.780 | 6 |
| 18.181 | 22,30 | 18.678 | 25 | 20.033 | 15 | 125.173 | 1 |
| 18.185 | 30 | 18.689 | 17 | 20.079 | 10 | 129.195 | 1 |
| 18.24 | 21,29 | 18.69 | 17 | 20.09 | 14 | 131.263 | 1 |
| 18.265 | 20 | 18.72 | 17 | 20.147 | 11 | 133.338 | 1 |
| 18.344 | 22 | 18.76 | 37 | 20.20 | 14 | 133.525 | 1 |
| 18.40 | 19,21 | 18.82 | 24 | 20.273 | 10 | 138.168 | 8 |
| 18.41 | 21 | 18.827 | 36 | 20.278 | 10 | 140.277 | 1 |
| 18.423 | 34 | 18.86 | 17 | 20.444 | 9,12 | 156.060 | 3 |
| 18.43 | 18 | 18.89 | 17 | 20.513 | 16 | 178.19 | 5 |
| 18.46 | 18 | 19.06 | 28 | 20.659 | 9 | | |

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22. | | $^3$P - $^3$S° | | | | | | | | | | | |
| | | | 18.181 | 0 | 5500200 | 5 | 3 | 9.4(+4) | 0.28 | 0.084 | 0.15 | D | 3 |
| | | | [18.344] | 48937 | 5500200 | 3 | 3 | 2400 | 0.012 | 0.0022 | −1.44 | D | 3 |
| 23. | | $^3$P - $^1$F° | | | | | | | | | | | |
| | | | [18.119] | 0 | 551910 | 5 | 7 | 2.5(+4) | 0.17 | 0.051 | −0.07 | E | 3 |
| 24. | $2p^4$ - $2p^3$($^2$D°)$3d$ | $^1$D - $^3$G° | | | | | | | | | | | |
| | | | [18.82] | | | 5 | 7 | 1300 | 0.010 | 0.0031 | −1.30 | E | 3 |
| 25. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [18.678] | 121039 | 5475000 | 5 | 7 | 1500 | 0.011 | 0.0034 | −1.26 | E | 3 |
| 26. | | $^1$D - $^3$S° | [18.678] | 121039 | 5500200 | 5 | 3 | 1.6(+4) | 0.051 | 0.016 | −0.59 | E | 3 |
| 27. | | $^1$D - $^1$F° | 18.525 | 121039 | 5519100 | 5 | 7 | 5.6(+4) | 0.40 | 0.12 | 0.30 | D | 3 |
| 28. | | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [19.06] | | | 1 | 3 | 1300 | 0.022 | 0.0014 | −1.66 | E | 3 |
| 29. | $2p^4$ - $2p^3$($^2$P°)$3d$ | $^3$P - $^3$F° | | | | | | | | | | | |
| | | | [18.07] | | | 5 | 7 | 6400 | 0.044 | 0.013 | −0.66 | E | 3 |
| | | | [18.24] | | | 3 | 5 | 4100 | 0.034 | 0.0061 | −0.99 | E | 3 |
| 30. | $2p^4$ - $2p^3$($^2$P°)$3d$ | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 18.181 | 48937 | 5549100 | 3 | 3 | 8300 | 0.041 | 0.0074 | −0.91 | D | 3 |
| | | | [18.18] | | | 3 | 1 | 7.6(+4) | 0.126 | 0.0226 | −0.423 | C− | 3 |
| | | | [18.185] | 49970 | 5549100 | 1 | 3 | 5.4(+4) | 0.81 | 0.048 | −0.09 | D | 3 |
| 31. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | [18.12] | | | 1 | 3 | 4.3(+4) | 0.64 | 0.038 | −0.19 | C− | 3 |
| | | | [18.12] | | | 3 | 3 | 6.9(+4) | 0.340 | 0.061 | 0.009 | C− | 3 |
| 32. | | $^3$P - $^1$P° | | | | | | | | | | | |
| | | | [17.868] | 48937 | 5645400 | 3 | 3 | 2300 | 0.011 | 0.0019 | −1.48 | E | 3 |
| 33. | | $^1$D - $^3$F° | | | | | | | | | | | |
| | | | [18.48] | | | 5 | 7 | 1400 | 0.010 | 0.0030 | −1.30 | E | 3 |
| | | | [18.49] | | | 5 | 5 | 7400 | 0.038 | 0.012 | −0.72 | E | 3 |
| 34. | $2p^4$ - $2p^3$($^2$P°)$3d$ | $^1$D - $^3$P° | | | | | | | | | | | |
| | | | [18.423] | 121039 | 5549100 | 5 | 3 | 3900 | 0.012 | 0.0036 | −1.22 | E | 3 |
| 35. | | $^1$D - $^1$P° | [18.102] | 121039 | 5645400 | 5 | 3 | 8100 | 0.024 | 0.0072 | −0.92 | D | 3 |
| 36. | | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [18.827] | 237705 | 5449100 | 1 | 3 | 1300 | 0.021 | 0.0013 | −1.68 | E | 3 |

V XVI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37. | | $^1$S - $^3$D° | | | | | | | | | | | |
| | | | [18.76] | | | 1 | 3 | 2900 | 0.046 | 0.0028 | −1.34 | E | 3 |
| 38. | | $^1$S - $^1$P° | 18.492 | 237705 | 5645400 | 1 | 3 | 1.5(+5) | 2.3 | 0.14 | 0.36 | D | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XVI

## Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^4$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

Transition probabilities for these same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these data are in quite good agreement with the data of Cheng *et al*. For this ion of the oxygen isoelectronic sequence, correlation effects due to mixing with configurations outside the complex were found by Froese Fischer and Saha to be rather small, as shown by a comparison of the results of their calculations employing an extensive basis to those derived by the same technique but limited to configurations within the $n=2$ complex.

The weakest lines are excluded from this compilation, as their transition probabilities are considered to be very uncertain.

### References

[1]K. T. Cheng, Y.-K Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).

V XVI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^4$–$2p^4$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | 2042.7 | 0 | 48937 | 5 | 3 | M1 | 2480 | 2.35 | C+ | 1 |
| | | | " | " | " | 5 | 3 | E2 | 0.057 | 0.0036 | E | 1 |
| | | | [96780] | 48937 | 49970 | 3 | 1 | M1 | 0.054 | 1.8 | D+ | 1 |
| | | | [2000.6] | 0 | 49970 | 5 | 1 | E2 | 0.10 | 0.0020 | E | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [826.18] | 0 | 121039 | 5 | 5 | M1 | 4000 | 0.42 | D | 1 |
| | | | " | " | " | 5 | 5 | E2 | 1.3 | 0.0015 | E | 1 |
| | | | [1386.9] | 48937 | 121039 | 3 | 5 | M1 | 300 | 0.15 | D | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | 529.9 | 48937 | 237705 | 3 | 1 | M1 | 4.2(+4)[a] | 0.23 | D | 1 |
| 4. | | $^1$D - $^1$S | [857.15] | 121039 | 237705 | 5 | 1 | E2 | 22 | 0.0061 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XVII

N Isoelectronic Sequence

Ground State: $1s^22s^22p^3\ ^4S^\circ_{3/2}$

Ionization Energy: 1168 eV = 9420000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 91.475 | 4 | 113.785 | 7 | 134.056 | 6 | 159.65 | 10 |
| 96.270 | 4 | 115.36 | 2 | 136.511 | 6 | 165.322 | 16 |
| 98.375 | 13 | 117.276 | 12 | 137.62 | 6 | 167.279 | 16 |
| 99.111 | 13 | 120.304 | 14 | 143.21 | 15 | 178.36 | 5 |
| 100.02 | 3 | 120.873 | 12 | 146.719 | 1 | 183.39 | 5 |
| 102.854 | 8 | 125.278 | 12 | 150.103 | 1 | 184.05 | 16 |
| 103.06 | 13 | 126.832 | 11 | 151.656 | 16 | 197.38 | 5 |
| 104.72 | 13 | 129.927 | 14 | 152.566 | 10 | 205.21 | 5 |
| 108.952 | 8 | 130.941 | 14 | 157.070 | 15 | 212.69 | 9 |
| 111.299 | 8 | 131.687 | 11 | 158.143 | 10 | 234.90 | 9 |
| 113.406 | 12 | 133.00 | 6 | 159.347 | 1 | 258.36 | 9 |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^3$–$2s2p^4$ and $2s2p^4$–$2p^5$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

### Reference

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

V XVII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^3$–$2s2p^4$ | $^4S^\circ$ - $^4P$ | *153.98* | 0 | *649450* | 4 | 12 | 120 | 0.13 | 0.27 | −0.27 | C | 1 |
| | | | 159.347 | 0 | 627560 | 4 | 6 | 110 | 0.062 | 0.13 | −0.61 | C | 1 |
| | | | 150.103 | 0 | 666210 | 4 | 4 | 134 | 0.0452 | 0.089 | −0.74 | C | 1 |
| | | | 146.719 | 0 | 681580 | 4 | 2 | 147 | 0.0238 | 0.0460 | −1.021 | C | 1 |
| 2. | | $^4S^\circ$ - $^2D$ | | | | | | | | | | | |
| | | | [115.36] | 0 | 866880 | 4 | 4 | 3.3 | 6.5(−4)[a] | 9.9(−4) | −2.59 | E | 1 |
| 3. | | $^4S^\circ$ - $^2S$ | | | | | | | | | | | |
| | | | [100.02] | 0 | 999840 | 4 | 2 | 6.3 | 4.7(−4) | 6.2(−4) | −2.73 | E | 1 |
| 4. | | $^4S^\circ$ - $^2P$ | | | | | | | | | | | |
| | | | 96.270 | 0 | 1038740 | 4 | 4 | 17 | 0.0024 | 0.0030 | −2.02 | E | 1 |
| | | | [91.475] | 0 | 1093200 | 4 | 2 | 1.6 | 1.0(−4) | 1.2(−4) | −3.40 | E | 1 |

V XVII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5. | | $^2D° - ^4P$ | | | | | | | | | | | |
| | | | [205.21] | 140260 | 627560 | 6 | 6 | 1.0 | 6.5(−4) | 0.0026 | −2.41 | E | 1 |
| | | | [183.39] | 120930 | 666210 | 4 | 4 | 0.22 | 1.1(−4) | 2.7(−4) | −3.36 | E | 1 |
| | | | [178.36] | 120930 | 681580 | 4 | 2 | 0.75 | 1.8(−4) | 4.2(−4) | −3.14 | E | 1 |
| | | | [197.38] | 120930 | 627560 | 4 | 6 | 1.6 | 0.0014 | 0.0036 | −2.25 | E | 1 |
| 6. | | $^2D° - ^2D$ | *135.52* | *132530* | *870440* | 10 | 10 | 280 | 0.076 | 0.34 | −0.12 | D | 1 |
| | | | 136.511 | 140260 | 872820 | 6 | 6 | 250 | 0.071 | 0.19 | −0.37 | C | 1 |
| | | | 134.056 | 120930 | 866880 | 4 | 4 | 310 | 0.083 | 0.15 | −0.48 | C | 1 |
| | | | [137.62] | 140260 | 866880 | 6 | 4 | 4.5 | 8.5(−4) | 0.0023 | −2.29 | E | 1 |
| | | | [133.00] | 120930 | 872820 | 4 | 6 | 0.070 | 2.8(−5) | 4.9(−5) | −3.95 | E | 1 |
| 7. | | $^2D° - ^2S$ | | | | | | | | | | | |
| | | | 113.785 | 120930 | 999840 | 4 | 2 | 290 | 0.028 | 0.042 | −0.95 | E | 1 |
| 8. | | $^2D° - ^2P$ | *108.18* | *132530* | *1056890* | 10 | 6 | 780 | 0.082 | 0.293 | −0.085 | C | 1 |
| | | | 111.299 | 140260 | 1038740 | 6 | 4 | 810 | 0.100 | 0.220 | −0.222 | C | 1 |
| | | | 102.854 | 120930 | 1093200 | 4 | 2 | 322 | 0.0255 | 0.0345 | −0.99 | C | 1 |
| | | | 108.952 | 120930 | 1038740 | 4 | 4 | 151 | 0.0269 | 0.0386 | −0.97 | C | 1 |
| 9. | | $^2P° - ^4P$ | | | | | | | | | | | |
| | | | [258.36] | 240500 | 627560 | 4 | 6 | 0.20 | 3.0(−4) | 0.0010 | −2.92 | E | 1 |
| | | | [234.90] | 240500 | 666210 | 4 | 4 | 0.86 | 7.1(−4) | 0.0022 | −2.55 | E | 1 |
| | | | [212.69] | 211420 | 681580 | 2 | 2 | 0.65 | 4.4(−4) | 6.2(−4) | −3.06 | E | 1 |
| 10. | | $^2P° - ^2D$ | *156.34* | *230810* | *870440* | 6 | 10 | 43 | 0.027 | 0.082 | −0.80 | C− | 1 |
| | | | 158.143 | 240500 | 872820 | 4 | 6 | 50 | 0.0281 | 0.059 | −0.95 | C | 1 |
| | | | 152.566 | 211420 | 866880 | 2 | 4 | 27.4 | 0.0191 | 0.0192 | −1.418 | C | 1 |
| | | | [159.65] | 240500 | 866880 | 4 | 4 | 5.2 | 0.0020 | 0.0042 | −2.10 | D | 1 |
| 11. | | $^2P° - ^2S$ | *130.03* | *230810* | 999840 | 6 | 2 | 340 | 0.028 | 0.073 | −0.77 | C− | 1 |
| | | | 131.687 | 240500 | 999840 | 4 | 2 | 68 | 0.0089 | 0.015 | −1.45 | D | 1 |
| | | | 126.832 | 211420 | 999840 | 2 | 2 | 290 | 0.069 | 0.058 | −0.86 | C | 1 |
| 12. | | $^2P° - ^2P$ | *121.05* | *230810* | *1056890* | 6 | 6 | 320 | 0.071 | 0.17 | −0.37 | C | 1 |
| | | | 125.278 | 240500 | 1038740 | 4 | 4 | 88 | 0.0207 | 0.0341 | −1.082 | C | 1 |
| | | | 113.406 | 211420 | 1093200 | 2 | 2 | 52 | 0.0101 | 0.0075 | −1.69 | C | 1 |
| | | | 117.276 | 240500 | 1093200 | 4 | 2 | 690 | 0.071 | 0.11 | −0.55 | C | 1 |
| | | | 120.873 | 211420 | 1038740 | 2 | 4 | 62 | 0.0271 | 0.0216 | −1.266 | C | 1 |
| 13. | $2s2p^4-2p^5$ | $^4P - ^2P°$ | | | | | | | | | | | |
| | | | [99.111] | 627560 | 1636530 | 6 | 4 | 12 | 0.0012 | 0.0023 | −2.14 | E | 1 |
| | | | [103.06] | 666210 | 1636530 | 4 | 4 | 4.9 | 7.8(−4) | 0.0011 | −2.51 | E | 1 |
| | | | [98.375] | 681580 | 1698100 | 2 | 2 | 4.1 | 5.9(−4) | 3.8(−4) | −2.93 | E | 1 |
| | | | [104.72] | 681580 | 1636530 | 2 | 4 | 1.6 | 5.4(−4) | 3.7(−4) | −2.97 | E | 1 |
| 14. | | $^2D - ^2P°$ | *127.13* | *870440* | *1657050* | 10 | 6 | 440 | 0.065 | 0.27 | −0.19 | C | 1 |
| | | | 130.941 | 872820 | 1636530 | 6 | 4 | 370 | 0.063 | 0.16 | −0.42 | C | 1 |
| | | | 120.304 | 866880 | 1698100 | 4 | 2 | 404 | 0.0438 | 0.069 | −0.76 | C | 1 |
| | | | 129.927 | 866880 | 1636530 | 4 | 4 | 105 | 0.0265 | 0.0453 | −0.97 | C | 1 |

V XVII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | | $^2S - ^2P^\circ$ | *152.16* | 999840 | *1657050* | 2 | 6 | 47.4 | 0.0493 | 0.0494 | −1.006 | C− | 1 |
| | | | 157.070 | 999840 | 1636530 | 2 | 4 | 63 | 0.0465 | 0.0481 | −1.032 | C | 1 |
| | | | [143.21] | 999840 | 1698100 | 2 | 2 | 4.6 | 0.0014 | 0.0013 | −2.55 | D | 1 |
| 16. | | $^2P - ^2P^\circ$ | *166.62* | *1056890* | *1657050* | 6 | 6 | 343 | 0.143 | 0.470 | −0.067 | C | 1 |
| | | | 167.279 | 1038740 | 1636530 | 4 | 4 | 267 | 0.112 | 0.247 | −0.349 | C | 1 |
| | | | 165.322 | 1093200 | 1698100 | 2 | 2 | 264 | 0.108 | 0.118 | −0.67 | C | 1 |
| | | | 151.656 | 1038740 | 1698100 | 4 | 2 | 226 | 0.0390 | 0.078 | −0.81 | C | 1 |
| | | | [184.05] | 1093200 | 1636530 | 2 | 4 | 21.7 | 0.0220 | 0.0267 | −1.357 | C | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## V XVII

### Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^3$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor $2/3$ which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. The weakest lines are excluded from this compilation, as their strengths are considered to be very uncertain.

*A*-values for the M1 and E2 components of the single transition within the $2p^5$ configuration were obtained by applying *Z*-expansion formulas published by Oboladze and Safronova.[2] Their values for the magnetic dipole contribution to this line are in very good agreement with the results of the scaled Thomas-Fermi calculations of Bhatia *et al.*[3] and Bhatia[4] for nitrogenlike Ti and Mn, respectively. It is not clear whether Oboladze and Safronova incorporated configuration interaction into their calculations. Thus the *A*-value for the E2 contribution should be considered rather uncertain.

### References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]N. S. Oboladze and U. I. Safronova, Opt. Spectrosc. (USSR) **48**, 469 (1980).
[3]A. K. Bhatia, U. Feldman, and G. A. Doschek, J. Appl. Phys. **51**, 1464 (1980).
[4]A. K. Bhatia, J. Appl. Phys. **53**, 59 (1982).

V XVII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^3$–$2p^3$ | $^4S^\circ - ^2D^\circ$ | | | | | | | | | | |
| | | | [712.96] | 0 | 140260 | 4 | 6 | M1 | 150 | 0.012 | D− | 1 |
| | | | [826.92] | 0 | 120930 | 4 | 4 | M1 | 3600 | 0.30 | D | 1 |
| 2. | | $^4S^\circ - ^2P^\circ$ | | | | | | | | | | |
| | | | [415.80] | 0 | 240500 | 4 | 4 | M1 | 1.1(+4)[a] | 0.12 | D | 1 |
| | | | [472.99] | 0 | 211420 | 4 | 2 | M1 | 8200 | 0.064 | D− | 1 |
| 3. | | $^2D^\circ - ^2D^\circ$ | | | | | | | | | | |
| | | | [5172] | 120930 | 140260 | 4 | 6 | M1 | 62 | 1.91 | C | 1 |
| | | | ″ | ″ | ″ | 4 | 6 | E2 | 1.7(−4) | 0.0023 | E | 1 |

V XVII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^2D^\circ - {}^2P^\circ$ | | | | | | | | | | |
| | | | [1405] | 140260 | 211420 | 6 | 2 | E2 | 0.58 | 0.0038 | E | 1 |
| | | | [997.61] | 140260 | 240500 | 6 | 4 | M1 | 3300 | 0.48 | D | 1 |
| | | | " | " | " | 6 | 4 | E2 | 4.3 | 0.010 | E | 1 |
| | | | [1105] | 120930 | 211420 | 4 | 2 | M1 | 2400 | 0.24 | D | 1 |
| | | | " | " | " | 4 | 2 | E2 | 2.3 | 0.0045 | E | 1 |
| | | | [836.33] | 120930 | 240500 | 4 | 4 | M1 | 9000 | 0.78 | D | 1 |
| | | | " | " | " | 4 | 4 | E2 | 2.0 | 0.0019 | E | 1 |
| 5. | | $^2P^\circ - {}^2P^\circ$ | | | | | | | | | | |
| | | | [3438] | 211420 | 240500 | 2 | 4 | M1 | 171 | 1.03 | C | 1 |
| | | | " | " | " | 2 | 4 | E2 | 8.7(−4) | 0.0010 | E | 1 |
| 6. | $2p^5$–$2p^5$ | $^2P^\circ - {}^2P^\circ$ | | | | | | | | | | |
| | | | [1624] | 1636530 | 1698100 | 4 | 2 | M1 | 4290 | 1.36 | C+ | 2 |
| | | | " | " | " | 4 | 2 | E2 | 0.25 | 0.0034 | E | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XVIII

C Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^2\ {}^3P_0$

Ionization Energy: 1260 eV = 10160000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 16.26 | 29 | 127.079 | 16 | 148.113 | 3 | 194.76 | 21 |
| 16.33 | 28 | 127.27 | 16 | 149.83 | 18 | 199.06 | 23 |
| 16.34 | 29 | 129.71 | 22 | 149.87 | 3 | 210.95 | 7 |
| 16.378 | 28 | 133.778 | 9 | 152.933 | 27 | 214.63 | 26 |
| 95.8 | 15 | 134 | 14 | 159.991 | 2 | 215 | 12 |
| 101 | 15 | 134.25 | 19 | 160 | 13 | 215.46 | 7 |
| 102.410 | 6 | 135.69 | 19 | 160.44 | 18 | 216.01 | 7 |
| 107.20 | 20 | 135.98 | 3 | 162.51 | 18 | 216.74 | 21 |
| 111.442 | 4 | 136.08 | 16 | 170.34 | 2 | 222.08 | 23 |
| 114.88 | 5 | 136.30 | 16 | 170.678 | 2 | 252.30 | 25 |
| 116.365 | 4 | 138.168 | 16 | 171.69 | 8 | 281 | 11 |
| 116.76 | 17 | 141.77 | 3 | 174.06 | 8 | 290.45 | 25 |
| 117.163 | 10 | 143.377 | 3 | 174.852 | 24 | 304 | 1 |
| 118.29 | 17 | 144.111 | 3 | 176.440 | 2 | 335 | 1 |
| 119.015 | 5 | 146.91 | 18 | 179.58 | 2 | | |
| 120.607 | 4 | 147.30 | 18 | 179.96 | 2 | | |
| 126.411 | 16 | 148.07 | 18 | 192.76 | 21 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^2$–$2s2p^3$ and $2s2p^3$–$2p^4$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

Transition probabilities for lines of the $2s^22p^2$–$2s2p^3$ array were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these two sources are in reasonably good agreement, particularly for the stronger transitions.

Data for a few lines of the $2p^2$–$2p3d$ array were interpolated from the HX (Hartree-Fock with statistical allowance for exchange) $f$-values of Bromage and Fawcett[3] for the isoelectronic ions Ca XV and Fe XXI.

## References


[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2] C. Froese Fischer and H. P. Saha, Phys. Scr. **32**, 181 (1985).

[3] G. E. Bromage and B. C. Fawcett, Mon. Not. R. Astron. Soc. **178**, 605 (1977).


V XVIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^2$–$2s2p^3$ | $^3$P – $^5$S° | | | | | | | | | | | |
| | | | [335] | | | 5 | 5 | 0.12 | 2.0(−4)[a] | 0.0011 | −3.00 | E | 1 |
| | | | [304] | | | 3 | 5 | 0.091 | 2.1(−4) | 6.3(−4) | −3.20 | E | 1 |
| 2. | | $^3$P – $^3$D° | *172.79* | *50537* | *629273* | 9 | 15 | 65 | 0.049 | 0.25 | −0.36 | D | 1 |
| | | | 176.440 | 68189 | 634954 | 5 | 7 | 56 | 0.0364 | 0.106 | −0.74 | C | 1 |
| | | | 170.678 | 37963 | 623862 | 3 | 5 | 74 | 0.054 | 0.091 | −0.79 | C | 1 |
| | | | 159.991 | 0 | 625035 | 1 | 3 | 76 | 0.087 | 0.046 | −1.06 | C | 1 |
| | | | [179.96] | 68189 | 623862 | 5 | 5 | 0.39 | 1.9(−4) | 5.6(−4) | −3.02 | E | 1 |
| | | | [170.34] | 37963 | 625035 | 3 | 3 | 12 | 0.0052 | 0.0087 | −1.81 | D | 1 |
| | | | [179.58] | 68189 | 625035 | 5 | 3 | 0.18 | 5.3(−5) | 1.6(−4) | −3.58 | E | 1 |
| 3. | | $^3$P – $^3$P° | *145.16* | *50537* | *739433* | 9 | 9 | 170 | 0.053 | 0.23 | −0.32 | C− | 1 |
| | | | 148.113 | 68189 | 743349 | 5 | 5 | 150 | 0.050 | 0.12 | −0.60 | C | 1 |
| | | | 143.377 | 37963 | 735425 | 3 | 3 | 101 | 0.0312 | 0.0442 | −1.029 | C | 1 |
| | | | [149.87] | 68189 | 735425 | 5 | 3 | 36 | 0.0073 | 0.018 | −1.44 | D | 1 |
| | | | 144.111 | 37963 | 731873 | 3 | 1 | 180 | 0.0187 | 0.0266 | −1.251 | C | 1 |
| | | | [141.77] | 37963 | 743349 | 3 | 5 | 8.8 | 0.0044 | 0.0062 | −1.88 | D | 1 |
| | | | [135.98] | 0 | 735425 | 1 | 3 | 39.3 | 0.0327 | 0.0146 | −1.485 | C | 1 |
| 4. | | $^3$P – $^3$S° | *118.09* | *50537* | 897330 | 9 | 3 | 820 | 0.057 | 0.20 | −0.29 | C | 1 |
| | | | 120.607 | 68189 | 897330 | 5 | 3 | 500 | 0.066 | 0.13 | −0.48 | C | 1 |
| | | | 116.365 | 37963 | 897330 | 3 | 3 | 237 | 0.0481 | 0.055 | −0.84 | C | 1 |
| | | | 111.442 | 0 | 897330 | 1 | 3 | 85 | 0.0473 | 0.0174 | −1.325 | C | 1 |
| 5. | | $^3$P – $^1$D° | | | | | | | | | | | |
| | | | 119.015 | 68189 | 908420 | 5 | 5 | 41 | 0.0088 | 0.017 | −1.36 | E | 1 |
| | | | [114.88] | 37963 | 908420 | 3 | 5 | 1.8 | 6.0(−4) | 6.8(−4) | −2.74 | E | 1 |
| 6. | | $^3$P – $^1$P° | | | | | | | | | | | |
| | | | 102.410 | 37963 | 1014420 | 3 | 3 | 28 | 0.0044 | 0.0045 | −1.88 | E | 1 |
| 7. | | $^1$D – $^3$D° | | | | | | | | | | | |
| | | | [210.95] | 160912 | 634954 | 5 | 7 | 4.6 | 0.0043 | 0.015 | −1.67 | E | 1 |
| | | | [216.01] | 160912 | 623862 | 5 | 5 | 0.30 | 2.1(−4) | 7.5(−4) | −2.98 | E | 1 |
| | | | [215.46] | 160912 | 625035 | 5 | 3 | 0.89 | 3.7(−4) | 0.0013 | −2.73 | E | 1 |

V XVIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^1D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [171.69] | 160912 | 743349 | 5 | 5 | 1.5 | 6.7(−4) | 0.0019 | −2.47 | E | 1 |
| | | | [174.06] | 160912 | 735425 | 5 | 3 | 2.4 | 6.5(−4) | 0.0019 | −2.49 | E | 1 |
| 9. | | $^1D - {}^1D^\circ$ | 133.778 | 160912 | 908420 | 5 | 5 | 410 | 0.110 | 0.242 | −0.260 | C | 1 |
| 10. | | $^1D - {}^1P^\circ$ | 117.163 | 160912 | 1014420 | 5 | 3 | 560 | 0.069 | 0.13 | −0.46 | C | 1 |
| 11. | | $^1S - {}^3D^\circ$ | | | | | | | | | | | |
| | | | [281] | | | 1 | 3 | 0.28 | 0.0010 | 9.3(−4) | −3.00 | E | 1 |
| 12. | | $^1S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [215] | | | 1 | 3 | 0.87 | 0.0018 | 0.0013 | −2.74 | E | 1 |
| 13. | | $^1S - {}^3S^\circ$ | [160] | | | 1 | 3 | 3.0 | 0.0035 | 0.0018 | −2.46 | E | 1 |
| 14. | | $^1S - {}^1P^\circ$ | [134] | | | 1 | 3 | 145 | 0.117 | 0.052 | −0.93 | C | 1 |
| 15. | $2s2p^3 - 2p^4$ | $^5S^\circ - {}^3P$ | | | | | | | | | | | |
| | | | [101] | | | 5 | 5 | 5.0 | 7.6(−4) | 0.0013 | −2.42 | E | 1 |
| | | | [95.8] | | | 5 | 3 | 1.5 | 1.2(−4) | 1.9(−4) | −3.22 | E | 1 |
| 16. | | $^3D^\circ - {}^3P$ | *132.77* | *629273* | *1382440* | 15 | 9 | 380 | 0.059 | 0.39 | −0.05 | C− | 1 |
| | | | 138.168 | 634954 | 1358710 | 7 | 5 | 270 | 0.056 | 0.18 | −0.41 | C | 1 |
| | | | 127.079 | 623862 | 1410770 | 5 | 3 | 202 | 0.0294 | 0.061 | −0.83 | C | 1 |
| | | | 126.411 | 625035 | 1416110 | 3 | 1 | 311 | 0.0248 | 0.0310 | −1.128 | C | 1 |
| | | | [136.08] | 623862 | 1358710 | 5 | 5 | 106 | 0.0295 | 0.066 | −0.83 | C | 1 |
| | | | [127.27] | 625035 | 1410770 | 3 | 3 | 124 | 0.0301 | 0.0378 | −1.044 | C | 1 |
| | | | [136.30] | 625035 | 1358710 | 3 | 5 | 19 | 0.0086 | 0.012 | −1.59 | D | 1 |
| 17. | | $^3D^\circ - {}^1D$ | | | | | | | | | | | |
| | | | [118.29] | 634954 | 1480330 | 7 | 5 | 29 | 0.0043 | 0.012 | −1.52 | E | 1 |
| | | | [116.76] | 623862 | 1480330 | 5 | 5 | 4.4 | 9.0(−4) | 0.0017 | −2.35 | E | 1 |
| 18. | | $^3P^\circ - {}^3P$ | *155.52* | *739433* | *1382440* | 9 | 9 | 102 | 0.0371 | 0.171 | −0.476 | C− | 1 |
| | | | [162.51] | 743349 | 1358710 | 5 | 5 | 35.1 | 0.0139 | 0.0372 | −1.158 | C | 1 |
| | | | [148.07] | 735425 | 1410770 | 3 | 3 | 0.49 | 1.6(−4) | 2.3(−4) | −3.32 | E | 1 |
| | | | [149.83] | 743349 | 1410770 | 5 | 3 | 120 | 0.0242 | 0.060 | −0.92 | C | 1 |
| | | | [146.91] | 735425 | 1416110 | 3 | 1 | 159 | 0.0172 | 0.0250 | −1.287 | C | 1 |
| | | | [160.44] | 735425 | 1358710 | 3 | 5 | 30.2 | 0.0194 | 0.0307 | −1.235 | C | 1 |
| | | | [147.30] | 731873 | 1410770 | 1 | 3 | 37.6 | 0.0367 | 0.0178 | −1.435 | C | 1 |
| 19. | | $^3P^\circ - {}^1D$ | | | | | | | | | | | |
| | | | [135.69] | 743349 | 1480330 | 5 | 5 | 6.2 | 0.0017 | 0.0038 | −2.07 | E | 1 |
| | | | [134.25] | 735425 | 1480330 | 3 | 5 | 4.9 | 0.0022 | 0.0029 | −2.18 | E | 1 |
| 20. | | $^3P^\circ - {}^1S$ | | | | | | | | | | | |
| | | | [107.20] | 735425 | 1668300 | 3 | 1 | 17 | 0.0010 | 0.0011 | −2.52 | E | 1 |
| 21. | | $^3S^\circ - {}^3P$ | *206.14* | 897330 | *1382440* | 3 | 9 | 77 | 0.15 | 0.30 | −0.35 | C | 1 |
| | | | [216.74] | 897330 | 1358710 | 3 | 5 | 60 | 0.070 | 0.15 | −0.68 | C | 1 |
| | | | [194.76] | 897330 | 1410770 | 3 | 3 | 98 | 0.056 | 0.11 | −0.77 | C | 1 |
| | | | [192.76] | 897330 | 1416110 | 3 | 1 | 124 | 0.0231 | 0.0440 | −1.159 | C | 1 |

V XVIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ (10$^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22. | | $^3$S° - $^1$S | [129.71] | 897330 | 1668300 | 3 | 1 | 37 | 0.0031 | 0.0040 | −2.03 | E | 1 |
| 23. | | $^1$D° - $^3$P | | | | | | | | | | | |
| | | | [222.08] | 908420 | 1358710 | 5 | 5 | 5.1 | 0.0038 | 0.014 | −1.72 | E | 1 |
| | | | [199.06] | 908420 | 1410770 | 5 | 3 | 0.90 | 3.2(−4) | 0.0010 | −2.80 | E | 1 |
| 24. | | $^1$D° - $^1$D | 174.852 | 908420 | 1480330 | 5 | 5 | 288 | 0.132 | 0.380 | −0.180 | C | 1 |
| 25. | | $^1$P° - $^3$P | | | | | | | | | | | |
| | | | [290.45] | 1014420 | 1358710 | 3 | 5 | 0.76 | 0.0016 | 0.0046 | −2.32 | E | 1 |
| | | | [252.30] | 1014420 | 1410770 | 3 | 3 | 3.6 | 0.0034 | 0.0085 | −1.99 | E | 1 |
| 26. | | $^1$P° - $^1$D | [214.63] | 1014420 | 1480330 | 3 | 5 | 37.9 | 0.0436 | 0.092 | −0.88 | C | 1 |
| 27. | | $^1$P° - $^1$S | 152.933 | 1014420 | 1668300 | 3 | 1 | 670 | 0.078 | 0.12 | −0.63 | C | 1 |
| 28. | $2p^2$–$2p3d$ | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 16.378 | 68189 | 6174000 | 5 | 7 | 1.1(+5) | 0.62 | 0.17 | 0.49 | E | *interp.* |
| | | | [16.33] | | | 1 | 3 | 1.1(+5) | 1.3 | 0.070 | 0.11 | D | *interp.* |
| 29. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | [16.26] | | | 3 | 3 | 5.8(+4) | 0.23 | 0.037 | −0.16 | E | *interp.* |
| | | | [16.34] | | | 5 | 3 | 2.9(+4) | 0.070 | 0.019 | −0.46 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## V XVIII

### Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^2$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. The weakest lines are excluded from this compilation, as their strengths are considered to be very uncertain.

Transition probabilities for these same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these data are in good agreement with the data of Cheng *et al.*

### References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Scr. **32**, 181 (1985).

V XVIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^2$–$2p^2$ | $^3P$ - $^3P$ | | | | | | | | | | |
| | | | [3307.5] | 37963 | 68189 | 3 | 5 | M1 | 324 | 2.17 | C+ | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.0023 | 0.0027 | E | 1 |
| | | | [2633.4] | 0 | 37963 | 1 | 3 | M1 | 921 | 1.87 | C+ | 1 |
| | | | [1466.5] | 0 | 68189 | 1 | 5 | E2 | 0.079 | 0.0016 | E | 1 |
| 2. | | $^3P$ - $^1D$ | | | | | | | | | | |
| | | | 1078.2 | 68189 | 160912 | 5 | 5 | M1 | 3700 | 0.85 | D+ | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.55 | 0.0024 | E | 1 |
| | | | [813.35] | 37963 | 160912 | 3 | 5 | M1 | 3200 | 0.32 | D | 1 |
| 3. | | $^3P$ - $^1S$ | | | | | | | | | | |
| | | | [433.0] | | | 3 | 1 | M1 | 4.3(+4)[a] | 0.13 | D | 1 |
| 4. | | $^1D$ - $^1S$ | [926.3] | | | 5 | 1 | E2 | 13 | 0.0052 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XIX

B Isoelectronic Sequence

Ground State: $1s^22s^22p\ ^2P^\circ_{1/2}$

Ionization Energy: 1355 eV = 10930000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 15.560 | 14 | 130 | 5 | 167.34 | 2 | 203.86 | 12 |
| 15.702 | 14 | 136.25 | 3 | 175.95 | 8 | 231 | 7 |
| 15.727 | 14 | 138.78 | 9 | 178.32 | 8 | 275.06 | 11 |
| 104 | 6 | 140.25 | 9 | 180.07 | 8 | 285.26 | 11 |
| 105 | 6 | 143.13 | 4 | 182.55 | 8 | 301 | 1 |
| 108 | 6 | 143.82 | 9 | 186.32 | 2 | 307 | 1 |
| 124.63 | 3 | 149.42 | 4 | 188.98 | 2 | 436 | 10 |
| 126 | 5 | 157.17 | 4 | 193.93 | 12 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p$–$2s2p^2$ and $2s2p^2$–$2p^3$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

According to several sources (see, e.g., introduction to Fe XXII), the two levels $2s2p^2\ ^2P_{1/2}$ and $^2S_{1/2}$ "cross" at about V XIX or Cr XX. Transitions to these levels in V XIX have been omitted from this compilation, since the precise location of the level crossing, and thus the correct designations of the levels, are uncertain.

The Hartree-Fock results of Shamey[2] for the isoelectronic ions Ar XIV and Fe XXII, which allowed for limited configuration interaction, were interpolated to provide *f*-values for the $2p$–$3s$, $2p$–$3d$, and $2p$–$4d$ transitions.

### References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]L. J. Shamey, J. Opt. Soc. Am. **61**, 942 (1971).

V XIX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p-2s2p^2$ | $^2P^\circ - ^4P$ | | | | | | | | | | | |
| | | | [307] | | | 4 | 6 | 0.22 | 4.6(−4)[a] | 0.0019 | −2.74 | E | 1 |
| | | | [301] | | | 2 | 2 | 0.29 | 3.9(−4) | 7.7(−4) | −3.11 | E | 1 |
| 2. | | $^2P^\circ - ^2D$ | *179.69* | *45620* | *602120* | 6 | 10 | 56 | 0.045 | 0.16 | −0.57 | D− | 1 |
| | | | 186.32 | 68430 | 605140 | 4 | 6 | 49.2 | 0.0384 | 0.094 | −0.81 | C | 1 |
| | | | 167.34 | 0 | 597590 | 2 | 4 | 73 | 0.061 | 0.067 | −0.91 | C | 1 |
| | | | [188.98] | 68430 | 597590 | 4 | 4 | 1.6 | 8.3(−4) | 0.0021 | −2.48 | E | 1 |
| 3. | | $^2P^\circ - ^2P$ | | | | | | | | | | | |
| | | | 136.25 | 68430 | 802370 | 4 | 4 | 340 | 0.096 | 0.17 | −0.42 | C | 1 |
| | | | [124.63] | 0 | 802370 | 2 | 4 | 54 | 0.0253 | 0.0208 | −1.296 | C | 1 |
| 4. | $2s2p^2-2p^3$ | $^4P - ^4S^\circ$ | *152.06* | | | 12 | 4 | 363 | 0.0420 | 0.252 | −0.298 | C | 1 |
| | | | 157.17 | | | 6 | 4 | 164 | 0.0406 | 0.126 | −0.61 | C | 1 |
| | | | 149.42 | | | 4 | 4 | 125 | 0.0420 | 0.083 | −0.77 | C | 1 |
| | | | 143.13 | | | 2 | 4 | 74 | 0.0456 | 0.0430 | −1.040 | C | 1 |
| 5. | | $^4P - ^2D^\circ$ | | | | | | | | | | | |
| | | | [130] | | | 6 | 6 | 6.7 | 0.0017 | 0.0044 | −1.99 | E | 1 |
| | | | [126] | | | 4 | 4 | 6.3 | 0.0015 | 0.0025 | −2.22 | E | 1 |
| 6. | | $^4P - ^2P^\circ$ | | | | | | | | | | | |
| | | | [108] | | | 6 | 4 | 0.86 | 1.0(−4) | 2.1(−4) | −3.22 | E | 1 |
| | | | [105] | | | 4 | 4 | 1.6 | 2.6(−4) | 3.6(−4) | −2.98 | E | 1 |
| | | | [104] | | | 2 | 2 | 1.1 | 1.8(−4) | 1.2(−4) | −3.44 | E | 1 |
| 7. | | $^2D - ^4S^\circ$ | | | | | | | | | | | |
| | | | [231] | | | 4 | 4 | 0.23 | 1.8(−4) | 5.5(−4) | −3.14 | E | 1 |
| 8. | | $^2D - ^2D^\circ$ | *179.02* | *602120* | *1160730* | 10 | 10 | 116 | 0.056 | 0.329 | −0.253 | C | 1 |
| | | | 178.32 | 605140 | 1165930 | 6 | 6 | 104 | 0.0496 | 0.175 | −0.53 | C | 1 |
| | | | 180.07 | 597590 | 1152930 | 4 | 4 | 69 | 0.0333 | 0.079 | −0.88 | C | 1 |
| | | | [182.55] | 605140 | 1152930 | 6 | 4 | 35.4 | 0.0118 | 0.0425 | −1.150 | C | 1 |
| | | | [175.95] | 597590 | 1165930 | 4 | 6 | 19.8 | 0.0138 | 0.0320 | −1.258 | C | 1 |
| 9. | | $^2D - ^2P^\circ$ | *141.32* | *602120* | *1309730* | 10 | 6 | 179 | 0.0322 | 0.150 | −0.492 | C | 1 |
| | | | 140.25 | 605140 | 1318150 | 6 | 4 | 121 | 0.0238 | 0.066 | −0.85 | C | 1 |
| | | | 143.82 | 597590 | 1292900 | 4 | 2 | 218 | 0.0338 | 0.064 | −0.87 | C | 1 |
| | | | 138.78 | 597590 | 1318150 | 4 | 4 | 38.4 | 0.0111 | 0.0203 | −1.353 | C | 1 |
| 10. | | $^2P - ^4S^\circ$ | | | | | | | | | | | |
| | | | [436] | | | 4 | 4 | 0.15 | 4.2(−4) | 0.0024 | −2.77 | E | 1 |
| 11. | | $^2P - ^2D^\circ$ | | | | | | | | | | | |
| | | | [275.06] | 802370 | 1165930 | 4 | 6 | 27.8 | 0.0473 | 0.171 | −0.72 | C | 1 |
| | | | [285.26] | 802370 | 1152930 | 4 | 4 | 0.65 | 7.9(−4) | 0.0030 | −2.50 | E | 1 |
| 12. | | $^2P - ^2P^\circ$ | | | | | | | | | | | |
| | | | 193.93 | 802370 | 1318150 | 4 | 4 | 140 | 0.078 | 0.20 | −0.51 | C | 1 |
| | | | [203.86] | 802370 | 1292900 | 4 | 2 | 23 | 0.0073 | 0.020 | −1.53 | D | 1 |

V XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13. | $2p$–$3s$ | $^2P^\circ$ - $^2S$ | | | | | | | | | | | |
| | | | | | | 4 | 2 | | 0.020 | | −1.10 | E | *interp.* |
| | | | | | | 2 | 2 | | 0.020 | | −1.40 | E | *interp.* |
| 14. | $2p$–$3d$ | $^2P^\circ$ - $^2D$ | *15.656* | *45740* | *6432900* | 6 | 10 | 1.1(+5) | 0.65 | 0.20 | 0.59 | D | *interp.* |
| | | | 15.702 | 68430 | 6437000 | 4 | 6 | 1.0(+5) | 0.58 | 0.12 | 0.37 | D | *interp.* |
| | | | 15.560 | 0 | 6426700 | 2 | 4 | 9.0(+4) | 0.65 | 0.067 | 0.11 | D | *interp.* |
| | | | [15.727] | 68430 | 6426700 | 4 | 4 | 1.7(+4) | 0.064 | 0.013 | −0.59 | D | *interp.* |
| 15. | $2p$–$4d$ | $^2P^\circ$ - $^2D$ | | | | | | | | | | | |
| | | | | | | 4 | 6 | | 0.11 | | −0.36 | D | *interp.* |
| | | | | | | 2 | 4 | | 0.12 | | −0.62 | E | *interp.* |
| | | | | | | 4 | 4 | | 0.012 | | −1.32 | D | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XIX

## Forbidden Transitions

The line strengths tabulated for the single magnetic dipole and single electric quadrupole transition within the $2s^22p$ ground state configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing is limited to the $n=2$ complex. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 in order to bring this value into conformance with the definition of the quadrupole strength used in the NBS tables.

Transition probabilities for the same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their orbital basis includes many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. The line strengths for both the M1 and E2 transitions, derived from these data by interpolation between appropriately spaced ions of the B sequence, are in very good agreement with the data of Cheng *et al.*[1]

### References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).

V XIX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p$–$2p$ | $^2P^\circ$ – $^2P^\circ$ | | | | | | | | | | |
| | | | 1457.6 | 0 | 68610 | 2 | 4 | M1 | 2900 | 1.33 | B | 1 |
| | | | " | " | " | 2 | 4 | E2 | 0.158 | 0.00247 | C | 1 |

# V XX

Be Isoelectronic Sequence

Ground State: $1s^2 2s^2\ ^1S_0$

Ionization Energy: 1486 eV = 11990000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 10.94 | 18 | 14.98 | 24 | 15.40 | 19 | 151.52 | 4 |
| 14.12 | 11 | 14.99 | 24 | 15.43 | 25 | 159.36 | 2 |
| 14.23 | 11 | 15.03 | 12,29 | 15.44 | 19 | 164.58 | 4 |
| 14.24 | 10 | 15.04 | 29 | 15.52 | 30 | 176.68 | 3 |
| 14.28 | 10 | 15.10 | 29 | 15.53 | 31 | 180.57 | 3 |
| 14.36 | 9 | 15.11 | 27,29 | 15.57 | 19 | 181.79 | 7 |
| 14.40 | 8 | 15.14 | 27 | 15.61 | 21 | 187.16 | 3 |
| 14.52 | 16 | 15.18 | 33 | 15.64 | 35 | 194.70 | 3 |
| 14.58 | 10 | 15.19 | 27 | 15.67 | 21 | 201.01 | 3 |
| 14.65 | 15 | 15.20 | 27 | 15.69 | 21 | 207.51 | 3 |
| 14.76 | 14 | 15.22 | 34 | 15.76 | 21 | 281.61 | 6 |
| 14.77 | 14 | 15.23 | 28 | 15.79 | 21 | 309.98 | 1 |
| 14.83 | 24 | 15.27 | 27 | 15.82 | 22 | 383.00 | 5 |
| 14.87 | 24 | 15.30 | 28 | 15.84 | 21 | 435.92 | 5 |
| 14.93 | 13 | 15.33 | 32 | 16.06 | 20 | 519.21 | 5 |
| 14.95 | 29 | 15.34 | 26 | 16.33 | 23 | | |

Oscillator strengths for transitions of the arrays $2s^2$–$2s2p$ and $2s2p$–$2p^2$ are taken from the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include the configuration interaction most relevant for the states of these configurations, as well as a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except for the weakest intercombination lines. (The $^3P_1^\circ$ – $^1S_0$ transition of the $2s2p$–$2p^2$ array has been omitted here, since the $f$-value is considerably smaller than those of the other lines of this array.)

A number of sources of reliable data, from other relativistic calculations, are available for the $2s$–$2p$ transitions. However, with the exception of some of the weaker lines, they all agree well with the results of Cheng *et al.*[1] The latter are quoted exclusively here since they provide data from a single set of comprehensive calculations, all done at a uniform and reasonably accurate level of approximation, for the valence shell $2s$–$2p$ transitions for all ions of the isoelectronic sequence.

The $f$-values for the $2s^2$–$2s3p$, $2s2p$–$2p3p$, $2s2p$–$2s3s$, $2p^2$–$2p3s$, $2s2p$–$2s3d$, and $2p^2$–$2p3d$ arrays of transitions are taken from the work of Fawcett,[2] who used Cowan's version of the relativistic Hartree-Fock method with intermediate coupling and configuration interaction. This work provides a comprehensive set of data for the entire isoelectronic sequence, calculated at a uniform level of approximation. Some of these transitions, for some ions of this sequence, have also been calculated by Bhatia *et al.*[3] using the program SUPERSTRUCTURE, which includes configuration interaction and intermediate coupling. Where they overlap, these two sets of calculations agree to within the uncertainties assigned here. Transitions involving the $J=1$ levels of $2p3p\ ^3S$ and $^3P$ have been omitted because of erratic behavior of the $f$-values along the sequence.

Oscillator strengths for the transition array $2s^2$–$2s4p$ are the results of the relativistic random phase approximation (RRPA) calculations of Lin and Johnson.[4]

A few multiplet $f$-values for transitions involving the outer electron alone, $2s3s$–$2s3p$ and $2s3p$–$2s3d$, have been interpolated along the isoelectronic sequence and assigned a low accuracy.

### References

[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2] B. C. Fawcett, At. Data Nucl. Data Tables **30**, 1 (1984); **33**, 479 (1985).
[3] A. K. Bhatia, U. Feldman, and J. F. Seely, At. Data Nucl. Data Tables **35**, 449 (1986).
[4] C. D. Lin and W. R. Johnson, Phys. Rev. A **15**, 1046 (1977).

V xx: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^2$–$2s2p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [309.98] | 0 | 322600 | 1 | 3 | 0.19 | 8.3(−4)[a] | 8.5(−4) | −3.08 | D | 1 |
| 2. | | $^1$S – $^1$P° | [159.36] | 0 | 627500 | 1 | 3 | 148 | 0.169 | 0.0887 | −0.772 | B | 1 |
| 3. | $2s2p$–$2p^2$ | $^3$P° – $^3$P | *191.98* | *349500* | *870400* | 9 | 9 | 110 | 0.0608 | 0.346 | −0.262 | B | 1 |
| | | | [194.70] | 375000 | 888600 | 5 | 5 | 71.8 | 0.0408 | 0.131 | −0.690 | B | 1 |
| | | | [187.16] | 322600 | 856900 | 3 | 3 | 31.0 | 0.0163 | 0.0301 | −1.311 | B | 1 |
| | | | [207.51] | 375000 | 856900 | 5 | 3 | 38.2 | 0.0148 | 0.0506 | −1.131 | B | 1 |
| | | | [201.01] | 322600 | 820100 | 3 | 1 | 103 | 0.0207 | 0.0411 | −1.207 | B | 1 |
| | | | [176.68] | 322600 | 888600 | 3 | 5 | 38.2 | 0.0298 | 0.0520 | −1.049 | B | 1 |
| | | | [180.57] | 303100 | 856900 | 1 | 3 | 46.9 | 0.0688 | 0.0409 | −1.162 | B | 1 |
| 4. | | $^3$P° – $^1$D | | | | | | | | | | | |
| | | | [164.58] | 375000 | 982600 | 5 | 5 | 21 | 0.0084 | 0.023 | −1.38 | C | 1 |
| | | | [151.52] | 322600 | 982600 | 3 | 5 | 1.7 | 9.8(−4) | 0.0015 | −2.53 | D | 1 |
| 5. | | $^1$P° – $^3$P | | | | | | | | | | | |
| | | | [383.00] | 627500 | 888600 | 3 | 5 | 1.5 | 0.0054 | 0.020 | −1.79 | D | 1 |
| | | | [435.92] | 627500 | 856900 | 3 | 3 | 0.029 | 8.3(−5) | 3.6(−4) | −3.60 | E | 1 |
| | | | [519.21] | 627500 | 820100 | 3 | 1 | 0.16 | 2.1(−4) | 0.0011 | −3.20 | E | 1 |
| 6. | | $^1$P° – $^1$D | [281.61] | 627500 | 982600 | 3 | 5 | 32.6 | 0.0646 | 0.180 | −0.713 | B | 1 |
| 7. | | $^1$P° – $^1$S | [181.79] | 627500 | 1177600 | 3 | 1 | 248 | 0.0409 | 0.0734 | −0.911 | B | 1 |
| 8. | $2s^2$–$2s3p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [14.40] | 0 | 6943800 | 1 | 3 | 3.3(+4) | 0.31 | 0.015 | −0.51 | C− | 2 |
| 9. | | $^1$S – $^1$P° | [14.36] | 0 | 6964000 | 1 | 3 | 4.1(+4) | 0.38 | 0.018 | −0.42 | C− | 2 |
| 10. | $2s2p$–$2p3p$ | $^3$P° – $^3$D | | | | | | | | | | | |
| | | | [14.28] | 375000 | 7378300 | 5 | 7 | 3.3(+4) | 0.14 | 0.033 | −0.15 | C− | 2 |
| | | | [14.28] | 322600 | 7325900 | 3 | 5 | 2.9(+4) | 0.15 | 0.021 | −0.35 | C− | 2 |
| | | | [14.24] | 303100 | [7324000] | 1 | 3 | 8800 | 0.080 | 0.0038 | −1.10 | D | 2 |
| | | | [14.58] | 375000 | 7235900 | 5 | 5 | 1900 | 0.0062 | 0.0015 | −1.51 | D | 2 |
| | | | [14.28] | 322600 | [7324000] | 3 | 3 | 1.4(+4) | 0.043 | 0.0061 | −0.89 | D | 2 |
| 11. | | $^3$P° – $^3$P | | | | | | | | | | | |
| | | | [14.23] | 375000 | 7402900 | 5 | 5 | 3.2(+4) | 0.098 | 0.023 | −0.31 | C− | 2 |
| | | | [14.23] | 322600 | [7350000] | 3 | 1 | 4.0(+4) | 0.040 | 0.0056 | −0.92 | D | 2 |
| | | | [14.12] | 322600 | 7402900 | 3 | 5 | 2600 | 0.013 | 0.0018 | −1.41 | D | 2 |
| 12. | | $^1$P° – $^1$P | [15.03] | 627500 | [7281000] | 3 | 3 | 1.5(+4) | 0.050 | 0.0074 | −0.82 | D | 2 |
| 13. | | $^1$P° – $^3$D | | | | | | | | | | | |
| | | | [14.93] | 627500 | [7324000] | 3 | 3 | 1.1(+4) | 0.037 | 0.0055 | −0.95 | D | 2 |
| 14. | | $^1$P° – $^3$P | | | | | | | | | | | |
| | | | [14.76] | 627500 | 7402900 | 3 | 5 | 8600 | 0.047 | 0.0069 | −0.85 | D | 2 |
| | | | [14.77] | 627500 | [7397000] | 3 | 3 | 730 | 0.0024 | 3.5(−4) | −2.14 | C− | 2 |

V xx: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | | $^1P^\circ$ - $^1D$ | [14.65] | 627500 | 7453900 | 3 | 5 | 4.5(+4) | 0.24 | 0.035 | −0.14 | C− | 2 |
| 16. | | $^1P^\circ$ - $^1S$ | [14.52] | 627500 | [7513000] | 3 | 1 | 3.8(+4) | 0.040 | 0.0057 | −0.92 | D | 2 |
| 17. | $2s^2$–$2s4p$ | $^1S$ - $^3P^\circ$ | | | | | | | | | | | |
| | | | | | | 1 | 3 | | 0.018 | | −1.74 | D | 4 |
| 18. | | $^1S$ - $^1P^\circ$ | [10.94] | 0 | 9140000 | 1 | 3 | 3.0(+4) | 0.16 | 0.0058 | −0.80 | D | 4 |
| 19. | $2s2p$–$2s3s$ | $^3P^\circ$ - $^3S$ | *15.51* | *349500* | [6798000] | 9 | 3 | 2.2(+4) | 0.026 | 0.012 | −0.63 | D | 2 |
| | | | [15.57] | 375000 | [6798000] | 5 | 3 | 1.2(+4) | 0.026 | 0.0067 | −0.89 | D | 2 |
| | | | [15.44] | 322600 | [6798000] | 3 | 3 | 7600 | 0.027 | 0.0041 | −1.09 | D | 2 |
| | | | [15.40] | 303100 | [6798000] | 1 | 3 | 2600 | 0.028 | 0.0014 | −1.55 | D | 2 |
| 20. | | $^1P^\circ$ - $^1S$ | [16.06] | 627500 | [6855000] | 3 | 1 | 7800 | 0.010 | 0.0016 | −1.52 | D | 2 |
| 21. | $2p^2$–$2p3s$ | $^3P$ - $^3P^\circ$ | *15.71* | *870400* | [*7234000*] | 9 | 9 | 1.5(+4) | 0.056 | 0.026 | −0.30 | D | 2 |
| | | | [15.69] | 888600 | [7262000] | 5 | 5 | 1.0(+4) | 0.038 | 0.0098 | −0.72 | D | 2 |
| | | | [15.76] | 856900 | [7203000] | 3 | 3 | 3000 | 0.011 | 0.0017 | −1.48 | D | 2 |
| | | | [15.84] | 888600 | [7203000] | 5 | 3 | 6600 | 0.015 | 0.0039 | −1.12 | D | 2 |
| | | | [15.79] | 856900 | [7191000] | 3 | 1 | 1.4(+4) | 0.017 | 0.0027 | −1.29 | D | 2 |
| | | | [15.61] | 856900 | [7262000] | 3 | 5 | 4900 | 0.030 | 0.0046 | −1.05 | D | 2 |
| | | | [15.67] | 820100 | [7203000] | 1 | 3 | 5200 | 0.057 | 0.0029 | −1.24 | D | 2 |
| 22. | | $^1D$ - $^1P^\circ$ | [15.82] | 982600 | [7303000] | 5 | 3 | 1.2(+4) | 0.028 | 0.0073 | −0.85 | D | 2 |
| 23. | | $^1S$ - $^1P^\circ$ | [16.33] | 1177600 | [7303000] | 1 | 3 | 4800 | 0.058 | 0.0031 | −1.24 | D | 2 |
| 24. | $2s2p$–$2s3d$ | $^3P^\circ$ - $^3D$ | *14.93* | *349500* | *7049600* | 9 | 15 | 1.3(+5) | 0.72 | 0.32 | 0.81 | C− | 2 |
| | | | [14.98] | 375000 | 7052400 | 5 | 7 | 1.3(+5) | 0.60 | 0.15 | 0.48 | C− | 2 |
| | | | [14.87] | 322600 | 7047500 | 3 | 5 | 1.0(+5) | 0.55 | 0.081 | 0.22 | C− | 2 |
| | | | [14.83] | 303100 | 7046600 | 1 | 3 | 7.5(+4) | 0.74 | 0.036 | −0.13 | C− | 2 |
| | | | [14.99] | 375000 | 7047500 | 5 | 5 | 3.3(+4) | 0.11 | 0.027 | −0.26 | C− | 2 |
| | | | [14.87] | 322600 | 7046600 | 3 | 3 | 5.4(+4) | 0.18 | 0.026 | −0.27 | C− | 2 |
| | | | [14.99] | 375000 | 7046600 | 5 | 3 | 3600 | 0.0072 | 0.0018 | −1.44 | C− | 2 |
| 25. | | $^1P^\circ$ - $^1D$ | [15.43] | 627500 | 7109600 | 3 | 5 | 1.0(+5) | 0.61 | 0.093 | 0.26 | C− | 2 |
| 26. | $2p^2$–$2p3d$ | $^3P$ - $^3F^\circ$ | | | | | | | | | | | |
| | | | [15.34] | 888600 | 7409200 | 5 | 7 | 2.8(+4) | 0.14 | 0.035 | −0.15 | C− | 2 |
| 27. | | $^3P$ - $^3D^\circ$ | *15.14* | *870400* | *7475200* | 9 | 15 | 1.2(+5) | 0.71 | 0.32 | 0.81 | C− | 2 |
| | | | [15.14] | 888600 | 7493200 | 5 | 7 | 1.5(+5) | 0.70 | 0.17 | 0.54 | C− | 2 |
| | | | [15.11] | 856900 | 7473300 | 3 | 5 | 7.9(+4) | 0.453 | 0.068 | 0.133 | C− | 2 |
| | | | [15.11] | 820100 | 7436500 | 1 | 3 | 1.25(+5) | 1.28 | 0.064 | 0.107 | C− | 2 |
| | | | [15.19] | 888600 | 7473300 | 5 | 5 | 7500 | 0.026 | 0.0065 | −0.89 | D | 2 |
| | | | [15.20] | 856900 | 7436500 | 3 | 3 | 2.9(+4) | 0.10 | 0.015 | −0.52 | C− | 2 |
| | | | [15.27] | 888600 | 7436500 | 5 | 3 | 620 | 0.0013 | 3.3(−4) | −2.19 | D | 2 |
| 28. | | $^3P$ - $^1D^\circ$ | | | | | | | | | | | |
| | | | [15.30] | 888600 | 7423300 | 5 | 5 | 6300 | 0.022 | 0.0055 | −0.96 | C− | 2 |
| | | | [15.23] | 856900 | 7423300 | 3 | 5 | 6.4(+4) | 0.37 | 0.056 | 0.05 | D | 2 |

V XX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | | $^3P$ - $^3P^{\circ}$ | *15.07* | *870400* | *[7507000]* | 9 | 9 | 9.7(+4) | 0.331 | 0.148 | 0.475 | C− | 2 |
| | | | [15.11] | 888600 | 7505000 | 5 | 5 | 8.4(+4) | 0.288 | 0.072 | 0.158 | C− | 2 |
| | | | [15.03] | 856900 | [7509000] | 3 | 3 | 6.5(+4) | 0.22 | 0.033 | −0.18 | C− | 2 |
| | | | [15.10] | 888600 | [7509000] | 5 | 3 | 3.9(+4) | 0.080 | 0.020 | −0.40 | C− | 2 |
| | | | [15.03] | 856900 | [7511000] | 3 | 1 | 9.7(+4) | 0.11 | 0.016 | −0.48 | C− | 2 |
| | | | [15.04] | 856900 | 7505000 | 3 | 5 | 8800 | 0.050 | 0.0074 | −0.82 | D | 2 |
| | | | [14.95] | 820100 | [7509000] | 1 | 3 | 760 | 0.0076 | 3.7(−4) | −2.12 | D | 2 |
| 30. | | $^1D$ - $^3F^{\circ}$ | | | | | | | | | | | |
| | | | [15.52] | 982600 | [7425000] | 5 | 5 | 7200 | 0.026 | 0.0066 | −0.89 | D | 2 |
| 31. | | $^1D$ - $^1D^{\circ}$ | [15.53] | 982600 | 7423300 | 5 | 5 | 1.7(+4) | 0.060 | 0.015 | −0.52 | C− | 2 |
| 32. | | $^1D$ - $^3P^{\circ}$ | | | | | | | | | | | |
| | | | [15.33] | 982600 | 7505000 | 5 | 5 | 2.6(+4) | 0.090 | 0.023 | −0.35 | C− | 2 |
| 33. | | $^1D$ - $^1P^{\circ}$ | [15.18] | 982600 | 7571900 | 5 | 3 | 7200 | 0.015 | 0.0037 | −1.12 | D | 2 |
| 34. | | $^1D$ - $^1F^{\circ}$ | [15.22] | 982600 | 7554600 | 5 | 7 | 2.16(+5) | 1.05 | 0.263 | 0.72 | C− | 2 |
| 35. | | $^1S$ - $^1P^{\circ}$ | [15.64] | 1177600 | 7571900 | 1 | 3 | 1.17(+5) | 1.29 | 0.066 | 0.111 | C− | 2 |
| 36. | $2s3s$–$2s3p$ | $^3S$ - $^3P^{\circ}$ | | | | 3 | 9 | | 0.14 | | −0.38 | D | *interp.* |
| 37. | | $^1S$ - $^1P^{\circ}$ | | | | 1 | 3 | | 0.058 | | −1.24 | E | *interp.* |
| 38. | $2s3p$–$2s3d$ | $^3P^{\circ}$ - $^3D$ | | | | 9 | 15 | | 0.031 | | −0.55 | E | *interp.* |
| 39. | | $^1P^{\circ}$ - $^1D$ | | | | 3 | 5 | | 0.054 | | −0.79 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XX

## Forbidden Transitions

Transition probabilities for magnetic dipole and electric quadrupole transitions within the $2s2p$ and $2p^2$ configurations were calculated by Oboladze and Safronova[1] and by Anderson and Anderson,[2] using a nuclear charge expansion method and a multiconfiguration relativistic Hartree-Fock method, respectively. We have given preference to the calculations of the Andersons, which we consider more advanced. However, they have treated only four of the listed transitions. In these cases, Oboladze and Safronova agree with them within 20%. For other ions of the Be sequence, the work of Oboladze and Safronova could be compared with that of various other authors, and the agreements were found to be similarly good.

### References

[1]N. S. Oboladze and U. I. Safronova, Opt. Spectrosc. (USSR) **48**, 469 (1980).
[2]E. K. Anderson and E. M. Anderson, Opt. Spectrosc. (USSR) **52**, 478 (1982).

V XX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s2p-2s2p$ | $^3P^\circ - {^3P^\circ}$ | | | | | | | | | | |
| | | | [1908] | 322600 | 375000 | 3 | 5 | M1 | 1910 | 2.46 | C+ | 2 |
| | | | [5126.8] | 303100 | 322600 | 1 | 3 | M1 | 129 | 1.93 | C+ | 1 |
| 2. | | $^3P^\circ - {^1P^\circ}$ | | | | | | | | | | |
| | | | [396.0] | 375000 | 627500 | 5 | 3 | M1 | 4500 | 0.031 | D | 1 |
| | | | [328.0] | 322600 | 627500 | 3 | 3 | M1 | 4800 | 0.019 | D− | 2 |
| | | | " | " | " | 3 | 3 | E2 | 15 | 1.0(−4)[a] | D− | 2 |
| | | | [308.3] | 303100 | 627500 | 1 | 3 | M1 | 7700 | 0.025 | D− | 1 |
| 3. | $2p^2-2p^2$ | $^3P - {^3P}$ | | | | | | | | | | |
| | | | [3154] | 856900 | 888600 | 3 | 5 | M1 | 353 | 2.05 | C | 1 |
| | | | [2717] | 820100 | 856900 | 1 | 3 | M1 | 830 | 1.9 | C | 1 |
| 4. | | $^3P - {^1D}$ | | | | | | | | | | |
| | | | [1063.8] | 888600 | 982600 | 5 | 5 | M1 | 4100 | 0.91 | D+ | 2 |
| | | | [795.5] | 856900 | 982600 | 3 | 5 | M1 | 4100 | 0.38 | D+ | 1 |
| 5. | | $^3P - {^1S}$ | | | | | | | | | | |
| | | | [311.8] | 856900 | 1177600 | 3 | 1 | M1 | 6.2(+4) | 0.070 | D | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XXI

Li Isoelectronic Sequence

Ground State: $1s^22s\ ^2S_{1/2}$

Ionization Energy: 1569.6 eV = 12660000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2.3888 | 4 | 9.175 | 17 | 22.0 | 23 | 41.696 | 24 |
| 2.398 | 1 | 9.352 | 8 | 22.4 | 29 | 41.745 | 24 |
| 2.3992 | 3 | 9.633 | 15 | 22.5 | 29 | 48.1 | 38 |
| 2.401 | 1,3 | 9.704 | 15 | 23.8 | 22 | 48.3 | 38 |
| 2.4013 | 2 | 10.413 | 7 | 24.3 | 27 | 58.1 | 36 |
| 2.4047 | 2 | 10.768 | 13 | 24.4 | 27 | 88.5 | 34 |
| 2.405 | 3 | 10.853 | 13 | 27.9 | 21 | 89.3 | 34 |
| 8.576 | 10 | 13.828 | 6 | 28.5 | 25 | 240.37 | 5 |
| 8.826 | 19 | 13.870 | 6 | 28.6 | 25 | 293.8 | 5 |
| 8.843 | 9 | 14.435 | 12 | 28.7 | 25 | | |
| 8.882 | 19 | 14.578 | 12 | 40.177 | 20 | | |
| 9.111 | 17 | 14.592 | 12 | 41.367 | 24 | | |

Transition probabilities for the strongest inner-shell transitions to doubly excited $n = 2$ states are taken from the multiconfiguration Dirac-Fock (MCDF) calculations of Hata and Grant.[1] Their results are in good agreement with the $Z$-expansion perturbation calculations of Vainshtein and Safronova,[2] who included relativistic corrections at the level of the Pauli approximation.

Oscillator strengths for lines of the principal ($2s$–$2p$) resonance multiplet are the results of the MCDF calculations of Cheng *et al.*,[3] which include a perturbative treatment of the Breit interaction and the Lamb shift. The results of the MCDF calculations of Armstrong *et al.*[4] were interpolated to provide $f$-values for the $2p$–$3d$ transitions.

The $f$-value for the $3d$–$4f$ transition was taken from a study of systematic trends along isoelectronic sequences by Smith and Wiese.[5] The tabulated data for many additional transitions were taken from the theoretical analysis of Martin and Wiese,[6] which was based on a generalized study of systematic trends for several spectral series of the lithium isoelectronic sequence.

Results of the relativistic Hartree-Fock calculations of Kim and Desclaux[7] for several ions of the Li sequence were incorporated into the data of Ref. 6 for the $2s$–$3p$ transitions. For all other transitions for which the results of Ref. 6 are quoted here, no relativistic calculations were available. However, the relativistic calculations of Younger and Weiss[8] for the hydrogen isoelectronic sequence provide a means of assessing the magnitude of relativistic corrections since the Li sequence is very similar in structure to the H sequence. For those transitions for which relativistic effects were estimated to be significant (specifically, whenever the ratio of the weighted relativistic hydrogenic $f$-values $g_i f_{ik}$ of any two lines within a multiplet was found to deviate from the corresponding $LS$-coupling linestrength ratio by more than 5% for the appropriate value of the nuclear charge $Z$), the $f$-values were excluded from the compilation. A more detailed discussion of this comparison is given in Ref. 6.

Although the $2p$–$3s$ multiplet did not satisfy the criterion described in the paragraph above, we have nevertheless quoted the multiplet $f$-value obtained by Onello[9] using a $Z$-expansion technique based on a variational calculation for O VI That allowed for large-scale configuration interaction. The resulting multiplet oscillator strengths for Fe XXIV and Ni XXVI are in very good agreement with data derived from the results of calculations that included relativistic effects.[10,11] We thus felt that the results of Ref. 9 should be sufficiently accurate for inclusion in this compilation.

Transition probability data are available for numerous transitions involving doubly excited states with the spectator electron occupying the $n=3$ shell, or higher.[12] These have not been tabulated, however, since they belong to, or are very close to belonging to, the unresolved satellites of the helium-like ion.

## References

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[10]M. A. Hayes, Mon. Not. R. Astron. Soc. **189**, 55P (1979).
[11]B. C. Fawcett, A. Ridgeley, and T. P. Hughes, Mon. Not. R. Astron. Soc. **188**, 365 (1979).
[12]L. A. Vainshtein and U. I. Safronova, At. Data Nucl. DataTables **25**, 311 (1980).

V XXI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^22s$–$1s(^2S)2s2p(^3P^\circ)$ | $^2S$ – $^2P^\circ$ | *2.398* | | | 2 | 6 | 3.4(+5)[a] | 0.089 | 0.0014 | −0.75 | D | 1 |
| | | | [2.348] | | | 2 | 4 | 7.2(+4) | 0.012 | 1.8(−4) | −1.62 | D | 1 |
| | | | [2.401] | | | 2 | 2 | 9.0(+5) | 0.078 | 0.0012 | −0.81 | C | 1 |
| 2. | $1s^22p$–$1s2p^2$ | $^2P^\circ$ – $^2D$ | | | | | | | | | | | |
| | | | 2.4047 | 416030 | 42001000 | 4 | 6 | 1.4(+6) | 0.18 | 0.0058 | −0.14 | C | 1 |
| | | | 2.4013 | [340400] | [41984000] | 2 | 4 | 1.9(+6) | 0.33 | 0.0052 | −0.18 | C | 1 |

V XXI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | | $^2P^\circ - ^2P$ | | | | | | | | | | | |
| | | | 2.3992 | 416030 | 42097000 | 4 | 4 | 3.9(+6) | 0.34 | 0.011 | 0.13 | C | 1 |
| | | | [2.401] | | | 2 | 2 | 3.3(+6) | 0.29 | 0.0045 | −0.24 | C | 1 |
| | | | [2.405] | | | 4 | 2 | 1.1(+6) | 0.048 | 0.0015 | −0.72 | C | 1 |
| 4. | | $^2P^\circ - ^2S$ | | | | | | | | | | | |
| | | | 2.3888 | 416030 | 42278000 | 4 | 2 | 1.4(+6) | 0.060 | 0.0019 | −0.62 | D | 1 |
| 5. | $2s$–$2p$ | $^2S - ^2P^\circ$ | *255.9* | 0 | [*390800*] | 2 | 6 | 23.8 | 0.0700 | 0.118 | −0.854 | B+ | 3 |
| | | | 240.37 | 0 | 416030 | 2 | 4 | 28.7 | 0.0498 | 0.0788 | −1.002 | B+ | 3 |
| | | | [293.8] | 0 | [340400] | 2 | 2 | 15.6 | 0.0202 | 0.0391 | −1.394 | B+ | 3 |
| 6. | $2s$–$3p$ | $^2S - ^2P^\circ$ | *13.842* | 0 | *7224400* | 2 | 6 | 4.29(+4) | 0.370 | 0.0337 | −0.131 | B | 6 |
| | | | 13.828 | 0 | 7231700 | 2 | 4 | 4.26(+4) | 0.244 | 0.0222 | −0.312 | B | 6 |
| | | | 13.870 | 0 | 7209800 | 2 | 2 | 4.37(+4) | 0.126 | 0.0115 | −0.599 | B | 6 |
| 7. | $2s$–$4p$ | $^2S - ^2P^\circ$ | 10.413 | 0 | 9603400 | 2 | 6 | 2.0(+4) | 0.099 | 0.0068 | −0.70 | C+ | 6 |
| 8. | $2s$–$5p$ | $^2S - ^2P^\circ$ | 9.352 | 0 | 10690000 | 2 | 6 | 1.0(+4) | 0.040 | 0.0025 | −1.10 | C+ | 6 |
| 9. | $2s$–$6p$ | $^2S - ^2P^\circ$ | 8.843 | 0 | 11310000 | 2 | 6 | 6030 | 0.0212 | 0.00123 | −1.373 | C+ | 6 |
| 10. | $2s$–$7p$ | $^2S - ^2P^\circ$ | 8.576 | 0 | 11660000 | 2 | 6 | 3750 | 0.0124 | 7.00(−4) | −1.606 | C+ | 6 |
| 11. | $2p$–$3s$ | $^2P^\circ - ^2S$ | *14.873* | [*390800*] | 7114400 | 6 | 2 | 1.6(+4) | 0.018 | 0.0053 | −0.97 | D | 9 |
| 12. | $2p$–$3d$ | $^2P^\circ - ^2D$ | *14.530* | [*390800*] | *7273100* | 6 | 10 | 1.28(+5) | 0.676 | 0.194 | 0.608 | B | *interp.* |
| | | | 14.578 | 416030 | 7275700 | 4 | 6 | 1.28(+5) | 0.610 | 0.117 | 0.387 | B | *interp.* |
| | | | 14.435 | [340400] | 7269100 | 2 | 4 | 1.07(+5) | 0.671 | 0.0638 | 0.128 | B | *interp.* |
| | | | 14.592 | 416030 | 7269100 | 4 | 4 | 2.1(+4) | 0.068 | 0.013 | −0.57 | B | *interp.* |
| 13. | $2p$–$4d$ | $^2P^\circ - ^2D$ | *10.825* | [*390800*] | [*9628900*] | 6 | 10 | 4.1(+4) | 0.12 | 0.026 | −0.14 | B | 6 |
| | | | 10.853 | 416030 | 9630000 | 4 | 6 | 4.2(+4) | 0.11 | 0.016 | −0.35 | B | *ls* |
| | | | 10.768 | [340400] | [9627200] | 2 | 4 | 3.5(+4) | 0.12 | 0.0087 | −0.61 | B | *ls* |
| | | | 10.853 | 416030 | [9627200] | 4 | 4 | 6700 | 0.012 | 0.0017 | −1.32 | C+ | *ls* |
| 14. | $2p$–$5s$ | $^2P^\circ - ^2S$ | | | | 6 | 2 | | 0.0017 | | −1.99 | D+ | 6 |
| 15. | $2p$–$5d$ | $^2P^\circ - ^2D$ | *9.671* | [*390800*] | [*10730000*] | 6 | 10 | 1.93(+4) | 0.0450 | 0.00860 | −0.569 | C+ | 6 |
| | | | 9.704 | 416030 | 10730000 | 4 | 6 | 1.91(+4) | 0.0404 | 0.00516 | −0.792 | C+ | *ls* |
| | | | 9.633 | [340400] | [10720000] | 2 | 4 | 1.63(+4) | 0.0453 | 0.00287 | −1.043 | C+ | *ls* |
| | | | 9.704 | 416030 | [10720000] | 4 | 4 | 3200 | 0.0045 | 5.7(−4) | −1.75 | D | *ls* |
| 16. | $2p$–$6s$ | $^2P^\circ - ^2S$ | | | | 6 | 2 | | 8.4(−4) | | −2.30 | D | 6 |
| 17. | $2p$–$6d$ | $^2P^\circ - ^2D$ | *9.149* | [*390800*] | [11320000] | 6 | 10 | 1.05(+4) | 0.0220 | 0.00398 | −0.879 | C+ | 6 |
| | | | 9.175 | 416030 | 11320000 | 4 | 6 | 1.04(+4) | 0.0198 | 0.00239 | −1.102 | C+ | *ls* |
| | | | 9.111 | [340400] | [11320000] | 2 | 4 | 8910 | 0.0222 | 0.00133 | −1.353 | C+ | *ls* |
| | | | 9.175 | 416030 | [11320000] | 4 | 4 | 1800 | 0.0022 | 2.7(−4) | −2.05 | D | *ls* |
| 18. | $2p$–$7s$ | $^2P^\circ - ^2S$ | | | | 6 | 2 | | 4.8(−4) | | −2.54 | D | 6 |

V XXI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19. | 2p–7d | $^2P^\circ - {}^2D$ | *8.857* | *[390800]* | *[11680000]* | 6 | 10 | 6430 | 0.0126 | 0.00220 | −1.121 | C+ | 6 |
| | | | 8.882 | 416030 | 11680000 | 4 | 6 | 6360 | 0.0113 | 0.00132 | −1.345 | C+ | ls |
| | | | 8.826 | [340400] | [11670000] | 2 | 4 | 5400 | 0.0126 | 7.33(−4) | −1.598 | C+ | ls |
| | | | 8.882 | 416030 | [11670000] | 4 | 4 | 1100 | 0.0013 | 1.5(−4) | −2.29 | D | ls |
| 20. | 3s–4p | $^2S - {}^2P^\circ$ | [40.177] | 7114400 | 9603400 | 2 | 6 | 5900 | 0.43 | 0.11 | −0.07 | C | 6 |
| 21. | 3s–5p | $^2S - {}^2P^\circ$ | [27.9] | 7114400 | 10690000 | 2 | 6 | 3060 | 0.107 | 0.0197 | −0.67 | C | 6 |
| 22. | 3s–6p | $^2S - {}^2P^\circ$ | [23.8] | 7114400 | 11310000 | 2 | 6 | 1800 | 0.047 | 0.0074 | −1.03 | C | 6 |
| 23. | 3s–7p | $^2S - {}^2P^\circ$ | [22.0] | 7114400 | 11660000 | 2 | 6 | 1140 | 0.0249 | 0.00361 | −1.303 | C | 6 |
| 24. | 3p–4d | $^2P^\circ - {}^2D$ | *41.589* | *7224400* | *[9628900]* | 6 | 10 | 1.4(+4) | 0.59 | 0.48 | 0.55 | B | 6 |
| | | | [41.696] | 7231700 | 9630000 | 4 | 6 | 1.4(+4) | 0.53 | 0.29 | 0.32 | B | ls |
| | | | [41.367] | 7209800 | [9627200] | 2 | 4 | 1.1(+4) | 0.59 | 0.16 | 0.07 | B | ls |
| | | | [41.745] | 7231700 | [9627200] | 4 | 4 | 2200 | 0.058 | 0.032 | −0.63 | C+ | ls |
| 25. | 3p–5d | $^2P^\circ - {}^2D$ | *28.5* | *7224400* | *[10730000]* | 6 | 10 | 6800 | 0.138 | 0.0777 | −0.082 | C+ | 6 |
| | | | [28.6] | 7231700 | 10730000 | 4 | 6 | 6730 | 0.124 | 0.0466 | −0.305 | C+ | ls |
| | | | [28.5] | 7209800 | [10720000] | 2 | 4 | 5670 | 0.138 | 0.0259 | −0.559 | C+ | ls |
| | | | [28.7] | 7231700 | [10720000] | 4 | 4 | 1100 | 0.014 | 0.0052 | −1.26 | D | ls |
| 26. | 3p–6s | $^2P^\circ - {}^2S$ | | | | 6 | 2 | | 0.0038 | | −1.64 | C− | 6 |
| 27. | 3p–6d | $^2P^\circ - {}^2D$ | *24.4* | *7224400* | [11320000] | 6 | 10 | 3750 | 0.0558 | 0.0269 | −0.475 | C+ | 6 |
| | | | [24.4] | 7231700 | 11320000 | 4 | 6 | 3740 | 0.0501 | 0.0161 | −0.698 | C+ | ls |
| | | | [24.3] | 7209800 | [11320000] | 2 | 4 | 3170 | 0.0561 | 0.00897 | −0.950 | C+ | ls |
| | | | [24.4] | 7231700 | [11320000] | 4 | 4 | 630 | 0.0056 | 0.0018 | −1.65 | D | ls |
| 28. | 3p–7s | $^2P^\circ - {}^2S$ | | | | 6 | 2 | | 0.0018 | | −1.97 | C− | 6 |
| 29. | 3p–7d | $^2P^\circ - {}^2D$ | *22.4* | *7224400* | *[11680000]* | 6 | 10 | 2310 | 0.0289 | 0.0128 | −0.761 | C+ | 6 |
| | | | [22.5] | 7231700 | 11680000 | 4 | 6 | 2280 | 0.0259 | 0.00768 | −0.984 | C+ | ls |
| | | | [22.4] | 7209800 | [11670000] | 2 | 4 | 1920 | 0.0290 | 0.00427 | −1.237 | C+ | ls |
| | | | [22.5] | 7231700 | [11670000] | 4 | 4 | 380 | 0.0029 | 8.5(−4) | −1.94 | D | ls |
| 30. | 3d–4f | $^2D - {}^2F^\circ$ | | | | 10 | 14 | | 1.00 | | 1.000 | B | 5 |
| 31. | 4s–5p | $^2S - {}^2P^\circ$ | | | | 2 | 6 | | 0.471 | | −0.026 | C | 6 |
| 32. | 4s–6p | $^2S - {}^2P^\circ$ | | | | 2 | 6 | | 0.127 | | −0.60 | C | 6 |
| 33. | 4s–7p | $^2S - {}^2P^\circ$ | | | | 2 | 6 | | 0.056 | | −0.95 | C | 6 |
| 34. | 4p–5d | $^2P^\circ - {}^2D$ | *88.5* | 9603400 | *[10730000]* | 6 | 10 | 2970 | 0.582 | 1.02 | 0.543 | C+ | 6 |
| | | | [88.5] | 9603400 | 10730000 | 4 | 6 | 2980 | 0.525 | 0.612 | 0.322 | C+ | ls |
| | | | [89.3] | 9603400 | [10720000] | 2 | 4 | 2420 | 0.578 | 0.340 | 0.063 | C+ | ls |
| | | | [89.3] | 9603400 | [10720000] | 4 | 4 | 480 | 0.058 | 0.068 | −0.64 | D | ls |
| 35. | 4p–6s | $^2P^\circ - {}^2S$ | | | | 6 | 2 | | 0.0146 | | −1.057 | C− | 6 |
| 36. | 4p–6d | $^2P^\circ - {}^2D$ | [58.1] | 9603400 | [11320000] | 6 | 10 | 1670 | 0.141 | 0.162 | −0.073 | C+ | 6 |
| 37. | 4p–7s | $^2P^\circ - {}^2S$ | | | | 6 | 2 | | 0.0060 | | −1.44 | C− | 6 |

V XXI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38. | $4p$–$7d$ | $^2$P° - $^2$D | *48.1* | 9603400 | [*11680000*] | 6 | 10 | 1070 | 0.0616 | 0.0585 | −0.432 | C+ | 6 |
| | | | [48.1] | 9603400 | 11680000 | 4 | 6 | 1070 | 0.0554 | 0.0351 | −0.654 | C+ | *ls* |
| | | | [48.3] | 9603400 | [11670000] | 2 | 4 | 877 | 0.0613 | 0.0195 | −0.911 | C+ | *ls* |
| | | | [48.3] | 9603400 | [11670000] | 4 | 4 | 180 | 0.0061 | 0.0039 | −1.61 | D | *ls* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# V XXI

## Forbidden Transitions

The single magnetic dipole transition within the $1s^2 2p$ configuration has the line strength of 1.33 in the absence of relativistic effects in the wavefunctions.[1] It is estimated that these effects are negligible, since comprehensive relativistic calculations by Cheng *et al.*[2] for the analogous transition in the $1s^2 2s^2 2p$ configuration of the boron sequence show that such relativistic corrections are negligible until much more highly charged ions.

The listed transition probability data are also expected to be quite accurate since the energy levels are derived from experimental data.

An electric quadrupole transition at the same wavelength is estimated to be of negligible strength, as calculated by Bhatia[3] for this transition in the case of Mn XXIII. (He obtains a ratio of about $10^{-3}$ for the ratio of E2 to M1 line strengths).

### References

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[2]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[3]A. K. Bhatia, private communication (1986).

V XXI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p$–$2p$ | $^2$P° - $^2$P | | | | | | | | | | |
| | | | [1323.6] | 340470 | 416020 | 2 | 4 | M1 | 3870 | 1.33 | B | *interp.* |

# V XXII

He Isoelectronic Sequence

Ground State: $1s^2\ ^1S_0$

Ionization Energy: 6851.3 eV = 55259000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 1.8820 | 17 | 2.296 | 7 | 9.8556 | 24 | 38.562 | 44 |
| 1.8824 | 16 | 2.297 | 3,7,10 | 9.8973 | 31 | 39.053 | 45 |
| 1.9254 | 15 | 2.298 | 7 | 10.073 | 32 | 81.110 | 55 |
| 1.9262 | 14 | 2.303 | 9 | 12.946 | 21 | 81.880 | 56 |
| 2.0262 | 13 | 2.310 | 5 | 13.225 | 22 | 83.612 | 58 |
| 2.0285 | 12 | 2.320 | 6 | 13.420 | 27 | 84.424 | 59 |
| 2.283 | 11 | 2.3817 | 2 | 13.680 | 28 | 242.2 | 19 |
| 2.289 | 4 | 2.3931 | 1 | 25.739 | 41 | 357.0 | 18 |
| 2.290 | 8 | 8.6578 | 25 | 26.047 | 42 | 468.2 | 18 |
| 2.291 | 3 | 8.8156 | 26 | 26.221 | 48 | 496.0 | 18 |
| 2.292 | 7 | 8.8306 | 35 | 26.529 | 49 | 514.9 | 20 |
| 2.294 | 7 | 8.9792 | 36 | 37.359 | 39 | | |
| 2.295 | 3 | 9.6694 | 23 | 37.847 | 40 | | |

Oscillator strengths for transitions of the $1s^2$–$1s2p$ array are taken from the results of Drake,[1] who incorporated accurate nonrelativistic matrix elements and Dirac hydrogenic matrix elements into a $Z$-expansion technique in order to provide $f$-values which would accurately reflect correlation effects for low-$Z$ ions and relativistic effects for high-$Z$ ions of the helium isoelectronic sequence. The $f$-values for the $1s^2\ ^1S$ - $1snp\ ^3P^\circ$ ($n=3$–5) transitions were interpolated from results of the relativistic random phase approximation (RRPA) calculations of Johnson and Lin.[2] Data for other $s$–$p$ and $p$–$s$ transitions were interpolated from the RRPA results of Lin *et al.*,[3] with the exception of the $2s$–$2p$ transitions, where we tabulate the actual published RRPA $A$-values of these same authors.[4]

The charge expansion results of Laughlin[5] are given for various $p$–$d$ and $d$–$p$ transitions, as well as transitions between $4d$ and $4f$ levels. For those multiplets involving no change in principal quantum number ($3p$–$3d$, $4p$–$4d$, $4d$–$4f$) the $f$-values should be considered rather uncertain, since they are sensitive to energy differences. Oscillator strengths for the $2p$–$3d$ transitions, and for $1s3p\ ^3P^\circ$ - $1s3d\ ^3D$, were interpolated from the variational calculations of Weiss.[6] Both of these calculations indicate that, unlike the triplets, the $nd\ ^1D$ energy levels ($n=3,4$) lie below the $np\ ^1P^\circ$ levels, and the $4f\ ^1F^\circ$ lies below the $4d\ ^1D$.

Brown and Cortez[7] have provided $f$-values for numerous $d$–$f$ and $f$–$d$ transitions for the isoelectronic sequence by fitting $Z$-expansion formulas to the results of variational calculations for the low-$Z$ ions. Their results for transitions between the lower-lying D and F° terms are tabulated here.

Transition probabilities for the stronger transitions involving the doubly excited $n=2$ states are taken from the comprehensive, charge expansion perturbation theory calculations of Vainshtein and Safronova.[8] Numerous data are also available for transitions involving doubly excited states where the spectator electron has principal quantum number $n=3$.[9] However, these data are not tabulated here since most of the transitions are very close to belonging to the unresolved satellites of the H-like ions, if they do not in fact do so.

### References


[1] G. W. F. Drake, Phys. Rev. A **19**, 1387 (1979).
[2] W. R. Johnson and C. D. Lin, Phys. Rev. A **14**, 565 (1976).
[3] C. D. Lin, W. R. Johnson, and A. Dalgarno, Astrophys. J. **217**, 1011 (1977).
[4] C. D. Lin, W. R. Johnson, and A. Dalgarno, Phys. Rev. A **15**, 154 (1977).
[5] C. J. Laughlin, J. Phys. B **6**, 1942 (1973).
[6] A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **71**, 163 (1967).
[7] R. T. Brown and J.-L. M. Cortez, Astrophys. J. **176**, 267 (1972).
[8] L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **21**, 49 (1978).
[9] L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **25**, 311 (1980).

V XXII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2$–$1s2p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [2.3931] | 0 | [41786800] | 1 | 3 | 1.64(+5)[a] | 0.0422 | 3.32(−4) | −1.375 | B | 1 |
| 2. | | $^1$S – $^1$P° | [2.3817] | 0 | [41986000] | 1 | 3 | 2.85(+6) | 0.728 | 0.00571 | −0.138 | B | 1 |
| 3. | $1s2s$–$2s2p$ | $^3$S – $^3$P° | *2.293* | [41573200] | [*85180000*] | 3 | 9 | 1.7(+6) | 0.40 | 0.0090 | 0.08 | C | 8 |
| | | | [2.291] | [41573200] | [85220000] | 3 | 5 | 1.7(+6) | 0.22 | 0.0050 | −0.17 | C | 8 |
| | | | [2.295] | [41573200] | [85140000] | 3 | 3 | 1.7(+6) | 0.13 | 0.0030 | −0.40 | C | 8 |
| | | | [2.297] | [41573200] | [85110000] | 3 | 1 | 1.7(+6) | 0.045 | 0.0010 | −0.87 | C | 8 |
| 4. | | $^1$S – $^1$P° | 2.289 | [41791800] | [85480000] | 1 | 3 | 1.7(+6) | 0.40 | 0.0030 | −0.40 | C | 8 |
| 5. | $1s2p$–$2s^2$ | $^3$P° – $^1$S | | | | | | | | | | | |
| | | | [2.310] | [41786800] | [85080000] | 3 | 1 | 2.0(+5) | 0.0053 | 1.2(−4) | −1.80 | D | 8 |
| 6. | | $^1$P° – $^1$S | [2.320] | [41986000] | [85080000] | 3 | 1 | 4.6(+5) | 0.012 | 2.8(−4) | −1.43 | C | 8 |
| 7. | $1s2p$–$2p^2$ | $^3$P° – $^3$P | *2.295* | [*41822400*] | [*85400000*] | 9 | 9 | 3.2(+6) | 0.25 | 0.017 | 0.35 | D+ | 8 |
| | | | [2.296] | [41853300] | [85420000] | 5 | 5 | 2.0(+6) | 0.16 | 0.0060 | −0.10 | C | 8 |
| | | | [2.294] | [41786800] | [85380000] | 3 | 3 | 8.2(+5) | 0.065 | 0.0015 | −0.71 | D | 8 |
| | | | [2.298] | [41853300] | [85380000] | 5 | 3 | 1.4(+6) | 0.067 | 0.0025 | −0.48 | C | 8 |
| | | | [2.297] | [41786800] | [85330000] | 3 | 1 | 3.2(+6) | 0.084 | 0.0019 | −0.60 | C | 8 |
| | | | [2.292] | [41786800] | [85420000] | 3 | 5 | 1.0(+6) | 0.13 | 0.0030 | −0.40 | C | 8 |
| | | | [2.294] | [41774800] | [85380000] | 1 | 3 | 1.2(+6) | 0.28 | 0.0021 | −0.55 | C | 8 |
| 8. | | $^3$P° – $^1$D | | | | | | | | | | | |
| | | | [2.290] | [41853300] | [85520000] | 5 | 5 | 5.6(+5) | 0.044 | 0.0017 | −0.66 | D | 8 |
| 9. | | $^1$P° – $^3$P | | | | | | | | | | | |
| | | | [2.303] | [41986000] | [85420000] | 3 | 5 | 4.3(+5) | 0.057 | 0.0013 | −0.77 | D | 8 |
| 10. | | $^1$P° – $^1$D | [2.297] | [41986000] | [85520000] | 3 | 5 | 2.9(+6) | 0.38 | 0.0087 | 0.06 | C | 8 |
| 11. | | $^1$P° – $^1$S | [2.283] | [41986000] | [85790000] | 3 | 1 | 2.9(+6) | 0.076 | 0.0017 | −0.64 | C | 8 |
| 12. | $1s^2$–$1s3p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [2.0285] | 0 | [49297400] | 1 | 3 | 5.9(+4) | 0.011 | 7.3(−5) | −1.96 | E | *interp.* |
| 13. | | $^1$S – $^1$P° | [2.0262] | 0 | [49353400] | 1 | 3 | 7.58(+5) | 0.140 | 9.34(−4) | −0.854 | C+ | *interp.* |
| 14. | $1s^2$–$1s4p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [1.9262] | 0 | [51915100] | 1 | 3 | 2.3(+4) | 0.0038 | 2.4(−5) | −2.42 | E | *interp.* |
| 15. | | $^1$S – $^1$P° | [1.9254] | 0 | [51938300] | 1 | 3 | 3.11(+5) | 0.0518 | 3.28(−4) | −1.286 | C+ | *interp.* |
| 16. | $1s^2$–$1s5p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [1.8824] | 0 | [53123500] | 1 | 3 | 1.2(+4) | 0.0019 | 1.2(−5) | −2.72 | E | *interp.* |
| 17. | | $^1$S – $^1$P° | [1.8820] | 0 | [53135300] | 1 | 3 | 1.57(+5) | 0.0250 | 1.55(−4) | −1.602 | C+ | *interp.* |
| 18. | $1s2s$–$1s2p$ | $^3$S – $^3$P° | *401.3* | [41573200] | [*41822400*] | 3 | 9 | 5.82 | 0.0421 | 0.167 | −0.898 | B | 4 |
| | | | [357.0] | [41573200] | [41853300] | 3 | 5 | 8.40 | 0.0268 | 0.0943 | −1.096 | B | 4 |
| | | | [468.2] | [41573200] | [41786800] | 3 | 3 | 3.56 | 0.0117 | 0.0541 | −1.455 | B | 4 |
| | | | [496.0] | [41573200] | [41774800] | 3 | 1 | 3.14 | 0.00386 | 0.0189 | −1.936 | B | 4 |

V XXII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19. | | $^3S - ^1P°$ | | | | | | | | | | | |
| | | | [242.2] | [41573200] | [41986000] | 3 | 3 | 1.41 | 0.00124 | 0.00297 | −2.429 | B | 4 |
| 20. | | $^1S - ^1P°$ | [514.9] | [41791800] | [41986000] | 1 | 3 | 2.74 | 0.0327 | 0.0554 | −1.486 | B | 4 |
| 21. | 1s2s–1s3p | $^3S - ^3P°$ | | | | | | | | | | | |
| | | | [12.946] | [41573200] | [49297400] | 3 | 3 | 4.94(+4) | 0.124 | 0.0159 | −0.429 | C | *interp.* |
| 22. | | $^1S - ^1P°$ | [13.225] | [41791800] | [49353400] | 1 | 3 | 4.70(+4) | 0.370 | 0.0161 | −0.432 | C | *interp.* |
| 23. | 1s2s–1s4p | $^3S - ^3P°$ | | | | | | | | | | | |
| | | | [9.6694] | [41573200] | [51915100] | 3 | 3 | 2.1(+4) | 0.030 | 0.0029 | −1.05 | C+ | *interp.* |
| 24. | | $^1S - ^1P°$ | [9.8556] | [41791800] | [51938300] | 1 | 3 | 2.1(+4) | 0.090 | 0.0029 | −1.05 | C+ | *interp.* |
| 25. | 1s2s–1s5p | $^3S - ^3P°$ | | | | | | | | | | | |
| | | | [8.6578] | [41573200] | [53123500] | 3 | 3 | 1.1(+4) | 0.012 | 0.0010 | −1.44 | C+ | *interp.* |
| 26. | | $^1S - ^1P°$ | [8.8156] | [41791800] | [53135300] | 1 | 3 | 1.1(+4) | 0.037 | 0.0011 | −1.43 | C+ | *interp.* |
| 27. | 1s2p–1s3s | $^3P° - ^3S$ | | | | | | | | | | | |
| | | | [13.420] | [41786800] | [49238400] | 3 | 3 | 5200 | 0.014 | 0.0019 | −1.38 | C− | *interp.* |
| 28. | | $^1P° - ^1S$ | [13.680] | [41986000] | [49296100] | 3 | 1 | 1.6(+4) | 0.015 | 0.0020 | −1.35 | C+ | *interp.* |
| 29. | 1s2p–1s3d | $^3P° - ^3D$ | | | | 9 | 15 | | 0.68 | | 0.79 | C+ | *interp.* |
| 30. | | $^1P° - ^1D$ | | | | 3 | 5 | | 0.70 | | 0.32 | C+ | *interp.* |
| 31. | 1s2p–1s4s | $^3P° - ^3S$ | | | | | | | | | | | |
| | | | [9.8973] | [41786800] | [51890600] | 3 | 3 | 2200 | 0.0032 | 3.1(−4) | −2.02 | D | *interp.* |
| 32. | | $^1P° - ^1S$ | [10.073] | [41986000] | [51914000] | 3 | 1 | 6100 | 0.0031 | 3.1(−4) | −2.03 | C | *interp.* |
| 33. | 1s2p–1s4d | $^3P° - ^3D$ | | | | 9 | 15 | | 0.12 | | 0.03 | C | 5 |
| 34. | | $^1P° - ^1D$ | | | | 3 | 5 | | 0.12 | | −0.44 | C | 5 |
| 35. | 1s2p–1s5s | $^3P° - ^3S$ | | | | | | | | | | | |
| | | | [8.8306] | [41786800] | [53111100] | 3 | 3 | 1100 | 0.0013 | 1.1(−4) | −2.41 | D | *interp.* |
| 36. | | $^1P° - ^1S$ | [8.9792] | [41986000] | [53122800] | 3 | 1 | 3200 | 0.0013 | 1.2(−4) | −2.41 | C | *interp.* |
| 37. | 1s3s–1s3p | $^3S - ^3P°$ | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.018 | | −1.27 | E | *interp.* |
| 38. | | $^1S - ^1P°$ | | | | 1 | 3 | | 0.058 | | −1.24 | D | *interp.* |
| 39. | 1s3s–1s4p | $^3S - ^3P°$ | | | | | | | | | | | |
| | | | [37.359] | [49238400] | [51915100] | 3 | 3 | 6500 | 0.136 | 0.050 | −0.389 | C | *interp.* |

V XXII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40. | | $^1$S - $^1$P° | [37.847] | [49296100] | [51938300] | 1 | 3 | 6300 | 0.408 | 0.051 | −0.389 | C | *interp.* |
| 41. | 1s3s–1s5p | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | [25.739] | [49238400] | [53123500] | 3 | 3 | 3500 | 0.035 | 0.0089 | −0.98 | C | *interp.* |
| 42. | | $^1$S - $^1$P° | [26.047] | [49296100] | [53135300] | 1 | 3 | 3440 | 0.105 | 0.00900 | −0.979 | C+ | *interp.* |
| 43. | 1s3p–1s3d | $^3$P° - $^3$D | | | | 9 | 15 | | 0.013 | | −0.93 | D | *interp.* |
| 44. | 1s3p–1s4s | $^3$P° - $^3$S | | | | | | | | | | | |
| | | | [38.562] | [49297400] | [51890600] | 3 | 3 | 1500 | 0.034 | 0.013 | −0.99 | C− | *interp.* |
| 45. | | $^1$P° - $^1$S | [39.053] | [49353400] | [51914000] | 3 | 1 | 4500 | 0.034 | 0.013 | −0.99 | C | *interp.* |
| 46. | 1s3p–1s4d | $^3$P° - $^3$D | | | | 9 | 15 | | 0.60 | | 0.73 | C | 5 |
| 47. | | $^1$P° - $^1$D | | | | 3 | 5 | | 0.62 | | 0.27 | C | 5 |
| 48. | 1s3p–1s5s | $^3$P° - $^3$S | | | | | | | | | | | |
| | | | [26.221] | [49297400] | [53111100] | 3 | 3 | 750 | 0.0077 | 0.0020 | −1.64 | D | *interp.* |
| 49. | | $^1$P° - $^1$S | [26.529] | [49353400] | [53122800] | 3 | 1 | 2200 | 0.0077 | 0.0020 | −1.64 | C | *interp.* |
| 50. | 1s3d–1s3p | $^1$D - $^1$P° | | | | 5 | 3 | | 0.0023 | | −1.94 | E | 5 |
| 51. | 1s3d–1s4p | $^3$D - $^3$P° | | | | 15 | 9 | | 0.012 | | −0.74 | C | 5 |
| 52. | | $^1$D - $^1$P° | | | | 5 | 3 | | 0.011 | | −1.26 | C | 5 |
| 53. | 1s4s–1s4p | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.026 | | −1.11 | E | *interp.* |
| 54. | | $^1$S - $^1$P° | | | | 1 | 3 | | 0.081 | | −1.09 | E | *interp.* |
| 55. | 1s4s–1s5p | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | [81.110] | [51890600] | [53123500] | 3 | 3 | 1540 | 0.152 | 0.122 | −0.341 | C | *interp.* |
| 56. | | $^1$S - $^1$P° | [81.880] | [51914000] | [53135300] | 1 | 3 | 1500 | 0.45 | 0.12 | −0.35 | D | *interp.* |
| 57. | 1s4p–1s4d | $^3$P° - $^3$D | | | | 9 | 15 | | 0.022 | | −0.70 | D | 5 |
| 58. | 1s4p–1s5s | $^3$P° - $^3$S | | | | | | | | | | | |
| | | | [83.612] | [51915100] | [53111100] | 3 | 3 | 520 | 0.055 | 0.045 | −0.78 | D | *interp.* |
| 59. | | $^1$P° - $^1$S | [84.424] | [51938300] | [53122800] | 3 | 1 | 1600 | 0.056 | 0.047 | −0.77 | C | *interp.* |
| 60. | 1s4d–1s4p | $^1$D - $^1$P° | | | | 5 | 3 | | 0.0035 | | −1.76 | E | 5 |
| 61. | 1s4d–1s4f | $^3$D - $^3$F° | | | | 15 | 21 | | 8.9(−4) | | −1.87 | E | 5 |
| 62. | 1s4d–1s5f | $^3$D - $^3$F° | | | | 15 | 21 | | 0.89 | | 1.13 | B | 7 |
| 63. | | $^1$D - $^1$F° | | | | 5 | 7 | | 0.89 | | 0.65 | B | 7 |
| 64. | 1s4f–1s4d | $^1$F° - $^1$D | | | | 7 | 5 | | 4.7(−4) | | −2.48 | E | 5 |

V XXII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65. | $1s4f-1s5d$ | $^3F^\circ - {}^3D$ | | | | 21 | 15 | | 0.0089 | | −0.73 | C | 7 |
| 66. | | $^1F^\circ - {}^1D$ | | | | 7 | 5 | | 0.0089 | | −1.21 | C | 7 |
| 67. | $1s5s-1s5p$ | $^3S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.032 | | −1.02 | E | *interp.* |
| 68. | | $^1S - {}^1P^\circ$ | | | | 1 | 3 | | 0.10 | | −1.00 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## V XXII

### Forbidden Transitions

The results of multi-configuration Dirac-Fock calculations by Hata and Grant[1] have been selected for this tabulation. Their work includes both a very detailed consideration of configuration interaction—with configurational wavefunction sets containing as many as 51 interacting states—as well as a fully relativistic treatment based on the Dirac Hamiltonian. Their calculated wavelengths are in very close agreement with experiment, and the agreement between an experimentally determined lifetime[2] for the $2s\ ^3S_1$ state and the theoretical result is excellent, the difference being only 2.5%. A comprehensive comparison table containing all experimental data on these He-sequence transitions is given in the introduction to the forbidden lines of Ti XXI.

### References


[1]J. Hata and I. P. Grant, Mon. Not. R. Astr. Soc. **211**, 549 (1984).
[2]H. Gould, R. Marrus, and P. J. Mohr, Phys. Rev. Lett. **33**, 676 (1974).


V XXII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2-1s2s$ | $^1S - {}^3S$ | [2.4057] | 0 | [41568280] | 1 | 3 | M1 | 6.07(+7)[a] | 9.40(−5) | B | 1 |
| 2. | $1s^2-1s2p$ | $^1S - {}^3P^\circ$ | | | | | | | | | | |
| | | | [2.3895] | 0 | [41849500] | 1 | 5 | M2 | 2.43(+9) | 0.143 | B | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## V XXIII

H Isoelectronic Sequence

Ground State: $1s\ ^2S_{1/2}$

Ionization Energy: 7246.18 eV = 58443900 cm$^{-1}$

### Allowed Transitions

Electric dipole transition probability data for this hydrogen-like ion can be obtained directly, in a non-relativistic approximation, from the data for neutral hydrogen.[1] The oscillator strength is independent of $Z$ along the entire isoelectronic sequence and is therefore identical to the value for the hydrogen atom. Line strengths scale as $Z^{-2}$ and transition probabilities scale as $Z^4$, i.e.,

$$S_Z = Z^{-2} S_H, \qquad A_Z = Z^4 A_H.$$

For higher nuclear charges in this sequence, relativistic corrections will cause these values to deviate increasingly from the non-relativistic ones. The first effect of relativity will be to alter the transition energies, or wavelengths, from the non-relativistic, even though the line strength itself is still well approximated by the non-relativistic value. In this case, experimental energies should be used in the standard conversion formulas, given in the general introduction to this volume, to calculate the most accurate values of $f$ and $A$. It should be noted that the relativistic removal of the $j$-degeneracy introduces dipole transitions which do not occur in the non-relativistic theory, e.g., $2s_{1/2} - 2p_{3/2}$.

For very high $Z$, it is necessary to use the four-component Dirac spinors rather than two-component Schroedinger functions in theoretical calculations, and this introduces relativistic corrections to the line strengths themselves. Several recent systematic studies of the problem[2,3] indicate that these corrections are not large for stages of ionization in the range 20–30. Corrections for $Z = 30$ are usually no larger than 5–10% and generally substantially less than 5%. If an accuracy greater than this is required, the reader is referred to these papers[2,3] for a more detailed error analysis.

## References


[1]W. L. Wiese, M. W. Smith, and B. M. Glennon, Atomic Transition Probabilities – Hydrogen through Neon (A Critical Data Compilation), Vol. I, 157 pp., Nat. Stand. Ref. Data Ser., Nat. Bur. Stand. (U.S.), 4 (May 1966).

[2]S. M. Younger and A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **79**, 629 (1975).

[3]S. J. Rose, Rutherford Appleton Laboratory Report RL–82–114 (December 1982).

# Chromium

## Cr I

Ground State: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s\ ^7S_3$

Ionization Energy: 6.76669 eV = 54575.6 $cm^{-1}$

### Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 1999.95 | 51 | 2703.48 | 32 | 3163.76 | 92 | 4065.71 | 173 |
| 2095.00 | 7 | 2716.18 | 31 | 3169.58 | 92 | 4081.74 | 68 |
| 2095.40 | 7 | 2726.50 | 15 | 3237.73 | 91 | 4097.69 | 82 |
| 2095.83 | 7 | 2731.90 | 15 | 3238.09 | 91 | 4109.58 | 69 |
| 2354.30 | 50 | 2736.46 | 15 | 3351.97 | 5 | 4111.33 | 82 |
| 2364.73 | 6 | 2751.58 | 30 | 3379.17 | 5 | 4126.51 | 57 |
| 2365.91 | 6 | 2752.85 | 30 | 3578.68 | 4 | 4165.52 | 193 |
| 2366.81 | 6 | 2757.09 | 30 | 3593.48 | 4 | 4203.59 | 57 |
| 2375.06 | 49 | 2761.74 | 30 | 3605.32 | 4 | 4204.48 | 168 |
| 2383.30 | 49 | 2764.36 | 30 | 3615.65 | 3 | 4211.48 | 90 |
| 2385.72 | 49 | 2769.90 | 30 | 3635.28 | 3 | 4213.18 | 115 |
| 2389.21 | 48 | 2780.70 | 30 | 3639.80 | 61 | 4222.75 | 104 |
| 2408.60 | 46 | 2871.63 | 29 | 3730.81 | 2 | 4230.49 | 104 |
| 2408.72 | 47 | 2879.27 | 29 | 3732.03 | 2 | 4232.23 | 188 |
| 2479.14 | 45 | 2887.00 | 29 | 3743.89 | 60 | 4234.52 | 126 |
| 2492.57 | 43 | 2889.22 | 29 | 3744.49 | 60 | 4235.99 | 103 |
| 2495.08 | 42 | 2893.25 | 29 | 3757.17 | 60 | 4237.72 | 103 |
| 2496.30 | 43 | 2894.17 | 29 | 3757.66 | 60 | 4238.96 | 102 |
| 2499.84 | 43 | 2896.76 | 29 | 3758.04 | 60 | 4242.84 | 102 |
| 2502.55 | 44 | 2899.20 | 29 | 3768.24 | 60 | 4248.34 | 102 |
| 2504.31 | 43 | 2905.48 | 29 | 3768.73 | 60 | 4252.24 | 102 |
| 2508.11 | 41 | 2909.05 | 29 | 3804.80 | 105 | 4254.33 | 1 |
| 2508.97 | 41 | 2910.89 | 29 | 3849.54 | 25 | 4255.50 | 89 |
| 2513.62 | 41 | 2911.15 | 29 | 3852.22 | 25 | 4257.35 | 102 |
| 2527.11 | 41 | 2967.64 | 28 | 3883.29 | 24 | 4261.35 | 81 |
| 2538.95 | 17 | 2971.10 | 28 | 3885.24 | 24 | 4261.63 | 127 |
| 2544.70 | 17 | 2975.48 | 28 | 3886.80 | 24 | 4262.37 | 114 |
| 2549.55 | 40 | 2980.78 | 28 | 3894.04 | 24 | 4263.15 | 161 |
| 2560.70 | 40 | 2988.64 | 14 | 3902.91 | 24 | 4268.79 | 167 |
| 2571.74 | 40 | 2991.88 | 28 | 3903.17 | 24 | 4269.96 | 114 |
| 2577.66 | 40 | 2994.06 | 14 | 3908.76 | 24 | 4271.07 | 114 |
| 2579.14 | 38 | 2995.09 | 13 | 3916.25 | 24 | 4272.93 | 81 |
| 2584.67 | 39 | 2996.57 | 28 | 3919.17 | 24 | 4274.81 | 1 |
| 2588.19 | 38 | 2998.78 | 14 | 3921.03 | 24 | 4275.98 | 155 |
| 2591.84 | 40 | 3000.88 | 28 | 3928.65 | 24 | 4280.42 | 161 |
| 2603.56 | 38 | 3005.06 | 28 | 3941.50 | 24 | 4280.89 | 145 |
| 2618.27 | 36 | 3013.72 | 27 | 3963.69 | 59 | 4283.00 | 187 |
| 2620.48 | 34 | 3015.20 | 26 | 3969.75 | 59 | 4288.40 | 124 |
| 2622.87 | 35 | 3020.67 | 26 | 3976.02 | 59 | 4289.73 | 1 |
| 2625.32 | 37 | 3021.58 | 26 | 3981.24 | 70 | 4291.97 | 145 |
| 2626.60 | 35 | 3024.36 | 27 | 3983.90 | 59 | 4293.58 | 81 |
| 2629.82 | 36 | 3029.17 | 27 | 3991.12 | 59 | 4296.11 | 200 |
| 2669.36 | 32 | 3030.25 | 26 | 4001.44 | 165 | 4296.30 | 124 |
| 2671.98 | 32 | 3031.35 | 26 | 4039.10 | 162 | 4296.63 | 161 |
| 2673.64 | 32 | 3034.19 | 27 | 4039.29 | 162 | 4297.06 | 67 |
| 2678.15 | 32 | 3037.05 | 26 | 4042.25 | 58 | 4297.75 | 161 |
| 2680.33 | 32 | 3040.84 | 26 | 4048.78 | 162 | 4298.05 | 200 |
| 2690.25 | 32 | 3053.87 | 27 | 4049.78 | 162 | 4299.72 | 81 |
| 2696.53 | 16 | 3148.44 | 92 | 4050.03 | 58 | 4300.52 | 145 |
| 2700.59 | 31 | 3155.16 | 92 | 4057.83 | 162 | 4301.19 | 145 |
| 2701.99 | 33 | 3160.62 | 92 | 4058.78 | 162 | 4302.78 | 199 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 4305.47 | 81 | 4442.28 | 86 | 4578.33 | 159 | 4727.13 | 83 |
| 4307.67 | 198 | 4443.72 | 152 | 4580.05 | 12 | 4729.84 | 119 |
| 4309.73 | 186 | 4459.75 | 99 | 4582.40 | 171 | 4730.69 | 108 |
| 4312.48 | 125 | 4460.76 | 66 | 4583.90 | 97 | 4737.33 | 108 |
| 4317.91 | 186 | 4462.79 | 99 | 4584.10 | 122 | 4741.09 | 183 |
| 4319.66 | 81 | 4464.66 | 99 | 4584.76 | 97 | 4743.12 | 177 |
| 4321.25 | 74 | 4465.37 | 99 | 4584.94 | 134 | 4745.31 | 64 |
| 4321.62 | 125 | 4467.57 | 99 | 4585.10 | 144 | 4752.07 | 178 |
| 4325.08 | 88 | 4475.36 | 80 | 4586.15 | 122 | 4754.73 | 118 |
| 4325.65 | 124 | 4477.05 | 66 | 4591.41 | 22 | 4755.14 | 95 |
| 4330.76 | 113 | 4480.27 | 135 | 4592.55 | 190 | 4756.09 | 108 |
| 4332.57 | 124 | 4480.36 | 151 | 4595.60 | 179 | 4757.31 | 177 |
| 4337.25 | 185 | 4482.88 | 135 | 4600.11 | 55 | 4757.58 | 149 |
| 4337.57 | 23 | 4490.55 | 164 | 4600.75 | 22 | 4764.28 | 149 |
| 4338.80 | 136 | 4491.69 | 80 | 4601.02 | 55 | 4764.65 | 94 |
| 4339.45 | 23 | 4491.86 | 74 | 4606.36 | 191 | 4767.26 | 149 |
| 4339.74 | 23 | 4492.31 | 135 | 4611.06 | 84 | 4767.86 | 149 |
| 4340.14 | 67 | 4495.28 | 174 | 4611.96 | 134 | 4770.68 | 94 |
| 4341.46 | 67 | 4496.85 | 12 | 4613.36 | 22 | 4775.12 | 148 |
| 4343.17 | 67 | 4498.73 | 71 | 4614.51 | 158 | 4789.32 | 52 |
| 4344.51 | 23 | 4500.29 | 112 | 4616.12 | 22 | 4792.49 | 118 |
| 4345.08 | 136 | 4501.79 | 71 | 4617.37 | 84 | 4796.15 | 176 |
| 4346.83 | 88 | 4503.04 | 201 | 4619.54 | 71 | 4797.68 | 148 |
| 4347.49 | 77 | 4506.84 | 182 | 4622.47 | 150 | 4801.02 | 118 |
| 4351.06 | 23 | 4510.02 | 197 | 4622.76 | 71 | 4806.25 | 64 |
| 4351.77 | 23 | 4511.90 | 112 | 4625.91 | 157 | 4810.71 | 107 |
| 4353.94 | 136 | 4514.36 | 181 | 4626.18 | 22 | 4814.25 | 107 |
| 4356.77 | 101 | 4515.44 | 96 | 4628.48 | 128 | 4816.13 | 196 |
| 4357.51 | 136 | 4524.84 | 172 | 4633.27 | 128 | 4819.30 | 170 |
| 4359.65 | 23 | 4526.44 | 56 | 4639.52 | 128 | 4823.90 | 195 |
| 4362.97 | 73 | 4527.33 | 56 | 4639.70 | 150 | 4825.50 | 107 |
| 4363.13 | 87 | 4527.45 | 76 | 4641.49 | 184 | 4831.63 | 143 |
| 4368.25 | 101 | 4529.84 | 56 | 4641.96 | 157 | 4836.85 | 107 |
| 4368.90 | 136 | 4530.48 | 85 | 4646.15 | 22 | 4838.42 | 194 |
| 4370.76 | 166 | 4530.68 | 56 | 4646.50 | 109 | 4870.79 | 106 |
| 4370.87 | 160 | 4530.73 | 56 | 4646.80 | 128 | 4874.65 | 117 |
| 4371.28 | 23 | 4530.93 | 96 | 4648.12 | 54 | 4880.04 | 117 |
| 4373.26 | 23 | 4531.24 | 96 | 4648.33 | 84 | 4885.77 | 53 |
| 4373.65 | 192 | 4535.13 | 56 | 4651.29 | 22 | 4885.97 | 106 |
| 4374.17 | 88 | 4535.69 | 56 | 4652.16 | 22 | 4887.01 | 106 |
| 4375.34 | 87 | 4535.75 | 56 | 4654.76 | 128 | 4903.25 | 52 |
| 4376.80 | 192 | 4539.76 | 56 | 4656.18 | 109 | 4922.28 | 106 |
| 4377.55 | 74 | 4540.49 | 56 | 4656.82 | 202 | 4936.34 | 116 |
| 4379.77 | 101 | 4540.72 | 112 | 4663.33 | 128 | 4942.49 | 11 |
| 4381.11 | 67 | 4541.06 | 56 | 4665.90 | 150 | 4944.57 | 156 |
| 4382.86 | 67 | 4541.51 | 111 | 4666.20 | 83 | 4953.73 | 116 |
| 4384.97 | 23 | 4543.73 | 85 | 4669.34 | 128 | 4954.81 | 116 |
| 4387.38 | 74 | 4544.60 | 56 | 4680.86 | 120 | 4964.92 | 11 |
| 4391.76 | 23 | 4545.33 | 56 | 4689.38 | 128 | 4966.80 | 156 |
| 4393.54 | 86 | 4545.95 | 12 | 4693.94 | 83 | 5013.31 | 63 |
| 4397.24 | 100 | 4548.65 | 180 | 4695.14 | 83 | 5032.54 | 189 |
| 4399.82 | 100 | 4553.95 | 172 | 4697.04 | 65 | 5034.65 | 189 |
| 4410.31 | 100 | 4554.82 | 123 | 4697.38 | 133 | 5045.04 | 189 |
| 4410.97 | 86 | 4555.31 | 144 | 4698.46 | 128 | 5051.90 | 10 |
| 4411.11 | 100 | 4556.18 | 123 | 4698.94 | 110 | 5072.93 | 10 |
| 4412.25 | 23 | 4563.24 | 159 | 4699.59 | 183 | 5112.50 | 20 |
| 4413.00 | 204 | 4563.43 | 72 | 4700.60 | 65 | 5123.47 | 21 |
| 4413.86 | 152 | 4563.66 | 122 | 4706.09 | 120 | 5139.60 | 142 |
| 4422.70 | 152 | 4564.17 | 203 | 4707.73 | 133 | 5177.42 | 137 |
| 4424.10 | 75 | 4565.51 | 22 | 4708.02 | 128 | 5192.01 | 137 |
| 4424.29 | 100 | 4569.63 | 123 | 4717.67 | 120 | 5193.50 | 141 |
| 4428.52 | 100 | 4570.99 | 123 | 4718.43 | 128 | 5196.45 | 142 |
| 4429.93 | 152 | 4571.10 | 98 | 4722.65 | 121 | 5200.20 | 137 |
| 4432.16 | 71 | 4571.67 | 54 | 4723.06 | 108 | 5204.51 | 9 |
| 4432.77 | 205 | 4575.11 | 134 | 4724.40 | 108 | 5206.02 | 9 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 5208.42 | 9 | 5300.74 | 19 | 5581.60 | 139 | 6630.00 | 18 |
| 5214.14 | 131 | 5304.19 | 147 | 5588.05 | 139 | 6661.10 | 175 |
| 5238.97 | 62 | 5312.88 | 147 | 5628.64 | 138 | 6669.27 | 175 |
| 5241.47 | 62 | 5318.79 | 147 | 5642.40 | 154 | 6882.40 | 146 |
| 5243.38 | 137 | 5328.36 | 79 | 5648.25 | 154 | 6883.05 | 146 |
| 5247.58 | 19 | 5329.17 | 79 | 5649.38 | 154 | 6925.22 | 146 |
| 5261.76 | 153 | 5329.76 | 79 | 5694.72 | 154 | 6978.46 | 146 |
| 5264.16 | 19 | 5340.46 | 147 | 5702.30 | 138 | 6979.81 | 146 |
| 5265.73 | 19 | 5344.77 | 147 | 5719.82 | 93 | 6980.91 | 146 |
| 5272.01 | 147 | 5345.77 | 19 | 5783.11 | 129 | 7170.56 | 169 |
| 5287.19 | 147 | 5348.30 | 19 | 5783.89 | 129 | 7355.93 | 78 |
| 5293.38 | 132 | 5400.58 | 130 | 5785.02 | 129 | 7400.22 | 78 |
| 5296.69 | 19 | 5409.78 | 19 | 5787.97 | 129 | 8916.24 | 163 |
| 5297.37 | 79 | 5442.40 | 140 | 5838.68 | 93 | 8939.21 | 163 |
| 5297.99 | 79 | 5548.61 | 139 | 5844.60 | 93 | 8955.76 | 163 |
| 5298.29 | 19 | 5566.55 | 139 | 6330.13 | 8 | | |

For this spectrum, we have utilized seventeen data sources, which are all fairly recent experiments. These include the absorption measurements of Bieniewski[1] and Blackwell and co-workers[15,16]; anomalous dispersion (hook) measurements (plus a few absorption measurements) of Huber and Sandeman[2]; emission experiments performed with a shock tube by Wolnik *et al.*,[9,10] with a hollow cathode by Cocke *et al.*,[11] and by Tozzi *et al.*,[17] and with a wall-stabilized arc by Wujec and Weniger[13]; shock tube absorption studies of Huber and Tobey[12]; and six lifetime determinations[4–8,19] from which oscillator strengths could be directly derived. Another source that we used in this compilation is that of Kostyk,[18] who derived log *gf*-values from solar spectra. The measurements of Cocke *et al.* were restricted to "branching ratio" determinations, which were then converted to transition probabilities by using available beam-foil lifetimes.

Accurate lifetime measurements are those by Marek,[6] by Measures and co-workers,[7,8] and by Hannaford and Lowe,[19] who all selectively populated the levels under study by means of dye laser excitation and then measured the corresponding radiative lifetimes. Other reliable lifetimes were measured by Becker *et al.*,[4] who employed the level-crossing (Hanle) method, and by Marek and Richter,[5] who used the phase-shift technique. It is possible to intercompare oscillator strengths derived from these lifetime sources for lines of the multiplets $a\,^7S - z\,^7P^\circ$ and $a\,^7S - y\,^7P^\circ$. This comparison, also including the absolute scale of Bieniewski, who has performed very careful absorption measurements with an electric furnace, is presented in Table 1. In converting the lifetimes to $f$-values, we did not include the contributions of non-resonance transitions because of lack of data. However, Huber and Sandeman estimated that these additional decay modes have a practically negligible effect ($\approx 0.5\%$) on the lifetimes involved. We consider the averaged $f$-values for these two multiplets to be accurate to within ten percent, as supported by the excellent mutual agreement among the selected data sources.

TABLE 1. Comparison of absorption and lifetime data

| Multiplet | λ(Å) | $f_{ik}$ (Bieniewski[1]) | $f_{ik}$[a] (Becker *et al.*[4])[b] | $f_{ik}$[a] (Marek and Richter[5])[c] | $f_{ik}$[a] (Marek[6])[d] | $f_{ik}$[a] (Measures *et al.*[7])[d] | $f_{ik}$[a] (Kwong and Measures[8])[d] | $f_{ik}$[a] (Hannaford and Lowe[19])[d] |
|---|---|---|---|---|---|---|---|---|
| $a\,^7S - z\,^7P^\circ$ (1) | 4254.33 | 0.106 | 0.111 | 0.111 | 0.110 | 0.112 | | 0.110 |
| | 4274.81 | 0.082 | 0.0849 | 0.0841 | | 0.0849 | | |
| | 4289.73 | 0.059 | 0.0616 | 0.0646 | | 0.0627 | 0.0633 | |
| $a\,^7S - y\,^7P^\circ$ (4) | 3578.68 | 0.34 | 0.355 | 0.402 | | | | |
| | 3593.48 | 0.28 | 0.271 | 0.319 | | | | |
| | 3605.32 | 0.21 | 0.220 | 0.244 | | | | |

[a]Listed oscillator strengths have been derived from lifetime measurements.
[b]Level-crossing technique.
[c]Phase shift method.
[d]Laser excitation technique.

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | $a\,^5$S – $z\,^7$D° (8) | | | | | | | | | | | |
| | | 5051.90 | 7593 | 27382 | 5 | 5 | 5.41(–4) | 2.07(–4) | 0.0172 | –2.985 | B | 15 |
| | | 5072.93 | 7593 | 27300 | 5 | 3 | 0.00159 | 3.69(–4) | 0.0308 | –2.734 | B | 15 |
| 11. | $a\,^5$S – $y\,^7$P° (9) | | | | | | | | | | | |
| | | 4942.49 | 7593 | 27820 | 5 | 7 | 0.00198 | 0.00102 | 0.0827 | –2.294 | B | 15 |
| | | 4964.92 | 7593 | 27729 | 5 | 5 | 0.00161 | 5.94(–4) | 0.0486 | –2.527 | B | 15 |
| 12. | $a\,^5$S – $y\,^5$P° (10) | *4529.6* | 7593 | *29664* | 5 | 15 | 0.029 | 0.027 | 2.0 | –0.87 | B | 15,17 |
| | | 4496.85 | 7593 | 29825 | 5 | 7 | 0.033 | 0.014 | 1.0 | –1.15 | B | 15,17 |
| | | 4545.95 | 7593 | 29585 | 5 | 5 | 0.027 | 0.0085 | 0.64 | –1.37 | B | 15,17 |
| | | 4580.05 | 7593 | 29421 | 5 | 3 | 0.024 | 0.0045 | 0.34 | –1.65 | B | 17 |
| 13. | $a\,^5$S – $y\,^5$F° (uv 3) | | | | | | | | | | | |
| | | 2995.09 | 7593 | 40971 | 5 | 5 | 0.43 | 0.058 | 2.8 | –0.54 | D | 2 |
| 14. | $a\,^5$S – $x\,^5$P° (uv 4) | *2992.5* | 7593 | *41000* | 5 | 15 | 0.41 | 0.16 | 8.1 | –0.09 | D | 2,15 |
| | | 2988.64 | 7593 | 41043 | 5 | 7 | 0.52 | 0.098 | 4.8 | –0.31 | C | 2 |
| | | 2994.06 | 7593 | 40983 | 5 | 5 | 0.25 | 0.034 | 1.7 | –0.77 | E | 2 |
| | | 2998.78 | 7593 | 40930 | 5 | 3 | 0.407 | 0.0329 | 1.62 | –0.784 | B | 15 |
| 15. | $a\,^5$S – $w\,^5$P° (uv 7) | *2730.3* | 7593 | *44208* | 5 | 15 | 0.76 | 0.256 | 11.5 | 0.107 | C | 2 |
| | | 2726.50 | 7593 | 44259 | 5 | 7 | 0.75 | 0.12 | 5.3 | –0.23 | C | 2 |
| | | 2731.90 | 7593 | 44187 | 5 | 5 | 0.78 | 0.087 | 3.9 | –0.36 | C | 2 |
| | | 2736.46 | 7593 | 44126 | 5 | 3 | 0.75 | 0.050 | 2.3 | –0.60 | D | 2 |
| 16. | $a\,^5$S – $v\,^5$P° (uv 8) | | | | | | | | | | | |
| | | 2696.53 | 7593 | 44667 | 5 | 3 | 0.12 | 0.0076 | 0.34 | –1.42 | D | 2 |
| 17. | $a\,^5$S – $u\,^5$P° (uv 9) | | | | | | | | | | | |
| | | 2544.70 | 7593 | 46879 | 5 | 7 | 0.11 | 0.014 | 0.61 | –1.14 | D– | 2 |
| | | 2538.95 | 7593 | 46968 | 5 | 5 | 0.11 | 0.010 | 0.44 | –1.28 | E | 2 |
| 18. | $a\,^5$D – $z\,^7$P° (16) | | | | | | | | | | | |
| | | 6630.00 | 8308 | 23386 | 9 | 7 | 6.0(–5) | 3.1(–5) | 0.0060 | –3.56 | D | 18 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19. | $a\ ^5D - z\ ^5P°$ (18) | *5345.2* | *8090* | *26793* | 25 | 15 | 0.086 | 0.022 | 9.7 | −0.26 | B | 15,17 |
| | | 5409.78 | 8308 | 26788 | 9 | 7 | 0.062 | 0.021 | 3.4 | −0.72 | B | 15,17 |
| | | 5345.77 | 8095 | 26796 | 7 | 5 | 0.049 | 0.015 | 1.8 | −0.98 | B | 15,17 |
| | | 5296.69 | 7927 | 26802 | 5 | 3 | 0.031 | 0.0079 | 0.69 | −1.40 | B | 15,17 |
| | | 5348.30 | 8095 | 26788 | 7 | 7 | 0.017 | 0.0073 | 0.90 | −1.29 | B | 15,17 |
| | | 5298.29 | 7927 | 26796 | 5 | 5 | 0.033 | 0.014 | 1.2 | −1.15 | B | 15,17 |
| | | 5264.16 | 7811 | 26802 | 3 | 3 | 0.041 | 0.017 | 0.88 | −1.29 | B | 15,17 |
| | | 5300.74 | 7927 | 26788 | 5 | 7 | 0.0025 | 0.0015 | 0.13 | −2.12 | B | 15,17 |
| | | 5265.73 | 7811 | 26796 | 3 | 5 | 0.0085 | 0.0059 | 0.31 | −1.75 | B | 15,17 |
| | | 5247.58 | 7751 | 26802 | 1 | 3 | 0.019 | 0.023 | 0.40 | −1.64 | B | 15,17 |
| 20. | $a\ ^5D - z\ ^7D°$ (19) | | | | | | | | | | | |
| | | 5112.50 | 8095 | 27650 | 7 | 9 | 5.7(−5) | 2.9(−5) | 0.0034 | −3.70 | D | 18 |
| 21. | $a\ ^5D - y\ ^7P°$ (20) | | | | | | | | | | | |
| | | 5123.47 | 8308 | 27820 | 9 | 7 | 4.0(−4) | 1.2(−4) | 0.018 | −2.96 | D | 18 |
| 22. | $a\ ^5D - y\ ^5P°$ (21) | *4633.9* | *8090* | *29664* | 25 | 15 | 0.11 | 0.022 | 8.2 | −0.27 | B | 15,17 |
| | | 4646.15 | 8308 | 29825 | 9 | 7 | 0.087 | 0.022 | 3.0 | −0.70 | B | 15,17 |
| | | 4652.16 | 8095 | 29585 | 7 | 5 | 0.058 | 0.013 | 1.4 | −1.03 | B | 17 |
| | | 4651.29 | 7927 | 29421 | 5 | 3 | 0.036 | 0.0070 | 0.54 | −1.46 | B | 15,17 |
| | | 4600.75 | 8095 | 29825 | 7 | 7 | 0.025 | 0.0079 | 0.84 | −1.26 | B | 15,17 |
| | | 4616.12 | 7927 | 29585 | 5 | 5 | 0.041 | 0.013 | 0.99 | −1.19 | B | 15,17 |
| | | 4626.18 | 7811 | 29421 | 3 | 3 | 0.050 | 0.016 | 0.73 | −1.32 | B | 15,17 |
| | | 4565.51 | 7927 | 29825 | 5 | 7 | 0.0041 | 0.0018 | 0.14 | −2.05 | B | 15,17 |
| | | 4591.41 | 7811 | 29585 | 3 | 5 | 0.011 | 0.0060 | 0.27 | −1.74 | B | 15,17 |
| | | 4613.36 | 7751 | 29421 | 1 | 3 | 0.022 | 0.021 | 0.32 | −1.68 | B | 15,17 |
| 23. | $a\ ^5D - z\ ^5F°$ (22) | *4350.4* | *8090* | *31070* | 25 | 35 | 0.117 | 0.0466 | 16.7 | 0.067 | C | 2,15 |
| | | 4351.77 | 8308 | 31280 | 9 | 11 | 0.12 | 0.040 | 5.2 | −0.44 | C | 2 |
| | | 4344.51 | 8095 | 31106 | 7 | 9 | 0.11 | 0.040 | 4.0 | −0.55 | C | 2 |
| | | 4339.45 | 7927 | 30965 | 5 | 7 | 0.0692 | 0.0274 | 1.95 | −0.864 | B | 15 |
| | | 4337.57 | 7811 | 30859 | 3 | 5 | 0.0548 | 0.0258 | 1.10 | −1.112 | B | 15 |
| | | 4339.74 | 7751 | 30787 | 1 | 3 | 0.0440 | 0.0372 | 0.532 | −1.429 | B | 15 |
| | | 4384.97 | 8308 | 31106 | 9 | 9 | 0.027 | 0.0079 | 1.0 | −1.15 | D | 2 |
| | | 4371.28 | 8095 | 30965 | 7 | 7 | 0.041 | 0.012 | 1.2 | −1.09 | C | 2 |
| | | 4359.65 | 7927 | 30859 | 5 | 5 | 0.054 | 0.016 | 1.1 | −1.11 | C | 2 |
| | | 4351.06 | 7811 | 30787 | 3 | 3 | 0.0418 | 0.0119 | 0.509 | −1.449 | B | 15 |
| | | 4412.25 | 8308 | 30965 | 9 | 7 | 9.86(−4) | 2.24(−4) | 0.0293 | −2.696 | B | 15 |
| | | 4391.76 | 8095 | 30859 | 7 | 5 | 0.00288 | 5.96(−4) | 0.0603 | −2.380 | B | 15 |
| | | 4373.26 | 7927 | 30787 | 5 | 3 | 0.00524 | 9.02(−4) | 0.0649 | −2.346 | B | 15 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24. | $a\,^5D - z\,^5D^\circ$ (23) | *3910.5* | *8090* | *33655* | 25 | 25 | 0.12 | 0.028 | 8.9 | −0.16 | C− | 2 |
| | | 3919.17 | 8308 | 33816 | 9 | 9 | 0.092 | 0.021 | 2.5 | −0.72 | C | 2 |
| | | 3908.76 | 8095 | 33672 | 7 | 7 | 0.062 | 0.014 | 1.3 | −1.00 | C− | 2 |
| | | 3902.91 | 7927 | 33542 | 5 | 5 | 0.035 | 0.0080 | 0.51 | −1.40 | D | 2 |
| | | 3903.17 | 7811 | 33424 | 3 | 3 | 0.018 | 0.0041 | 0.16 | −1.91 | D− | 2 |
| | | 3941.50 | 8308 | 33672 | 9 | 7 | 0.028 | 0.0051 | 0.59 | −1.34 | C− | 2 |
| | | 3928.65 | 8095 | 33542 | 7 | 5 | 0.052 | 0.0086 | 0.78 | −1.22 | C | 2 |
| | | 3921.03 | 7927 | 33424 | 5 | 3 | 0.058 | 0.0080 | 0.51 | −1.40 | C | 2 |
| | | 3916.25 | 7811 | 33338 | 3 | 1 | 0.097 | 0.0075 | 0.29 | −1.65 | C | 2 |
| | | 3886.80 | 8095 | 33816 | 7 | 9 | 0.022 | 0.0065 | 0.58 | −1.34 | C− | 2 |
| | | 3883.29 | 7927 | 33672 | 5 | 7 | 0.039 | 0.012 | 0.79 | −1.21 | C | 2 |
| | | 3885.24 | 7811 | 33542 | 3 | 5 | 0.039 | 0.015 | 0.56 | −1.36 | C− | 2 |
| | | 3894.04 | 7751 | 33424 | 1 | 3 | 0.039 | 0.026 | 0.34 | −1.58 | C− | 2 |
| 25. | $a\,^5D - z\,^3P^\circ$ (24) | | | | | | | | | | | |
| | | 3849.54 | 7927 | 33897 | 5 | 3 | 0.023 | 0.0030 | 0.19 | −1.82 | E | 2 |
| | | 3852.22 | 7811 | 33763 | 3 | 1 | 0.070 | 0.0052 | 0.20 | −1.81 | E | 2 |
| 26. | $a\,^5D - y\,^5F^\circ$ (27) | | | | | | | | | | | |
| | | 3021.58 | 8308 | 41393 | 9 | 11 | 2.91 | 0.487 | 43.6 | 0.642 | B | 15 |
| | | 3015.20 | 7751 | 40906 | 1 | 3 | 1.63 | 0.668 | 6.63 | −0.175 | B | 15 |
| | | 3037.05 | 8308 | 41225 | 9 | 9 | 0.54 | 0.075 | 6.8 | −0.17 | C | 2 |
| | | 3030.25 | 8095 | 41086 | 7 | 7 | 1.1 | 0.15 | 10 | 0.02 | C | 2 |
| | | 3020.67 | 7811 | 40906 | 3 | 3 | 1.5 | 0.21 | 6.1 | −0.21 | D− | 2 |
| | | 3040.84 | 8095 | 40971 | 7 | 5 | 0.74 | 0.073 | 5.1 | −0.29 | D | 2 |
| | | 3031.35 | 7927 | 40906 | 5 | 3 | 0.31 | 0.026 | 1.3 | −0.89 | E | 2 |
| 27. | $a\,^5D - x\,^5P^\circ$ (26) | | | | | | | | | | | |
| | | 3053.87 | 8308 | 41043 | 9 | 7 | 0.797 | 0.0866 | 7.84 | −0.108 | B | 15 |
| | | 3029.17 | 7927 | 40930 | 5 | 3 | 0.38 | 0.032 | 1.6 | −0.80 | E | 2 |
| | | 3034.19 | 8095 | 41043 | 7 | 7 | 0.35 | 0.048 | 3.4 | −0.47 | D | 2 |
| | | 3024.36 | 7927 | 40983 | 5 | 5 | 1.27 | 0.174 | 8.65 | −0.061 | B | 15 |
| | | 3013.72 | 7811 | 40983 | 3 | 5 | 0.83 | 0.19 | 5.6 | −0.25 | C | 2 |
| 28. | $a\,^5D - y\,^5D^\circ$ (uv 11) | | | | | | | | | | | |
| | | 3005.06 | 8308 | 41575 | 9 | 7 | 0.92 | 0.097 | 8.6 | −0.06 | C− | 2 |
| | | 3000.88 | 8095 | 41409 | 7 | 5 | 1.6 | 0.15 | 10 | 0.02 | C− | 2 |
| | | 2996.57 | 7927 | 41289 | 5 | 3 | 2.0 | 0.16 | 7.8 | −0.10 | C | 2 |
| | | 2991.88 | 7811 | 41225 | 3 | 1 | 3.0 | 0.14 | 4.0 | −0.39 | D | 2 |
| | | 2967.64 | 8095 | 41782 | 7 | 9 | 0.39 | 0.067 | 4.6 | −0.33 | D | 2 |
| | | 2971.10 | 7927 | 41575 | 5 | 7 | 0.71 | 0.13 | 6.5 | −0.18 | C | 2 |
| | | 2975.48 | 7811 | 41409 | 3 | 5 | 0.89 | 0.20 | 5.8 | −0.23 | C | 2 |
| | | 2980.78 | 7751 | 41289 | 1 | 3 | 0.510 | 0.204 | 2.00 | −0.691 | B | 15 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | $a\,^5D - x\,^5D°$ (uv 12) | *2893.5* | *8090* | *42640* | 25 | 25 | 0.93 | 0.117 | 27.9 | 0.467 | C− | 2 |
| | | 2889.22 | 8308 | 42909 | 9 | 9 | 0.66 | 0.082 | 7.1 | −0.13 | C | 2 |
| | | 2893.25 | 8095 | 42648 | 7 | 7 | 0.52 | 0.065 | 4.4 | −0.34 | C | 2 |
| | | 2896.76 | 7927 | 42439 | 5 | 5 | 0.30 | 0.037 | 1.8 | −0.73 | C− | 2 |
| | | 2899.20 | 7811 | 42293 | 3 | 3 | 0.15 | 0.019 | 0.55 | −1.24 | D− | 2 |
| | | 2911.15 | 8308 | 42648 | 9 | 7 | 0.26 | 0.025 | 2.2 | −0.64 | D | 2 |
| | | 2910.89 | 8095 | 42439 | 7 | 5 | 0.34 | 0.031 | 2.1 | −0.66 | D | 2 |
| | | 2909.05 | 7927 | 42293 | 5 | 3 | 0.68 | 0.051 | 2.5 | −0.59 | C | 2 |
| | | 2905.48 | 7811 | 42218 | 3 | 1 | 1.3 | 0.053 | 1.5 | −0.80 | D | 2 |
| | | 2871.63 | 8095 | 42909 | 7 | 9 | 0.12 | 0.018 | 1.2 | −0.89 | D− | 2 |
| | | 2879.27 | 7927 | 42648 | 5 | 7 | 0.21 | 0.036 | 1.7 | −0.74 | D | 2 |
| | | 2887.00 | 7811 | 42439 | 3 | 5 | 0.27 | 0.055 | 1.6 | −0.78 | D | 2 |
| | | 2894.17 | 7751 | 42293 | 1 | 3 | 0.33 | 0.12 | 1.2 | −0.91 | D− | 2 |
| 30. | $a\,^5D - w\,^5P°$ (uv 15) | | | | | | | | | | | |
| | | 2780.70 | 8308 | 44259 | 9 | 7 | 1.4 | 0.13 | 11 | 0.07 | C | 2 |
| | | 2769.90 | 8095 | 44187 | 7 | 5 | 1.1 | 0.090 | 5.8 | −0.20 | C | 2 |
| | | 2761.74 | 7927 | 44126 | 5 | 3 | 0.68 | 0.047 | 2.1 | −0.63 | D | 2 |
| | | 2764.36 | 8095 | 44259 | 7 | 7 | 0.37 | 0.042 | 2.7 | −0.53 | D | 2 |
| | | 2757.09 | 7927 | 44187 | 5 | 5 | 0.68 | 0.078 | 3.5 | −0.41 | C | 2 |
| | | 2752.85 | 7811 | 44126 | 3 | 3 | 0.87 | 0.098 | 2.7 | −0.53 | D | 2 |
| | | 2751.58 | 7927 | 44259 | 5 | 7 | 0.069 | 0.011 | 0.50 | −1.26 | D− | 2 |
| 31. | $a\,^5D - v\,^5P°$ (uv 17) | | | | | | | | | | | |
| | | 2716.18 | 8308 | 45113 | 9 | 7 | 0.11 | 0.0092 | 0.74 | −1.08 | C | 2 |
| | | 2700.59 | 8095 | 45113 | 7 | 7 | 0.075 | 0.0082 | 0.51 | −1.24 | D | 2 |
| 32. | $a\,^5D - x\,^5F°$ (uv 18) | | | | | | | | | | | |
| | | 2678.15 | 7927 | 45256 | 5 | 7 | 0.12 | 0.018 | 0.79 | −1.05 | C | 2 |
| | | 2671.98 | 7811 | 45225 | 3 | 5 | 0.12 | 0.022 | 0.57 | −1.19 | D− | 2 |
| | | 2669.36 | 7751 | 45202 | 1 | 3 | 0.12 | 0.039 | 0.34 | −1.41 | E | 2 |
| | | 2703.48 | 8308 | 45286 | 9 | 9 | 0.063 | 0.0069 | 0.55 | −1.21 | D | 2 |
| | | 2690.25 | 8095 | 45256 | 7 | 7 | 0.085 | 0.0092 | 0.57 | −1.19 | D | 2 |
| | | 2680.33 | 7927 | 45225 | 5 | 5 | 0.10 | 0.011 | 0.47 | −1.27 | D | 2 |
| | | 2673.64 | 7811 | 45202 | 3 | 3 | 0.18 | 0.019 | 0.51 | −1.24 | E | 2 |
| 33. | $a\,^5D - (\,°)^b$ | | | | | | | | | | | |
| | | 2701.99 | 8308 | 45306 | 9 | 11 | 0.21 | 0.028 | 2.2 | −0.60 | C | 2 |
| 34. | $a\,^5D - (\,°)^b$ | | | | | | | | | | | |
| | | 2620.48 | 7927 | 46077 | 5 | 3 | 0.19 | 0.012 | 0.50 | −1.24 | E | 2 |
| 35. | $a\,^5D - w\,^5D°$ (uv 21) | | | | | | | | | | | |
| | | 2622.87 | 8308 | 46422 | 9 | 9 | 0.13 | 0.013 | 1.0 | −0.92 | D− | 2 |
| | | 2626.60 | 8308 | 46368 | 9 | 7 | 0.093 | 0.0075 | 0.58 | −1.17 | E | 2 |
| 36. | $a\,^5D - (\,°)^b$ | | | | | | | | | | | |
| | | 2629.82 | 8095 | 46109 | 7 | 5 | 0.10 | 0.0077 | 0.46 | −1.27 | E | 2 |
| | | 2618.27 | 7927 | 46109 | 5 | 5 | 0.095 | 0.0098 | 0.42 | −1.31 | E | 2 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37. | $a\ ^5D - (\ ^\circ)^b$ | | | | | | | | | | | |
| | | 2625.32 | 8095 | 46174 | 7 | 7 | 0.091 | 0.0094 | 0.57 | −1.18 | E | 2 |
| 38. | $a\ ^5D - w\ ^5F^\circ$ (uv 22) | | | | | | | | | | | |
| | | 2603.56 | 8308 | 46705 | 9 | 11 | 0.062 | 0.0077 | 0.59 | −1.16 | E | 2 |
| | | 2588.19 | 8095 | 46721 | 7 | 9 | 0.088 | 0.011 | 0.68 | −1.10 | E | 2 |
| | | 2579.14 | 7927 | 46688 | 5 | 7 | 0.11 | 0.015 | 0.64 | −1.12 | D− | 2 |
| 39. | $a\ ^5D - z\ ^3G^\circ$ (uv 23) | | | | | | | | | | | |
| | | 2584.67 | 8308 | 46986 | 9 | 11 | 0.061 | 0.0075 | 0.58 | −1.17 | E | 2 |
| 40. | $a\ ^5D - u\ ^5P^\circ$ (uv 24) | | | | | | | | | | | |
| | | 2591.84 | 8308 | 46879 | 9 | 7 | 0.65 | 0.051 | 3.9 | −0.34 | C | 2 |
| | | 2571.74 | 8095 | 46968 | 7 | 5 | 0.64 | 0.045 | 2.7 | −0.50 | E | 2 |
| | | 2577.66 | 8095 | 46879 | 7 | 7 | 0.26 | 0.025 | 1.5 | −0.75 | D− | 2 |
| | | 2560.70 | 7927 | 46968 | 5 | 5 | 0.43 | 0.042 | 1.8 | −0.68 | D− | 2 |
| | | 2549.55 | 7811 | 47022 | 3 | 3 | 0.48 | 0.047 | 1.2 | −0.85 | D− | 2 |
| 41. | $a\ ^5D - v\ ^5D^\circ$ (uv 30) | | | | | | | | | | | |
| | | 2527.11 | 8308 | 47866 | 9 | 9 | 0.53 | 0.051 | 3.8 | −0.34 | E | 2 |
| | | 2508.11 | 7927 | 47786 | 5 | 5 | 0.21 | 0.020 | 0.81 | −1.01 | D− | 2 |
| | | 2508.97 | 7927 | 47772 | 5 | 3 | 0.38 | 0.021 | 0.89 | −0.97 | C− | 2 |
| | | 2513.62 | 8095 | 47866 | 7 | 9 | 0.11 | 0.014 | 0.81 | −1.01 | C | 2 |
| 42. | $a\ ^5D - (\ ^\circ)^b$ | | | | | | | | | | | |
| | | 2495.08 | 7811 | 47878 | 3 | 3 | 0.27 | 0.025 | 0.62 | −1.12 | C | 2 |
| 43. | $a\ ^5D - u\ ^5F^\circ$ (uv 31) | | | | | | | | | | | |
| | | 2504.31 | 8095 | 48014 | 7 | 9 | 0.45 | 0.054 | 3.1 | −0.42 | C | 2 |
| | | 2496.30 | 7927 | 47975 | 5 | 7 | 0.56 | 0.073 | 3.0 | −0.44 | C | 2 |
| | | 2492.57 | 7811 | 47918 | 3 | 5 | 0.45 | 0.070 | 1.7 | −0.68 | C | 2 |
| | | 2499.84 | 7927 | 47918 | 5 | 5 | 0.16 | 0.015 | 0.61 | −1.13 | E | 2 |
| 44. | $a\ ^5D - (\ ^\circ)^b$ | | | | | | | | | | | |
| | | 2502.55 | 8095 | 48043 | 7 | 9 | 0.22 | 0.026 | 1.5 | −0.74 | D | 2 |
| 45. | $a\ ^5D - ^3D^\circ$ | | | | | | | | | | | |
| | | 2479.14 | 7924 | 48252 | 5 | 7 | 0.098 | 0.013 | 0.51 | −1.20 | D | 2 |
| 46. | $a\ ^5D - t\ ^5P^\circ$ (uv 36) | | | | | | | | | | | |
| | | 2408.60 | 8308 | 49812 | 9 | 7 | 0.67 | 0.045 | 3.2 | −0.39 | D− | 2 |
| 47. | $a\ ^5D - (\ ^\circ)^b$ | | | | | | | | | | | |
| | | 2408.72 | 8095 | 49598 | 7 | 5 | 0.29 | 0.018 | 1.0 | −0.90 | D− | 2 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48. | $a\ ^5D - x\ ^3F°$ (uv 37) | | | | | | | | | | | |
| | | 2389.21 | 7811 | 49653 | 3 | 5 | 0.23 | 0.033 | 0.77 | −1.01 | D− | 2 |
| 49. | $a\ ^5D - s\ ^5F°$ (uv 39) | | | | | | | | | | | |
| | | 2383.30 | 8308 | 50253 | 9 | 11 | 0.41 | 0.042 | 3.0 | −0.42 | D− | 2 |
| | | 2385.72 | 8308 | 50211 | 9 | 9 | 0.17 | 0.014 | 1.0 | −0.89 | D− | 2 |
| | | 2375.06 | 7927 | 50019 | 5 | 3 | 0.17 | 0.0085 | 0.33 | −1.37 | E | 2 |
| 50. | $a\ ^5D - u\ ^5D°$ (uv 40) | | | | | | | | | | | |
| | | 2354.30 | 8095 | 50558 | 7 | 9 | 0.081 | 0.0086 | 0.47 | −1.22 | D− | 2 |
| 51. | $a\ ^5D - r^5D°$ (uv 48) | | | | | | | | | | | |
| | | 1999.95 | 8308 | 58293 | 9 | 9 | 1.4 | 0.082 | 4.9 | −0.13 | D− | 2 |
| 52. | $a\ ^5G - y\ ^5F°$ (31) | | | | | | | | | | | |
| | | 4789.32 | 20520 | 41393 | 13 | 11 | 0.114 | 0.0331 | 6.79 | −0.366 | B | 16 |
| | | 4903.25 | 20517 | 40906 | 5 | 3 | 0.074 | 0.016 | 1.3 | −1.10 | D | 10*n* |
| 53. | $a\ ^5G - x\ ^5P°$ (30) | | | | | | | | | | | |
| | | 4885.77 | 20521 | 40983 | 7 | 5 | 0.0492 | 0.0126 | 1.42 | −1.055 | B | 16 |
| 54. | $a\ ^5G - z\ ^5H°$ (32) | | | | | | | | | | | |
| | | 4571.67 | 20520 | 42387 | 13 | 15 | 0.036 | 0.013 | 2.5 | −0.77 | D | 13 |
| | | 4648.12 | 20517 | 42026 | 5 | 7 | 0.018 | 0.0082 | 0.62 | −1.39 | D | 13 |
| 55. | $a\ ^5G - (\ °)^b$ | | | | | | | | | | | |
| | | 4601.02 | 20524 | 42252 | 11 | 13 | 0.015 | 0.0056 | 0.94 | −1.21 | D | 13 |
| | | 4600.11 | 20520 | 42252 | 13 | 13 | 0.016 | 0.0051 | 1.0 | −1.18 | D | 18 |
| 56. | $a\ ^5G - z\ ^5G°$ (33) | *4533.7* | *20522* | *42573* | 45 | 45 | 0.205 | 0.0633 | 42.5 | 0.454 | B | 16,17 |
| | | 4526.44 | 20520 | 42606 | 13 | 13 | 0.175 | 0.0538 | 10.4 | −0.156 | B | 17 |
| | | 4530.73 | 20524 | 42589 | 11 | 11 | 0.158 | 0.0486 | 7.98 | −0.272 | B | 17 |
| | | 4535.69 | 20524 | 42565 | 9 | 9 | 0.149 | 0.0460 | 6.18 | −0.383 | B | 17 |
| | | 4540.49 | 20521 | 42539 | 7 | 7 | 0.150 | 0.0465 | 4.87 | −0.487 | B | 16,17 |
| | | 4544.60 | 20517 | 42515 | 5 | 5 | 0.169 | 0.0523 | 3.91 | −0.582 | B | 17 |
| | | 4529.84 | 20520 | 42589 | 13 | 11 | 0.011 | 0.0030 | 0.58 | −1.41 | C+ | 17 |
| | | 4535.75 | 20524 | 42565 | 11 | 9 | 0.025 | 0.0063 | 1.0 | −1.16 | C+ | 17 |
| | | 4541.06 | 20524 | 42539 | 9 | 7 | 0.034 | 0.0081 | 1.1 | −1.14 | B | 16,17 |
| | | 4545.33 | 20521 | 42515 | 7 | 5 | 0.034 | 0.0075 | 0.79 | −1.28 | B | 17 |
| | | 4527.33 | 20524 | 42606 | 11 | 13 | 0.021 | 0.0077 | 1.3 | −1.07 | B | 17 |
| | | 4530.68 | 20524 | 42589 | 9 | 11 | 0.036 | 0.014 | 1.8 | −0.91 | B | 17 |
| | | 4535.13 | 20521 | 42565 | 7 | 9 | 0.038 | 0.015 | 1.6 | −0.98 | B | 16,17 |
| | | 4539.76 | 20517 | 42539 | 5 | 7 | 0.032 | 0.014 | 1.0 | −1.15 | B | 16,17 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57. | $a\ ^5G - y\ ^5G°$ (35) | | | | | | | | | | | |
| | | 4126.51 | 20520 | 44746 | 13 | 13 | 0.0671 | 0.0171 | 3.03 | −0.652 | B | 16 |
| | | 4203.59 | 20517 | 44300 | 5 | 5 | 0.057 | 0.015 | 1.0 | −1.12 | D | 10*n* |
| 58. | $a\ ^5G - x\ ^5F°$ (36) | | | | | | | | | | | |
| | | 4042.25 | 20524 | 45256 | 9 | 7 | 0.0088 | 0.0017 | 0.20 | −1.82 | D | 18 |
| | | 4050.03 | 20517 | 45202 | 5 | 3 | 0.012 | 0.0017 | 0.12 | −2.06 | D | 18 |
| 59. | $a\ ^5G - y\ ^5H°$ (38) | | | | | | | | | | | |
| | | 3963.69 | 20520 | 45741 | 13 | 15 | 1.3 | 0.36 | 61 | 0.67 | D− | 2 |
| | | 3969.75 | 20524 | 45707 | 11 | 13 | 1.2 | 0.35 | 50 | 0.58 | D− | 2 |
| | | 3983.90 | 20521 | 45615 | 7 | 9 | 1.05 | 0.32 | 29 | 0.35 | C− | 11 |
| | | 3991.12 | 20517 | 45566 | 5 | 7 | 1.07 | 0.357 | 23.5 | 0.252 | B | 16 |
| | | 3976.02 | 20520 | 45663 | 13 | 11 | 0.0023 | 4.6(−4) | 0.078 | −2.22 | D | 11 |
| 60. | $a\ ^5G - x\ ^5G°$ (43) | | | | | | | | | | | |
| | | 3743.89 | 20520 | 47222 | 13 | 13 | 0.761 | 0.160 | 25.6 | 0.318 | B | 16 |
| | | 3757.66 | 20521 | 47126 | 7 | 7 | 0.413 | 0.0875 | 7.58 | −0.213 | B | 16 |
| | | 3768.24 | 20517 | 47047 | 5 | 5 | 0.510 | 0.109 | 6.74 | −0.265 | B | 16 |
| | | 3758.04 | 20524 | 47126 | 9 | 7 | 0.116 | 0.0192 | 2.14 | −0.763 | B | 16 |
| | | 3768.73 | 20521 | 47047 | 7 | 5 | 0.119 | 0.0181 | 1.57 | −0.897 | B | 16 |
| | | 3744.49 | 20524 | 47222 | 11 | 13 | 0.0501 | 0.0124 | 1.69 | −0.864 | B | 16 |
| | | 3757.17 | 20517 | 47126 | 5 | 7 | 0.0616 | 0.0182 | 1.13 | −1.040 | B | 16 |
| 61. | $a\ ^5G - u\ ^5F°$ (47) | | | | | | | | | | | |
| | | 3639.80 | 20520 | 47986 | 13 | 11 | 1.8 | 0.30 | 47 | 0.59 | D | 12 |
| 62. | $a\ ^5P - x\ ^5P°$ (59) | | | | | | | | | | | |
| | | 5241.47 | 21857 | 40930 | 3 | 3 | 0.0067 | 0.0028 | 0.14 | −2.08 | D | 18 |
| | | 5238.97 | 21848 | 40930 | 5 | 3 | 0.0401 | 0.00991 | 0.855 | −1.305 | B | 16 |
| 63. | $a\ ^5P - y\ ^5D°$ (60) | | | | | | | | | | | |
| | | 5013.31 | 21841 | 41782 | 7 | 9 | 0.035 | 0.017 | 2.0 | −0.92 | D | 10*n* |
| 64. | $a\ ^5P - x\ ^5D°$ (61) | | | | | | | | | | | |
| | | 4745.31 | 21841 | 42909 | 7 | 9 | 0.020 | 0.0087 | 0.95 | −1.22 | D | 10*n* |
| | | 4806.25 | 21848 | 42648 | 5 | 7 | 0.0056 | 0.0027 | 0.21 | −1.87 | D− | 13 |
| 65. | $a\ ^5P - z\ ^5S°$ (62) | | | | | | | | | | | |
| | | 4697.04 | 21841 | 43125 | 7 | 5 | 0.053 | 0.012 | 1.2 | −1.06 | D | 18 |
| | | 4700.60 | 21857 | 43125 | 3 | 5 | 0.0336 | 0.0185 | 0.860 | −1.255 | B | 16 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66. | $a\ ^5P - w\ ^5P°$ (63) | | | | | | | | | | | |
| | | 4460.76 | 21848 | 44259 | 5 | 7 | 0.015 | 0.0065 | 0.48 | −1.49 | D | 18 |
| | | 4477.05 | 21857 | 44187 | 3 | 5 | 0.013 | 0.0065 | 0.29 | −1.71 | D | 18 |
| 67. | $a\ ^5P - v\ ^5P°$ (64) | | | | | | | | | | | |
| | | 4341.46 | 21848 | 44875 | 5 | 5 | 0.0064 | 0.0018 | 0.13 | −2.04 | E | 13 |
| | | 4382.86 | 21857 | 44667 | 3 | 3 | 0.030 | 0.0086 | 0.37 | −1.59 | D− | 13 |
| | | 4340.14 | 21841 | 44875 | 7 | 5 | 0.12 | 0.024 | 2.4 | −0.77 | D | 13 |
| | | 4381.11 | 21848 | 44667 | 5 | 3 | 0.10 | 0.018 | 1.3 | −1.05 | D | 10*n* |
| | | 4297.06 | 21848 | 45113 | 5 | 7 | 0.048 | 0.019 | 1.3 | −1.03 | D | 13 |
| | | 4343.17 | 21857 | 44875 | 3 | 5 | 0.036 | 0.017 | 0.73 | −1.29 | D | 13 |
| 68. | $a\ ^5P - w\ ^5D°$ (66) | | | | | | | | | | | |
| | | 4081.74 | 21857 | 46350 | 3 | 5 | 0.012 | 0.0050 | 0.20 | −1.82 | D | 18 |
| 69. | $a\ ^5P - (\ °)^b$ | | | | | | | | | | | |
| | | 4109.58 | 21848 | 46174 | 5 | 7 | 0.031 | 0.011 | 0.74 | −1.26 | D | 18 |
| 70. | $a\ ^5P - u\ ^5P°$ (67) | | | | | | | | | | | |
| | | 3981.24 | 21857 | 46968 | 3 | 5 | 0.11 | 0.045 | 1.8 | −0.87 | D | 10*n* |
| 71. | $a\ ^3P - y\ ^3P°$ (81) | | | | | | | | | | | |
| | | 4619.54 | 24093 | 45734 | 5 | 5 | 0.16 | 0.051 | 3.9 | −0.59 | D | 13 |
| | | 4501.79 | 23512 | 45719 | 3 | 3 | 0.10 | 0.030 | 1.4 | −1.04 | D | 13 |
| | | 4622.76 | 24093 | 45719 | 5 | 3 | 0.11 | 0.021 | 1.6 | −0.98 | D | 18 |
| | | 4498.73 | 23512 | 45734 | 3 | 5 | 0.079 | 0.040 | 1.8 | −0.92 | D | 18 |
| | | 4432.16 | 23163 | 45719 | 1 | 3 | 0.18 | 0.16 | 2.3 | −0.80 | D | 18 |
| 72. | $a\ ^3P - y\ ^3F°$ | | | | | | | | | | | |
| | | 4563.43 | 24093 | 46000 | 5 | 7 | 0.0055 | 0.0024 | 0.18 | −1.92 | D− | 13 |
| 73. | $a\ ^3P - (\ °)^b$ | | | | | | | | | | | |
| | | 4362.97 | 23163 | 46077 | 1 | 3 | 0.032 | 0.027 | 0.39 | −1.56 | D− | 13 |
| 74. | $a\ ^3P - w\ ^5D°$ (83) | | | | | | | | | | | |
| | | 4491.86 | 24093 | 46350 | 5 | 5 | 0.034 | 0.010 | 0.76 | −1.29 | D | 18 |
| | | 4387.38 | 23512 | 46298 | 3 | 3 | 0.054 | 0.016 | 0.68 | −1.33 | D | 13 |
| | | 4377.55 | 23512 | 46350 | 3 | 5 | 0.033 | 0.016 | 0.69 | −1.32 | D | 18 |
| | | 4321.25 | 23163 | 46298 | 1 | 3 | 0.034 | 0.029 | 0.41 | −1.54 | D− | 13 |
| 75. | $a\ ^3P - (\ °)^b$ | | | | | | | | | | | |
| | | 4424.10 | 23512 | 46109 | 3 | 5 | 0.057 | 0.028 | 1.2 | −1.08 | D | 13 |
| 76. | $a\ ^3P - (\ °)^b$ | | | | | | | | | | | |
| | | 4527.45 | 24093 | 46174 | 5 | 7 | 0.062 | 0.027 | 2.0 | −0.87 | D | 13 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 77. | $a\,^3P - z\,^3S^\circ$ | | | | | | | | | | | |
| | | 4347.49 | 24093 | 47088 | 5 | 3 | 0.019 | 0.0032 | 0.23 | −1.79 | D− | 13 |
| 78. | $z\,^7P^\circ - e\,^7S$ (93) | | | | | | | | | | | |
| | | 7400.22 | 23386 | 36896 | 7 | 7 | 0.135 | 0.111 | 18.9 | −0.111 | B | 16 |
| | | 7355.93 | 23305 | 36896 | 5 | 7 | 0.0914 | 0.104 | 12.6 | −0.285 | B | 16 |
| 79. | $z\,^7P^\circ - e\,^7D$ (94) | | | | | | | | | | | |
| | | 5328.36 | 23499 | 42261 | 9 | 11 | 0.62 | 0.32 | 51 | 0.46 | D | 9*n* |
| | | 5297.37 | 23386 | 42258 | 7 | 9 | 0.388 | 0.210 | 25.6 | 0.167 | B | 16 |
| | | 5329.17 | 23499 | 42258 | 9 | 9 | 0.225 | 0.0959 | 15.1 | −0.064 | B | 16 |
| | | 5297.99 | 23386 | 42256 | 7 | 7 | 0.30 | 0.12 | 15 | −0.06 | D | 18 |
| | | 5329.76 | 23499 | 42256 | 9 | 7 | 0.0538 | 0.0178 | 2.81 | −0.795 | B | 16 |
| 80. | $z\,^7P^\circ - f\,^7S$ (95) | | | | | | | | | | | |
| | | 4491.69 | 23386 | 45643 | 7 | 7 | 0.044 | 0.013 | 1.4 | −1.03 | D | 18 |
| | | 4475.36 | 23305 | 45643 | 5 | 7 | 0.030 | 0.013 | 0.93 | −1.20 | D | 18 |
| 81. | $z\,^7P^\circ - f\,^7D$ (96) | | | | | | | | | | | |
| | | 4261.35 | 23499 | 46959 | 9 | 11 | 0.066 | 0.022 | 2.8 | −0.70 | D | 13 |
| | | 4272.93 | 23386 | 46783 | 7 | 9 | 0.047 | 0.017 | 1.6 | −0.94 | D | 13 |
| | | 4293.58 | 23499 | 46783 | 9 | 9 | 0.025 | 0.0070 | 0.89 | −1.20 | D | 18 |
| | | 4299.72 | 23386 | 46637 | 7 | 7 | 0.061 | 0.017 | 1.7 | −0.93 | D | 13 |
| | | 4305.47 | 23305 | 46525 | 5 | 5 | 0.076 | 0.021 | 1.5 | −0.98 | D | 10*n* |
| | | 4319.66 | 23305 | 46449 | 5 | 3 | 0.18 | 0.030 | 2.1 | −0.82 | D | 10*n* |
| 82. | $z\,^7P^\circ - g\,^7D$ (97) | | | | | | | | | | | |
| | | 4097.69 | 23305 | 47702 | 5 | 7 | 0.053 | 0.019 | 1.3 | −1.03 | D | 18 |
| | | 4111.33 | 23386 | 47702 | 7 | 7 | 0.12 | 0.031 | 2.9 | −0.67 | D | 18 |
| 83. | $a\,^3H - z\,^3H^\circ$ (99) | | | | | | | | | | | |
| | | 4727.13 | 24200 | 45349 | 13 | 13 | 0.051 | 0.017 | 3.4 | −0.66 | D | 10*n* |
| | | 4693.94 | 24056 | 45354 | 11 | 11 | 0.034 | 0.011 | 1.9 | −0.91 | D | 18 |
| | | 4666.20 | 23934 | 45359 | 9 | 9 | 0.036 | 0.012 | 1.6 | −0.98 | D | 13 |
| | | 4695.14 | 24056 | 45349 | 11 | 13 | 0.015 | 0.0060 | 1.0 | −1.18 | D | 18 |
| 84. | $a\,^3H - y\,^5H^\circ$ | | | | | | | | | | | |
| | | 4617.37 | 24056 | 45707 | 11 | 13 | 5.1(−4) | 1.9(−4) | 0.032 | −2.67 | D− | 11 |
| | | 4648.33 | 24200 | 45707 | 13 | 13 | 0.0015 | 4.9(−4) | 0.097 | −2.20 | D− | 11 |
| | | 4611.06 | 23934 | 45615 | 9 | 9 | 0.0020 | 6.4(−4) | 0.087 | −2.24 | D− | 11 |
| 85. | $a\,^3H - y\,^3F^\circ$ (100) | | | | | | | | | | | |
| | | 4543.73 | 24056 | 46058 | 11 | 9 | 0.010 | 0.0025 | 0.42 | −1.56 | D− | 13 |
| | | 4530.48 | 23934 | 46000 | 9 | 7 | 0.0067 | 0.0016 | 0.22 | −1.84 | D− | 13 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 86. | $a\ ^3H - w\ ^5F^\circ$ (102) | | | | | | | | | | | |
| | | 4442.28 | 24200 | 46705 | 13 | 11 | 0.019 | 0.0048 | 0.90 | −1.21 | D | 13 |
| | | 4410.97 | 24056 | 46721 | 11 | 9 | 0.023 | 0.0055 | 0.88 | −1.22 | D | 13 |
| | | 4393.54 | 23934 | 46688 | 9 | 7 | 0.007 | 0.002 | 0.2 | −1.8 | E | 13 |
| 87. | $a\ ^3H - z\ ^3G^\circ$ (103) | | | | | | | | | | | |
| | | 4375.34 | 24056 | 46905 | 11 | 9 | 0.072 | 0.017 | 2.7 | −0.73 | D | 10*n* |
| | | 4363.13 | 23934 | 46847 | 9 | 7 | 0.16 | 0.036 | 4.6 | −0.50 | D | 13 |
| 88. | $a\ ^3H - y\ ^3G^\circ$ (104) | | | | | | | | | | | |
| | | 4374.17 | 24200 | 47055 | 13 | 11 | 0.103 | 0.0250 | 4.68 | −0.488 | C− | 11 |
| | | 4346.83 | 24056 | 47055 | 11 | 9 | 0.090 | 0.021 | 3.3 | −0.64 | D | 18 |
| | | 4325.08 | 23934 | 47048 | 9 | 7 | 0.14 | 0.031 | 3.9 | −0.56 | D | 13 |
| 89. | $a\ ^3H - z\ ^3I^\circ$ (105) | | | | | | | | | | | |
| | | 4255.50 | 24200 | 47693 | 13 | 15 | 0.061 | 0.019 | 3.5 | −0.60 | D | 13 |
| 90. | $a\ ^3H - x\ ^5H^\circ$ (106) | | | | | | | | | | | |
| | | 4211.48 | 24056 | 47794 | 11 | 11 | 0.0071 | 0.0019 | 0.29 | −1.68 | D | 18 |
| 91. | $a\ ^3H - v\ ^3H^\circ$ (114) | | | | | | | | | | | |
| | | 3238.09 | 24056 | 54930 | 11 | 11 | 0.20 | 0.032 | 3.7 | −0.46 | D | 12 |
| | | 3237.73 | 23934 | 54811 | 9 | 9 | 1.3 | 0.20 | 19 | 0.25 | D | 12 |
| 92. | $a\ ^3H - x\ ^3I^\circ$ (115) | | | | | | | | | | | |
| | | 3163.76 | 24200 | 55799 | 13 | 15 | 0.60 | 0.10 | 14 | 0.13 | B | 17 |
| | | 3155.16 | 24056 | 55741 | 11 | 13 | 0.57 | 0.10 | 11 | 0.04 | B | 17 |
| | | 3148.44 | 23934 | 55686 | 9 | 11 | 0.56 | 0.10 | 9.5 | −0.04 | B | 17 |
| | | 3169.58 | 24200 | 55741 | 13 | 13 | 0.022 | 0.0033 | 0.45 | −1.37 | E | 17 |
| | | 3160.62 | 24056 | 55686 | 11 | 11 | 0.027 | 0.0041 | 0.46 | −1.35 | D− | 17 |
| 93. | $b\ ^5D - y\ ^5D^\circ$ (119) | | | | | | | | | | | |
| | | 5844.60 | 24304 | 41409 | 7 | 5 | 0.0068 | 0.0025 | 0.33 | −1.76 | D | 18 |
| | | 5719.82 | 24304 | 41782 | 7 | 9 | 0.00496 | 0.00313 | 0.412 | −1.660 | B | 16 |
| | | 5838.68 | 24287 | 41409 | 3 | 5 | 0.0065 | 0.0055 | 0.32 | −1.78 | D | 18 |
| 94. | $b\ ^5D - x\ ^5F^\circ$ (124) | | | | | | | | | | | |
| | | 4764.65 | 24304 | 45286 | 7 | 9 | 0.0073 | 0.0032 | 0.35 | −1.65 | D− | 13 |
| | | 4770.68 | 24300 | 45256 | 5 | 7 | 0.0098 | 0.0047 | 0.37 | −1.63 | D | 18 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95. | $b\,^5$D - ( °)$^b$ | | | | | | | | | | | |
| | | 4755.14 | 24282 | 45306 | 9 | 11 | 0.0096 | 0.0040 | 0.56 | −1.45 | D | 13 |
| 96. | $b\,^5$D - $w\,^5$D° (126) | | | | | | | | | | | |
| | | 4515.44 | 24282 | 46422 | 9 | 9 | 0.022 | 0.0067 | 0.90 | −1.22 | D | 13 |
| | | 4530.93 | 24304 | 46368 | 7 | 7 | 0.0065 | 0.0020 | 0.21 | −1.85 | D− | 13 |
| | | 4531.24 | 24287 | 46350 | 3 | 5 | 0.010 | 0.0051 | 0.23 | −1.81 | D− | 13 |
| 97. | $b\,^5$D - ( °)$^b$ | | | | | | | | | | | |
| | | 4584.76 | 24304 | 46109 | 7 | 5 | 0.0075 | 0.0017 | 0.18 | −1.93 | D− | 13 |
| | | 4583.90 | 24300 | 46109 | 5 | 5 | 0.016 | 0.0050 | 0.38 | −1.60 | D− | 13 |
| 98. | $b\,^5$D - ( °)$^b$ | | | | | | | | | | | |
| | | 4571.10 | 24304 | 46174 | 7 | 7 | 0.0095 | 0.0030 | 0.31 | −1.68 | D− | 13 |
| 99. | $b\,^5$D - $w\,^5$F° (127) | | | | | | | | | | | |
| | | 4459.75 | 24304 | 46721 | 7 | 9 | 0.084 | 0.032 | 3.3 | −0.65 | D | 13 |
| | | 4465.37 | 24300 | 46688 | 5 | 7 | 0.059 | 0.025 | 1.8 | −0.91 | D | 18 |
| | | 4462.79 | 24277 | 46678 | 1 | 3 | 0.056 | 0.050 | 0.74 | −1.30 | D | 13 |
| | | 4467.57 | 24300 | 46677 | 5 | 5 | 0.037 | 0.011 | 0.81 | −1.26 | D | 18 |
| | | 4464.66 | 24287 | 46678 | 3 | 3 | 0.049 | 0.015 | 0.65 | −1.36 | D | 13 |
| 100. | $b\,^5$D - $u\,^5$P° (129) | | | | | | | | | | | |
| | | 4424.29 | 24282 | 46879 | 9 | 7 | 0.21 | 0.048 | 6.3 | −0.37 | D | 13 |
| | | 4411.11 | 24304 | 46968 | 7 | 5 | 0.13 | 0.027 | 2.8 | −0.72 | D | 13 |
| | | 4399.82 | 24300 | 47022 | 5 | 3 | 0.098 | 0.017 | 1.2 | −1.07 | D | 10*n* |
| | | 4428.52 | 24304 | 46879 | 7 | 7 | 0.055 | 0.016 | 1.7 | −0.95 | D | 13 |
| | | 4410.31 | 24300 | 46968 | 5 | 5 | 0.067 | 0.020 | 1.4 | −1.01 | D | 13 |
| | | 4397.24 | 24287 | 47022 | 3 | 3 | 0.10 | 0.029 | 1.3 | −1.06 | D | 10*n* |
| 101. | $b\,^5$D - $x\,^5$G° (130) | | | | | | | | | | | |
| | | 4356.77 | 24282 | 47229 | 9 | 11 | 0.022 | 0.0077 | 0.99 | −1.16 | D | 13 |
| | | 4368.25 | 24304 | 47190 | 7 | 9 | 0.021 | 0.0077 | 0.78 | −1.27 | D | 13 |
| | | 4379.77 | 24300 | 47126 | 5 | 7 | 0.019 | 0.0076 | 0.55 | −1.42 | D | 13 |
| 102. | $b\,^5$D - $v\,^5$D° (131) | | | | | | | | | | | |
| | | 4238.96 | 24282 | 47866 | 9 | 9 | 0.074 | 0.020 | 2.5 | −0.74 | D | 10*n* |
| | | 4252.24 | 24304 | 47814 | 7 | 7 | 0.051 | 0.014 | 1.4 | −1.01 | D | 13 |
| | | 4248.34 | 24282 | 47814 | 9 | 7 | 0.028 | 0.0059 | 0.74 | −1.28 | D | 13 |
| | | 4257.35 | 24304 | 47786 | 7 | 5 | 0.029 | 0.0057 | 0.56 | −1.40 | D | 18 |
| | | 4242.84 | 24304 | 47866 | 7 | 9 | 0.018 | 0.0062 | 0.61 | −1.36 | D | 13 |
| 103. | $b\,^5$D - ( °)$^b$ | | | | | | | | | | | |
| | | 4235.99 | 24277 | 47878 | 1 | 3 | 0.066 | 0.053 | 0.74 | −1.27 | D | 13 |
| | | 4237.72 | 24287 | 47878 | 3 | 3 | 0.040 | 0.011 | 0.45 | −1.49 | D | 13 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 104. | $b\ ^5D - u\ ^5F°$ (132) | | | | | | | | | | | |
| | | 4222.75 | 24300 | 47975 | 5 | 7 | 0.056 | 0.021 | 1.5 | −0.98 | D | 18 |
| | | 4230.49 | 24287 | 47918 | 3 | 5 | 0.051 | 0.023 | 0.95 | −1.16 | D | 13 |
| 105. | $b\ ^5D - u\ ^5D°$ (139) | | | | | | | | | | | |
| | | 3804.80 | 24282 | 50558 | 9 | 9 | 0.69 | 0.15 | 17 | 0.13 | D | 9*n* |
| 106. | $a\ ^3G - z\ ^3H°$ (143) | | | | | | | | | | | |
| | | 4922.28 | 25039 | 45349 | 11 | 13 | 0.40 | 0.17 | 30 | 0.27 | D | 9*n* |
| | | 4887.01 | 24898 | 45354 | 9 | 11 | 0.32 | 0.14 | 20 | 0.10 | D | 9*n* |
| | | 4870.79 | 24834 | 45359 | 7 | 9 | 0.35 | 0.16 | 18 | 0.05 | D | 9*n* |
| | | 4885.97 | 24898 | 45359 | 9 | 9 | 0.0244 | 0.00874 | 1.27 | −1.104 | B | 16 |
| 107. | $a\ ^3G - y\ ^5H°$ (144) | | | | | | | | | | | |
| | | 4836.85 | 25039 | 45707 | 11 | 13 | 0.0160 | 0.00665 | 1.16 | −1.136 | B | 16 |
| | | 4814.25 | 24898 | 45663 | 9 | 11 | 0.0161 | 0.0068 | 0.98 | −1.211 | C− | 11 |
| | | 4810.71 | 24834 | 45615 | 7 | 9 | 0.016 | 0.0071 | 0.79 | −1.30 | D | 11 |
| | | 4825.50 | 24898 | 45615 | 9 | 9 | 0.0036 | 0.0013 | 0.18 | −1.95 | D− | 11 |
| 108. | $a\ ^3G - y\ ^3F°$ (145) | | | | | | | | | | | |
| | | 4756.09 | 25039 | 46058 | 11 | 9 | 0.40 | 0.11 | 19 | 0.09 | D | 18 |
| | | 4737.33 | 24898 | 46000 | 9 | 7 | 0.338 | 0.0885 | 12.4 | −0.099 | B | 16 |
| | | 4730.69 | 24834 | 45966 | 7 | 5 | 0.383 | 0.0918 | 10.0 | −0.192 | B | 16 |
| | | 4724.40 | 24898 | 46058 | 9 | 9 | 0.0614 | 0.0205 | 2.88 | −0.733 | B | 16 |
| | | 4723.06 | 24834 | 46000 | 7 | 7 | 0.093 | 0.031 | 3.4 | −0.66 | D | 10*n* |
| 109. | $a\ ^3G - w\ ^5D°$ (147) | | | | | | | | | | | |
| | | 4656.18 | 24898 | 46368 | 9 | 7 | 0.0327 | 0.00826 | 1.14 | −1.129 | B | 16 |
| | | 4646.50 | 24834 | 46350 | 7 | 5 | 0.058 | 0.013 | 1.4 | −1.03 | D | 13 |
| 110. | $a\ ^3G - (\ °)^b$ | | | | | | | | | | | |
| | | 4698.94 | 24834 | 46109 | 7 | 5 | 0.022 | 0.0052 | 0.56 | −1.44 | D | 13 |
| 111. | $a\ ^3G - z\ ^3G°$ (149) | | | | | | | | | | | |
| | | 4541.51 | 24834 | 46847 | 7 | 7 | 0.038 | 0.012 | 1.2 | −1.08 | D | 13 |
| 112. | $a\ ^3G - y\ ^3G°$ (150) | | | | | | | | | | | |
| | | 4540.72 | 25039 | 47055 | 11 | 11 | 0.314 | 0.0970 | 15.9 | 0.028 | B | 16 |
| | | 4511.90 | 24898 | 47055 | 9 | 9 | 0.165 | 0.0504 | 6.74 | −0.343 | B | 16 |
| | | 4500.29 | 24834 | 47048 | 7 | 7 | 0.21 | 0.064 | 6.6 | −0.35 | D | 13 |
| 113. | $a\ ^3G - u\ ^5F°$ | | | | | | | | | | | |
| | | 4330.76 | 24834 | 47918 | 7 | 5 | 0.014 | 0.0028 | 0.28 | −1.71 | D− | 13 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 114. | $a\,^3G - y\,^3H°$ (154) | | | | | | | | | | | |
| | | 4271.07 | 25039 | 48445 | 11 | 13 | 0.053 | 0.017 | 2.6 | −0.73 | D | 10*n* |
| | | 4269.96 | 24898 | 48310 | 9 | 11 | 0.032 | 0.011 | 1.4 | −1.02 | D | 13 |
| | | 4262.37 | 24834 | 48288 | 7 | 9 | 0.024 | 0.0084 | 0.83 | −1.23 | D | 13 |
| 115. | $a\,^3G - x\,^3G°$ (155) | | | | | | | | | | | |
| | | 4213.18 | 24834 | 48562 | 7 | 9 | 0.079 | 0.027 | 2.6 | −0.72 | D | 10*n* |
| 116. | $a\,^3F - z\,^3H°$ (166) | | | | | | | | | | | |
| | | 4954.81 | 25177 | 45354 | 9 | 11 | 0.12 | 0.056 | 8.2 | −0.30 | D | 10*n* |
| | | 4936.34 | 25106 | 45359 | 7 | 9 | 0.14 | 0.066 | 7.5 | −0.34 | D | 10*n* |
| | | 4953.73 | 25177 | 45359 | 9 | 9 | 0.0085 | 0.0031 | 0.46 | −1.55 | D | 18 |
| 117. | $a\,^3F - y\,^5H°$ (167) | | | | | | | | | | | |
| | | 4880.04 | 25177 | 45663 | 9 | 11 | 0.0081 | 0.0035 | 0.51 | −1.50 | D | 18 |
| | | 4874.65 | 25106 | 45615 | 7 | 9 | 0.0069 | 0.0032 | 0.36 | −1.66 | D | 11 |
| 118. | $a\,^3F - y\,^3F°$ (168) | | | | | | | | | | | |
| | | 4754.73 | 24941 | 45966 | 5 | 5 | 0.026 | 0.0088 | 0.69 | −1.36 | D | 13 |
| | | 4801.02 | 25177 | 46000 | 9 | 7 | 0.306 | 0.0822 | 11.7 | −0.131 | B | 16 |
| | | 4792.49 | 25106 | 45966 | 7 | 5 | 0.26 | 0.064 | 7.1 | −0.35 | D | 10*n* |
| 119. | $a\,^3F - (\;°)^b$ | | | | | | | | | | | |
| | | 4729.84 | 24941 | 46077 | 5 | 3 | 0.17 | 0.035 | 2.7 | −0.76 | D | 10*n* |
| 120. | $a\,^3F - w\,^5D°$ (170) | | | | | | | | | | | |
| | | 4717.67 | 25177 | 46368 | 9 | 7 | 0.0077 | 0.0020 | 0.28 | −1.75 | D− | 13 |
| | | 4706.09 | 25106 | 46350 | 7 | 5 | 0.035 | 0.0084 | 0.91 | −1.23 | D | 18 |
| | | 4680.86 | 24941 | 46298 | 5 | 3 | 0.16 | 0.031 | 2.4 | −0.81 | D | 18 |
| 121. | $a\,^3F - (\;°)^b$ | | | | | | | | | | | |
| | | 4722.65 | 24941 | 46109 | 5 | 5 | 0.0069 | 0.0023 | 0.18 | −1.94 | D− | 13 |
| 122. | $a\,^3F - z\,^3G°$ (172) | | | | | | | | | | | |
| | | 4584.10 | 25177 | 46986 | 9 | 11 | 0.021 | 0.0081 | 1.1 | −1.14 | D | 13 |
| | | 4586.15 | 25106 | 46905 | 7 | 9 | 0.027 | 0.011 | 1.2 | −1.12 | D | 13 |
| | | 4563.66 | 24941 | 46847 | 5 | 7 | 0.023 | 0.010 | 0.76 | −1.30 | D | 13 |
| 123. | $a\,^3F - y\,^3G°$ (173) | | | | | | | | | | | |
| | | 4554.82 | 25106 | 47055 | 7 | 9 | 0.020 | 0.0080 | 0.84 | −1.25 | D | 18 |
| | | 4569.63 | 25177 | 47055 | 9 | 9 | 0.082 | 0.026 | 3.5 | −0.64 | D | 13 |
| | | 4556.18 | 25106 | 47048 | 7 | 7 | 0.077 | 0.024 | 2.5 | −0.78 | D | 13 |
| | | 4570.99 | 25177 | 47048 | 9 | 7 | 0.0043 | 0.0010 | 0.14 | −2.03 | E | 13 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 124. | $a\,^3F - ^3D°$ | | | | | | | | | | | |
| | | 4332.57 | 25177 | 48252 | 9 | 7 | 0.021 | 0.0046 | 0.59 | −1.38 | D | 13 |
| | | 4325.65 | 25106 | 48218 | 7 | 5 | 0.028 | 0.0056 | 0.56 | −1.41 | D | 13 |
| | | 4296.30 | 24941 | 48210 | 5 | 3 | 0.032 | 0.0053 | 0.38 | −1.58 | D− | 13 |
| | | 4288.40 | 24941 | 48252 | 5 | 7 | 0.028 | 0.011 | 0.76 | −1.27 | D | 13 |
| 125. | $a\,^3F - y\,^3H°$ (177) | | | | | | | | | | | |
| | | 4321.62 | 25177 | 48310 | 9 | 11 | 0.017 | 0.0058 | 0.74 | −1.28 | D | 13 |
| | | 4312.48 | 25106 | 48288 | 7 | 9 | 0.017 | 0.0061 | 0.61 | −1.37 | D | 13 |
| 126. | $a\,^3F - x\,^3G°$ (178) | | | | | | | | | | | |
| | | 4234.52 | 25177 | 48786 | 9 | 11 | 0.022 | 0.0072 | 0.91 | −1.19 | D | 13 |
| 127. | $a\,^3F - ^3F°$ | | | | | | | | | | | |
| | | 4261.63 | 25177 | 48636 | 9 | 7 | 0.064 | 0.014 | 1.7 | −0.91 | D | 13 |
| 128. | $z\,^7F° - f\,^7D$ (186) | | | | | | | | | | | |
| | | 4718.43 | 25771 | 46959 | 13 | 11 | 0.34 | 0.095 | 19 | 0.09 | D | 18 |
| | | 4708.02 | 25549 | 46783 | 11 | 9 | 0.431 | 0.117 | 20.0 | 0.110 | B | 16 |
| | | 4698.46 | 25360 | 46637 | 9 | 7 | 0.22 | 0.057 | 7.9 | −0.29 | D | 13 |
| | | 4689.38 | 25206 | 46525 | 7 | 5 | 0.23 | 0.054 | 5.8 | −0.42 | D | 10*n* |
| | | 4669.34 | 25549 | 46959 | 11 | 11 | 0.0908 | 0.0297 | 5.02 | −0.486 | B | 16 |
| | | 4663.33 | 25011 | 46449 | 3 | 3 | 0.20 | 0.065 | 3.0 | −0.71 | D | 13 |
| | | 4628.48 | 25360 | 46959 | 9 | 11 | 0.012 | 0.0045 | 0.62 | −1.39 | D | 18 |
| | | 4633.27 | 25206 | 46783 | 7 | 9 | 0.020 | 0.0082 | 0.88 | −1.24 | D | 18 |
| | | 4639.52 | 25089 | 46637 | 5 | 7 | 0.095 | 0.043 | 3.3 | −0.67 | D | 10*n* |
| | | 4646.80 | 25011 | 46525 | 3 | 5 | 0.078 | 0.042 | 1.9 | −0.90 | D | 13 |
| | | 4654.76 | 24971 | 46449 | 1 | 3 | 0.091 | 0.089 | 1.4 | −1.05 | D | 13 |
| 129. | $z\,^5P° - e\,^5D$ (188) | | | | | | | | | | | |
| | | 5787.97 | 26796 | 44069 | 5 | 7 | 0.235 | 0.165 | 15.7 | −0.083 | B | 16 |
| | | 5785.02 | 26788 | 44069 | 7 | 7 | 0.119 | 0.0596 | 7.94 | −0.380 | B | 16 |
| | | 5783.89 | 26796 | 44081 | 5 | 5 | 0.202 | 0.101 | 9.65 | −0.295 | B | 16 |
| | | 5783.11 | 26802 | 44089 | 3 | 3 | 0.21 | 0.11 | 6.0 | −0.50 | D | 18 |
| 130. | $b\,^3P - y\,^3P°$ (191) | | | | | | | | | | | |
| | | 5400.58 | 27223 | 45734 | 5 | 5 | 0.16 | 0.068 | 6.0 | −0.47 | D | 10*n* |
| 131. | $b\,^3P - w\,^5D°$ (193) | | | | | | | | | | | |
| | | 5214.14 | 27176 | 46350 | 3 | 5 | 0.089 | 0.061 | 3.1 | −0.74 | D | 18 |
| 132. | $b\,^3P - (\ °)^b$ | | | | | | | | | | | |
| | | 5293.38 | 27223 | 46109 | 5 | 5 | 0.021 | 0.0087 | 0.76 | −1.36 | D | 18 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 133. | $b\ ^3P - x\ ^3P°$ (195) | | | | | | | | | | | |
| | | 4707.73 | 27223 | 48459 | 5 | 5 | 0.031 | 0.010 | 0.80 | −1.29 | D | 13 |
| | | 4697.38 | 27176 | 48459 | 3 | 5 | 0.031 | 0.017 | 0.79 | −1.29 | D | 13 |
| 134. | $b\ ^3P - x\ ^3D°$ (196) | | | | | | | | | | | |
| | | 4575.11 | 27176 | 49028 | 3 | 5 | 0.068 | 0.036 | 1.6 | −0.97 | D | 18 |
| | | 4611.96 | 27163 | 48840 | 1 | 3 | 0.080 | 0.077 | 1.2 | −1.12 | D | 13 |
| | | 4584.94 | 27223 | 49028 | 5 | 5 | 0.039 | 0.012 | 0.93 | −1.21 | D | 13 |
| 135. | $b\ ^3P - y\ ^3S°$ (197) | | | | | | | | | | | |
| | | 4492.31 | 27223 | 49477 | 5 | 3 | 0.447 | 0.0811 | 6.00 | −0.392 | B | 16 |
| | | 4482.88 | 27176 | 49477 | 3 | 3 | 0.30 | 0.090 | 4.0 | −0.57 | D | 10*n* |
| | | 4480.27 | 27163 | 49477 | 1 | 3 | 0.10 | 0.090 | 1.3 | −1.04 | D | 13 |
| 136. | $b\ ^3P - w\ ^3D°$ (198) | | | | | | | | | | | |
| | | 4338.80 | 27223 | 50264 | 5 | 7 | 0.070 | 0.028 | 2.0 | −0.86 | D | 13 |
| | | 4345.08 | 27176 | 50184 | 3 | 5 | 0.098 | 0.046 | 2.0 | −0.86 | D | 18 |
| | | 4357.51 | 27163 | 50106 | 1 | 3 | 0.068 | 0.058 | 0.83 | −1.24 | D | 13 |
| | | 4353.94 | 27223 | 50184 | 5 | 5 | 0.13 | 0.037 | 2.7 | −0.73 | D | 18 |
| | | 4368.90 | 27223 | 50106 | 5 | 3 | 0.058 | 0.010 | 0.72 | −1.30 | D | 13 |
| 137. | $z\ ^7D° - f\ ^7D$ (201) | | | | | | | | | | | |
| | | 5243.38 | 27382 | 46449 | 5 | 3 | 0.219 | 0.0542 | 4.68 | −0.567 | B | 16 |
| | | 5177.42 | 27650 | 46959 | 9 | 11 | 0.061 | 0.030 | 4.6 | −0.57 | D | 10*n* |
| | | 5192.01 | 27382 | 46637 | 5 | 7 | 0.14 | 0.081 | 6.9 | −0.39 | D | 10*n* |
| | | 5200.20 | 27300 | 46525 | 3 | 5 | 0.11 | 0.073 | 3.7 | −0.66 | D | 18 |
| 138. | $b\ ^3G - z\ ^3H°$ (203) | | | | | | | | | | | |
| | | 5702.30 | 27817 | 45349 | 11 | 13 | 0.0340 | 0.0196 | 4.04 | −0.667 | B | 16 |
| | | 5628.64 | 27597 | 45359 | 7 | 9 | 0.0395 | 0.0241 | 3.13 | −0.772 | B | 16 |
| 139. | $b\ ^3G - y\ ^5H°$ | | | | | | | | | | | |
| | | 5588.05 | 27817 | 45707 | 11 | 13 | 0.0011 | 6.1(−4) | 0.12 | −2.17 | E | 11 |
| | | 5566.55 | 27704 | 45663 | 9 | 11 | 0.0015 | 8.5(−4) | 0.14 | −2.12 | D | 11 |
| | | 5548.61 | 27597 | 45615 | 7 | 9 | 0.0019 | 0.0011 | 0.14 | −2.10 | D− | 11 |
| | | 5581.60 | 27704 | 45615 | 9 | 9 | 0.0019 | 8.9(−4) | 0.15 | −2.10 | E | 11 |
| 140. | $b\ ^3G - y\ ^3F°$ (204) | | | | | | | | | | | |
| | | 5442.40 | 27597 | 45966 | 7 | 5 | 0.039 | 0.012 | 1.6 | −1.06 | D | 18 |
| 141. | $b\ ^3G - z\ ^3G°$ (206) | | | | | | | | | | | |
| | | 5193.50 | 27597 | 46847 | 7 | 7 | 0.067 | 0.027 | 3.2 | −0.72 | D | 10*n* |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 142. | $b\ ^3G - y\ ^3G°$ (207) | | | | | | | | | | | |
| | | 5196.45 | 27817 | 47055 | 11 | 11 | 0.12 | 0.049 | 9.1 | −0.27 | D | 11 |
| | | 5139.60 | 27597 | 47048 | 7 | 7 | 0.13 | 0.050 | 5.9 | −0.46 | D | 10*n* |
| 143. | $b\ ^3G - y\ ^3H°$ (208) | | | | | | | | | | | |
| | | 4831.63 | 27597 | 48288 | 7 | 9 | 0.012 | 0.0054 | 0.60 | −1.42 | D | 13 |
| 144. | $b\ ^3G - x\ ^3F°$ (212) | | | | | | | | | | | |
| | | 4585.10 | 27817 | 49621 | 11 | 9 | 0.033 | 0.0085 | 1.4 | −1.03 | D | 18 |
| | | 4555.31 | 27704 | 49650 | 9 | 7 | 0.029 | 0.0070 | 0.95 | −1.20 | D | 18 |
| 145. | $b\ ^3G - w\ ^3F°$ | | | | | | | | | | | |
| | | 4301.19 | 27817 | 51060 | 11 | 9 | 0.26 | 0.059 | 9.2 | −0.19 | D | 13 |
| | | 4300.52 | 27704 | 50950 | 9 | 7 | 0.19 | 0.041 | 5.2 | −0.43 | D | 13 |
| | | 4291.97 | 27597 | 50890 | 7 | 5 | 0.24 | 0.047 | 4.7 | −0.48 | D | 13 |
| | | 4280.89 | 27597 | 50950 | 7 | 7 | 0.019 | 0.0052 | 0.51 | −1.44 | D | 13 |
| 146. | $y\ ^7P° - e\ ^7D$ (222) | | | | | | | | | | | |
| | | 6978.46 | 27935 | 42261 | 9 | 11 | 0.173 | 0.154 | 31.9 | 0.142 | B | 16 |
| | | 6979.81 | 27935 | 42258 | 9 | 9 | 0.059 | 0.043 | 8.9 | −0.41 | D | 18 |
| | | 6925.22 | 27820 | 42256 | 7 | 7 | 0.093 | 0.067 | 11 | −0.33 | D | 18 |
| | | 6882.40 | 27729 | 42255 | 5 | 5 | 0.119 | 0.0843 | 9.55 | −0.375 | B | 16 |
| | | 6980.91 | 27935 | 42256 | 9 | 7 | 0.015 | 0.0084 | 1.7 | −1.12 | D | 18 |
| | | 6883.05 | 27729 | 42253 | 5 | 3 | 0.178 | 0.0760 | 8.61 | −0.420 | B | 16 |
| 147. | $y\ ^7P° - f\ ^7D$ (225) | | | | | | | | | | | |
| | | 5272.01 | 27820 | 46783 | 7 | 9 | 0.101 | 0.0541 | 6.57 | −0.422 | B | 16 |
| | | 5287.19 | 27729 | 46637 | 5 | 7 | 0.0422 | 0.0248 | 2.16 | −0.907 | B | 16 |
| | | 5304.19 | 27935 | 46783 | 9 | 9 | 0.0535 | 0.0226 | 3.55 | −0.692 | B | 16 |
| | | 5312.88 | 27820 | 46637 | 7 | 7 | 0.0926 | 0.0392 | 4.80 | −0.562 | B | 16 |
| | | 5318.79 | 27729 | 46525 | 5 | 5 | 0.0967 | 0.0410 | 3.59 | −0.688 | B | 16 |
| | | 5344.77 | 27820 | 46525 | 7 | 5 | 0.041 | 0.012 | 1.5 | −1.06 | D | 18 |
| | | 5340.46 | 27729 | 46449 | 5 | 3 | 0.145 | 0.0372 | 3.27 | −0.731 | B | 16 |
| 148. | $a\ ^3D - w\ ^5G°$ (230) | | | | | | | | | | | |
| | | 4775.12 | 28637 | 49573 | 7 | 9 | 0.029 | 0.013 | 1.4 | −1.05 | D | 18 |
| | | 4797.68 | 28682 | 49520 | 5 | 7 | 0.013 | 0.0063 | 0.50 | −1.50 | D− | 13 |
| 149. | $a\ ^3D - x\ ^3F°$ (231) | | | | | | | | | | | |
| | | 4764.28 | 28637 | 49621 | 7 | 9 | 0.17 | 0.075 | 8.2 | −0.28 | D | 18 |
| | | 4767.86 | 28682 | 49650 | 5 | 7 | 0.12 | 0.059 | 4.6 | −0.53 | D | 18 |
| | | 4757.58 | 28637 | 49650 | 7 | 7 | 0.051 | 0.017 | 1.9 | −0.92 | D | 13 |
| | | 4767.26 | 28682 | 49653 | 5 | 5 | 0.056 | 0.019 | 1.5 | −1.02 | D | 13 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150. | $a\ ^3D - w\ ^3D°$ (233) | | | | | | | | | | | |
| | | 4622.47 | 28637 | 50264 | 7 | 7 | 0.41 | 0.13 | 14 | −0.04 | D | 18 |
| | | 4665.90 | 28679 | 50106 | 3 | 3 | 0.30 | 0.098 | 4.5 | −0.53 | D | 13 |
| | | 4639.70 | 28637 | 50184 | 7 | 5 | 0.077 | 0.018 | 1.9 | −0.91 | D | 13 |
| 151. | $a\ ^3D - w\ ^3F°$ | | | | | | | | | | | |
| | | 4480.36 | 28637 | 50950 | 7 | 7 | 0.035 | 0.011 | 1.1 | −1.13 | D | 13 |
| 152. | $a\ ^3D - w\ ^3P°$ (234) | | | | | | | | | | | |
| | | 4413.86 | 28637 | 51287 | 7 | 5 | 0.27 | 0.057 | 5.8 | −0.40 | D | 18 |
| | | 4443.72 | 28679 | 51177 | 3 | 1 | 0.45 | 0.044 | 1.9 | −0.88 | D | 13 |
| | | 4422.70 | 28682 | 51287 | 5 | 5 | 0.27 | 0.079 | 5.8 | −0.40 | D | 13 |
| | | 4429.93 | 28679 | 51247 | 3 | 3 | 0.24 | 0.071 | 3.1 | −0.67 | D | 13 |
| 153. | $y\ ^5P° - f\ ^5D$ (237) | | | | | | | | | | | |
| | | 5261.76 | 29825 | 48825 | 7 | 9 | 0.13 | 0.069 | 8.4 | −0.32 | D | 10*n* |
| 154. | $z\ ^5F° - f\ ^5D$ (239) | | | | | | | | | | | |
| | | 5694.72 | 31106 | 48662 | 9 | 7 | 0.14 | 0.054 | 9.2 | −0.31 | D | 18 |
| | | 5642.40 | 31106 | 48825 | 9 | 9 | 0.034 | 0.016 | 2.7 | −0.83 | D | 18 |
| | | 5649.38 | 30965 | 48862 | 7 | 7 | 0.051 | 0.024 | 3.2 | −0.77 | D | 18 |
| | | 5648.25 | 30859 | 48559 | 5 | 5 | 0.042 | 0.020 | 1.9 | −1.00 | D | 18 |
| 155. | $z\ ^5F° - e\ ^5F$ (240) | | | | | | | | | | | |
| | | 4275.98 | 31280 | 54660 | 11 | 11 | 0.22 | 0.060 | 9.3 | −0.18 | D | 13 |
| 156. | $b\ ^3D - w\ ^3P°$ (259) | | | | | | | | | | | |
| | | 4944.57 | 31028 | 51247 | 5 | 3 | 0.13 | 0.029 | 2.4 | −0.84 | D | 18 |
| | | 4966.80 | 31049 | 51177 | 3 | 1 | 0.30 | 0.037 | 1.8 | −0.95 | D | 18 |
| 157. | $a\ ^3I - y\ ^3I°$ (244) | | | | | | | | | | | |
| | | 4625.91 | 31049 | 52661 | 13 | 13 | 0.12 | 0.038 | 7.5 | −0.31 | D | 18 |
| | | 4641.96 | 31055 | 52592 | 11 | 11 | 0.060 | 0.019 | 3.3 | −0.67 | D | 18 |
| 158. | $a\ ^3I - ^3G°$ | | | | | | | | | | | |
| | | 4614.51 | 31055 | 52720 | 11 | 9 | 0.057 | 0.015 | 2.5 | −0.79 | D | 13 |
| 159. | $a\ ^3I - x\ ^3H°$ (246) | | | | | | | | | | | |
| | | 4578.33 | 31049 | 52885 | 13 | 11 | 0.040 | 0.011 | 2.1 | −0.86 | D | 13 |
| | | 4563.24 | 31055 | 52963 | 11 | 9 | 0.10 | 0.026 | 4.3 | −0.54 | D | 18 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 160. | $a\ ^3I - v\ ^3G^\circ$ | | | | | | | | | | | |
| | | 4370.87 | 31055 | 53928 | 11 | 9 | 0.050 | 0.012 | 1.9 | −0.89 | D | 13 |
| 161. | $a\ ^3I - z\ ^3K^\circ$ (247) | | | | | | | | | | | |
| | | 4263.15 | 31048 | 54498 | 15 | 17 | 0.64 | 0.20 | 42 | 0.47 | D | 13 |
| | | 4280.42 | 31049 | 54405 | 13 | 15 | 0.47 | 0.15 | 27 | 0.29 | D | 10*n* |
| | | 4297.75 | 31055 | 54317 | 11 | 13 | 0.49 | 0.16 | 25 | 0.25 | D | 10*n* |
| | | 4296.63 | 31049 | 54317 | 13 | 13 | 0.028 | 0.0077 | 1.4 | −1.00 | D | 13 |
| 162. | $a\ ^3I - x\ ^3I^\circ$ (251) | | | | | | | | | | | |
| | | 4039.10 | 31048 | 55799 | 15 | 15 | 0.67 | 0.16 | 33 | 0.39 | B | 17 |
| | | 4048.78 | 31049 | 55741 | 13 | 13 | 0.64 | 0.16 | 27 | 0.31 | B | 17 |
| | | 4058.78 | 31055 | 55686 | 11 | 11 | 0.67 | 0.17 | 24 | 0.26 | B | 17 |
| | | 4057.83 | 31049 | 55686 | 13 | 11 | 0.0072 | 0.0015 | 0.26 | −1.71 | D | 11 |
| | | 4039.29 | 31049 | 55799 | 13 | 15 | 0.060 | 0.017 | 2.9 | −0.66 | D | 17 |
| | | 4049.78 | 31055 | 55741 | 11 | 13 | 0.056 | 0.016 | 2.4 | −0.75 | D | 17 |
| 163. | $a\ ^5F - z\ ^5G^\circ$ | | | | | | | | | | | |
| | | 8916.24 | 31393 | 42606 | 11 | 13 | 0.0025 | 0.0035 | 1.1 | −1.41 | D | 17 |
| | | 8939.21 | 31355 | 42539 | 5 | 7 | 9.9(−4) | 0.0017 | 0.24 | −2.08 | D | 17 |
| | | 8955.76 | 31352 | 42515 | 3 | 5 | 0.0020 | 0.0040 | 0.35 | −1.92 | D | 17 |
| 164. | $a\ ^5F - s\ ^5D^\circ$ (267) | | | | | | | | | | | |
| | | 4490.55 | 31378 | 53641 | 9 | 7 | 0.39 | 0.092 | 12 | −0.08 | D | 13 |
| 165. | $a\ ^5F - v\ ^5G^\circ$ (268) | | | | | | | | | | | |
| | | 4001.44 | 31378 | 56362 | 9 | 11 | 0.68 | 0.20 | 24 | 0.26 | D | 10*n* |
| 166. | $a\ ^1I - z\ ^1K^\circ$ | 4370.76 | 32097 | 54970 | 13 | 15 | 0.025 | 0.0083 | 1.5 | −0.97 | D | 13 |
| 167. | $a\ ^1I - (\ ^\circ)^b$ | | | | | | | | | | | |
| | | 4268.79 | 32097 | 55517 | 13 | 13 | 0.17 | 0.046 | 8.5 | −0.22 | D | 13 |
| 168. | $a\ ^1I - u\ ^3H^\circ$ (272) | | | | | | | | | | | |
| | | 4204.48 | 32097 | 55875 | 13 | 11 | 0.31 | 0.070 | 13 | −0.04 | D | 18 |
| 169. | $b\ ^3F - y\ ^3G^\circ$ | | | | | | | | | | | |
| | | 7170.56 | 33113 | 47055 | 9 | 11 | 0.0025 | 0.0024 | 0.50 | −1.67 | E | 11 |
| 170. | $b\ ^3F - v\ ^3G^\circ$ | | | | | | | | | | | |
| | | 4819.30 | 33061 | 53805 | 7 | 7 | 0.13 | 0.045 | 5.0 | −0.50 | D | 13 |
| 171. | $b\ ^3F - v\ ^3H^\circ$ | | | | | | | | | | | |
| | | 4582.40 | 33113 | 54930 | 9 | 11 | 0.032 | 0.012 | 1.7 | −0.96 | D | 13 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 172. | $b\ ^3F - v\ ^3F°$ (275) | | | | | | | | | | | |
| | | 4524.84 | 33113 | 55207 | 9 | 9 | 0.11 | 0.034 | 4.5 | −0.52 | D | 13 |
| | | 4553.95 | 33040 | 54993 | 5 | 5 | 0.12 | 0.037 | 2.8 | −0.73 | D | 13 |
| 173. | $b\ ^3F - t\ ^3G°$ (279) | | | | | | | | | | | |
| | | 4065.71 | 33113 | 57702 | 9 | 11 | 0.35 | 0.11 | 13 | −0.02 | D | 18 |
| 174. | $b\ ^3F - u\ ^3F°$ (280) | | | | | | | | | | | |
| | | 4495.28 | 33113 | 55353 | 9 | 7 | 0.20 | 0.047 | 6.3 | −0.37 | D | 13 |
| 175. | $z\ ^5D° - f\ ^5D$ (282) | | | | | | | | | | | |
| | | 6661.10 | 33816 | 48825 | 9 | 9 | 0.11 | 0.072 | 14 | −0.19 | D | 18 |
| | | 6669.27 | 33672 | 48662 | 7 | 7 | 0.059 | 0.039 | 6.0 | −0.56 | D | 18 |
| 176. | $z\ ^5D° - e^5F$ (283) | | | | | | | | | | | |
| | | 4796.15 | 33816 | 54660 | 9 | 11 | 0.13 | 0.055 | 7.8 | −0.31 | D | 13 |
| 177. | $z\ ^3P° - e\ ^3D$ (290) | | | | | | | | | | | |
| | | 4757.31 | 34190 | 55205 | 5 | 7 | 0.12 | 0.057 | 4.5 | −0.55 | D | 13 |
| | | 4743.12 | 33897 | 54975 | 3 | 5 | 0.080 | 0.045 | 2.1 | −0.87 | D | 13 |
| 178. | $b\ ^1I - ^3K°$ | | | | | | | | | | | |
| | | 4752.07 | 33763 | 54800 | 13 | 13 | 0.62 | 0.21 | 43 | 0.44 | D | 13 |
| 179. | $b\ ^1I - (\ °)^b$ | 4595.60 | 33763 | 55517 | 13 | 13 | 0.47 | 0.15 | 30 | 0.29 | D | 10*n* |
| 180. | $b\ ^1I - x\ ^3I°$ | | | | | | | | | | | |
| | | 4548.65 | 33763 | 55741 | 13 | 13 | 0.028 | 0.0086 | 1.7 | −0.95 | E | 17 |
| 181. | $b\ ^1I - (\ °)^b$ | | | | | | | | | | | |
| | | 4514.36 | 33763 | 55908 | 13 | 13 | 0.11 | 0.034 | 6.5 | −0.36 | D | 13 |
| 182. | $b\ ^1I - y\ ^1H°$ | 4506.84 | 33763 | 55945 | 13 | 11 | 0.27 | 0.069 | 13 | −0.05 | D | 10*n* |
| 183. | $c\ ^3D - v\ ^3F°$ | | | | | | | | | | | |
| | | 4699.59 | 33935 | 55207 | 7 | 9 | 0.13 | 0.055 | 6.0 | −0.41 | D | 13 |
| | | 4741.09 | 33907 | 54993 | 3 | 5 | 0.22 | 0.12 | 5.8 | −0.43 | D | 13 |
| 184. | $c\ ^3D - u\ ^3F°$ | | | | | | | | | | | |
| | | 4641.49 | 33935 | 55474 | 7 | 5 | 0.038 | 0.0088 | 0.94 | −1.21 | D | 13 |
| 185. | $c\ ^3D - (\ °)^b$ | | | | | | | | | | | |
| | | 4337.25 | 33936 | 56986 | 5 | 7 | 0.20 | 0.079 | 5.6 | −0.40 | D | 13 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 186. | $c\ ^3D - u\ ^3P°$ | | | | | | | | | | | |
| | | 4317.91 | 33935 | 57088 | 7 | 5 | 0.11 | 0.022 | 2.2 | −0.81 | D | 13 |
| | | 4309.73 | 33936 | 57133 | 5 | 3 | 0.17 | 0.028 | 2.0 | −0.85 | D | 13 |
| 187. | $c\ ^3D - (\ °)^b$ | | | | | | | | | | | |
| | | 4283.00 | 33935 | 57276 | 7 | 7 | 0.088 | 0.024 | 2.4 | −0.77 | D | 13 |
| 188. | $c\ ^3D - t\ ^3G°$ (294) | | | | | | | | | | | |
| | | 4232.23 | 33936 | 57557 | 5 | 7 | 0.17 | 0.064 | 4.5 | −0.50 | D | 13 |
| 189. | $b\ ^3H - x\ ^3I°$ | | | | | | | | | | | |
| | | 5032.54 | 35934 | 55799 | 13 | 15 | 0.020 | 0.0088 | 1.9 | −0.94 | E | 17 |
| | | 5034.65 | 35884 | 55741 | 11 | 13 | 0.017 | 0.0076 | 1.4 | −1.08 | E | 17 |
| | | 5045.04 | 35871 | 55686 | 9 | 11 | 0.018 | 0.0084 | 1.3 | −1.12 | D | 11 |
| 190. | $b\ ^3H - t\ ^3G°$ (303) | | | | | | | | | | | |
| | | 4592.55 | 35934 | 57702 | 13 | 11 | 0.13 | 0.035 | 6.8 | −0.34 | D | 13 |
| 191. | $b\ ^3H - (\ °)^b$ | | | | | | | | | | | |
| | | 4606.36 | 35884 | 57587 | 11 | 9 | 0.12 | 0.031 | 5.2 | −0.46 | D | 13 |
| 192. | $b\ ^3H - t\ ^3H°$ (304) | | | | | | | | | | | |
| | | 4376.80 | 35934 | 58775 | 13 | 13 | 0.32 | 0.092 | 17 | 0.08 | D | 13 |
| | | 4373.65 | 35871 | 58728 | 9 | 9 | 0.28 | 0.080 | 10 | −0.14 | D | 13 |
| 193. | $b\ ^3H - w\ ^3I°$ (305) | | | | | | | | | | | |
| | | 4165.52 | 35884 | 59884 | 11 | 13 | 0.75 | 0.23 | 35 | 0.40 | D | 10*n* |
| 194. | $d\ ^3F - (\ °)^b$ | | | | | | | | | | | |
| | | 4838.42 | 36559 | 57221 | 5 | 5 | 0.11 | 0.039 | 3.1 | −0.71 | D | 13 |
| 195. | $d\ ^3F - (\ °)^b$ | | | | | | | | | | | |
| | | 4823.90 | 36552 | 57276 | 7 | 7 | 0.12 | 0.042 | 4.7 | −0.53 | D | 13 |
| 196. | $d\ ^3F - (\ °)^b$ | | | | | | | | | | | |
| | | 4816.13 | 36578 | 57335 | 9 | 9 | 0.18 | 0.061 | 8.7 | −0.26 | D | 18 |
| 197. | $d\ ^3F - (\ °)^b$ | | | | | | | | | | | |
| | | 4510.02 | 36559 | 58725 | 5 | 3 | 0.0041 | 7.5(−4) | 0.056 | −2.43 | E | 13 |
| 198. | $c\ ^3G - x\ ^1I°$ | | | | | | | | | | | |
| | | 4307.67 | 37234 | 60441 | 11 | 13 | 0.082 | 0.027 | 4.2 | −0.53 | D | 13 |
| 199. | $c\ ^3G - (\ °)^b$ | | | | | | | | | | | |
| | | 4302.78 | 37234 | 60468 | 11 | 11 | 0.25 | 0.069 | 11 | −0.12 | D | 13 |

Cr I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 200. | $c\ ^3G - s\ ^3G°$ | | | | | | | | | | | |
| | | 4298.05 | 37244 | 60504 | 9 | 9 | 0.26 | 0.072 | 9.2 | −0.19 | D | 13 |
| | | 4296.11 | 37234 | 60504 | 11 | 9 | 0.089 | 0.020 | 3.1 | −0.65 | D | 13 |
| 201. | $e\ ^5S - x\ ^3S°$ (310) | 4503.04 | 37883 | 60084 | 5 | 3 | 0.083 | 0.015 | 1.1 | −1.12 | D | 13 |
| 202. | $a\ ^1H - (\ °)^b$ | | | | | | | | | | | |
| | | 4656.82 | 38538 | 60006 | 11 | 11 | 0.11 | 0.036 | 6.0 | −0.41 | D | 13 |
| 203. | $a\ ^1H - x\ ^1I°$ | 4564.17 | 38538 | 60441 | 11 | 13 | 0.51 | 0.19 | 31 | 0.32 | D | 18 |
| 204. | $a\ ^1H - (\ °)^b$ | | | | | | | | | | | |
| | | 4413.00 | 38538 | 61192 | 11 | 13 | 0.097 | 0.033 | 5.3 | −0.43 | D | 13 |
| 205. | $z\ ^5H° - e\ ^5H$ | | | | | | | | | | | |
| | | 4432.77 | 42387 | 64940 | 15 | 15 | 0.49 | 0.14 | 32 | 0.34 | D | 13 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.
[b]The term designation for the level in question was not provided by Sugar and Corliss in their energy level compilation (J. Phys. Chem. Ref. Data 14, Suppl. 2 (1985)), so we have accordingly omitted it from this work.

# Cr II

V Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5\ ^6S_{5/2}$

Ionization Energy: 16.4858 eV = 132966 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2653.57 | 3 | 2867.09 | 6 | 3136.68 | 5 | 4848.24 | 16 |
| 2658.59 | 4 | 2867.65 | 1 | 4054.10 | 8 | 4856.18 | 16 |
| 2666.02 | 4 | 2870.43 | 6 | 4087.60 | 8 | 4876.41 | 16 |
| 2668.71 | 4 | 2873.81 | 6 | 4113.24 | 7 | 4884.58 | 16 |
| 2671.80 | 4 | 2878.45 | 1 | 4539.61 | 19 | 5097.33 | 10 |
| 2672.83 | 3 | 2880.86 | 6 | 4555.01 | 21 | 5237.35 | 20 |
| 2740.09 | 2 | 2898.53 | 18 | 4558.66 | 21 | 5246.76 | 9 |
| 2744.97 | 12 | 2921.81 | 18 | 4565.77 | 19 | 5249.43 | 9 |
| 2787.61 | 12 | 2930.83 | 11 | 4587.30 | 27 | 5279.88 | 20 |
| 2822.38 | 14 | 2935.12 | 11 | 4588.22 | 21 | 5305.86 | 10 |
| 2835.63 | 1 | 2953.34 | 11 | 4589.89 | 21 | 5308.46 | 20 |
| 2840.01 | 14 | 2966.03 | 17 | 4592.07 | 21 | 5310.73 | 20 |
| 2843.24 | 1 | 2971.90 | 13 | 4616.64 | 21 | 5313.61 | 20 |
| 2849.83 | 1 | 2979.73 | 13 | 4618.82 | 21 | 5346.12 | 10 |
| 2851.35 | 14 | 2985.32 | 13 | 4634.10 | 21 | 5369.36 | 15 |
| 2856.77 | 6 | 2989.18 | 13 | 4697.61 | 26 | 5420.91 | 9 |
| 2857.40 | 6 | 3118.64 | 5 | 4715.12 | 25 | 5502.07 | 22 |
| 2860.92 | 1 | 3120.36 | 5 | 4812.34 | 16 | 5508.63 | 22 |
| 2862.57 | 1 | 3122.59 | 23 | 4824.12 | 16 | 6053.48 | 24 |
| 2866.72 | 1 | 3128.69 | 5 | 4836.22 | 16 | 6129.23 | 24 |

For this spectrum, we have chosen the experiments by Musielok and Wujec[1] and by Wujec and Weniger,[2] who measured relative oscillator strengths in emission with similar wall-stabilized arc sources. To obtain an absolute scale, Musielok and Wujec normalized their data to beam-foil lifetimes measured by Engman *et al.*[3] Wujec and Weniger, in turn, normalized their data directly to the $f$-value of the 4242.36 Å line tabulated in Ref. 1. In both experiments, a photographic detection system was employed, and a low-current carbon arc served as the absolute radiation standard.

Another data source which we utilized in this compilation is the work of Kostyk and Orlova.[4] These authors derived log $gf$-values from solar spectra by using equivalent widths taken from the Liege solar atlas.[8] In the case of Fe I, Kostyk and co-workers[9] used a similar approach in deriving $f$-values, which are of approximately 50 percent accuracy. We feel that the data of Ref. 4 tabulated here are of similar accuracy.

For the evaluation of these data sources, we found very few cases of overlap, so that no significant direct comparisons were possible. Refs. 1 and 2 overlap only for the 4242.36 Å line, where the log $gf$-value of Ref. 2 was made to agree with that of Ref. 1. Thus, to obtain some indication of systematic errors or scatter for these data sources, we compared the experimental data to the comprehensive semiempirical calculations of Kurucz and Peytremann.[5] We had found earlier that for many neutral and singly-ionized members of the iron-group elements,[6] the $f$-values of Ref. 5 compare reasonably well with more reliable data sources. While these calculated data show considerable scatter in comparison to experiment, the $f$-values of Ref. 5 appear to be generally devoid of gross systematic errors in the absolute scale. If the weaker lines and the intercombination lines are excluded, the majority of the data of Ref. 5 is generally accurate within a factor of two.

By comparing various experimental data to the calculations of Kurucz and Peytremann for Cr II, we found indications of systematic deviations and/or errors in absolute scale in the experimental results. For example, the data of Ref. 1 exhibit a pronounced wavelength dependence. The authors indeed suggest that there may be problems with their standard source in certain spectral regions. The $f$-values of Ref. 2 show a similar (though not as pronounced) dependence—the log $gf$-values of near *uv* lines are too strong. On the basis of these comparisons, we have limited the tabulation of data from Ref. 1 to lines having wavelengths shorter than 3150 Å and upper energy levels less than 67000 $cm^{-1}$.

Wujec and Weniger[2] normalized their data to the 4242.36 Å line of Ref. 1, which appears to be an inappropriate choice, since this wavelength falls in the region strongly affected by calibration problems with the carbon arc, due to molecular-band emission. Additional errors in the work of Wujec and Weniger may have occurred because of inconsistencies in the temperature measurement (discussed by us in the Cr I introduction). On the basis of a comparison with Ref. 5, we have shifted all log $gf$-values of Ref. 2 downward by 0.84 dex and have omitted all lines having wavelengths less than 4500 Å.

A comparison of Refs. 4 and 5 reveals considerable scatter, as well as a shift in scale — the log $gf$-values of Kostyk and Orlova are, on the average, about 50 percent higher than those of Kurucz and Peytremann. This comparison, however, deals only with the weak lines (log $gf < -1.00$), where the data of Ref. 5 are known to be less accurate. Therefore, we have tabulated the data of Kostyk and Orlova without renormalization.

Another reference which we originally considered for this spectrum is the paper by Goly and Weniger.[7] These authors measured $f$-values for over one hundred lines in the 2413 - 2718 Å region by using a wall-stabilized arc. Our graphical comparisons indicate that these data exhibit pronounced scatter, as well as a substantial deviation in absolute scale. Therefore, they have not been included in this compilation.

## References

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[9] E. A. Gurtovenko and R. I. Kostyk, Astron. Astrophys., Suppl. Ser. **47**, 193 (1982).

Cr II: Allowed transitions

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $a\,^6D - z\,^6F^o$ (uv 5) | | | | | | | | | | | |
| | | 2835.63 | 12497 | 47752 | 10 | 12 | 2.0 | 0.29 | 27 | 0.46 | C | 3 |
| | | 2843.24 | 12304 | 47465 | 8 | 10 | 0.64 | 0.097 | 7.3 | −0.11 | D | 1 |
| | | 2849.83 | 12148 | 47228 | 6 | 8 | 0.92 | 0.15 | 8.4 | −0.05 | D | 1 |
| | | 2860.92 | 11962 | 46906 | 2 | 4 | 0.69 | 0.17 | 3.2 | −0.47 | D | 1 |
| | | 2862.57 | 12304 | 47228 | 8 | 8 | 0.63 | 0.077 | 5.8 | −0.21 | D | 1 |
| | | 2866.72 | 12033 | 46906 | 4 | 4 | 1.2 | 0.15 | 5.6 | −0.23 | D | 1 |
| | | 2867.65 | 11962 | 46824 | 2 | 2 | 1.1 | 0.14 | 2.6 | −0.57 | D | 1 |
| | | 2878.45 | 12497 | 47228 | 10 | 8 | 0.074 | 0.0074 | 0.70 | −1.13 | D− | 1 |
| 2. | $a\,^6D - z\,^6P^o$ (uv 6) | | | | | | | | | | | |
| | | 2740.09 | 12148 | 48632 | 6 | 8 | 0.11 | 0.017 | 0.89 | −1.00 | D− | 1 |
| 3. | $a\,^6D - z\,^4P^o$ (uv 7) | | | | | | | | | | | |
| | | 2672.83 | 12304 | 49706 | 8 | 6 | 0.55 | 0.044 | 3.1 | −0.45 | D | 1 |
| | | 2653.57 | 12033 | 49706 | 4 | 6 | 0.35 | 0.055 | 1.9 | −0.65 | D | 1 |
| 4. | $a\,^6D - z\,^6D^o$ (uv 8) | | | | | | | | | | | |
| | | 2671.80 | 12148 | 49565 | 6 | 4 | 1.0 | 0.071 | 3.8 | −0.37 | D | 1 |
| | | 2668.71 | 12033 | 49493 | 4 | 2 | 1.4 | 0.075 | 2.6 | −0.52 | D | 1 |
| | | 2666.02 | 12148 | 49646 | 6 | 8 | 0.59 | 0.084 | 4.4 | −0.30 | D | 1 |
| | | 2658.59 | 11962 | 49565 | 2 | 4 | 0.58 | 0.12 | 2.2 | −0.61 | D | 1 |
| 5. | $a\,^4D - z\,^4F^o$ (5) | | | | | | | | | | | |
| | | 3120.36 | 19631 | 51670 | 4 | 6 | 1.5 | 0.33 | 13 | 0.12 | D | 1 |
| | | 3118.64 | 19528 | 51584 | 2 | 4 | 1.7 | 0.50 | 10 | −0.00 | D | 1 |
| | | 3136.68 | 19798 | 51670 | 6 | 6 | 0.64 | 0.094 | 5.8 | −0.25 | D | 1 |
| | | 3128.69 | 19631 | 51584 | 4 | 4 | 0.81 | 0.12 | 4.9 | −0.32 | D | 1 |
| 6. | $a\,^4D - z\,^4D^o$ (uv 11) | | | | | | | | | | | |
| | | 2870.43 | 19798 | 54626 | 6 | 6 | 1.3 | 0.16 | 9.1 | −0.02 | D | 1 |
| | | 2867.09 | 19631 | 54500 | 4 | 4 | 1.1 | 0.14 | 5.1 | −0.27 | D | 1 |
| | | 2880.86 | 19798 | 54500 | 6 | 4 | 0.79 | 0.066 | 3.7 | −0.41 | D | 1 |
| | | 2873.81 | 19631 | 54418 | 4 | 2 | 0.88 | 0.054 | 2.1 | −0.66 | D | 1 |
| | | 2857.40 | 19798 | 54785 | 6 | 8 | 0.28 | 0.046 | 2.6 | −0.56 | D | 1 |
| | | 2856.77 | 19631 | 54626 | 4 | 6 | 0.43 | 0.079 | 3.0 | −0.50 | D | 1 |
| 7. | $b\,^4D - z\,^4P^o$ (18) | | | | | | | | | | | |
| | | 4113.24 | 25047 | 49706 | 6 | 6 | 0.0012 | 3.0(−4)[a] | 0.025 | −2.74 | D | 4 |
| 8. | $b\,^4D - z\,^6D^o$ (19) | | | | | | | | | | | |
| | | 4054.10 | 25047 | 49352 | 6 | 6 | 0.0017 | 4.3(−4) | 0.034 | −2.59 | D | 4 |
| | | 4087.60 | 25036 | 49493 | 2 | 2 | 0.0012 | 3.0(−4) | 0.0081 | −3.22 | D | 4 |

Cr II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9. | $b\,^4P - z\,^4P°$ (23) | | | | | | | | | | | |
| | | 5420.91 | 30308 | 48750 | 4 | 2 | 0.0050 | 0.0011 | 0.78 | −2.36 | D | 4 |
| | | 5249.43 | 30308 | 49706 | 4 | 6 | 9.7(−4) | 6.0(−4) | 0.041 | −2.62 | D | 4 |
| | | 5246.76 | 29952 | 49006 | 2 | 4 | 0.0021 | 0.0018 | 0.061 | −2.45 | D | 4 |
| 10. | $b\,^4P - z\,^6D°$ (24) | | | | | | | | | | | |
| | | 5097.33 | 29952 | 49565 | 2 | 4 | 0.0015 | 0.0011 | 0.038 | −2.64 | D | 4 |
| | | 5305.86 | 20865 | 49352 | 6 | 6 | 0.0033 | 0.0014 | 0.15 | −2.08 | D | 4 |
| | | 5346.12 | 30865 | 49565 | 6 | 4 | 0.0013 | 3.7(−4) | 0.039 | −2.65 | D | 4 |
| 11. | $b\,^4P - y\,^4D°$ (uv 55) | | | | | | | | | | | |
| | | 2935.12 | 30865 | 64924 | 6 | 8 | 1.8 | 0.31 | 18 | 0.27 | D | 1 |
| | | 2930.83 | 29952 | 64062 | 2 | 4 | 1.1 | 0.28 | 5.5 | −0.25 | D | 1 |
| | | 2953.34 | 29952 | 63802 | 2 | 2 | 1.8 | 0.24 | 4.6 | −0.33 | D | 1 |
| 12. | $b\,^4P - y\,^4P°$ (uv 58) | | | | | | | | | | | |
| | | 2787.61 | 30865 | 66727 | 6 | 6 | 1.5 | 0.17 | 9.6 | 0.02 | D | 1 |
| | | 2744.97 | 30308 | 66727 | 4 | 6 | 0.85 | 0.14 | 5.2 | −0.24 | D | 1 |
| 13. | $a\,^4H - z\,^4H°$ (uv 80) | | | | | | | | | | | |
| | | 2971.90 | 30392 | 64031 | 14 | 14 | 2.0 | 0.26 | 36 | 0.57 | D | 1 |
| | | 2979.73 | 30299 | 63849 | 12 | 12 | 1.8 | 0.24 | 28 | 0.46 | D | 1 |
| | | 2985.32 | 30219 | 63707 | 10 | 10 | 2.2 | 0.29 | 29 | 0.47 | D | 1 |
| | | 2989.18 | 30157 | 63601 | 8 | 8 | 2.2 | 0.29 | 23 | 0.37 | D | 1 |
| 14. | $a\,^4H - z\,^4I°$ (uv 82) | | | | | | | | | | | |
| | | 2822.38 | 30392 | 65813 | 14 | 16 | 2.3 | 0.31 | 41 | 0.64 | C | 3 |
| | | 2840.01 | 30219 | 65420 | 10 | 12 | 2.7 | 0.39 | 37 | 0.59 | D | 1 |
| | | 2851.35 | 30157 | 65218 | 8 | 10 | 2.2 | 0.34 | 25 | 0.43 | D | 1 |
| 15. | $a\,^4F - z\,^6D°$ (29) | | | | | | | | | | | |
| | | 5369.36 | 31219 | 49838 | 10 | 10 | 3.2(−4) | 1.4(−4) | 0.024 | −2.86 | D | 4 |
| 16. | $a\,^4F - z\,^4F°$ (30) | | | | | | | | | | | |
| | | 4824.12 | 31219 | 51943 | 10 | 10 | 0.017 | 0.0060 | 0.96 | −1.22 | D | 2$n$ |
| | | 4848.24 | 31169 | 51789 | 8 | 8 | 0.026 | 0.0091 | 1.2 | −1.14 | D | 4 |
| | | 4876.41 | 31169 | 51670 | 8 | 6 | 0.016 | 0.0043 | 0.56 | −1.46 | D | 4 |
| | | 4884.58 | 31118 | 51584 | 6 | 4 | 0.0058 | 0.0014 | 0.13 | −2.08 | D | 4 |
| | | 4812.34 | 31169 | 51943 | 8 | 10 | 0.0046 | 0.0020 | 0.25 | −1.80 | D | 4 |
| | | 4836.22 | 31118 | 51789 | 6 | 8 | 0.0020 | 9.4(−4) | 0.090 | −2.25 | D | 2$n$ |
| | | 4856.18 | 31083 | 51670 | 4 | 6 | 0.0026 | 0.0014 | 0.088 | −2.26 | D | 4 |

Cr II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17. | $a\,^4F - y\,^4D°$ (uv 94) | | | | | | | | | | | |
| | | 2966.03 | 31219 | 64924 | 10 | 8 | 0.54 | 0.057 | 5.6 | −0.24 | D | 1 |
| 18. | $a\,^4F - z\,^4G°$ (uv 95) | | | | | | | | | | | |
| | | 2898.53 | 31219 | 65170 | 10 | 12 | 1.2 | 0.18 | 17 | 0.26 | D | 1 |
| | | 2921.81 | 31169 | 65384 | 8 | 10 | 0.90 | 0.14 | 11 | 0.06 | D | 1 |
| 19. | $a\,^2F - z\,^4D°$ (39) | | | | | | | | | | | |
| | | 4539.61 | 32604 | 54626 | 6 | 6 | 0.0016 | 4.9(−4) | 0.044 | −2.53 | D | 2*n* |
| | | 4565.77 | 32604 | 54500 | 6 | 4 | 0.0062 | 0.0013 | 0.12 | −2.11 | D | 2*n* |
| 20. | $b\,^4F - z\,^4F°$ (43) | | | | | | | | | | | |
| | | 5237.35 | 32854 | 51943 | 10 | 10 | 0.017 | 0.0069 | 1.2 | −1.16 | D | 4 |
| | | 5313.61 | 32855 | 51670 | 6 | 6 | 0.0088 | 0.0037 | 0.39 | −1.65 | D | 4 |
| | | 5279.88 | 32854 | 51789 | 10 | 8 | 0.0024 | 7.9(−4) | 0.14 | −2.10 | D | 4 |
| | | 5308.46 | 32837 | 51670 | 8 | 6 | 0.0061 | 0.0019 | 0.27 | −1.81 | D | 4 |
| | | 5310.73 | 32845 | 51670 | 4 | 6 | 0.0021 | 0.0013 | 0.092 | −2.28 | D | 4 |
| 21. | $b\,^4F - z\,^4D°$ (44) | | | | | | | | | | | |
| | | 4558.66 | 32854 | 54785 | 10 | 8 | 0.088 | 0.022 | 3.3 | −0.66 | D | 2*n* |
| | | 4588.22 | 32837 | 54626 | 8 | 6 | 0.12 | 0.029 | 3.5 | −0.63 | D | 4 |
| | | 4618.82 | 32855 | 54500 | 6 | 4 | 0.061 | 0.013 | 1.2 | −1.11 | D | 2*n* |
| | | 4634.10 | 32845 | 54418 | 4 | 2 | 0.089 | 0.014 | 0.88 | −1.24 | D | 2*n* |
| | | 4555.01 | 32837 | 54785 | 8 | 8 | 0.017 | 0.0052 | 0.63 | −1.38 | D | 4 |
| | | 4592.07 | 32855 | 54626 | 6 | 6 | 0.032 | 0.010 | 0.91 | −1.22 | D | 4 |
| | | 4616.64 | 32845 | 54500 | 4 | 4 | 0.040 | 0.013 | 0.78 | −1.29 | D | 4 |
| | | 4589.89 | 32845 | 54626 | 4 | 6 | 0.0012 | 5.5(−4) | 0.033 | −2.66 | D | 2*n* |
| 22. | $b\,^4G - z\,^4F°$ (50) | | | | | | | | | | | |
| | | 5502.07 | 33619 | 51789 | 10 | 8 | 0.0028 | 0.0010 | 0.19 | −1.99 | D | 4 |
| | | 5508.63 | 33521 | 51670 | 8 | 6 | 0.0028 | 9.7(−4) | 0.14 | −2.11 | D | 4 |
| 23. | $b\,^4G - z\,^4G°$ (54) | | | | | | | | | | | |
| | | 3122.59 | 33694 | 65710 | 12 | 12 | 0.44 | 0.064 | 7.9 | −0.11 | D | 1 |
| 24. | $c\,^4D - z\,^4D°$ (105) | | | | | | | | | | | |
| | | 6053.48 | 38270 | 54785 | 8 | 8 | 0.0016 | 8.6(−4) | 0.14 | −2.16 | D | 4 |
| | | 6129.23 | 38315 | 54626 | 6 | 6 | 0.0011 | 6.1(−4) | 0.073 | −2.44 | D | 4 |
| 25. | $c\,^2D - {}^2P°$ | | | | | | | | | | | |
| | | 4715.12 | 45670 | 66872 | 4 | 2 | 0.0073 | 0.0012 | 0.076 | −2.31 | D | 2*n* |

Cr II: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26. | $c\ ^2$D - $y\ ^4$F° | | | | | | | | | | | |
| | | 4697.61 | 45731 | 67012 | 6 | 6 | 0.0066 | 0.0022 | 0.20 | −1.88 | D | 2$n$ |
| 27. | $d\ ^2$G - $x\ ^2$F° | | | | | | | | | | | |
| | | 4587.30 | 52321 | 74114 | 10 | 8 | 0.0089 | 0.0022 | 0.34 | −1.65 | D | 2$n$ |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr II

## Forbidden Transitions

For this spectrum, we selected the work of Nussbaumer and Swings,[1] who calculated numerous M1 and E2 transition probabilities. They derived their radial wavefunctions by using a central potential which was adjusted to give the optimum fit to observed energy levels. Their calculation included spin-orbit interaction but neglected the effects of configuration interaction. Because of the strong likelihood of configuration interaction, we have tabulated only the E2 transitions of the $a\ ^6$S - $a\ ^6$D multiplet. These lines have been observed in stellar spectra.

Another data source for lines in the $a\ ^6$S - $a\ ^6$D multiplet is that of Garstang.[2] His calculated $A$-values are approximately 15 percent less than those of Nussbaumer and Swings, because different radial wavefunctions were used. The data tabulated here are estimated to be accurate to within a factor of two.

### References

[1]H. Nussbaumer and J. P. Swings, Astrophys. J. **162**, 589 (1970).
[2]R. H. Garstang, J. Res. Nat. Bur. Stand., Sect A **68**, 61 (1964).

Cr II: Forbidden transitions

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $a\ ^6$S - $a\ ^6$D (1F) | | | | | | | | | | |
| | | [8000.1] | 0 | 12496 | 6 | 10 | E2 | 0.10 | 20 | E | 1 |
| | | [8125.3] | 0 | 12304 | 6 | 8 | E2 | 0.094 | 16 | E | 1 |
| | | [8229.7] | 0 | 12148 | 6 | 6 | E2 | 0.088 | 12 | E | 1 |
| | | [8308.5] | 0 | 12033 | 6 | 4 | E2 | 0.084 | 7.9 | E | 1 |
| | | [8357.6] | 0 | 11962 | 6 | 2 | E2 | 0.082 | 4.0 | E | 1 |

# Cr IV

Sc Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3\ ^4F_{3/2}$

Ionization Energy: 49.16 eV = 396500 cm$^{-1}$

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 1881.7 | 7 | 2966.1 | 16 | 5294.3 | 4 | 7297.9 | 17 |
| 1887.6 | 7 | 2973.3 | 16 | 5323.5 | 21 | 7339.5 | 2 |
| 1890.1 | 7 | 2980.9 | 16 | 5371.4 | 21 | 7390.8 | 2 |
| 1896.1 | 7 | 2988.2 | 16 | 5378.6 | 21 | 7410.9 | 19 |
| 1901.6 | 7 | 2991.5 | 6 | 5427.5 | 21 | 7518.2 | 19 |
| 1907.7 | 7 | 3076.7 | 18 | 6613.0 | 15 | 7664.7 | 19 |
| 1921.9 | 7 | 3078.1 | 18 | 6648.8 | 15 | 16142 | 9 |
| 2557.8 | 10 | 3092.6 | 18 | 6698.4 | 15 | 16180 | 9 |
| 2565.6 | 10 | 3094.0 | 18 | 6734.0 | 3 | 16625 | 11 |
| 2568.8 | 10 | 3133.0 | 20 | 6747.5 | 3 | 16891 | 11 |
| 2576.6 | 10 | 4837.6 | 5 | 6896.0 | 3 | 17649 | 11 |
| 2585.1 | 10 | 4841.0 | 5 | 6915.2 | 3 | 18307 | 8 |
| 2596.3 | 10 | 4893.9 | 5 | 7023.1 | 2 | 18584 | 8 |
| 2624.6 | 13 | 4897.3 | 5 | 7051.5 | 2 | 18999 | 8 |
| 2636.2 | 13 | 4971.5 | 5 | 7086.2 | 3 | 20127 | 8 |
| 2660.6 | 13 | 5125.9 | 12 | 7110.5 | 2 | 81537 | 14 |
| 2892.9 | 6 | 5142.8 | 4 | 7171.6 | 2 | 82513 | 14 |
| 2912.9 | 6 | 5177.0 | 12 | 7184.1 | 2 | 88456 | 14 |
| 2929.4 | 6 | 5206.3 | 4 | 7189.2 | 17 | 256900 | 1 |
| 2940.3 | 6 | 5219.3 | 12 | 7196.7 | 17 | 313400 | 1 |
| 2957.0 | 6 | 5272.3 | 12 | 7232.6 | 2 | | |

For this spectrum, we have chosen the work of Pasternack,[1] who calculated M1 and E2 transition probabilities within the $3d^3$ configuration by using the central-field approximation without consideration of configuration interaction. However, the $3d^3$ configuration is well-separated from the next configuration—$3d^2 4s$. For electric quadrupole transitions, we modified the data of Ref. 1 by applying correction factors suggested by Garstang.[2] These factors were introduced because of the availability of better wavefunctions. In the case of Fe VI, which is isoelectronic to Cr IV, we compared the $A$-values of Ref. 1 to those of Nussbaumer and Storey,[3] who could utilize, in their much later work, modern theoretical and computational techniques. The agreement between Refs. 1 and 3 is surprisingly good—generally within 50 percent—even for the E2 transitions (after undergoing Garstang's correction). Weak lines are subject to greater uncertainties, so we have omitted lines having $A$-values less than 0.001 s$^{-1}$.

## References

[1]S. Pasternack, Astrophys. J. **92**, 129 (1940).
[2]R. H. Garstang, J. Res. Nat. Bur. Stand., Sect. A **68**, 61 (1964).
[3]H. Nussbaumer and P. J. Storey, Astron. Astrophys. **70**, 37 (1978).

Cr IV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^3$-$3d^3$ | $^4$F - $^4$F | | | | | | | | | | |
| | | | [256900] | 556.4 | 945.5 | 8 | 10 | M1 | 0.0017 | 11 | C | 1 |
| | | | [313400] | 237.4 | 556.4 | 6 | 8 | M1 | 0.0014 | 13 | C | 1 |
| 2. | | $^4$F - $^4$P (1F) | | | | | | | | | | |
| | | | [7390.8] | 945.5 | 14472 | 10 | 6 | E2 | 0.035 | 2.8 | E | 1*n* |
| | | | [7339.5] | 556.4 | 14178 | 8 | 4 | E2 | 0.026 | 1.3 | E | 1*n* |
| | | | [7232.6] | 237.4 | 14060 | 6 | 2 | E2 | 0.022 | 0.52 | E | 1*n* |
| | | | [7184.1] | 556.4 | 14472 | 8 | 6 | E2 | 0.013 | 0.89 | E | 1*n* |
| | | | [7171.6] | 237.4 | 14178 | 6 | 4 | E2 | 0.020 | 0.90 | E | 1*n* |
| | | | [7110.5] | 0.0 | 14060 | 4 | 2 | E2 | 0.035 | 0.76 | E | 1*n* |
| | | | [7023.1] | 237.4 | 14472 | 6 | 6 | E2 | 0.0032 | 0.20 | E | 1*n* |
| | | | [7051.5] | 0.0 | 14178 | 4 | 4 | E2 | 0.0073 | 0.30 | E | 1*n* |
| 3. | | $^4$F - $^2$G (2F) | | | | | | | | | | |
| | | | [6915.2] | 945.5 | 15402 | 10 | 10 | M1 | 0.093 | 0.011 | E | 1 |
| | | | [6896.0] | 556.4 | 15054 | 8 | 8 | M1 | 0.035 | 0.0034 | E | 1 |
| | | | [7086.2] | 945.5 | 15054 | 10 | 8 | M1 | 0.0023 | 2.4(−4)[a] | E | 1 |
| | | | [6734.0] | 556.4 | 15402 | 8 | 10 | M1 | 0.036 | 0.0041 | E | 1 |
| | | | [6747.5] | 237.4 | 15054 | 6 | 8 | M1 | 0.032 | 0.0029 | E | 1 |
| 4. | | $^4$F - $^2$P (3F) | | | | | | | | | | |
| | | | [5294.3] | 556.4 | 19439 | 8 | 4 | E2 | 0.0011 | 0.011 | E | 1*n* |
| | | | [5206.3] | 237.4 | 19439 | 6 | 4 | M1 | 0.055 | 0.0012 | E | 1 |
| | | | [5142.8] | 0.0 | 19439 | 4 | 4 | M1 | 0.034 | 6.9(−4) | E | 1 |
| 5. | | $^4$F - $^2$D2 (4F) | | | | | | | | | | |
| | | | [4971.5] | 556.4 | 20666 | 8 | 6 | M1 | 0.16 | 0.0044 | E | 1 |
| | | | [4897.3] | 237.4 | 20651 | 6 | 4 | M1 | 0.13 | 0.0023 | E | 1 |
| | | | [4893.9] | 237.4 | 20666 | 6 | 6 | M1 | 0.020 | 5.2(−4) | E | 1 |
| | | | [4841.0] | 0.0 | 20651 | 4 | 4 | M1 | 0.071 | 0.0012 | E | 1 |
| | | | [4837.6] | 0.0 | 20666 | 4 | 6 | M1 | 0.0073 | 1.8(−4) | E | 1 |
| 6. | | $^4$F - $^2$F | | | | | | | | | | |
| | | | [2991.5] | 945.5 | 34364 | 10 | 8 | M1 | 0.034 | 2.7(−4) | D | 1 |
| | | | ″ | ″ | ″ | 10 | 8 | E2 | 0.0011 | 0.0013 | E | 1*n* |
| | | | [2940.3] | 556.4 | 34557 | 8 | 6 | M1 | 0.0060 | 3.4(−5) | D | 1 |
| | | | [2957.0] | 556.4 | 34364 | 8 | 8 | M1 | 0.0034 | 2.6(−5) | D | 1 |
| | | | [2912.9] | 237.4 | 34557 | 6 | 6 | M1 | 0.0046 | 2.5(−5) | D | 1 |
| | | | [2929.4] | 237.4 | 34364 | 6 | 8 | M1 | 0.013 | 9.7(−5) | D | 1 |
| | | | [2892.9] | 0.0 | 34557 | 4 | 6 | M1 | 0.031 | 1.7(−4) | D | 1 |
| | | | ″ | ″ | ″ | 4 | 6 | E2 | 0.0011 | 8.0(−4) | E | 1*n* |
| 7. | | $^4$F - $^2$D1 | | | | | | | | | | |
| | | | [1921.9] | 945.5 | 52976 | 10 | 6 | E2 | 0.017 | 0.0016 | E | 1*n* |
| | | | [1901.6] | 556.4 | 53144 | 8 | 4 | E2 | 0.0039 | 2.3(−4) | E | 1*n* |
| | | | [1907.7] | 556.4 | 52976 | 8 | 6 | M1 | 0.043 | 6.6(−5) | E | 1 |
| | | | ″ | ″ | ″ | 8 | 6 | E2 | 0.0011 | 9.9(−5) | E | 1*n* |
| | | | [1890.1] | 237.4 | 53144 | 6 | 4 | M1 | 0.048 | 4.8(−5) | E | 1 |
| | | | [1896.1] | 237.4 | 52976 | 6 | 6 | M1 | 0.0046 | 7.0(−6) | E | 1 |
| | | | [1881.7] | 0.0 | 53144 | 4 | 4 | M1 | 0.025 | 2.5(−5) | E | 1 |
| | | | ″ | ″ | ″ | 4 | 4 | E2 | 0.0013 | 7.3(−5) | E | 1*n* |
| | | | [1887.6] | 0.0 | 52976 | 4 | 6 | M1 | 0.0016 | 2.4(−6) | E | 1 |

Cr IV: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^4P - ^2P$ | | | | | | | | | | |
| | | | [20127] | 14472 | 19439 | 6 | 4 | M1 | 0.020 | 0.024 | D | 1 |
| | | | [18999] | 14178 | 19439 | 4 | 4 | M1 | 0.028 | 0.028 | D | 1 |
| | | | [18307] | 14060 | 19521 | 2 | 2 | M1 | 0.052 | 0.024 | D | 1 |
| | | | [18584] | 14060 | 19439 | 2 | 4 | M1 | 0.013 | 0.012 | D | 1 |
| 9. | | $^4P - ^2D2$ | | | | | | | | | | |
| | | | [16142] | 14472 | 20666 | 6 | 6 | M1 | 0.0077 | 0.0072 | E | 1 |
| | | | [16180] | 14472 | 20651 | 6 | 4 | M1 | 0.018 | 0.011 | E | 1 |
| 10. | | $^4P - ^2D1$ | | | | | | | | | | |
| | | | [2596.3] | 14472 | 52976 | 6 | 6 | M1 | 0.23 | 9.0(−4) | E | 1 |
| | | | [2565.6] | 14178 | 53144 | 4 | 4 | M1 | 0.089 | 2.2(−4) | E | 1 |
| | | | " | " | " | 4 | 4 | E2 | 0.024 | 0.0064 | E | 1n |
| | | | [2585.1] | 14472 | 53144 | 6 | 4 | M1 | 0.022 | 5.6(−5) | E | 1 |
| | | | [2576.6] | 14178 | 52976 | 4 | 6 | M1 | 0.041 | 1.6(−4) | E | 1 |
| | | | " | " | " | 4 | 6 | E2 | 0.026 | 0.011 | E | 1n |
| | | | [2557.8] | 14060 | 53144 | 2 | 4 | M1 | 0.023 | 5.7(−5) | E | 1 |
| | | | " | " | " | 2 | 4 | E2 | 0.0092 | 0.0024 | E | 1n |
| | | | [2568.8] | 14060 | 52976 | 2 | 6 | E2 | 0.0024 | 9.6(−4) | E | 1n |
| 11. | | $^2G - ^2H$ | | | | | | | | | | |
| | | | [16891] | 15402 | 21321 | 10 | 12 | M1 | 0.016 | 0.034 | E | 1 |
| | | | [16625] | 15054 | 21067 | 8 | 10 | M1 | 0.016 | 0.027 | E | 1 |
| | | | [17649] | 15402 | 21067 | 10 | 10 | M1 | 0.030 | 0.061 | E | 1 |
| 12. | | $^2G - ^2F$ | | | | | | | | | | |
| | | | [5219.3] | 15402 | 34557 | 10 | 6 | E2 | 0.0012 | 0.017 | E | 1n |
| | | | [5272.3] | 15402 | 34364 | 10 | 8 | M1 | 0.019 | 8.3(−4) | E | 1 |
| | | | " | " | " | 10 | 8 | E2 | 0.088 | 1.7 | E | 1n |
| | | | [5125.9] | 15054 | 34557 | 8 | 6 | M1 | 0.022 | 6.6(−4) | E | 1 |
| | | | " | " | " | 8 | 6 | E2 | 0.098 | 1.2 | E | 1n |
| | | | [5177.0] | 15054 | 34364 | 8 | 8 | M1 | 0.041 | 0.0017 | E | 1 |
| | | | " | " | " | 8 | 8 | E2 | 0.0085 | 0.15 | E | 1n |
| 13. | | $^2G - ^2D1$ | | | | | | | | | | |
| | | | [2660.6] | 15402 | 52976 | 10 | 6 | E2 | 8.2 | 3.9 | E | 1n |
| | | | [2624.6] | 15054 | 53144 | 8 | 4 | E2 | 9.4 | 2.8 | E | 1n |
| | | | [2636.2] | 15054 | 52976 | 8 | 6 | E2 | 0.71 | 0.32 | E | 1n |
| 14. | | $^2P - ^2D2$ | | | | | | | | | | |
| | | | [81537] | 19439 | 20666 | 4 | 6 | M1 | 0.0062 | 0.75 | E | 1 |
| | | | [88456] | 19521 | 20651 | 2 | 4 | M1 | 0.0041 | 0.42 | E | 1 |
| | | | [82513] | 19439 | 20651 | 4 | 4 | M1 | 0.011 | 0.92 | E | 1 |
| 15. | | $^2P - ^2F$ | | | | | | | | | | |
| | | | [6698.4] | 19439 | 34364 | 4 | 8 | E2 | 0.016 | 1.0 | E | 1n |
| | | | [6648.8] | 19521 | 34557 | 2 | 6 | E2 | 0.0095 | 0.44 | E | 1n |
| | | | [6613.0] | 19439 | 34557 | 4 | 6 | E2 | 0.0040 | 0.18 | E | 1n |

Cr IV: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16. | | $^2$P - $^2$D1 | | | | | | | | | | |
| | | | [2988.2] | 19521 | 52976 | 2 | 6 | E2 | 0.52 | 0.44 | E | 1*n* |
| | | | [2980.9] | 19439 | 52976 | 4 | 6 | M1 | 0.040 | 2.4(−4) | E | 1 |
| | | | " | " | " | 4 | 6 | E2 | 0.79 | 0.66 | E | 1*n* |
| | | | [2973.3] | 19521 | 53144 | 2 | 4 | E2 | 1.2 | 0.66 | E | 1*n* |
| | | | [2966.1] | 19439 | 53144 | 4 | 4 | E2 | 1.9 | 1.0 | E | 1*n* |
| 17. | | $^2$D2 - $^2$F | | | | | | | | | | |
| | | | [7297.9] | 20666 | 34364 | 6 | 8 | M1 | 0.0015 | 1.7(−4) | E | 1 |
| | | | " | " | " | 6 | 8 | E2 | 0.027 | 2.7 | E | 1*n* |
| | | | [7189.2] | 20651 | 34557 | 4 | 6 | M1 | 0.0010 | 8.3(−5) | E | 1 |
| | | | " | " | " | 4 | 6 | E2 | 0.023 | 1.6 | E | 1*n* |
| | | | [7196.7] | 20666 | 34557 | 6 | 6 | M1 | 0.0039 | 3.2(−4) | E | 1 |
| | | | " | " | " | 6 | 6 | E2 | 0.0065 | 0.45 | E | 1*n* |
| 18. | | $^2$D2 - $^2$D1 | | | | | | | | | | |
| | | | [3094.0] | 20666 | 52976 | 6 | 6 | E2 | 0.69 | 0.70 | E | 1*n* |
| | | | [3076.7] | 20651 | 53144 | 4 | 4 | E2 | 0.0060 | 0.0039 | E | 1*n* |
| | | | [3078.1] | 20666 | 53144 | 6 | 4 | M1 | 0.14 | 6.1(−4) | D | 1 |
| | | | " | " | " | 6 | 4 | E2 | 0.29 | 0.19 | E | 1*n* |
| | | | [3092.6] | 20651 | 52976 | 4 | 6 | M1 | 0.063 | 4.1(−4) | D | 1 |
| | | | " | " | " | 4 | 6 | E2 | 1.1 | 1.1 | E | 1*n* |
| 19. | | $^2$H - $^2$F | | | | | | | | | | |
| | | | [7664.7] | 21321 | 34364 | 12 | 8 | E2 | 0.039 | 4.9 | E | 1*n* |
| | | | [7410.9] | 21067 | 34557 | 10 | 6 | E2 | 0.046 | 3.7 | E | 1*n* |
| | | | [7518.2] | 21067 | 34364 | 10 | 8 | E2 | 0.0012 | 0.14 | E | 1*n* |
| 20. | | $^2$H - $^2$D1 | | | | | | | | | | |
| | | | [3133.0] | 21067 | 52976 | 10 | 6 | E2 | 0.040 | 0.043 | E | 1*n* |
| 21. | | $^2$F - $^2$D1 | | | | | | | | | | |
| | | | [5323.5] | 34364 | 53144 | 8 | 4 | E2 | 0.075 | 0.76 | E | 1*n* |
| | | | [5371.4] | 34364 | 52976 | 8 | 6 | M1 | 0.057 | 0.0020 | E | 1 |
| | | | " | " | " | 8 | 6 | E2 | 0.40 | 6.4 | E | 1*n* |
| | | | [5378.6] | 34557 | 53144 | 6 | 4 | M1 | 0.060 | 0.0014 | E | 1 |
| | | | " | " | " | 6 | 4 | E2 | 0.40 | 4.3 | E | 1*n* |
| | | | [5427.5] | 34557 | 52976 | 6 | 6 | M1 | 0.10 | 0.0036 | E | 1 |
| | | | " | " | " | 6 | 6 | E2 | 0.069 | 1.2 | E | 1*n* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr V

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 582.42 | 12 | 642.44 | 16 | 829.52 | 20 | 6709.9 | 3 |
| 584.15 | 12 | 645.57 | 13 | 859.52 | 19 | 7580.6 | 2 |
| 586.32 | 12 | 648.08 | 13 | 1955.2 | 5 | 7884.4 | 2 |
| 594.92 | 11 | 649.40 | 13 | 2633.7 | 8 | 8299.0 | 2 |
| 596.73 | 11 | 656.11 | 15 | 2818.5 | 10 | 11320 | 7 |
| 597.05 | 11 | 657.68 | 15 | 2847.7 | 10 | 35041 | 6 |
| 598.17 | 11 | 657.90 | 15 | 4540.2 | 4 | 40172 | 6 |
| 598.86 | 11 | 658.70 | 15 | 4647.5 | 4 | 157800 | 1 |
| 598.99 | 11 | 660.07 | 15 | 4788.5 | 4 | 196700 | 1 |
| 599.99 | 11 | 660.28 | 15 | 6232.3 | 3 | 274300 | 9 |
| 601.14 | 11 | 661.66 | 15 | 6377.2 | 3 | 541000 | 9 |
| 630.87 | 14 | 668.10 | 18 | 6436.2 | 3 | | |
| 640.18 | 16 | 684.60 | 17 | 6453.2 | 3 | | |
| 640.94 | 16 | 687.42 | 17 | 6590.8 | 3 | | |

For this ion, we selected the work of Warner and Kirkpatrick,[1] who used a single-configuration approximation and calculated radial integrals with scaled Thomas-Fermi wavefunctions. We have tabulated M1 and E2 transition probabilities for 23 lines within the $3d^2$ (ground) configuration and E2 data for 30 lines in the $3d^2$–$3d4s$ transition array. For long-wavelength lines within the $3d^2\ ^3$F and $3d^2\ ^3$P terms, we have recalculated Warner and Kirkpatrick's $A$-values by using observed energy-level data instead of theoretically derived values.

### Reference

[1]B. Warner and R. C. Kirkpatrick, Mon. Not. R. Astron. Soc. **144**, 397 (1969).

Cr V: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^2$-$3d^2$ | $^3$F - $^3$F | | | | | | | | | | |
| | | | [157800] | 508.2 | 1141.7 | 7 | 9 | M1 | 0.0051 | 6.7 | C | 1$n$ |
| | | | [196700] | 0.0 | 508.2 | 5 | 7 | M1 | 0.0037 | 7.3 | C | 1$n$ |
| 2. | | $^3$F - $^1$D (1F) | | | | | | | | | | |
| | | | [8299.0] | 1141.7 | 13188 | 9 | 5 | E2 | 3.4(−4)[a] | 0.040 | E | 1 |
| | | | [7884.4] | 508.2 | 13188 | 7 | 5 | M1 | 0.10 | 0.0091 | E | 1 |
| | | | " | " | " | 7 | 5 | E2 | 8.2(−5) | 0.0074 | E | 1 |
| | | | [7580.6] | 0.0 | 13188 | 5 | 5 | M1 | 0.057 | 0.0046 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 5.7(−5) | 0.0042 | E | 1 |
| 3. | | $^3$F - $^3$P (2F) | | | | | | | | | | |
| | | | [6709.9] | 1141.7 | 16041 | 9 | 5 | E2 | 0.031 | 1.3 | E | 1 |
| | | | [6590.8] | 508.2 | 15677 | 7 | 3 | E2 | 0.031 | 0.69 | E | 1 |
| | | | [6453.2] | 0.0 | 15492 | 5 | 1 | E2 | 0.051 | 0.34 | E | 1 |
| | | | [6436.2] | 508.2 | 16041 | 7 | 5 | M1 | 0.0034 | 1.7(−4) | E | 1 |
| | | | " | " | " | 7 | 5 | E2 | 0.010 | 0.33 | E | 1 |
| | | | [6377.2] | 0.0 | 15677 | 5 | 3 | M1 | 1.0(−4) | 2.9(−6) | E | 1 |
| | | | " | " | " | 5 | 3 | E2 | 0.018 | 0.34 | E | 1 |
| | | | [6232.3] | 0.0 | 16041 | 5 | 5 | M1 | 8.7(−4) | 3.9(−5) | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.0016 | 0.045 | E | 1 |

Cr V: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^3$F - $^1$G (3F) | | | | | | | | | | |
| | | | [4788.5] | 1141.7 | 22019 | 9 | 9 | M1 | 0.072 | 0.0026 | E | 1 |
| | | | " | " | " | 9 | 9 | E2 | 4.2(−5) | 5.7(−4) | E | 1 |
| | | | [4647.5] | 508.2 | 22019 | 7 | 9 | M1 | 0.047 | 0.0016 | E | 1 |
| | | | [4540.2] | 0.0 | 22019 | 5 | 9 | E2 | 8.9(_5) | 9.2(−4) | E | 1 |
| 5. | | $^3$F - $^1$S | | | | | | | | | | |
| | | | [1955.2] | 0.0 | 51146 | 5 | 1 | E2 | 0.025 | 4.3(−4) | E | 1 |
| 6. | | $^1$D - $^3$P | | | | | | | | | | |
| | | | [35041] | 13188 | 16041 | 5 | 5 | M1 | 0.024 | 0.19 | E | 1 |
| | | | [40172] | 13188 | 15677 | 5 | 3 | M1 | 0.0092 | 0.066 | E | 1 |
| 7. | | $^1$D - $^1$G | [11320] | 13188 | 22019 | 5 | 9 | E2 | 6.1(−4) | 0.61 | E | 1 |
| 8. | | $^1$D - $^1$S (4F) | [2633.7] | 13188 | 51146 | 5 | 1 | E2 | 9.8 | 0.74 | E | 1 |
| 9. | | $^3$P - $^3$P | | | | | | | | | | |
| | | | [274300] | 15677 | 16041 | 3 | 5 | M1 | 5.2(−4) | 2.0 | C | 1*n* |
| | | | [541000] | 15492 | 15677 | 1 | 3 | M1 | 1.27(−4) | 2.24 | C | 1*n* |
| 10. | | $^3$P - $^1$S (5F) | | | | | | | | | | |
| | | | [2847.7] | 16041 | 51146 | 5 | 1 | E2 | 0.21 | 0.023 | E | 1 |
| | | | [2818.5] | 15677 | 51146 | 3 | 1 | M1 | 1.1 | 9.1(−4) | E | 1 |
| 11. | $3d^2$-$3d4s$ | $^3$F - $^3$D | | | | | | | | | | |
| | | | [601.14] | 1141.7 | 167491 | 9 | 5 | E2 | 2700 | 0.63 | E | 1 |
| | | | [599.99] | 508.2 | 167176 | 7 | 3 | E2 | 4300 | 0.60 | E | 1 |
| | | | [598.99] | 1141.7 | 168090 | 9 | 7 | E2 | 1.0(+4) | 3.2 | E | 1 |
| | | | [598.86] | 508.2 | 167491 | 7 | 5 | E2 | 6500 | 1.5 | E | 1 |
| | | | [598.17] | 0.0 | 167176 | 5 | 3 | E2 | 8800 | 1.2 | E | 1 |
| | | | [596.73] | 508.2 | 168090 | 7 | 7 | E2 | 2900 | 0.91 | E | 1 |
| | | | [597.05] | 0.0 | 167491 | 5 | 5 | E2 | 3800 | 0.86 | E | 1 |
| | | | [594.92] | 0.0 | 168090 | 5 | 7 | E2 | 270 | 0.084 | E | 1 |
| 12. | | $^3$F - $^1$D | | | | | | | | | | |
| | | | [586.32] | 1141.7 | 171698 | 9 | 5 | E2 | 16 | 0.0033 | E | 1 |
| | | | [584.15] | 508.2 | 171698 | 7 | 5 | E2 | 88 | 0.018 | E | 1 |
| | | | [582.42] | 0.0 | 171698 | 5 | 5 | E2 | 11 | 0.0022 | E | 1 |
| 13. | | $^1$D - $^3$D | | | | | | | | | | |
| | | | [645.57] | 13188 | 168090 | 5 | 7 | E2 | 77 | 0.036 | E | 1 |
| | | | [648.08] | 13188 | 167491 | 5 | 5 | E2 | 200 | 0.068 | E | 1 |
| | | | [649.40] | 13188 | 167176 | 5 | 3 | E2 | 61 | 0.013 | E | 1 |
| 14. | | $^1$D - $^1$D | [630.87] | 13188 | 171698 | 5 | 5 | E2 | 6800 | 2.0 | E | 1 |

Cr v: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | | $^3$P - $^3$D | | | | | | | | | | |
| | | | [656.11] | 15677 | 168090 | 3 | 7 | E2 | 1200 | 0.61 | E | 1 |
| | | | [657.90] | 15492 | 167491 | 1 | 5 | E2 | 1200 | 0.44 | E | 1 |
| | | | [657.68] | 16041 | 168090 | 5 | 7 | E2 | 2300 | 1.2 | E | 1 |
| | | | [658.70] | 15677 | 167491 | 3 | 5 | E2 | 290 | 0.11 | E | 1 |
| | | | [660.28] | 16041 | 167491 | 5 | 5 | E2 | 1800 | 0.67 | E | 1 |
| | | | [660.07] | 15677 | 167176 | 3 | 3 | E2 | 2600 | 0.58 | E | 1 |
| | | | [661.66] | 16041 | 167176 | 5 | 3 | E2 | 810 | 0.18 | E | 1 |
| 16. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [642.44] | 16041 | 171698 | 5 | 5 | E2 | 340 | 0.11 | E | 1 |
| | | | [640.94] | 15677 | 171698 | 3 | 5 | E2 | 4.0 | 0.0013 | E | 1 |
| | | | [640.18] | 15492 | 171698 | 1 | 5 | E2 | 10 | 0.0032 | E | 1 |
| 17. | | $^1$G - $^3$D | | | | | | | | | | |
| | | | [687.42] | 22019 | 167491 | 9 | 5 | E2 | 89 | 0.041 | E | 1 |
| | | | [684.60] | 22019 | 168090 | 9 | 7 | E2 | 1.2 | 7.5(−4) | E | 1 |
| 18. | | $^1$G - $^1$D | [668.10] | 22019 | 171698 | 9 | 5 | E2 | 9600 | 3.8 | E | 1 |
| 19. | | $^1$S - $^3$D | | | | | | | | | | |
| | | | [859.52] | 51146 | 167491 | 1 | 5 | E2 | 2.4 | 0.0034 | E | 1 |
| 20. | | $^1$S - $^1$D | [829.52] | 51146 | 171698 | 1 | 5 | E2 | 380 | 0.44 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr VI

K Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^63d\ ^2D_{3/2}$

Ionization Energy: 90.6356 eV = 731020 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 161.687 | 8 | 172.487 | 6 | 202.442 | 5 | 269.776 | 2 |
| 161.930 | 8 | 172.841 | 6 | 202.739 | 5 | 279.154 | 1 |
| 162.565 | 9 | 201.007 | 4 | 226.241 | 3 | 280.143 | 1 |
| 168.088 | 7 | 201.224 | 4 | 227.202 | 3 | 280.879 | 1 |
| 168.355 | 7 | 201.388 | 4 | 227.689 | 3 | | |
| 169.435 | 7 | 201.606 | 4 | 264.078 | 2 | | |
| 172.204 | 6 | 202.057 | 5 | 264.732 | 2 | | |

For this spectrum, we have chosen the data of Tiwary,[1,2] who calculated absolute multiplet oscillator strengths for the $3p^63d$-$3p^53d^2$ and $3p^63d$-$3p^53d4s$ arrays by using configuration interaction wavefunctions. For the $3p^63d$-$3p^53d4s$ array, $LS$-coupling line strengths generally agree quite well with the intermediate coupling calculations of Cowan.[3] For the few cases where the agreement is not good (worse than ±50%), we have omitted the lines from this compilation. Within this transition array, we have normalized Cowan's line strengths to the multiplet strengths of Ref. 2.

For lines within the $3p^63d$-$3p^53d^2$ transition array, we have obtained line strengths from Tiwary's multiplet strengths by applying $LS$-coupling rules. We estimate these data to be accurate within fifty percent for stronger lines.

## References


[1]S. N. Tiwary, Chem. Phys. Lett. **93**, 47 (1982).
[2]S. N. Tiwary, Astrophys. J. **269**, 803 (1983).
[3]R. D. Cowan, Astrophys. J. **147**, 377 (1967).


Cr VI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^63d$-$3p^5(^2P^\circ)3d^2(^1G)$ | $^2$D - $^2$F° | *279.60* | *564* | *358221* | 10 | 14 | 6.1 | 0.010 | 0.092 | −1.00 | D− | 1 |
| | | | 279.154 | 940 | 359165 | 6 | 8 | 6.2 | 0.0096 | 0.053 | −1.24 | D− | *ls* |
| | | | 280.143 | 0 | 356962 | 4 | 6 | 5.7 | 0.010 | 0.037 | −1.40 | D− | *ls* |
| | | | 280.879 | 940 | 356962 | 6 | 6 | 0.40 | 4.7(−4)[a] | 0.0026 | −2.55 | E | *ls* |
| 2. | $3p^63d$-$3p^5(^2P^\circ)3d^2(^1D)$ | $^2$D - $^2$F° | *267.32* | *564* | *374643* | 10 | 14 | 27 | 0.041 | 0.36 | −0.39 | D− | 1 |
| | | | 269.776 | 940 | 371618 | 6 | 8 | 27 | 0.039 | 0.21 | −0.63 | D− | *ls* |
| | | | 264.078 | 0 | 378677 | 4 | 6 | 26 | 0.040 | 0.14 | −0.79 | D− | *ls* |
| | | | 264.732 | 940 | 378677 | 6 | 6 | 1.8 | 0.0019 | 0.010 | −1.94 | E | *ls* |
| 3. | $3p^63d$-$3p^5(^2P^\circ)3d^2(^3F)$ | $^2$D - $^2$F° | *226.67* | *564* | *441741* | 10 | 14 | 710 | 0.77 | 5.7 | 0.89 | D− | 1 |
| | | | 226.241 | 940 | 442945 | 6 | 8 | 720 | 0.74 | 3.3 | 0.65 | D− | *ls* |
| | | | 227.202 | 0 | 440135 | 4 | 6 | 660 | 0.77 | 2.3 | 0.49 | D− | *ls* |
| | | | 227.689 | 940 | 440135 | 6 | 6 | 46 | 0.036 | 0.16 | −0.67 | E | *ls* |
| 4. | | $^2$D - $^2$D° | *201.37* | *564* | *497173* | 10 | 10 | 2600 | 1.6 | 11 | 1.20 | D− | 1 |
| | | | 201.606 | 940 | 496958 | 6 | 6 | 2600 | 1.6 | 6.2 | 0.97 | D− | *ls* |
| | | | 201.007 | 0 | 497495 | 4 | 4 | 2500 | 1.5 | 4.0 | 0.78 | D− | *ls* |
| | | | 201.388 | 940 | 497495 | 6 | 4 | 270 | 0.11 | 0.44 | −0.18 | E | *ls* |
| | | | 201.224 | 0 | 496958 | 4 | 6 | 180 | 0.17 | 0.44 | −0.18 | E | *ls* |
| 5. | $3p^63d$-$3p^5(^2P^\circ)3d^2(^3P)$ | $^2$D - $^2$P° | *202.51* | *564* | *494356* | 10 | 6 | 1200 | 0.44 | 2.9 | 0.64 | D− | 1 |
| | | | 202.442 | 940 | 494911 | 6 | 4 | 1000 | 0.43 | 1.7 | 0.41 | D− | *ls* |
| | | | 202.739 | 0 | 493247 | 4 | 2 | 1200 | 0.36 | 0.97 | 0.16 | D− | *ls* |
| | | | 202.057 | 0 | 494911 | 4 | 4 | 120 | 0.071 | 0.19 | −0.54 | E | *ls* |
| 6. | $3p^63d$-$3p^53d(^3P^\circ)4s$ | $^2$D - $^2$P° | *172.59* | *564* | *579987* | 10 | 6 | 120 | 0.032 | 0.18 | −0.49 | D | 2 |
| | | | 172.487 | 940 | 580697 | 6 | 4 | 110 | 0.032 | 0.11 | −0.71 | D | 3*n* |
| | | | 172.841 | 0 | 578566 | 4 | 2 | 120 | 0.026 | 0.060 | −0.98 | D | 3*n* |
| | | | 172.204 | 0 | 580697 | 4 | 4 | 16 | 0.0071 | 0.016 | −1.55 | E | 3*n* |

Cr VI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7. | $3p^63d-3p^53d(^3F^\circ)4s$ | $^2D-^2F^\circ$ | *168.86* | *564* | *592761* | 10 | 14 | 180 | 0.11 | 0.61 | 0.04 | D | 2 |
| | | | 169.435 | 940 | 591137 | 6 | 8 | 160 | 0.093 | 0.31 | −0.26 | D | 3*n* |
| | | | 168.088 | 0 | 594926 | 4 | 6 | 200 | 0.13 | 0.28 | −0.30 | D | 3*n* |
| | | | 168.355 | 940 | 594926 | 6 | 6 | 11 | 0.0045 | 0.015 | −1.57 | E | 3*n* |
| 8. | $3p^63d-3p^53d(^3D^\circ)4s$ | $^2D-^2D^\circ$ | *161.73* | *564* | *618862* | 10 | 10 | 190 | 0.073 | 0.39 | −0.14 | D | 2 |
| | | | 161.687 | 940 | 618491 | 6 | 6 | 170 | 0.066 | 0.21 | −0.40 | D | 3*n* |
| | | | 161.687 | 0 | 619419 | 4 | 4 | 140 | 0.056 | 0.12 | −0.65 | D | 3*n* |
| | | | 161.930 | 940 | 619419 | 6 | 4 | 30 | 0.0078 | 0.025 | −1.33 | E | 3*n* |
| 9. | $3p^63d-3p^53d(^1F^\circ)4s$ | $^2D-^2F^\circ$ | *162.66* | *564* | *615353* | 10 | 14 | 79 | 0.044 | 0.24 | −0.36 | D | 2 |
| | | | 162.565 | 940 | 616079 | 6 | 8 | 83 | 0.044 | 0.14 | −0.58 | D | 3*n* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr VII

Ar Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^6\ ^1S_0$

Ionization Energy: 160.18 eV = 1291900 $cm^{-1}$

## Allowed Transitions

Line strengths for the $3p^6$–$3p^53d$ resonance transitions of this argon-like ion were interpolated from the superposition-of-configurations (SOC) calculations of Weiss,[1] which are expected to be fairly accurate.

Oscillator strengths for transitions of the $3p^6$–$3p^54s$ array were interpolated from the Dirac-Hartree-Fock data of Lin *et al.*,[2] who included correlation only in the lower state. Their results for lines of the $3p^6$–$3p^54d$ array in nearby Ar-like species have not been interpolated to provide *f*-values for Cr VII, since cancellation effects at or near V VI—one of the ions treated—introduce considerable uncertainty into the results at the low-*Z* end of the Ar sequence.

### References

[1]A. W. Weiss, private communication.

[2]D. L. Lin, W. Fielder, Jr., and L. Armstrong, Jr., Phys. Rev. A **16**, 589 (1977).

Cr VII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^6$–$3p^5 3d$ | $^1$S - $^3$D° | | | | | | | | | | | |
| | | | 259.181 | 0 | 385828 | 1 | 3 | 0.93 | 0.0028 | 0.0024 | −2.55 | E | *interp.* |
| 2. | | $^1$S - $^1$P° | 202.828 | 0 | 493035 | 1 | 3 | 1670 | 3.09 | 2.06 | 0.489 | C | *interp.* |
| 3. | $3p^6$–$3p^5(^2P^\circ_{3/2})4s$ | $^1$S - ($^3/_2$,$^1/_2$)° | | | | | | | | | | | |
| | | | 148.714 | 0 | 672428 | 1 | 3 | 130 | 0.13 | 0.064 | −0.89 | D | *interp.* |
| 4. | $3p^6$–$3p^5(^2P^\circ_{1/2})4s$ | $^1$S - ($^1/_2$,$^1/_2$)° | | | | | | | | | | | |
| | | | 146.497 | 0 | 682610 | 1 | 3 | 300 | 0.29 | 0.14 | −0.54 | D | *interp.* |

# Cr VIII

Cl Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s^2 3p^5\ ^2P^\circ_{3/2}$

Ionization Energy: 184.7 eV = 1490000 cm$^{-1}$

## Allowed Transitions

Line strengths for transitions of the arrays $3s^2 3p^5$–$3s3p^6$ and $3p^5$–$3p^4 3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang *et al.*[1] These relativistic calculations include a perturbative treatment of the Breit interaction and the Lamb shift. Configuration mixing was limited to some configurations within the $n=3$ complex. Those configurations which were assumed to lie far above $3p^5$ or $3p^4 3d$ in energy were excluded, as were all configurations outside the complex.

According to the semi-empirical HX (Hartree-Fock with statistical allowance for exchange) calculations of Bromage *et al.*[2] for Fe X, some levels of the $3p^4 3d$ configuration are strongly mixed in the *LS* basis, and in a few cases the *LS* designations given in Ref. 2 differed from those of Huang *et al*. The level designations used in this compilation are in accord with the theoretical results of Refs. 1 and 2 for Fe X. Percentage compositions published by Bromage[3] for the levels of the $3p^4 3d$ configuration in V VII and Ni XII indicate that the designations for the iron ion are appropriate for the neighboring ions of the chlorine isoelectronic sequence. Transitions involving highly mixed levels have been excluded, as have the very weak transitions.

The calculated wavelengths of Huang *et al.* differ appreciably from the observed ones found in the literature. Thus the available experimentally determined wavelengths were used in making the conversion from line strengths to $f$- and $A$-values. (Otherwise, the calculated wavelengths of Huang *et al.* were used, but they provide only a rough idea of the spectral-line positions.) Bromage *et al.* indicate that it was necessary to scale down some configuration-interaction parameters by a greater amount than usual in order to fit their calculated energy levels for Fe X to the experimental data. This could be an indication that neglecting to take configuration interaction into account on a larger scale yields significant errors in the energy levels and/or $f$-values.

## References


[1]K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables **28**, 355 (1983).

[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Phys. Scr. **15**, 177 (1977).

[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).


Cr VIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^5$–$3s3p^6$ | $^2P^\circ$ – $^2S$ | *418.82* | *3297* | 242065 | 6 | 2 | 40.3 | 0.0353 | 0.292 | −0.67 | C− | 1 |
| | | | 413.112 | 0 | 242065 | 4 | 2 | 27.9 | 0.0357 | 0.194 | −0.85 | C− | 1 |
| | | | 430.713 | 9892 | 242065 | 2 | 2 | 12 | 0.035 | 0.098 | −1.16 | C− | 1 |
| 2. | $3p^5$–$3p^4(^3P)3d$ | $^2P^\circ$ – $^4F$ | | | | | | | | | | | |
| | | | [265] | | | 4 | 6 | 0.083 | 1.3(−4)[a] | 4.6(−4) | −3.28 | E | 1 |
| | | | [271] | | | 2 | 4 | 0.11 | 2.4(−4) | 4.2(−4) | −3.33 | E | 1 |
| 3. | | $^2P^\circ$ – $^4P$ | | | | | | | | | | | |
| | | | [265] | | | 2 | 4 | 0.25 | 5.2(−4) | 9.1(−4) | −2.98 | E | 1 |
| | | | [259] | | | 4 | 4 | 0.27 | 2.7(−4) | 9.3(−4) | −2.96 | E | 1 |
| | | | [267] | | | 2 | 2 | 0.27 | 2.8(−4) | 5.0(−4) | −3.25 | E | 1 |
| | | | [261] | | | 4 | 2 | 0.85 | 4.4(−4) | 0.0015 | −2.76 | E | 1 |
| 4. | | $^2P^\circ$ – $^2D$ | *204.99* | *3297* | *491140* | 6 | 10 | 1500 | 1.6 | 6.5 | 0.98 | C− | 1 |
| | | | 205.01 | 0 | 487780 | 4 | 6 | 1520 | 1.44 | 3.88 | 0.76 | C | 1 |
| | | | 205.65 | 9892 | 496180 | 2 | 4 | 1440 | 1.83 | 2.48 | 0.56 | C | 1 |
| | | | 201.54 | 0 | 496180 | 4 | 4 | 68 | 0.041 | 0.11 | −0.78 | D | 1 |
| 5. | $3p^5$–$3p^4(^1D)3d$ | $^2P^\circ$ – $^2F$ | | | | | | | | | | | |
| | | | [233] | | | 4 | 6 | 0.56 | 6.8(−4) | 0.0021 | −2.56 | E | 1 |
| 6. | | $^2P^\circ$ – $^2S$ | *218.23* | *3297* | 461530 | 6 | 2 | 1310 | 0.311 | 1.34 | 0.271 | C− | 1 |
| | | | 216.67 | 0 | 461530 | 4 | 2 | 950 | 0.33 | 0.95 | 0.12 | C− | 1 |
| | | | 221.41 | 9892 | 461530 | 2 | 2 | 368 | 0.270 | 0.394 | −0.267 | C− | 1 |
| 7. | $3p^5$–$3p^4(^1S)3d$ | $^2P^\circ$ – $^2D$ | *218* | | | 6 | 10 | 2.5 | 0.0030 | 0.013 | −1.74 | E | 1 |
| | | | [216] | | | 4 | 6 | 0.37 | 3.9(−4) | 0.0011 | −2.81 | E | 1 |
| | | | [222] | | | 2 | 4 | 5.1 | 0.0075 | 0.011 | −1.82 | E | 1 |
| | | | [217] | | | 4 | 4 | 0.59 | 4.2(−4) | 0.0012 | −2.77 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr VIII

## Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $3p^5$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for mixing among odd-parity configurations was limited to the set $3s^23p^5$, $3s3p^53d$, $3p^53d^2$, and $3s^23p^33d^2$. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables **28**, 355 (1983).

Cr VIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^5$–$3p^5$ | $^2P^\circ$ - $^2P^\circ$ | | | | | | | | | | |
| | | | [10110] | 0 | 9892 | 4 | 2 | M1 | 17.4 | 1.33 | B | 1 |
| | | | ″ | ″ | ″ | 4 | 2 | E2 | 0.0028 | 0.35 | D− | 1 |

# Cr IX

S Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^4\ ^3P_2$

Ionization Energy: 209.3 eV = 1688000 cm$^{-1}$

## Allowed Transitions

Oscillator strengths for a few transitions of the arrays $3s^23p^4$–$3s3p^5$ and $3p^4$–$3p^33d$ were interpolated from the results of Bromage[1] for V VIII and those of Mason[2] and Bromage *et al.*[3] for Fe XI. The term designations used here are in accord with the results of Refs. 1 and 3.

### References


[1]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).
[2]H. E. Mason, Mon. Not. R. Astron. Soc. **170**, 651 (1975).
[3]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Phys. Scr. **15**, 177 (1977).


Cr IX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^4$–$3s3p^5$ | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 418.290 | 0 | 239069 | 5 | 5 | 14 | 0.037 | 0.25 | −0.73 | E | *interp.* |
| 2. | | $^1$D - $^1$P° | 363.271 | 30284 | 305561 | 5 | 3 | 57 | 0.068 | 0.41 | −0.47 | D | *interp.* |
| 3. | $3p^4$–$3p^3(^2D°)3d$ | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | 220.02 | 0 | 454500 | 5 | 5 | 920 | 0.67 | 2.4 | 0.53 | E | *interp.* |
| | | | | | | 3 | 1 | | 0.29 | | −0.06 | E | *interp.* |
| 4. | | $^1$D - $^1$D° | 215.97 | 30284 | 493310 | 5 | 5 | 1100 | 0.75 | 2.7 | 0.57 | D | *interp.* |
| 5. | | $^1$D - $^1$F° | 209.44 | 30284 | 507740 | 5 | 7 | 1400 | 1.3 | 4.5 | 0.81 | D | *interp.* |
| 6. | $3p^4$–$3p^3(^2P°)3d$ | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | | | | 5 | 5 | | 0.021 | | −0.98 | D | *interp.* |
| 7. | | $^1$S - $^1$P° | 215.04 | 66855 | 531890 | 1 | 3 | 1300 | 2.6 | 1.8 | 0.41 | D | *interp.* |

# Cr IX

## Forbidden Transitions

Transition probabilities for magnetic dipole and electric quadrupole lines within the $3p^4$ configuration are the results of the scaled Thomas-Fermi calculations of Mendoza and Zeippen.[1] They included a number of correlation configurations in their basis set and introduced Breit-Pauli relativistic corrections as a perturbation to the nonrelativistic Hamiltonian.

### Reference

[1]C. Mendoza and C. J. Zeippen, Mon. Not. R. Astron. Soc. **202**, 981 (1983).

Cr IX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^4$–$3p^4$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | [12790] | 0 | 7818 | 5 | 3 | M1 | 10.5 | 2.44 | C+ | 1 |
| | | | " | " | " | 5 | 3 | E2 | 5.4(−4)[a] | 0.33 | D− | 1 |
| | | | [57790] | 7818 | 9548 | 3 | 1 | M1 | 0.270 | 1.93 | C+ | 1 |
| | | | [10470] | 0 | 9548 | 5 | 1 | E2 | 0.0021 | 0.16 | D− | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [3301.1] | 0 | 30284 | 5 | 5 | M1 | 30 | 0.20 | D− | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.053 | 0.062 | E | 1 |
| | | | [4449.9] | 7818 | 30284 | 3 | 5 | M1 | 4.2 | 0.069 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.0018 | 0.0093 | E | 1 |
| | | | [4821.2] | 9548 | 30284 | 1 | 5 | E2 | 6.1(−4) | 0.0047 | E | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [1495.8] | 0 | 66855 | 5 | 1 | E2 | 0.88 | 0.0039 | E | 1 |
| | | | [1693.9] | 7818 | 66855 | 3 | 1 | M1 | 330 | 0.059 | E | 1 |
| 4. | | $^1$D - $^1$S | [2733.6] | 30284 | 66855 | 5 | 1 | E2 | 6.4 | 0.58 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr X

P Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^3\ ^4S^o_{3/2}$

Ionization Energy: 244.4 eV = 1971000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 209.79 | 9 | 228.63 | 11 | 248.40 | 7 | 399.707 | 2 |
| 216.72 | 8 | 228.71 | 11 | 253 | 10 | 411.655 | 1 |
| 217.71 | 12 | 231.21 | 14 | 254 | 4 | 416.690 | 1 |
| 218.83 | 12 | 232.96 | 14 | 256 | 4 | 427.551 | 1 |
| 223.86 | 5 | 242.20 | 13 | 286 | 6 | 443.062 | 3 |
| 224.74 | 5 | 244.10 | 13 | 287 | 6 | 447.529 | 3 |
| 226.24 | 5 | 244.13 | 7 | 394.47 | 2 | 449.48 | 3 |
| 227.42 | 11 | 244.19 | 13 | 395.984 | 2 | | |
| 227.50 | 11 | 246.97 | 7 | 398.150 | 2 | | |

Line strengths for transitions of the arrays $3s^23p^3$–$3s3p^4$ and $3p^3$–$3p^23d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to configurations within the $n=3$ complex having no more than two electrons in the $3d$ subshell.

Huang published neither an energy-level diagram nor percentage compositions for levels of the $3s^23p^3$, $3s3p^4$, and $3s^23p^23d$ configurations in Cr X. We have used the percentages given by Bromage *et al.*[2] for Fe XII, and by Bromage[3] for V IX and Ni XIV, as a guide to naming the levels; their values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to a few configurations within the $n=3$ complex. Whenever a term designation of a level in Fe XII, as given in Ref. 1, is different from that indicated in Ref. 2, all transitions involving the corresponding level in Cr X are omitted from this compilation.

Transitions involving levels which are indicated to be of low purity in $LS$ coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings; the weakest lines have been excluded.

## References

[1]K.-N. Huang, At. Data Nucl. Data Tables **30**, 313 (1984).
[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).
[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).

Cr X: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^3$–$3s3p^4$ | $^4S^o$ - $^4P$ | *421.18* | 0 | *237428* | 4 | 12 | 12 | 0.097 | 0.54 | −0.41 | D | 1 |
| | | | 427.551 | 0 | 233890 | 4 | 6 | 12 | 0.048 | 0.27 | −0.72 | D | 1 |
| | | | 416.690 | 0 | 239987 | 4 | 4 | 13 | 0.033 | 0.18 | −0.88 | D | 1 |
| | | | 411.655 | 0 | 242922 | 4 | 2 | 13 | 0.017 | 0.090 | −1.18 | D | 1 |
| 2. | | $^2D^o$ - $^2D$ | *397.28* | *38507* | *290218* | 10 | 10 | 23 | 0.055 | 0.72 | −0.26 | E | 1 |
| | | | 398.150 | 39444 | 290606 | 6 | 6 | 21 | 0.051 | 0.40 | −0.52 | D | 1 |
| | | | 395.984 | 37102 | 289637 | 4 | 4 | 24 | 0.058 | 0.30 | −0.64 | D | 1 |
| | | | 399.707 | 39444 | 289637 | 6 | 4 | 0.71 | 0.0011 | 0.0090 | −2.16 | E | 1 |
| | | | [394.47] | 37102 | 290606 | 4 | 6 | 0.34 | 0.0012 | 0.0062 | −2.32 | E | 1 |

Cr X: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | | $^2P^\circ - {}^2D$ | *446.16* | *66083* | *290218* | 6 | 10 | 3.4 | 0.017 | 0.15 | −0.99 | D− | 1 |
| | | | 447.529 | 67157 | 290606 | 4 | 6 | 4.1 | 0.019 | 0.11 | −1.13 | D | 1 |
| | | | 443.062 | 63935 | 289637 | 2 | 4 | 2.4 | 0.014 | 0.041 | −1.55 | D | 1 |
| | | | [449.48] | 67157 | 289637 | 4 | 4 | 0.033 | 1.0(−4)[a] | 5.9(−4) | −3.40 | E | 1 |
| 4. | $3p^3$–$3p^2(^3P)3d$ | $^4S^\circ - {}^4D$ | | | | | | | | | | | |
| | | | [254] | | | 4 | 6 | 1.1 | 0.0015 | 0.0051 | −2.21 | E | 1 |
| | | | [256] | | | 4 | 4 | 1.1 | 0.0011 | 0.0036 | −2.37 | E | 1 |
| 5. | | $^4S^\circ - {}^4P$ | *225.34* | 0 | *443780* | 4 | 12 | 750 | 1.7 | 5.1 | 0.84 | D | 1 |
| | | | 226.24 | 0 | 442010 | 4 | 6 | 730 | 0.84 | 2.5 | 0.53 | D | 1 |
| | | | 224.74 | 0 | 444960 | 4 | 4 | 760 | 0.57 | 1.7 | 0.36 | D | 1 |
| | | | 223.86 | 0 | 446710 | 4 | 2 | 770 | 0.23 | 0.85 | 0.06 | D | 1 |
| 6. | | $^2D^\circ - {}^4D$ | | | | | | | | | | | |
| | | | [287] | | | 6 | 4 | 1.3 | 0.0010 | 0.0059 | −2.20 | E | 1 |
| | | | [286] | | | 4 | 2 | 1.7 | 0.0011 | 0.0040 | −2.37 | E | 1 |
| 7. | | $^2D^\circ - {}^4P$ | | | | | | | | | | | |
| | | | [248.40] | 39444 | 442010 | 6 | 6 | 5.7 | 0.0053 | 0.026 | −1.50 | E | 1 |
| | | | [244.13] | 37102 | 446710 | 4 | 2 | 3.4 | 0.0015 | 0.0049 | −2.21 | E | 1 |
| | | | [246.97] | 37102 | 442010 | 4 | 6 | 1.6 | 0.0022 | 0.0071 | −2.06 | E | 1 |
| 8. | | $^2D^\circ - {}^2F$ | | | | | | | | | | | |
| | | | 216.72 | 39444 | 500860 | 6 | 8 | 900 | 0.84 | 3.6 | 0.70 | E | 1 |
| 9. | $3p^3$–$3p^2(^1D)3d$ | $^4S^\circ - {}^2D$ | | | | | | | | | | | |
| | | | [209.79] | 0 | 476670 | 4 | 6 | 1.1 | 0.0011 | 0.0030 | −2.36 | E | 1 |
| 10. | | $^2D^\circ - {}^2G$ | | | | | | | | | | | |
| | | | [253] | | | 6 | 8 | 1.0 | 0.0013 | 0.0066 | −2.10 | E | 1 |
| 11. | | $^2D^\circ - {}^2D$ | *228.20* | *38507* | *476730* | 10 | 10 | 530 | 0.41 | 3.1 | 0.62 | D | 1 |
| | | | 228.71 | 39444 | 476670 | 6 | 6 | 450 | 0.35 | 1.6 | 0.33 | D | 1 |
| | | | 227.42 | 37102 | 476820 | 4 | 4 | 520 | 0.40 | 1.2 | 0.20 | D | 1 |
| | | | [228.63] | 39444 | 476820 | 6 | 4 | 81 | 0.042 | 0.19 | −0.60 | D | 1 |
| | | | [227.50] | 37102 | 476670 | 4 | 6 | 18 | 0.021 | 0.064 | −1.07 | D | 1 |
| 12. | | $^2D^\circ - {}^2P$ | | | | | | | | | | | |
| | | | [218.83] | 39444 | 496420 | 6 | 4 | 10 | 0.0049 | 0.021 | −1.54 | E | 1 |
| | | | [217.71] | 37102 | 496420 | 4 | 4 | 7.4 | 0.0052 | 0.015 | −1.68 | E | 1 |
| 13. | | $^2P^\circ - {}^2D$ | *243.52* | *66083* | *476730* | 6 | 10 | 55 | 0.081 | 0.39 | −0.31 | E | 1 |
| | | | [244.19] | 67157 | 476670 | 4 | 6 | 58 | 0.078 | 0.25 | −0.51 | D | 1 |
| | | | [242.20] | 63935 | 476820 | 2 | 4 | 50 | 0.088 | 0.14 | −0.76 | D | 1 |
| | | | [244.10] | 67157 | 476820 | 4 | 4 | 1.0 | 9.3(−4) | 0.0030 | −2.43 | E | 1 |
| 14. | | $^2P^\circ - {}^2P$ | | | | | | | | | | | |
| | | | 232.96 | 67157 | 496420 | 4 | 4 | 440 | 0.36 | 1.1 | 0.16 | E | 1 |
| | | | 231.21 | 63935 | 496420 | 2 | 4 | 120 | 0.20 | 0.30 | −0.40 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr X

## Forbidden Transitions

Line strengths for magnetic dipole and electric quadrupole transitions within the $3p^3$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to configurations within the $n=3$ complex having no more than two electrons in the $3d$ subshell. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor $^2/_3$ which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. We have excluded from this compilation the electric quadrupole contributions to the $^4S^\circ_{3/2}-{}^2P^\circ_{3/2}$ and $^4S^\circ_{3/2}-{}^2P^\circ_{1/2}$ transitions, since their strengths are very small and thus subject to considerable uncertainty.

Data for these same transitions calculated by Mendoza and Zeippen[2] with the scaled Thomas-Fermi approach with allowance for correlation are generally in very good agreement with the results of Ref. 1. These latter calculations treated relativistic effects by introducing Breit-Pauli corrections as a perturbation to the nonrelativistic Hamiltonian.

### References

[1]K.-N. Huang, At. Data Nucl. Data Tables **30**, 313 (1984).

[2]C. Mendoza and C. J. Zeippen, Mon. Not. R. Astron. Soc. **198**, 127 (1982).

Cr X: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^3$–$3p^3$ | $^4S^\circ-{}^2D^\circ$ | | | | | | | | | | |
| | | | [2534.5] | 0 | 39444 | 4 | 6 | M1 | 0.30 | 0.0011 | E | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 6 | E2 | 0.040 | 0.015 | E | 1 |
| | | | [2694.5] | 0 | 37102 | 4 | 4 | M1 | 11 | 0.033 | D | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 4 | E2 | 0.020 | 0.0066 | E | 1 |
| 2. | | $^4S^\circ-{}^2P^\circ$ | | | | | | | | | | |
| | | | 1489.04 | 0 | 67157 | 4 | 4 | M1 | 120 | 0.059 | D | 1 |
| | | | 1564.10 | 0 | 63935 | 4 | 2 | M1 | 60 | 0.017 | D | 1 |
| 3. | | $^2D^\circ-{}^2D^\circ$ | | | | | | | | | | |
| | | | [42690] | 37102 | 39444 | 4 | 6 | M1 | 0.127 | 2.20 | C+ | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 6 | E2 | 1.8(−7)[a] | 0.092 | E | 1 |
| 4. | | $^2D^\circ-{}^2P^\circ$ | | | | | | | | | | |
| | | | [4082.0] | 39444 | 63935 | 6 | 2 | E2 | 0.25 | 0.34 | D− | 1 |
| | | | [3607.4] | 39444 | 67157 | 6 | 4 | M1 | 27 | 0.19 | C | 1 |
| | | | 〃 | 〃 | 〃 | 6 | 4 | E2 | 0.76 | 1.1 | D− | 1 |
| | | | [3725.7] | 37102 | 63935 | 4 | 2 | M1 | 26 | 0.10 | C | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 2 | E2 | 0.55 | 0.47 | D− | 1 |
| | | | [3326.3] | 37102 | 67157 | 4 | 4 | M1 | 62 | 0.34 | C | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 4 | E2 | 0.36 | 0.35 | D− | 1 |
| 5. | | $^2P^\circ-{}^2P^\circ$ | | | | | | | | | | |
| | | | [31030] | 63935 | 67157 | 2 | 4 | M1 | 0.273 | 1.21 | C+ | 1 |
| | | | 〃 | 〃 | 〃 | 2 | 4 | E2 | 5.1(−7) | 0.035 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XI

Si Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^2\ ^3P_0$

Ionization Energy: 270.8 eV = 2184000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 198 | 9 | 250.28 | 11 | 366.942 | 2 | 431.154 | 1 |
| 214.31 | 8 | 273 | 5 | 374.927 | 2 | 433.88 | 1 |
| 226.45 | 12 | 299 | 10 | 375.35 | 2 | 434.09 | 1 |
| 232 | 6 | 359.20 | 2 | 412.629 | 1 | 483.27 | 3 |
| 235.53 | 7 | 366.085 | 2 | 422.083 | 1 | 496 | 4 |
| 240.76 | 13 | 366.491 | 2 | 422.282 | 1 | | |

Line strengths for transitions of the arrays $3s^23p^2$–$3s3p^3$ and $3p^2$–$3p3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published neither an energy-level diagram nor percentage compositions for levels of the $3s^23p^2$, $3s3p^3$, and $3s^23p3d$ configurations in Cr XI. We have used the percentages given by Bromage *et al.*[2] for Fe XIII, and by Bromage[3] for V X and Ni XV, as a guide to naming the levels; their values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to a partial set of configurations within the $n=3$ complex. Whenever the term designation of a level in Fe XIII, as given in Ref. 1, is different from that indicated in Ref. 2, all transitions involving the corresponding level in Cr XI are omitted from this compilation.

Transitions involving levels which are indicated to be of low purity in *LS* coupling are omitted here. Lines which are characterized by very small *f*-values are assigned lower accuracy ratings; the weakest lines have been excluded.

### References


[1]K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985).
[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).
[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).


Cr XI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8\ s^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^2$–$3s3p^3$ | $^3P$ - $^3D°$ | *426.23* | *8502* | *243117* | 9 | 15 | 10 | 0.048 | 0.60 | −0.37 | D− | 1 |
| | | | 431.154 | 11981 | 243917 | 5 | 7 | 9.8 | 0.038 | 0.27 | −0.72 | D | 1 |
| | | | 422.083 | 5539 | 242459 | 3 | 5 | 10 | 0.046 | 0.19 | −0.86 | D | 1 |
| | | | 412.629 | 0 | 242348 | 1 | 3 | 8.3 | 0.063 | 0.086 | −1.20 | D | 1 |
| | | | [433.88] | 11981 | 242459 | 5 | 5 | 0.74 | 0.0021 | 0.015 | −1.98 | D− | 1 |
| | | | 422.282 | 5539 | 242348 | 3 | 3 | 3.0 | 0.0079 | 0.033 | −1.62 | D− | 1 |
| | | | [434.09] | 11981 | 242348 | 5 | 3 | 0.083 | 1.4(−4)[a] | 0.0010 | −3.16 | E | 1 |
| 2. | | $^3P$ - $^3P°$ | *370.33* | *8502* | *278528* | 9 | 9 | 28 | 0.058 | 0.64 | −0.28 | D | 1 |
| | | | 374.927 | 11981 | 278700 | 5 | 5 | 23 | 0.049 | 0.30 | −0.61 | D | 1 |
| | | | 366.491 | 5539 | 278397 | 3 | 3 | 12 | 0.024 | 0.087 | −1.14 | D | 1 |
| | | | [375.35] | 11981 | 278397 | 5 | 3 | 8.0 | 0.010 | 0.063 | −1.29 | D | 1 |
| | | | 366.942 | 5539 | 278062 | 3 | 1 | 30 | 0.020 | 0.073 | −1.22 | C− | 1 |
| | | | 366.085 | 5539 | 278700 | 3 | 5 | 4.1 | 0.014 | 0.050 | −1.38 | D | 1 |
| | | | [359.20] | 0 | 278397 | 1 | 3 | 9.5 | 0.055 | 0.065 | −1.26 | D | 1 |

Cr XI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [483.27] | 36994 | 243917 | 5 | 7 | 0.31 | 0.0015 | 0.012 | −2.12 | E | 1 |
| 4. | | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [496] | | | 1 | 3 | 0.094 | 0.0010 | 0.0017 | −2.98 | E | 1 |
| 5. | $3p^2$–$3p3d$ | $^3$P - $^3$F° | | | | | | | | | | | |
| | | | [273] | | | 5 | 7 | 1.3 | 0.0020 | 0.0091 | −1.99 | E | 1 |
| 6. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | [232] | | | 3 | 1 | 410 | 0.11 | 0.25 | −0.49 | D | 1 |
| 7. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 235.53 | 11981 | 436550 | 5 | 7 | 550 | 0.64 | 2.5 | 0.51 | D | 1 |
| 8. | | $^3$P - $^1$F° | | | | | | | | | | | |
| | | | [214.31] | 11981 | 478590 | 5 | 7 | 14 | 0.013 | 0.046 | −1.19 | E | 1 |
| 9. | | $^3$P - $^1$P° | | | | | | | | | | | |
| | | | [198] | | | 1 | 3 | 2.9 | 0.0051 | 0.0033 | −2.30 | E | 1 |
| 10. | | $^1$D - $^3$F° | | | | | | | | | | | |
| | | | [299] | | | 5 | 5 | 1.5 | 0.0020 | 0.010 | −1.99 | E | 1 |
| 11. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [250.28] | 36994 | 436550 | 5 | 7 | 10 | 0.013 | 0.054 | −1.18 | E | 1 |
| 12. | | $^1$D - $^1$F° | 226.45 | 36994 | 478590 | 5 | 7 | 600 | 0.65 | 2.41 | 0.51 | C | 1 |
| 13. | | $^1$S - $^1$P° | 240.76 | | | 1 | 3 | 480 | 1.2 | 0.99 | 0.10 | D | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XI

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 519.13 | 11 | 1500 | 5 | 2799.2 | 8 | 15520 | 1 |
| 520 | 10 | 1590 | 3 | 2807.9 | 8 | 18050 | 1 |
| 710 | 9 | 2630 | 4 | 2874.1 | 8 | 63720 | 7 |
| 740 | 9 | 2750.1 | 8 | 2899.4 | 8 | 68570 | 7 |
| 940 | 6 | 2758.5 | 8 | 3178.2 | 2 | 901000 | 7 |
| 1400 | 5 | 2773.2 | 8 | 3996.8 | 2 | | |
| 1440 | 3 | 2781.7 | 8 | 8344.3 | 1 | | |

Line strengths for magnetic dipole and electric quadrupole transitions are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration interaction encompassed all configurations within the $n=3$ complex. Huang calculated line strengths for transitions within the $3p^2$ configuration, as well as for transitions between pairs of odd-parity levels whose lower level is one of the four lowest-lying odd-parity levels in the $n=3$ complex. Transitions involving odd-parity levels which are indicated by Bromage *et al.*[2] (for Fe XIII) or Bromage[3] (for V X and Ni XV) to be of low purity in *LS* coupling in Fe-group species are omitted here, as are lines whose strengths are very small. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

## References


[1]K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985) and private communication.

[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).

[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).


Cr XI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^3$–$3p^3$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | [15520] | 5539 | 11981 | 3 | 5 | M1 | 3.45 | 2.39 | C+ | 1 |
| | | | " | " | " | 3 | 5 | E2 | 1.0(−4)[a] | 0.27 | D− | 1 |
| | | | [18050] | 0 | 5539 | 1 | 3 | M1 | 2.98 | 1.95 | C+ | 1 |
| | | | [8344.3] | 0 | 11981 | 1 | 5 | E2 | 0.0011 | 0.13 | D− | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | 3996.8 | 11981 | 36994 | 5 | 5 | M1 | 26 | 0.31 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.027 | 0.081 | E | 1 |
| | | | [3178.2] | 5539 | 36994 | 3 | 5 | M1 | 18 | 0.11 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.012 | 0.012 | E | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [1590] | | | 5 | 1 | E2 | 1.5 | 0.0092 | E | 1 |
| | | | [1440] | | | 3 | 1 | M1 | 370 | 0.041 | E | 1 |
| 4. | | $^1$D - $^1$S | [2630] | | | 5 | 1 | E2 | 6.9 | 0.52 | D− | 1 |
| 5. | $3s3p^3$–$3s3p^3$ | $^5$S° - $^3$D° | | | | | | | | | | |
| | | | [1400] | | | 5 | 7 | E2 | 0.25 | 0.0056 | E | 1 |
| | | | [1500] | | | 5 | 5 | M1 | 7.5 | 0.0047 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.16 | 0.0037 | E | 1 |
| 6. | | $^5$S° - $^3$P° | | | | | | | | | | |
| | | | [940] | | | 5 | 5 | M1 | 240 | 0.037 | E | 1 |
| | | | [940] | | | 5 | 3 | M1 | 130 | 0.012 | E | 1 |
| 7. | | $^3$D° - $^3$D° | | | | | | | | | | |
| | | | [68570] | 242459 | 243917 | 5 | 7 | M1 | 0.054 | 4.52 | C− | 1 |
| | | | " | " | " | 5 | 7 | E2 | 7.3(−9) | 0.046 | E | 1 |
| | | | [901000] | 242348 | 242459 | 3 | 5 | M1 | 3.2(−5) | 4.4 | E | 1 |
| | | | [63720] | 242348 | 243917 | 3 | 7 | E2 | 2.5(−9) | 0.011 | E | 1 |

Cr XI: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^3D^\circ - {}^3P^\circ$ | | | | | | | | | | |
| | | | [2899.4] | 243917 | 278397 | 7 | 3 | E2 | 1.4 | 0.53 | D− | 1 |
| | | | [2807.9] | 242459 | 278062 | 5 | 1 | E2 | 3.5 | 0.36 | D− | 1 |
| | | | [2874.1] | 243917 | 278700 | 7 | 5 | M1 | 32 | 0.14 | E | 1 |
| | | | " | " | " | 7 | 5 | E2 | 1.7 | 0.99 | D− | 1 |
| | | | [2781.7] | 242459 | 278397 | 5 | 3 | E2 | 0.28 | 0.083 | E | 1 |
| | | | [2799.2] | 242348 | 278062 | 3 | 1 | M1 | 42 | 0.034 | E | 1 |
| | | | [2758.5] | 242459 | 278700 | 5 | 5 | M1 | 25 | 0.098 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 1.3 | 0.60 | D− | 1 |
| | | | [2773.2] | 242348 | 278397 | 3 | 3 | M1 | 42 | 0.099 | E | 1 |
| | | | " | " | " | 3 | 3 | E2 | 1.6 | 0.47 | D− | 1 |
| | | | [2750.1] | 242348 | 278700 | 3 | 5 | M1 | 7.3 | 0.028 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.38 | 0.18 | D− | 1 |
| 9. | $3s3p^3$–$3s^23p3d$ | $^3D^\circ - {}^3F^\circ$ | | | | | | | | | | |
| | | | [710] | | | 5 | 9 | E2 | 6.5 | 0.0063 | E | 1 |
| | | | [740] | | | 3 | 7 | E2 | 3.0 | 0.0028 | E | 1 |
| | | | [710] | | | 7 | 9 | M1 | 540 | 0.064 | E | 1 |
| 10. | | $^3D^\circ - {}^3P^\circ$ | | | | | | | | | | |
| | | | [520] | | | 5 | 1 | E2 | 250 | 0.0057 | E | 1 |
| 11. | | $^3D^\circ - {}^3D^\circ$ | | | | | | | | | | |
| | | | [519.13] | 243917 | 436550 | 7 | 7 | M1 | 41 | 0.0015 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XII

Al Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p\ ^2P^\circ_{1/2}$

Ionization Energy: 298.0 eV = 2404000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 196 | 29 | 247 | 19,20 | 269 | 28 | 308 | 15 |
| 198 | 22 | 248 | 25 | 273 | 28 | 309 | 15,16 |
| 209 | 31 | 250 | 20 | 274 | 28 | 311.55 | 3 |
| 216 | 30 | 251 | 35 | 275 | 6 | 318.82 | 2 |
| 217 | 30 | 251.52 | 17 | 278 | 6,28 | 320.20 | 5 |
| 218 | 30 | 252 | 19 | 280 | 18 | 324 | 14 |
| 221 | 21 | 252.11 | 17 | 282 | 18 | 325 | 4,14 |
| 222 | 26 | 254 | 25,34,35 | 286 | 24 | 325.13 | 5 |
| 239 | 32 | 255 | 25 | 294 | 23 | 327 | 14 |
| 244 | 19 | 256 | 19,27 | 294.77 | 3 | 330 | 8 |
| 244.70 | 17 | 259 | 27 | 300.32 | 3 | 331 | 8 |
| 246 | 20 | 265 | 33 | 305.81 | 3 | 331.95 | 2 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 332 | 8 | 401 | 7 | 410.91 | 1 | 449 | 11 |
| 332.06 | 5 | 402 | 12 | 412.46 | 1 | 458 | 11 |
| 338 | 4 | 403 | 7 | 413 | 9 | 461 | 11 |
| 344 | 13 | 405 | 7 | 417 | 12 | 599 | 10 |
| 346 | 13 | 407 | 7 | 419 | 12 | | |
| 393.00 | 1 | 410 | 9 | 446 | 11 | | |

Line strengths for transitions of the arrays $3s^23p$–$3s3p^2$, $3s3p^2$–$3p^3$, $3s^23d$–$3s3p3d$, $3s^23p$–$3s^23d$, and $3s3p^2$–$3s3p3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published neither an energy-level diagram nor percentage compositions for levels of the $3s^23p$, $3s3p^2$, $3s^23d$, $3p^3$, and $3s3p3d$ configurations in Cr XII. We have used the percentages given by Fawcett[2] as a guide to naming the levels; the latter's values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to all configurations within the $n=3$ complex.

Transitions involving levels which are indicated to be of low purity in *LS* coupling are omitted here. Lines which are characterized by very small *f*-values are assigned lower accuracy ratings; the weakest lines have been excluded. A few wavelengths computed by Huang differ significantly from those which resulted from the fitting and scaling procedure applied by Fawcett[2]; lines for which the wavelengths are in serious disagreement have been omitted.

## References


[1]K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986) and private communication.

[2]B. C. Fawcett, At. Data Nucl. Data Tables **28**, 557 (1983).


Cr XII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p$–$3s3p^2$ | $^2$P° - $^2$D | *404.86* | *8000* | *255000* | 6 | 10 | 16 | 0.064 | 0.51 | −0.42 | E | 1 |
| | | | 410.91 | 12000 | 255360 | 4 | 6 | 15 | 0.055 | 0.30 | −0.65 | D | 1 |
| | | | 393.00 | 0 | 254450 | 2 | 4 | 17 | 0.077 | 0.20 | −0.81 | D | 1 |
| | | | 412.46 | 12000 | 254450 | 4 | 4 | 0.94 | 0.0024 | 0.013 | −2.02 | E | 1 |
| 2. | | $^2$P° - $^2$S | *327.16* | *8000* | 313660 | 6 | 2 | 130 | 0.068 | 0.44 | −0.39 | D | 1 |
| | | | 331.95 | 12000 | 313660 | 4 | 2 | 21 | 0.017 | 0.075 | −1.16 | D | 1 |
| | | | 318.82 | 0 | 313660 | 2 | 2 | 110 | 0.17 | 0.36 | −0.46 | D | 1 |
| 3. | | $^2$P° - $^2$P | *303.80* | *8000* | *337160* | 6 | 6 | 330 | 0.45 | 2.7 | 0.43 | D | 1 |
| | | | 305.81 | 12000 | 339250 | 4 | 4 | 276 | 0.387 | 1.56 | 0.190 | C− | 1 |
| | | | [300.32] | 0 | 332980 | 2 | 2 | 140 | 0.19 | 0.38 | −0.42 | D | 1 |
| | | | 311.55 | 12000 | 332980 | 4 | 2 | 160 | 0.12 | 0.48 | −0.33 | D | 1 |
| | | | 294.77 | 0 | 339250 | 2 | 4 | 60 | 0.157 | 0.304 | −0.50 | C− | 1 |
| 4. | $3s3p^2$–$3p^3$ | $^4$P - $^2$D° | | | | | | | | | | | |
| | | | [338] | | | 6 | 4 | 1.6 | 0.0018 | 0.012 | −1.97 | E | 1 |
| | | | [325] | | | 2 | 4 | 0.56 | 0.0018 | 0.0038 | −2.45 | E | 1 |
| 5. | | $^4$P - $^4$S° | *327.71* | | | 12 | 4 | 290 | 0.15 | 2.0 | 0.27 | D | 1 |
| | | | 332.06 | | | 6 | 4 | 140 | 0.15 | 1.0 | −0.04 | D | 1 |
| | | | 325.13 | | | 4 | 4 | 99 | 0.16 | 0.67 | −0.20 | D | 1 |
| | | | 320.20 | | | 2 | 4 | 52 | 0.16 | 0.34 | −0.49 | D | 1 |

Cr XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6. | | $^4P - ^2P°$ | | | | | | | | | | | |
| | | | [278] | | | 4 | 4 | 2.2 | 0.0026 | 0.0095 | −1.98 | E | 1 |
| | | | [275] | | | 2 | 4 | 0.97 | 0.0022 | 0.0040 | −2.35 | E | 1 |
| 7. | | $^2D - ^2D°$ | *404* | | | 10 | 10 | 28 | 0.069 | 0.92 | −0.16 | E | 1 |
| | | | [403] | | | 6 | 6 | 26 | 0.064 | 0.51 | −0.42 | E | 1 |
| | | | [405] | | | 4 | 4 | 21 | 0.051 | 0.27 | −0.69 | E | 1 |
| | | | [407] | | | 6 | 4 | 6.6 | 0.011 | 0.088 | −1.18 | E | 1 |
| | | | [401] | | | 4 | 6 | 2.5 | 0.0089 | 0.047 | −1.45 | E | 1 |
| 8. | | $^2D - ^2P°$ | *331* | | | 10 | 6 | 100 | 0.10 | 1.1 | 0.00 | D | 1 |
| | | | [331] | | | 6 | 4 | 85 | 0.093 | 0.61 | −0.25 | D | 1 |
| | | | [332] | | | 4 | 2 | 110 | 0.087 | 0.38 | −0.46 | D | 1 |
| | | | [330] | | | 4 | 4 | 11 | 0.018 | 0.077 | −1.15 | D | 1 |
| 9. | | $^2S - ^2P°$ | *411* | | | 2 | 6 | 12 | 0.089 | 0.24 | −0.75 | E | 1 |
| | | | [410] | | | 2 | 4 | 16 | 0.081 | 0.22 | −0.79 | D | 1 |
| | | | [413] | | | 2 | 2 | 3.0 | 0.0077 | 0.021 | −1.81 | E | 1 |
| 10. | | $^2P - ^4S°$ | | | | | | | | | | | |
| | | | [599] | | | 4 | 4 | 0.31 | 0.0016 | 0.013 | −2.18 | E | 1 |
| 11. | | $^2P - ^2P°$ | *455* | | | 6 | 6 | 26 | 0.081 | 0.73 | −0.31 | E | 1 |
| | | | [458] | | | 4 | 4 | 22 | 0.070 | 0.42 | −0.56 | D | 1 |
| | | | [449] | | | 2 | 2 | 27 | 0.081 | 0.24 | −0.79 | D | 1 |
| | | | [461] | | | 4 | 2 | 6.5 | 0.010 | 0.063 | −1.38 | D | 1 |
| | | | [446] | | | 2 | 4 | 0.23 | 0.0014 | 0.0041 | −2.55 | E | 1 |
| 12. | $3s^23d - 3s3p(^3P°)3d$ | $^2D - ^2F°$ | *408* | | | 10 | 14 | 17 | 0.061 | 0.82 | −0.21 | E | 1 |
| | | | [402] | | | 6 | 8 | 19 | 0.60 | 0.48 | −0.44 | E | 1 |
| | | | [417] | | | 4 | 6 | 14 | 0.053 | 0.29 | −0.68 | E | 1 |
| | | | [419] | | | 6 | 6 | 2.4 | 0.0063 | 0.052 | −1.42 | E | 1 |
| 13. | | $^2D - ^2P°$ | | | | | | | | | | | |
| | | | [346] | | | 6 | 4 | 2.1 | 0.0025 | 0.017 | −1.83 | E | 1 |
| | | | [344] | | | 4 | 4 | 2.6 | 0.0046 | 0.021 | −1.73 | E | 1 |
| 14. | $3s^23d - 3s3p(^1P°)3d$ | $^2D - ^2F°$ | *326* | | | 10 | 14 | 230 | 0.50 | 5.4 | 0.70 | E | 1 |
| | | | [327] | | | 6 | 8 | 220 | 0.48 | 3.1 | 0.46 | E | 1 |
| | | | [324] | | | 4 | 6 | 220 | 0.52 | 2.2 | 0.31 | E | 1 |
| | | | [325] | | | 6 | 6 | 9.8 | 0.016 | 0.10 | −1.03 | E | 1 |
| 15. | | $^2D - ^2D°$ | | | | | | | | | | | |
| | | | [309] | | | 6 | 6 | 160 | 0.23 | 1.4 | 0.14 | E | 1 |
| | | | [308] | | | 4 | 6 | 5.0 | 0.011 | 0.043 | −1.37 | E | 1 |
| 16. | | $^2D - ^2P°$ | | | | | | | | | | | |
| | | | [309] | | | 4 | 2 | 270 | 0.19 | 0.79 | −0.11 | D | 1 |

Cr XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17. | $3p$–$3d$ | $^2P^\circ$ – $^2D$ | *249.25* | *8000* | *409210* | 6 | 10 | 350 | 0.55 | 2.7 | 0.52 | D | 1 |
| | | | 251.52 | 12000 | 409580 | 4 | 6 | 340 | 0.48 | 1.6 | 0.29 | D | 1 |
| | | | 244.70 | 0 | 408660 | 2 | 4 | 300 | 0.55 | 0.88 | 0.04 | D | 1 |
| | | | [252.11] | 12000 | 408660 | 4 | 4 | 66 | 0.063 | 0.21 | −0.60 | D | 1 |
| 18. | $3s3p^2$–$3s3p(^3P^\circ)3d$ | $^4P$ – $^4F^\circ$ | | | | | | | | | | | |
| | | | [282] | | | 6 | 8 | 1.2 | 0.0020 | 0.011 | −1.93 | E | 1 |
| | | | [280] | | | 4 | 6 | 0.72 | 0.0013 | 0.0047 | −2.29 | E | 1 |
| 19. | | $^4P$ – $^4P^\circ$ | | | | | | | | | | | |
| | | | [256] | | | 6 | 6 | 34 | 0.034 | 0.17 | −0.70 | D | 1 |
| | | | [244] | | | 2 | 2 | 12 | 0.011 | 0.017 | −1.67 | D | 1 |
| | | | [247] | | | 4 | 2 | 240 | 0.11 | 0.36 | −0.35 | D | 1 |
| | | | [252] | | | 4 | 6 | 200 | 0.28 | 0.94 | 0.05 | D | 1 |
| 20. | | $^4P$ – $^4D^\circ$ | | | | | | | | | | | |
| | | | [250] | | | 6 | 8 | 350 | 0.437 | 2.16 | 0.419 | C− | 1 |
| | | | [246] | | | 4 | 6 | 110 | 0.15 | 0.48 | −0.23 | D | 1 |
| | | | [250] | | | 6 | 6 | 220 | 0.20 | 1.0 | 0.08 | D | 1 |
| | | | [247] | | | 2 | 2 | 330 | 0.30 | 0.49 | −0.22 | D | 1 |
| 21. | | $^4P$ – $^2F^\circ$ | | | | | | | | | | | |
| | | | [221] | | | 6 | 8 | 1.9 | 0.0019 | 0.0082 | −1.95 | E | 1 |
| 22. | | $^4P$ – $^2P^\circ$ | | | | | | | | | | | |
| | | | [198] | | | 2 | 4 | 1.6 | 0.0018 | 0.0024 | −2.43 | E | 1 |
| 23. | | $^2D$ – $^4P^\circ$ | | | | | | | | | | | |
| | | | [294] | | | 6 | 6 | 4.9 | 0.0064 | 0.037 | −1.42 | E | 1 |
| 24. | | $^2D$ – $^4D^\circ$ | | | | | | | | | | | |
| | | | [286] | | | 6 | 8 | 1.5 | 0.0025 | 0.014 | −1.83 | E | 1 |
| 25. | | $^2D$ – $^2F^\circ$ | *251* | | | 10 | 14 | 140 | 0.18 | 1.5 | 0.26 | E | 1 |
| | | | [248] | | | 6 | 8 | 140 | 0.17 | 0.84 | 0.01 | E | 1 |
| | | | [254] | | | 4 | 6 | 120 | 0.17 | 0.57 | −0.17 | E | 1 |
| | | | [255] | | | 6 | 6 | 18 | 0.017 | 0.086 | −0.99 | E | 1 |
| 26. | | $^2D$ – $^2P^\circ$ | | | | | | | | | | | |
| | | | [222] | | | 4 | 2 | 0.44 | 1.6(−4)[a] | 4.8(−4) | −3.18 | E | 1 |
| 27. | | $^2S$ – $^2P^\circ$ | *258* | | | 2 | 6 | 280 | 0.82 | 1.4 | 0.22 | D | 1 |
| | | | [259] | | | 2 | 4 | 320 | 0.65 | 1.1 | 0.11 | D | 1 |
| | | | [256] | | | 2 | 2 | 150 | 0.15 | 0.25 | −0.53 | D | 1 |
| 28. | | $^2P$ – $^2P^\circ$ | *275* | | | 6 | 6 | 150 | 0.17 | 0.93 | 0.01 | D | 1 |
| | | | [278] | | | 4 | 4 | 97 | 0.11 | 0.41 | −0.35 | D | 1 |
| | | | [269] | | | 2 | 2 | 210 | 0.23 | 0.40 | −0.35 | D | 1 |
| | | | [274] | | | 4 | 2 | 42 | 0.024 | 0.086 | −1.02 | D | 1 |
| | | | [273] | | | 2 | 4 | 7.7 | 0.017 | 0.031 | −1.46 | D | 1 |

Cr XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | $3s3p^2$–$3s3p(^1P^\circ)3d$ | $^4P$ - $^2F^\circ$ | | | | | | | | | | | |
| | | | [196] | | | 6 | 8 | 1.6 | 0.0012 | 0.0048 | −2.13 | E | 1 |
| 30. | | $^2D$ - $^2F^\circ$ | *217* | | | 10 | 14 | 250 | 0.25 | 1.8 | 0.40 | E | 1 |
| | | | [218] | | | 6 | 8 | 240 | 0.23 | 1.0 | 0.14 | E | 1 |
| | | | [216] | | | 4 | 6 | 240 | 0.25 | 0.72 | 0.01 | E | 1 |
| | | | [217] | | | 6 | 6 | 14 | 0.010 | 0.043 | −1.22 | E | 1 |
| 31. | | $^2D$ - $^2P^\circ$ | | | | | | | | | | | |
| | | | [209] | | | 4 | 2 | 1.7 | 5.5(−4) | 0.0015 | −2.66 | E | 1 |
| 32. | | $^2S$ - $^2P^\circ$ | | | | | | | | | | | |
| | | | [239] | | | 2 | 2 | 160 | 0.13 | 0.21 | −0.57 | D | 1 |
| 33. | | $^2P$ - $^2F^\circ$ | | | | | | | | | | | |
| | | | [265] | | | 4 | 6 | 1.3 | 0.0020 | 0.0070 | −2.10 | E | 1 |
| 34. | | $^2P$ - $^2D^\circ$ | | | | | | | | | | | |
| | | | [254] | | | 4 | 6 | 520 | 0.75 | 2.5 | 0.48 | E | 1 |
| 35. | | $^2P$ - $^2P^\circ$ | | | | | | | | | | | |
| | | | [251] | | | 2 | 2 | 70 | 0.067 | 0.11 | −0.88 | D | 1 |
| | | | [254] | | | 4 | 2 | 75 | 0.0362 | 0.121 | −0.84 | C− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XII

## Forbidden Transitions

Line strengths for magnetic dipole and electric quadrupole transitions within the $3s^23p$ $^2P^\circ$ and $3s3p^2$ $^4P$ terms are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor $2/3$ which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986).

Cr XII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p$–$3p$ | $^2P^\circ$ - $^2P^\circ$ | | | | | | | | | | |
| | | | [8331] | 0 | 12000 | 2 | 4 | M1 | 15.5 | 1.33 | C | 1 |
| | | | " | " | " | 2 | 4 | E2 | 0.0025 | 0.24 | D− | 1 |
| 2. | $3s3p^2$–$3s3p^2$ | $^4P$ - $^4P$ | | | | | | | | | | |
| | | | [15600] | | | 4 | 6 | M1 | 4.24 | 3.58 | C | 1 |
| | | | " | | | 4 | 6 | E2 | 1.1(−4)[a] | 0.36 | D− | 1 |
| | | | [21100] | | | 2 | 4 | M1 | 2.38 | 3.31 | C | 1 |
| | | | " | | | 2 | 4 | E2 | 3.0(−6) | 0.030 | E | 1 |
| | | | [8966] | | | 2 | 6 | E2 | 0.0013 | 0.27 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XIII

Mg Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^2\ ^1S_0$

Ionization Energy: 354.8 eV = 2862000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 49.59 | 14 | 276.4 | 18 | 362.6 | 4 | 449.76 | 7 |
| 67.01 | 13 | 277 | 22 | 363.96 | 3 | 451.7 | 7 |
| 224 | 21 | 279.32 | 16 | 367.9 | 9 | 461.60 | 7 |
| 228 | 20 | 286 | 24 | 368.06 | 3 | 463.2 | 7 |
| 259.68 | 15 | 298 | 19 | 369.13 | 9 | 465.1 | 7 |
| 261.91 | 15 | 328.29 | 2 | 371 | 8 | 482.2 | 1 |
| 262.33 | 15 | 342.69 | 3 | 374 | 12 | 560.11 | 5 |
| 267.73 | 15 | 345 | 23 | 375.1 | 4 | 638 | 10 |
| 268.4 | 15 | 351.14 | 3 | 377.60 | 6 | | |
| 268.9 | 15 | 353.81 | 3 | 385 | 11 | | |
| 270 | 17 | 356.12 | 3 | 437.05 | 7 | | |

Oscillator strengths for the three transitions $3s^2\ ^1S_0$–$3snp\ ^1P_1^\circ$ ($n=3$–5) are the results of the relativistic random phase approximation (RRPA) calculations of Shorer *et al.*,[1] who allowed for correlation within the context of a frozen core. Oscillator strength data of Fawcett,[2] quoted for most transitions of the arrays $3s3p$–$3p^2$, $3s3d$–$3p3d$, $3s3p$–$3s3d$, and $3p^2$–$3p3d$, were derived by means of Hartree-Fock calculations which included relativistic effects and statistical allowance for exchange (HXR); he incorporated correlation effects due to all configurations in the $n=3$ complex. Froese Fischer and Godefroid[3] determined $f$-values for singlet–singlet transitions within the complex by applying a nonrelativistic multiconfiguration Hartree-Fock (MCHF) technique with large-scale allowance for configuration interaction; their resluts are quoted for two transitions of the $3p3d$-$3d^2$ array for which we estimate the contribution of singlet–triplet mixing to the $f$-value to be insignificant. $A$-values for the three intercombination lines tabulated here were calculated by Kastner and Bhatia[4] using a scaled Thomas-Fermi approach that allowed for correlation due to all configurations in the $n=3$ complex.

Transitions involving levels which are indicated in Ref. 2 to be of low purity in $LS$ coupling are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings.

## References

[1]P. Shorer, C. D. Lin, and W. R. Johnson, Phys. Rev. A **16**, 1109 (1977).
[2]B. C. Fawcett, At. Data Nucl. Data Tables **28**, 579 (1983).
[3]C. Froese Fischer and M. Godefroid, Nucl. Instrum. Methods **202**, 307 (1982).
[4]S. O. Kastner and A. K. Bhatia, J. Opt. Soc. Am. **69**, 1391 (1979).

Cr XIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^2$–$3s3p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | 482.2 | 0 | 207400 | 1 | 3 | 0.18 | 0.0019 | 0.0030 | −2.73 | E | 4 |
| 2. | | $^1$S – $^1$P° | 328.29 | 0 | 304610 | 1 | 3 | 186 | 0.902 | 0.975 | −0.045 | B | 1 |
| 3. | $3s3p$–$3p^2$ | $^3$P° – $^3$P | *355.2* | *212100* | *493600* | 9 | 9 | 150 | 0.28 | 2.9 | 0.39 | D | 2 |
| | | | 353.81 | 216600 | 499200 | 5 | 5 | 100 | 0.19 | 1.1 | −0.02 | D | 2 |
| | | | 356.12 | 207400 | 488200 | 3 | 3 | 40 | 0.077 | 0.27 | −0.64 | C | 2 |
| | | | 368.06 | 216600 | 488200 | 5 | 3 | 61 | 0.074 | 0.45 | −0.43 | C | 2 |
| | | | 363.96 | 207400 | 482200 | 3 | 1 | 150 | 0.10 | 0.36 | −0.52 | C | 2 |
| | | | 342.69 | 207400 | 499200 | 3 | 5 | 34 | 0.10 | 0.34 | −0.52 | D | 2 |
| | | | 351.14 | 203400 | 488200 | 1 | 3 | 56 | 0.31 | 0.36 | −0.51 | C | 2 |
| 4. | | $^3$P° – $^1$D | | | | | | | | | | | |
| | | | [375.1] | 216600 | 483150 | 5 | 5 | 13 | 0.027 | 0.17 | −0.86 | E | 4 |
| | | | [362.6] | 207400 | 483150 | 3 | 5 | 6.4 | 0.021 | 0.075 | −1.20 | E | 4 |
| 5. | | $^1$P° – $^1$D | 560.11 | 304610 | 483150 | 3 | 5 | 13 | 0.10 | 0.55 | −0.52 | E | 2 |
| 6. | | $^1$P° – $^1$S | 377.60 | 304610 | 569440 | 3 | 1 | 150 | 0.11 | 0.41 | −0.48 | C | 2 |
| 7. | $3s3d$–$3p3d$ | $^3$D – $^3$F° | *447.2* | *589500* | *813100* | 15 | 21 | 42 | 0.18 | 3.9 | 0.42 | D | 2 |
| | | | 437.05 | 590100 | 818900 | 7 | 9 | 46.4 | 0.171 | 1.72 | 0.078 | C | 2 |
| | | | 449.76 | 589200 | 811500 | 5 | 7 | 35 | 0.15 | 1.1 | −0.12 | C | 2 |
| | | | 461.60 | 588500 | 805100 | 3 | 5 | 28 | 0.15 | 0.68 | −0.35 | D | 2 |
| | | | [451.7] | 590100 | 811500 | 7 | 7 | 6.9 | 0.021 | 0.22 | −0.83 | C | 2 |
| | | | [463.2] | 589200 | 805100 | 5 | 5 | 6.8 | 0.022 | 0.17 | −0.96 | D | 2 |
| | | | [465.1] | 590100 | 805100 | 7 | 5 | 0.13 | 2.9(−4)[a] | 0.0031 | −2.69 | E | 2 |
| 8. | | $^3$D – $^3$P° | | | | | | | | | | | |
| | | | [371] | | | 3 | 1 | 87 | 0.060 | 0.22 | −0.74 | C | 2 |
| 9. | | $^3$D – $^3$D° | | | | | | | | | | | |
| | | | 369.13 | 590100 | 861000 | 7 | 7 | 64 | 0.13 | 1.1 | −0.04 | C | 2 |
| | | | [367.9] | 589200 | 861000 | 5 | 7 | 13 | 0.038 | 0.23 | −0.72 | C | 2 |
| 10. | | $^1$D – $^1$D° | [638] | | | 5 | 5 | 5.9 | 0.036 | 0.38 | −0.74 | D | 2 |
| 11. | | $^1$D – $^1$F° | [385] | | | 5 | 7 | 150 | 0.48 | 3.0 | 0.38 | D | 2 |
| 12. | | $^1$D – $^1$P° | [374] | | | 5 | 3 | 100 | 0.13 | 0.80 | −0.19 | D | 2 |
| 13. | $3s^2$–$3s4p$ | $^1$S – $^1$P° | 67.01 | 0 | 1492000 | 1 | 3 | 1670 | 0.338 | 0.075 | −0.471 | C | 1 |
| 14. | $3s^2$–$3s5p$ | $^1$S – $^1$P° | 49.59 | 0 | 2017000 | 1 | 3 | 990 | 0.109 | 0.0178 | −0.96 | C | 1 |

Cr XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | $3s3p-3s3d$ | $^3P^\circ - ^3D$ | *265.0* | *212100* | *589500* | 9 | 15 | 197 | 0.345 | 2.71 | 0.492 | C | 2 |
| | | | 267.73 | 216600 | 590100 | 5 | 7 | 190 | 0.286 | 1.26 | 0.155 | C | 2 |
| | | | 261.91 | 207400 | 589200 | 3 | 5 | 150 | 0.26 | 0.67 | −0.11 | C | 2 |
| | | | 259.68 | 203400 | 588500 | 1 | 3 | 120 | 0.35 | 0.30 | −0.46 | C | 2 |
| | | | [268.4] | 216600 | 589200 | 5 | 5 | 48 | 0.052 | 0.23 | −0.59 | C | 2 |
| | | | 262.33 | 207400 | 588500 | 3 | 3 | 84 | 0.087 | 0.23 | −0.58 | C | 2 |
| | | | [268.9] | 216600 | 588500 | 5 | 3 | 5.2 | 0.0034 | 0.015 | −1.77 | D | 2 |
| 16. | | $^1P^\circ - ^1D$ | 279.32 | 304610 | 662620 | 3 | 5 | 350 | 0.69 | 1.9 | 0.32 | D | 2 |
| 17. | $3p^2-3p3d$ | $^3P - ^3P^\circ$ | | | | | | | | | | | |
| | | | [270] | | | 3 | 1 | 170 | 0.063 | 0.17 | −0.72 | C | 2 |
| 18. | | $^3P - ^3D^\circ$ | | | | | | | | | | | |
| | | | [276.4] | 499200 | 861000 | 5 | 7 | 220 | 0.35 | 1.6 | 0.24 | D | 2 |
| 19. | | $^1D - ^1D^\circ$ | [298] | | | 5 | 5 | 130 | 0.17 | 0.83 | −0.07 | E | 2 |
| 20. | | $^1D - ^1F^\circ$ | [228] | | | 5 | 7 | 180 | 0.20 | 0.75 | 0.00 | E | 2 |
| 21. | | $^1D - ^1P^\circ$ | [224] | | | 5 | 3 | 2.9 | 0.0013 | 0.0048 | −2.19 | E | 2 |
| 22. | | $^1S - ^1P^\circ$ | [277] | | | 1 | 3 | 210 | 0.73 | 0.67 | −0.14 | C | 2 |
| 23. | $3p3d-3d^2$ | $^1F^\circ - ^1G$ | [345] | | | 7 | 9 | 174 | 0.399 | 3.17 | 0.446 | C− | 3 |
| 24. | | $^1P^\circ - ^1S$ | [286] | | | 3 | 1 | 460 | 0.188 | 0.53 | −0.249 | C− | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XIV

Na Isoelectronic Sequence

Ground State: $1s^22s^22p^63s\ ^2S_{1/2}$

Ionization Energy: 384.171 eV = 3098520 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 36.466 | 6 | 54.164 | 10 | 104.5 | 48 | 217.2 | 51 |
| 38.036 | 5 | 60.699 | 21 | 107.7 | 47 | 217.4 | 62 |
| 39.796 | 17 | 60.756 | 21 | 107.8 | 47 | 221.5 | 43 |
| 40.016 | 17 | 60.761 | 21 | 109.8 | 37 | 221.9 | 43 |
| 40.018 | 17 | 63.324 | 2 | 110.4 | 37 | 222.9 | 43 |
| 40.782 | 4 | 63.539 | 2 | 111.2 | 53 | 223.3 | 70 |
| 40.800 | 4 | 63.935 | 20 | 117.6 | 36 | 223.4 | 70 |
| 41.556 | 15 | 64.005 | 20 | 118.3 | 36 | 238.8 | 69 |
| 41.788 | 15 | 64.045 | 20 | 125.2 | 46 | 239.0 | 69 |
| 41.796 | 15 | 68.594 | 9 | 125.3 | 46 | 241.5 | 74 |
| 42.207 | 14 | 69.213 | 9 | 133.1 | 45 | 241.7 | 74 |
| 42.453 | 14 | 69.247 | 9 | 133.2 | 45 | 286.3 | 56 |
| 44.597 | 13 | 79.126 | 32 | 133.3 | 45 | 287.2 | 56 |
| 44.869 | 13 | 84.631 | 41 | 136.0 | 52 | 289.735 | 7 |
| 44.873 | 13 | 85.012 | 41 | 148.5 | 29 | 297.9 | 61 |
| 45.835 | 12 | 85.020 | 41 | 149.1 | 29 | 300.1 | 61 |
| 46.125 | 12 | 86.060 | 19 | 156.4 | 58 | 300.271 | 7 |
| 46.417 | 26 | 86.169 | 19 | 157.1 | 35 | 300.3 | 61 |
| 46.453 | 26 | 86.185 | 19 | 158.4 | 35 | 301.814 | 7 |
| 46.468 | 3 | 86.911 | 31 | 165.0 | 65 | 346.3 | 68 |
| 46.527 | 3 | 93.006 | 39 | 165.7 | 65 | 346.5 | 68 |
| 48.300 | 25 | 93.432 | 39 | 187.02 | 44 | 346.6 | 68 |
| 48.338 | 25 | 93.467 | 39 | 187.2 | 44 | 363.5 | 60 |
| 48.340 | 25 | 95.997 | 49 | 187.30 | 44 | 367.1 | 60 |
| 48.991 | 24 | 96.061 | 49 | 188.0 | 71 | 389.81 | 1 |
| 49.032 | 24 | 96.330 | 38 | 188.1 | 71 | 400.3 | 73 |
| 50.821 | 11 | 96.824 | 38 | 189.1 | 34 | 400.5 | 73 |
| 51.172 | 11 | 99.443 | 54 | 190.0 | 57 | 400.6 | 73 |
| 51.180 | 11 | 99.453 | 54 | 191.0 | 34 | 411.99 | 1 |
| 52.321 | 23 | 99.473 | 54 | 192.3 | 75 | 413.7 | 67 |
| 52.363 | 23 | 100.88 | 18 | 200.1 | 63 | 414.3 | 67 |
| 52.367 | 23 | 101.05 | 18 | 201.0 | 63 | 415.6 | 67 |
| 53.642 | 22 | 101.42 | 18 | 201.2 | 63 | 789.3 | 33 |
| 53.674 | 22 | 102.7 | 30 | 216.1 | 62 | 819.0 | 33 |
| 53.691 | 22 | 102.8 | 30 | 217.0 | 51 | 823.7 | 33 |
| 53.760 | 10 | 104.4 | 48 | 217.1 | 51 | | |

Strengths of the lines of the $3s$–$3p$ and $3p$–$3d$ transitions were taken from Edlén's interpolation formulae.[1] These were based on the results of Weiss' Hartree-Fock calculations,[2] in which ratios of relativistic Dirac to nonrelativistic line strengths in hydrogenic ions were applied as scaling factors to the nonrelativistic Hartree-Fock line strengths in the corresponding sodiumlike species. Oscillator strengths for the $4p$–$4d$ transitions were derived by Gruzdev and Sherstyuk[3] using the relativistic variant of their effective orbital quantum number method, which utilizes a Coulomb potential in conjunction with a semiempirical orbital quantum number which is determined from experimental energy levels. Strengths of the lines of the $3s$–$4p$ transition were interpolated from the results of the relativistic single-configuration Hartree-Fock calculations of Kim and Desclaux[4] for V XIII and Fe XVI.

Multiplet $f$-values calculated by Biemont[5] using a fully variational Hartree-Fock approach are quoted for numerous transitions $nl$–$n'l'$ ($3 \leqslant n \leqslant 5$; $4 \leqslant n' \leqslant 8$; $l$, $l'=s,p,d,f$). Data for additional transitions (namely, those for which $n > 5$, where $n$ is the principal quantum number of the lower state) can be found in Ref. 5. Whenever wavelengths of individual lines within a multiplet either were available directly or could be determined from the energy levels, the multiplet strength was distributed among the lines according to *LS*-coupling rules, except in cases where the wavelengths of all the lines in the multiplet are identical. The strength of the $3p\ ^2P^\circ - 4s\ ^2S$ multiplet was not distributed between the two lines in the multiplet, however, since the relativistic single-configuration Hartree-Fock calculations of Kim and Cheng[6] indicate that in the corresponding transition in sodiumlike iron the ratio of the two line strengths deviates somewhat from the value that would be obtained in the case of pure *LS* coupling.

Transitions with small *f*-values were generally assigned lower accuracy ratings.

## References


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[2]A. W. Weiss, J. Quant. Spectrosc. Radiat. Transfer **18**, 481 (1977).
[3]P. F. Gruzdev and A. I. Sherstyuk, Opt. Spectrosc. (USSR) **46**, 353 (1979).
[4]Y.-K. Kim and J.-P. Desclaux, Argonne National Laboratory Report ANL–76–88, Part I (1976).
[5]E. Biemont, Astron. Astrophys., Suppl. Ser. **31**, 285 (1978).
[6]Y.-K. Kim and K.-T. Cheng, J. Opt. Soc. Am. **68**, 836 (1978).


Cr XIV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s-3p$ | $^2S - ^2P^\circ$ | *396.94* | 0 | *251930* | 2 | 6 | 60.5 | 0.429 | 1.12 | −0.067 | B | 1 |
| | | | 389.81 | 0 | 256540 | 2 | 4 | 64.1 | 0.292 | 0.750 | −0.233 | B | 1 |
| | | | 411.99 | 0 | 242720 | 2 | 2 | 53.7 | 0.137 | 0.371 | −0.563 | B | 1 |
| 2. | $3s-4p$ | $^2S - ^2P^\circ$ | *63.395* | 0 | *1577410* | 2 | 6 | 1090 | 0.197 | 0.0823 | −0.404 | C+ | *interp.* |
| | | | 63.324 | 0 | 1579180 | 2 | 4 | 1070 | 0.129 | 0.0537 | −0.589 | C+ | *interp.* |
| | | | 63.539 | 0 | 1573860 | 2 | 2 | 1130 | 0.0684 | 0.0286 | −0.864 | C+ | *interp.* |
| 3. | $3s-5p$ | $^2S - ^2P^\circ$ | *46.488* | 0 | *2151100* | 2 | 6 | 660 | 0.064 | 0.020 | −0.89 | C | 5 |
| | | | 46.468 | 0 | 2152000 | 2 | 4 | 660 | 0.042 | 0.013 | −1.07 | C | *ls* |
| | | | 46.527 | 0 | 2149300 | 2 | 2 | 670 | 0.022 | 0.0067 | −1.36 | C | *ls* |
| 4. | $3s-6p$ | $^2S - ^2P^\circ$ | *40.788* | 0 | *2451700* | 2 | 6 | 390 | 0.0292 | 0.0078 | −1.234 | C | 5 |
| | | | 40.782 | 0 | 2452100 | 2 | 4 | 390 | 0.019 | 0.0052 | −1.41 | C | *ls* |
| | | | 40.800 | 0 | 2451000 | 2 | 2 | 390 | 0.0097 | 0.0026 | −1.71 | D | *ls* |
| 5. | $3s-7p$ | $^2S - ^2P^\circ$ | 38.036 | 0 | 2629100 | 2 | 6 | 247 | 0.0161 | 0.00403 | −1.492 | C | 5 |
| 6. | $3s-8p$ | $^2S - ^2P^\circ$ | 36.466 | 0 | 2742300 | 2 | 6 | 167 | 0.0100 | 0.00240 | −1.70 | C | 5 |
| 7. | $3p-3d$ | $^2P^\circ - ^2D$ | *296.77* | *251930* | *588890* | 6 | 10 | 146 | 0.321 | 1.88 | 0.284 | B | 1 |
| | | | 300.271 | 256540 | 589570 | 4 | 6 | 141 | 0.286 | 1.13 | 0.058 | B | 1 |
| | | | 289.735 | 242720 | 587860 | 2 | 4 | 131 | 0.329 | 0.627 | −0.182 | B | 1 |
| | | | 301.814 | 256540 | 587860 | 4 | 4 | 23.0 | 0.0315 | 0.125 | −0.900 | B | 1 |
| 8. | $3p-4s$ | $^2P^\circ - ^2S$ | *81.526* | *251930* | 1478500 | 6 | 2 | 2000 | 0.066 | 0.11 | −0.40 | C | 5 |
| 9. | $3p-4d$ | $^2P^\circ - ^2D$ | *69.008* | *251930* | *1701000* | 6 | 10 | 2340 | 0.278 | 0.379 | 0.222 | C | 5 |
| | | | 69.213 | 256540 | 1701300 | 4 | 6 | 2310 | 0.249 | 0.227 | −0.002 | C | *ls* |
| | | | 68.594 | 242720 | 1700600 | 2 | 4 | 1980 | 0.279 | 0.126 | −0.253 | C | *ls* |
| | | | 69.247 | 256540 | 1700600 | 4 | 4 | 380 | 0.027 | 0.025 | −0.96 | D | *ls* |
| 10. | $3p-5s$ | $^2P^\circ - ^2S$ | *54.028* | *251930* | 2102800 | 6 | 2 | 880 | 0.0129 | 0.0138 | −1.111 | C | 5 |
| | | | 54.164 | 256540 | 2102800 | 4 | 2 | 590 | 0.013 | 0.0092 | −1.29 | C | *ls* |
| | | | 53.760 | 242720 | 2102800 | 2 | 2 | 300 | 0.0130 | 0.00460 | −1.59 | C | *ls* |
| 11. | $3p-5d$ | $^2P^\circ - ^2D$ | *51.054* | *251930* | *2210600* | 6 | 10 | 1400 | 0.091 | 0.092 | −0.26 | C | 5 |
| | | | 51.172 | 256540 | 2210700 | 4 | 6 | 1400 | 0.082 | 0.055 | −0.49 | C | *ls* |
| | | | 50.821 | 242720 | 2210400 | 2 | 4 | 1200 | 0.093 | 0.031 | −0.73 | C | *ls* |
| | | | [51.180] | 256540 | 2210400 | 4 | 4 | 230 | 0.0091 | 0.0061 | −1.44 | D | *ls* |

Cr XIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | 3*p*–6*s* | $^2P^\circ - ^2S$ | *46.030* | *251930* | 2424400 | 6 | 2 | 470 | 0.0050 | 0.0045 | −1.52 | D | 5 |
| | | | 46.125 | 256540 | 2424400 | 4 | 2 | 310 | 0.0049 | 0.0030 | −1.70 | D | *ls* |
| | | | 45.835 | 242720 | 2424400 | 2 | 2 | 160 | 0.0050 | 0.0015 | −2.00 | D | *ls* |
| 13. | 3*p*–6*d* | $^2P^\circ - ^2D$ | *44.779* | *251930* | *2485100* | 6 | 10 | 840 | 0.0421 | 0.0372 | −0.60 | C | 5 |
| | | | 44.869 | 256540 | 2485200 | 4 | 6 | 830 | 0.0377 | 0.0223 | −0.82 | C | *ls* |
| | | | 44.597 | 242720 | 2485000 | 2 | 4 | 710 | 0.0422 | 0.0124 | −1.073 | C | *ls* |
| | | | [44.873] | 256540 | 2485000 | 4 | 4 | 140 | 0.0042 | 0.0025 | −1.77 | D | *ls* |
| 14. | 3*p*–7*s* | $^2P^\circ - ^2S$ | *42.371* | *251930* | 2612000 | 6 | 2 | 290 | 0.0026 | 0.0022 | −1.81 | D | 5 |
| | | | 42.453 | 256540 | 2612000 | 4 | 2 | 200 | 0.0027 | 0.0015 | −1.97 | D | *ls* |
| | | | [42.207] | 242720 | 2612000 | 2 | 2 | 98 | 0.0026 | 7.3(−4)[a] | −2.28 | D | *ls* |
| 15. | 3*p*–7*d* | $^2P^\circ - ^2D$ | *41.712* | *251930* | *2649300* | 6 | 10 | 540 | 0.0233 | 0.0192 | −0.85 | C | 5 |
| | | | 41.788 | 256540 | 2649500 | 4 | 6 | 530 | 0.0209 | 0.0115 | −1.078 | C | *ls* |
| | | | 41.556 | 242720 | 2649100 | 2 | 4 | 450 | 0.023 | 0.0064 | −1.33 | C | *ls* |
| | | | [41.796] | 256540 | 2649100 | 4 | 4 | 90 | 0.0024 | 0.0013 | −2.02 | D | *ls* |
| 16. | 3*p*–8*s* | $^2P^\circ - ^2S$ | | | | 6 | 2 | | 0.0015 | | −2.05 | D | 5 |
| 17. | 3*p*–8*d* | $^2P^\circ - ^2D$ | *39.944* | *251930* | *2755400* | 6 | 10 | 361 | 0.0144 | 0.0114 | −1.063 | C | 5 |
| | | | 40.018 | 256540 | 2755400 | 4 | 6 | 360 | 0.013 | 0.0068 | −1.29 | C | *ls* |
| | | | 39.796 | 242720 | 2755500 | 2 | 4 | 305 | 0.0145 | 0.00380 | −1.54 | C | *ls* |
| | | | [40.016] | 256540 | 2755500 | 4 | 4 | 60 | 0.0014 | 7.6(−4) | −2.24 | D | *ls* |
| 18. | 3*d*–4*p* | $^2D - ^2P^\circ$ | *101.16* | *588890* | *1577410* | 10 | 6 | 485 | 0.0446 | 0.149 | −0.351 | C | 5 |
| | | | 101.05 | 589570 | 1579180 | 6 | 4 | 440 | 0.045 | 0.089 | −0.57 | C | *ls* |
| | | | 101.42 | 587860 | 1573860 | 4 | 2 | 483 | 0.0372 | 0.0497 | −0.83 | C | *ls* |
| | | | [100.88] | 587860 | 1579180 | 4 | 4 | 49 | 0.0075 | 0.0099 | −1.53 | D | *ls* |
| 19. | 3*d*–4*f* | $^2D - ^2F^\circ$ | *86.125* | *588890* | *1750000* | 10 | 14 | 5900 | 0.92 | 2.6 | 0.96 | C | 5 |
| | | | 86.169 | 589570 | 1750100 | 6 | 8 | 5900 | 0.88 | 1.5 | 0.72 | C | *ls* |
| | | | 86.060 | 587860 | 1749900 | 4 | 6 | 5300 | 0.88 | 1.0 | 0.55 | C | *ls* |
| | | | [86.185] | 589570 | 1749900 | 6 | 6 | 390 | 0.043 | 0.074 | −0.58 | D | *ls* |
| 20. | 3*d*–5*p* | $^2D - ^2P^\circ$ | *64.012* | *588890* | *2151100* | 10 | 6 | 190 | 0.0070 | 0.015 | −1.15 | D | 5 |
| | | | 64.005 | 589570 | 2152000 | 6 | 4 | 170 | 0.0071 | 0.0090 | −1.37 | D | *ls* |
| | | | [64.045] | 587860 | 2149300 | 4 | 2 | 190 | 0.0059 | 0.0050 | −1.62 | D | *ls* |
| | | | [63.935] | 587860 | 2152000 | 4 | 4 | 19 | 0.0012 | 0.0010 | −2.32 | E | *ls* |
| 21. | 3*d*–5*f* | $^2D - ^2F^\circ$ | *60.731* | *588890* | *2235500* | 10 | 14 | 2200 | 0.170 | 0.340 | 0.230 | C | 5 |
| | | | 60.756 | 589570 | 2235500 | 6 | 8 | 2190 | 0.162 | 0.194 | −0.013 | C | *ls* |
| | | | 60.699 | 587860 | 2235400 | 4 | 6 | 2050 | 0.170 | 0.136 | −0.167 | C | *ls* |
| | | | [60.761] | 589570 | 2235400 | 6 | 6 | 150 | 0.0081 | 0.0097 | −1.31 | D | *ls* |
| 22. | 3*d*–6*p* | $^2D - ^2P^\circ$ | *53.683* | *588890* | *2451700* | 10 | 6 | 96 | 0.0025 | 0.0044 | −1.60 | D | 5 |
| | | | [53.691] | 589570 | 2452100 | 6 | 4 | 85 | 0.0025 | 0.0026 | −1.83 | D | *ls* |
| | | | [53.674] | 587860 | 2451000 | 4 | 2 | 98 | 0.0021 | 0.0015 | −2.07 | D | *ls* |
| | | | [53.642] | 587860 | 2452100 | 4 | 4 | 9.5 | 4.1(−4) | 2.9(−4) | −2.78 | E | *ls* |

Cr XIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23. | 3d–6f | $^2$D – $^2$F° | *52.345* | *588890* | *2499300* | 10 | 14 | 1100 | 0.063 | 0.11 | −0.20 | C | 5 |
| | | | 52.363 | 589570 | 2499300 | 6 | 8 | 1100 | 0.061 | 0.063 | −0.44 | C | ls |
| | | | 52.321 | 587860 | 2499200 | 4 | 6 | 1000 | 0.064 | 0.044 | −0.59 | C | ls |
| | | | [52.367] | 589570 | 2499200 | 6 | 6 | 73 | 0.0030 | 0.0031 | −1.75 | D | ls |
| 24. | 3d–7p | $^2$D – $^2$P° | *49.015* | *588890* | 2629100 | 10 | 6 | 56 | 0.0012 | 0.0019 | −1.92 | D | 5 |
| | | | [49.032] | 589570 | 2629100 | 6 | 4 | 47 | 0.0011 | 0.0011 | −2.17 | D | ls |
| | | | [48.991] | 587860 | 2629100 | 4 | 2 | 54 | 9.8(−4) | 6.3(−4) | −2.41 | E | ls |
| | | | [48.991] | 587860 | 2629100 | 4 | 4 | 5.6 | 2.0(−4) | 1.3(−4) | −3.09 | E | ls |
| 25. | 3d–7f | $^2$D – $^2$F° | *48.321* | *588890* | *2658400* | 10 | 14 | 640 | 0.0312 | 0.0496 | −0.51 | C | 5 |
| | | | 48.338 | 589570 | 2658400 | 6 | 8 | 630 | 0.0296 | 0.0283 | −0.75 | C | ls |
| | | | 48.300 | 587860 | 2658300 | 4 | 6 | 590 | 0.0311 | 0.0198 | −0.90 | C | ls |
| | | | [48.340] | 589570 | 2658300 | 6 | 6 | 42 | 0.0015 | 0.0014 | −2.06 | D | ls |
| 26. | 3d–8p | $^2$D – $^2$P° | *46.438* | *588890* | 2742300 | 10 | 6 | 36 | 7.0(−4) | 0.0011 | −2.15 | E | 5 |
| | | | [46.453] | 589570 | 2742300 | 6 | 4 | 33 | 7.2(−4) | 6.6(−4) | −2.36 | E | ls |
| | | | [46.417] | 587860 | 2742300 | 4 | 2 | 37 | 6.1(−4) | 3.7(−4) | −2.62 | E | ls |
| | | | [46.417] | 587860 | 2742300 | 4 | 4 | 3.7 | 1.2(−4) | 7.3(−5) | −3.32 | E | ls |
| 27. | 3d–8f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.0180 | | −0.74 | C | 5 |
| 28. | 4s–4p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.60 | | 0.08 | C | 5 |
| 29. | 4s–5p | $^2$S – $^2$P° | *148.7* | 1478500 | *2151100* | 2 | 6 | 217 | 0.216 | 0.211 | −0.365 | C | 5 |
| | | | [148.5] | 1478500 | 2152000 | 2 | 4 | 218 | 0.144 | 0.141 | −0.54 | C | ls |
| | | | [149.1] | 1478500 | 2149300 | 2 | 2 | 210 | 0.071 | 0.070 | −0.85 | C | ls |
| 30. | 4s–6p | $^2$S – $^2$P° | *102.8* | 1478500 | *2451700* | 2 | 6 | 150 | 0.070 | 0.047 | −0.85 | C | 5 |
| | | | [102.7] | 1478500 | 2452100 | 2 | 4 | 140 | 0.046 | 0.031 | −1.04 | C | ls |
| | | | [102.8] | 1478500 | 2451000 | 2 | 2 | 150 | 0.024 | 0.016 | −1.33 | C | ls |
| 31. | 4s–7p | $^2$S – $^2$P° | [86.911] | 1478500 | 2629100 | 2 | 6 | 96 | 0.0327 | 0.0187 | −1.184 | C | 5 |
| 32. | 4s–8p | $^2$S – $^2$P° | [79.126] | 1478500 | 2742300 | 2 | 6 | 66 | 0.0185 | 0.0096 | −1.432 | C | 5 |
| 33. | 4p–4d | $^2$P° – $^2$D | *809.1* | *1577410* | *1701000* | 6 | 10 | 29 | 0.47 | 7.5 | 0.45 | C | 3 |
| | | | [819.0] | 1579180 | 1701300 | 4 | 6 | 28 | 0.42 | 4.5 | 0.23 | C | 3 |
| | | | [789.3] | 1573860 | 1700600 | 2 | 4 | 26 | 0.48 | 2.5 | −0.02 | C | 3 |
| | | | [823.7] | 1579180 | 1700600 | 4 | 4 | 4.5 | 0.046 | 0.50 | −0.74 | C | 3 |
| 34. | 4p–5s | $^2$P° – $^2$S | *190.3* | *1577410* | 2102800 | 6 | 2 | 620 | 0.113 | 0.425 | −0.169 | C | 5 |
| | | | [191.0] | 1579180 | 2102800 | 4 | 2 | 411 | 0.113 | 0.283 | −0.347 | C | ls |
| | | | [189.1] | 1573860 | 2102800 | 2 | 2 | 213 | 0.114 | 0.142 | −0.64 | C | ls |
| 35. | 4p–5d | $^2$P° – $^2$D | *157.9* | *1577410* | *2210600* | 6 | 10 | 379 | 0.236 | 0.74 | 0.151 | C | 5 |
| | | | [158.4] | 1579180 | 2210700 | 4 | 6 | 370 | 0.21 | 0.44 | −0.07 | C | ls |
| | | | [157.1] | 1573860 | 2210400 | 2 | 4 | 330 | 0.24 | 0.25 | −0.32 | C | ls |
| | | | [158.4] | 1579180 | 2210400 | 4 | 4 | 62 | 0.023 | 0.049 | −1.03 | D | ls |
| 36. | 4p–6s | $^2$P° – $^2$S | *118.1* | *1577410* | 2424400 | 6 | 2 | 316 | 0.0220 | 0.051 | −0.88 | C | 5 |
| | | | [118.3] | 1579180 | 2424400 | 4 | 2 | 210 | 0.022 | 0.034 | −1.06 | C | ls |
| | | | [117.6] | 1573860 | 2424400 | 2 | 2 | 110 | 0.022 | 0.017 | −1.36 | C | ls |

Cr XIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37. | 4p–6d | $^2P^\circ - {}^2D$ | *110.2* | *1577410* | *2485100* | 6 | 10 | 270 | 0.083 | 0.18 | −0.30 | C | 5 |
| | | | [110.4] | 1579180 | 2485200 | 4 | 6 | 280 | 0.076 | 0.11 | −0.52 | C | *ls* |
| | | | [109.8] | 1573860 | 2485000 | 2 | 4 | 230 | 0.083 | 0.060 | −0.78 | C | *ls* |
| | | | [110.4] | 1579180 | 2485000 | 4 | 4 | 45 | 0.0083 | 0.012 | −1.48 | D | *ls* |
| 38. | 4p–7s | $^2P^\circ - {}^2S$ | *96.656* | *1577410* | 2612000 | 6 | 2 | 180 | 0.0086 | 0.016 | −1.29 | D | 5 |
| | | | [96.824] | 1579180 | 2612000 | 4 | 2 | 120 | 0.0086 | 0.011 | −1.46 | D | *ls* |
| | | | [96.330] | 1573860 | 2612000 | 2 | 2 | 60 | 0.0084 | 0.0053 | −1.78 | D | *ls* |
| 39. | 4p–7d | $^2P^\circ - {}^2D$ | *93.292* | *1577410* | *2649300* | 6 | 10 | 185 | 0.0402 | 0.074 | −0.62 | C | 5 |
| | | | [93.432] | 1579180 | 2649500 | 4 | 6 | 180 | 0.036 | 0.044 | −0.84 | C | *ls* |
| | | | [93.006] | 1573860 | 2649100 | 2 | 4 | 160 | 0.041 | 0.025 | −1.09 | C | *ls* |
| | | | [93.467] | 1579180 | 2649100 | 4 | 4 | 30 | 0.0040 | 0.0049 | −1.80 | D | *ls* |
| 40. | 4p–8s | $^2P^\circ - {}^2S$ | | | | 6 | 2 | | 0.0044 | | −1.58 | D | 5 |
| 41. | 4p–8d | $^2P^\circ - {}^2D$ | *84.890* | *1577410* | *2755400* | 6 | 10 | 128 | 0.0230 | 0.0386 | −0.86 | C | 5 |
| | | | [85.020] | 1579180 | 2755400 | 4 | 6 | 127 | 0.0207 | 0.0232 | −1.082 | C | *ls* |
| | | | [84.631] | 1573860 | 2755500 | 2 | 4 | 108 | 0.0232 | 0.0129 | −1.334 | C | *ls* |
| | | | [85.012] | 1579180 | 2755500 | 4 | 4 | 21 | 0.0023 | 0.0026 | −2.03 | D | *ls* |
| 42. | 4d–4f | $^2D - {}^2F^\circ$ | | | | 10 | 14 | | 0.122 | | 0.086 | C | 5 |
| 43. | 4d–5p | $^2D - {}^2P^\circ$ | *222.2* | *1701000* | *2151100* | 10 | 6 | 220 | 0.099 | 0.72 | −0.00 | C | 5 |
| | | | [221.9] | 1701300 | 2152000 | 6 | 4 | 200 | 0.098 | 0.43 | −0.23 | C | *ls* |
| | | | [222.9] | 1700600 | 2149300 | 4 | 2 | 220 | 0.082 | 0.24 | −0.49 | C | *ls* |
| | | | [221.5] | 1700600 | 2152000 | 4 | 4 | 22 | 0.016 | 0.048 | −1.18 | D | *ls* |
| 44. | 4d–5f | $^2D - {}^2F^\circ$ | *187.1* | *1701000* | *2235500* | 10 | 14 | 970 | 0.71 | 4.4 | 0.85 | C | 5 |
| | | | 187.30 | 1701300 | 2235500 | 6 | 8 | 960 | 0.68 | 2.5 | 0.61 | C | *ls* |
| | | | 187.02 | 1700600 | 2235400 | 4 | 6 | 930 | 0.73 | 1.8 | 0.47 | C | *ls* |
| | | | [187.2] | 1701300 | 2235400 | 6 | 6 | 67 | 0.035 | 0.13 | −0.68 | D | *ls* |
| 45. | 4d–6p | $^2D - {}^2P^\circ$ | *133.2* | *1701000* | *2451700* | 10 | 6 | 103 | 0.0165 | 0.072 | −0.78 | C | 5 |
| | | | [133.2] | 1701300 | 2452100 | 6 | 4 | 92 | 0.016 | 0.043 | −1.01 | C | *ls* |
| | | | [133.3] | 1700600 | 2451000 | 4 | 2 | 100 | 0.014 | 0.024 | −1.26 | C | *ls* |
| | | | [133.1] | 1700600 | 2452100 | 4 | 4 | 10 | 0.0027 | 0.0048 | −1.96 | D | *ls* |
| 46. | 4d–6f | $^2D - {}^2F^\circ$ | *125.3* | *1701000* | *2499300* | 10 | 14 | 540 | 0.178 | 0.73 | 0.250 | C | 5 |
| | | | [125.3] | 1701300 | 2499300 | 6 | 8 | 540 | 0.17 | 0.42 | 0.01 | C | *ls* |
| | | | [125.2] | 1700600 | 2499200 | 4 | 6 | 500 | 0.18 | 0.29 | −0.15 | C | *ls* |
| | | | [125.3] | 1701300 | 2499200 | 6 | 6 | 36 | 0.0085 | 0.021 | −1.29 | D | *ls* |
| 47. | 4d–7p | $^2D - {}^2P^\circ$ | *107.7* | *1701000* | 2629100 | 10 | 6 | 58 | 0.0060 | 0.021 | −1.22 | D | 5 |
| | | | [107.8] | 1701300 | 2629100 | 6 | 4 | 53 | 0.0061 | 0.013 | −1.44 | D | *ls* |
| | | | [107.7] | 1700600 | 2629100 | 4 | 2 | 57 | 0.0049 | 0.0070 | −1.70 | D | *ls* |
| | | | [107.7] | 1700600 | 2629100 | 4 | 4 | 5.7 | 9.9(−4) | 0.0014 | −2.40 | E | *ls* |
| 48. | 4d–7f | $^2D - {}^2F^\circ$ | *104.4* | *1701000* | *2658400* | 10 | 14 | 320 | 0.074 | 0.25 | −0.13 | C | 5 |
| | | | [104.5] | 1701300 | 2658400 | 6 | 8 | 310 | 0.068 | 0.14 | −0.39 | C | *ls* |
| | | | [104.4] | 1700600 | 2658300 | 4 | 6 | 300 | 0.073 | 0.10 | −0.54 | C | *ls* |
| | | | [104.5] | 1701300 | 2658300 | 6 | 6 | 21 | 0.0034 | 0.0071 | −1.69 | D | *ls* |

Cr XIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49. | 4d–8p | $^2$D – $^2$P° | *96.034* | *1701000* | 2742300 | 10 | 6 | 36 | 0.0030 | 0.0095 | −1.52 | D | 5 |
| | | | [96.061] | 1701300 | 2742300 | 6 | 4 | 33 | 0.0030 | 0.0057 | −1.74 | D | *ls* |
| | | | [95.997] | 1700600 | 2742300 | 4 | 2 | 37 | 0.0025 | 0.0032 | −1.99 | D | *ls* |
| | | | [95.997] | 1700600 | 2742300 | 4 | 4 | 3.6 | 5.0(−4) | 6.3(−4) | −2.70 | E | *ls* |
| 50. | 4d–8f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.0389 | | −0.410 | C | 5 |
| 51. | 4f–5d | $^2$F° – $^2$D | *217.1* | *1750000* | *2210600* | 14 | 10 | 39.8 | 0.0201 | 0.201 | −0.55 | C | 5 |
| | | | [217.1] | 1750100 | 2210700 | 8 | 6 | 38.0 | 0.0201 | 0.115 | −0.79 | C | *ls* |
| | | | [217.2] | 1749900 | 2210400 | 6 | 4 | 40 | 0.019 | 0.080 | −0.95 | C | *ls* |
| | | | [217.0] | 1749900 | 2210700 | 6 | 6 | 1.9 | 0.0013 | 0.0057 | −2.10 | D | *ls* |
| 52. | 4f–6d | $^2$F° – $^2$D | [136.0] | *1750000* | *2485100* | 14 | 10 | 17 | 0.0034 | 0.021 | −1.32 | D | 5 |
| 53. | 4f–7d | $^2$F° – $^2$D | [111.2] | *1750000* | *2649300* | 14 | 10 | 9.1 | 0.0012 | 0.0062 | −1.77 | D | 5 |
| 54. | 4f–8d | $^2$F° – $^2$D | *99.463* | *1750000* | *2755400* | 14 | 10 | 5.4 | 5.7(−4) | 0.0026 | −2.10 | E | 5 |
| | | | [99.473] | 1750100 | 2755400 | 8 | 6 | 5.1 | 5.7(−4) | 0.0015 | −2.34 | E | *ls* |
| | | | [99.443] | 1749900 | 2755500 | 6 | 4 | 5.2 | 5.1(−4) | 0.0010 | −2.52 | E | *ls* |
| | | | [99.453] | 1749900 | 2755400 | 6 | 6 | 0.25 | 3.8(−5) | 7.4(−5) | −3.65 | E | *ls* |
| 55. | 5s–5p | $^2$S – $^2$P° | | | | 2 | 6 | | 0.78 | | 0.19 | C | 5 |
| 56. | 5s–6p | $^2$S – $^2$P° | *286.6* | 2102800 | *2451700* | 2 | 6 | 63 | 0.233 | 0.440 | −0.332 | C | 5 |
| | | | [286.3] | 2102800 | 2452100 | 2 | 4 | 63 | 0.155 | 0.293 | −0.51 | C | *ls* |
| | | | [287.2] | 2102800 | 2451000 | 2 | 2 | 63 | 0.078 | 0.147 | −0.81 | C | *ls* |
| 57. | 5s–7p | $^2$S – $^2$P° | [190.0] | 2102800 | 2629100 | 2 | 6 | 47 | 0.076 | 0.095 | −0.82 | C | 5 |
| 58. | 5s–8p | $^2$S – $^2$P° | [156.4] | 2102800 | 2742300 | 2 | 6 | 32.7 | 0.0360 | 0.0371 | −1.143 | C | 5 |
| 59. | 5p–5d | $^2$P° – $^2$D | | | | 6 | 10 | | 0.67 | | 0.60 | C | 5 |
| 60. | 5p–6s | $^2$P° – $^2$S | *365.9* | *2151100* | 2424400 | 6 | 2 | 241 | 0.161 | 1.16 | −0.015 | C | 5 |
| | | | [367.1] | 2152000 | 2424400 | 4 | 2 | 160 | 0.16 | 0.77 | −0.20 | C | *ls* |
| | | | [363.5] | 2149300 | 2424400 | 2 | 2 | 82 | 0.162 | 0.387 | −0.490 | C | *ls* |
| 61. | 5p–6d | $^2$P° – $^2$D | *299.4* | *2151100* | *2485100* | 6 | 10 | 98 | 0.219 | 1.30 | 0.119 | C | 5 |
| | | | [300.1] | 2152000 | 2485200 | 4 | 6 | 97 | 0.20 | 0.78 | −0.10 | C | *ls* |
| | | | [297.9] | 2149300 | 2485000 | 2 | 4 | 83 | 0.221 | 0.433 | −0.355 | C | *ls* |
| | | | [300.3] | 2152000 | 2485000 | 4 | 4 | 16 | 0.022 | 0.087 | −1.06 | D | *ls* |
| 62. | 5p–7s | $^2$P° – $^2$S | *217.0* | *2151100* | 2612000 | 6 | 2 | 133 | 0.0313 | 0.134 | −0.73 | C | 5 |
| | | | [217.4] | 2152000 | 2612000 | 4 | 2 | 88 | 0.031 | 0.089 | −0.91 | C | *ls* |
| | | | [216.1] | 2149300 | 2612000 | 2 | 2 | 44.9 | 0.0314 | 0.0447 | −1.202 | C | *ls* |
| 63. | 5p–7d | $^2$P° – $^2$D | *200.7* | *2151100* | *2649300* | 6 | 10 | 78 | 0.079 | 0.31 | −0.32 | C | 5 |
| | | | [201.0] | 2152000 | 2649500 | 4 | 6 | 79 | 0.072 | 0.19 | −0.54 | C | *ls* |
| | | | [200.1] | 2149300 | 2649100 | 2 | 4 | 63 | 0.076 | 0.10 | −0.82 | C | *ls* |
| | | | [201.2] | 2152000 | 2649100 | 4 | 4 | 13 | 0.0079 | 0.021 | −1.50 | D | *ls* |
| 64. | 5p–8s | $^2$P° – $^2$S | | | | 6 | 2 | | 0.0123 | | −1.132 | C | 5 |

Cr XIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65. | $5p$–$8d$ | $^2P^\circ$ – $^2D$ | 165.5 | 2151100 | 2755400 | 6 | 10 | 57 | 0.0392 | 0.128 | −0.63 | C | 5 |
| | | | [165.7] | 2152000 | 2755400 | 4 | 6 | 57 | 0.035 | 0.077 | −0.85 | C | *ls* |
| | | | [165.0] | 2149300 | 2755500 | 2 | 4 | 48.1 | 0.0393 | 0.0427 | −1.105 | C | *ls* |
| | | | [165.7] | 2152000 | 2755500 | 4 | 4 | 9.5 | 0.0039 | 0.0085 | −1.81 | D | *ls* |
| 66. | $5d$–$5f$ | $^2D$ – $^2F^\circ$ | | | | 10 | 14 | | 0.214 | | 0.330 | C | 5 |
| 67. | $5d$–$6p$ | $^2D$ – $^2P^\circ$ | 414.8 | 2210600 | 2451700 | 10 | 6 | 101 | 0.157 | 2.14 | 0.196 | C | 5 |
| | | | [414.3] | 2210700 | 2452100 | 6 | 4 | 91 | 0.156 | 1.28 | −0.028 | C | *ls* |
| | | | [415.6] | 2210400 | 2451000 | 4 | 2 | 100 | 0.13 | 0.71 | −0.28 | C | *ls* |
| | | | [413.7] | 2210400 | 2452100 | 4 | 4 | 10 | 0.026 | 0.14 | −0.99 | D | *ls* |
| 68. | $5d$–$6f$ | $^2D$ – $^2F^\circ$ | 346.4 | 2210600 | 2499300 | 10 | 14 | 250 | 0.63 | 7.2 | 0.80 | C | 5 |
| | | | [346.5] | 2210700 | 2499300 | 6 | 8 | 250 | 0.60 | 4.1 | 0.56 | C | *ls* |
| | | | [346.3] | 2210400 | 2499200 | 4 | 6 | 240 | 0.64 | 2.9 | 0.41 | C | *ls* |
| | | | [346.6] | 2210700 | 2499200 | 6 | 6 | 17 | 0.031 | 0.21 | −0.74 | D | *ls* |
| 69. | $5d$–$7p$ | $^2D$ – $^2P^\circ$ | 238.9 | 2210600 | 2629100 | 10 | 6 | 52 | 0.0269 | 0.212 | −0.57 | C | 5 |
| | | | [239.0] | 2210700 | 2629100 | 6 | 4 | 47.1 | 0.0269 | 0.127 | −0.79 | C | *ls* |
| | | | [238.8] | 2210400 | 2629100 | 4 | 2 | 53 | 0.023 | 0.071 | −1.04 | C | *ls* |
| | | | [238.8] | 2210400 | 2629100 | 4 | 4 | 5.2 | 0.0045 | 0.014 | −1.75 | D | *ls* |
| 70. | $5d$–$7f$ | $^2D$ – $^2F^\circ$ | 223.3 | 2210600 | 2658400 | 10 | 14 | 166 | 0.174 | 1.28 | 0.241 | C | 5 |
| | | | [223.4] | 2210700 | 2658400 | 6 | 8 | 170 | 0.17 | 0.73 | −0.00 | C | *ls* |
| | | | [223.3] | 2210400 | 2658300 | 4 | 6 | 150 | 0.17 | 0.51 | −0.16 | C | *ls* |
| | | | [223.4] | 2210700 | 2658300 | 6 | 6 | 11 | 0.0084 | 0.037 | −1.30 | D | *ls* |
| 71. | $5d$–$8p$ | $^2D$ – $^2P^\circ$ | 188.1 | 2210600 | 2742300 | 10 | 6 | 31.4 | 0.0100 | 0.062 | −1.000 | C | 5 |
| | | | [188.1] | 2210700 | 2742300 | 6 | 4 | 28 | 0.010 | 0.037 | −1.22 | C | *ls* |
| | | | [188.0] | 2210400 | 2742300 | 4 | 2 | 32 | 0.0085 | 0.021 | −1.47 | D | *ls* |
| | | | [188.0] | 2210400 | 2742300 | 4 | 4 | 3.1 | 0.0017 | 0.0041 | −2.18 | D | *ls* |
| 72. | $5d$–$8f$ | $^2D$ – $^2F^\circ$ | | | | 10 | 14 | | 0.077 | | −0.11 | C | 5 |
| 73. | $5f$–$6d$ | $^2F^\circ$ – $^2D$ | 400.6 | 2235500 | 2485100 | 14 | 10 | 28.4 | 0.0488 | 0.90 | −0.165 | C | 5 |
| | | | [400.5] | 2235500 | 2485200 | 8 | 6 | 27 | 0.048 | 0.51 | −0.41 | C | *ls* |
| | | | [400.6] | 2235400 | 2485000 | 6 | 4 | 28 | 0.045 | 0.36 | −0.56 | C | *ls* |
| | | | [400.3] | 2235400 | 2485200 | 6 | 6 | 1.4 | 0.0033 | 0.026 | −1.70 | D | *ls* |
| 74. | $5f$–$7d$ | $^2F^\circ$ – $^2D$ | 241.7 | 2235500 | 2649300 | 14 | 10 | 14 | 0.0086 | 0.096 | −0.92 | D | 5 |
| | | | [241.5] | 2235500 | 2649500 | 8 | 6 | 13 | 0.0086 | 0.055 | −1.16 | D | *ls* |
| | | | [241.7] | 2235400 | 2649100 | 6 | 4 | 14 | 0.0080 | 0.038 | −1.32 | D | *ls* |
| | | | [241.5] | 2235400 | 2649500 | 6 | 6 | 0.65 | 5.7(−4) | 0.0027 | −2.47 | E | *ls* |
| 75. | $5f$–$8d$ | $^2F^\circ$ – $^2D$ | [192.3] | 2235500 | 2755400 | 14 | 10 | 7.8 | 0.0031 | 0.027 | −1.36 | D | 5 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XIV

## Forbidden Transitions

The electric quadrupole *gf*-value for the 3*s*–3*d* multiplet in this sodiumlike ion was reported by Godefroid *et al.*;[1] it was calculated earlier by Biemont and Godefroid[2] using a fully variational Hartree-Fock approach. This *f*-value was converted to a multiplet strength, which was then distributed between the two lines of the multiplet according to *LS*-coupling rules.

### References


[1]M. Godefroid, C. E. Magnusson, P. O. Zetterberg, and I. Joelsson, Phys. Scr. **32**, 125 (1985).

[2]E. Biemont and M. Godefroid, Phys. Scr. **18**, 323 (1978).


Cr XIV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 3*s*–3*d* | $^2$S – $^2$D | | | | | | | | | | |
| | | | [169.62] | 0 | 589570 | 2 | 6 | E2 | 5.5(+5)[a] | 0.277 | C | 1,*ls* |
| | | | [170.11] | 0 | 587860 | 2 | 4 | E2 | 5.5(+5) | 0.185 | C | 1,*ls* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XV

Ne Isoelectronic Sequence

Ground State: $1s^22s^22p^6\ ^1S_0$

Ionization Energy: 1010.6 eV = 8151000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 18.497 | 9 | 102 | 3 | 293 | 13 | 327 | 14 |
| 18.782 | 8 | 102.18 | 1 | 304 | 13 | 405.127 | 11 |
| 19.015 | 7 | 103 | 3 | 309 | 13 | 417 | 16 |
| 20.863 | 6 | 105 | 4 | 321.262 | 15 | 469 | 10 |
| 21.153 | 5 | 111.27 | 2 | 324 | 17 | 703 | 12 |

For resonance transitions to $J = 1$ levels of the $2p^53s$ and $2p^53d$ configurations, we quote *A*-values which were calculated by Vainshtein and Safronova[1] using a charge-expansion perturbation theory approach with allowance for mixing of the $2p^53s$, $2p^53d$, and $2s2p^63p$ configurations. Their results for the $2p^6$–$2p^53d$ transitions in the isoelectronic ions Ar IX and Fe XVII are in rather good agreement with those of Shorer,[2] who used the relativistic random phase approximation (RRPA) with allowance for mixing between configurations of type $2p^5ns$ and $2p^5nd$, as well as correlation effects due to configurations having a vacancy in the 1*s* or 2*s* subshell. But the data of Ref. 1 for the two $2p^6$–$2p^53s$ transitions are approximately a factor of two smaller than those of Shorer for the abovementioned neon-like species, so we have increased the transition probabilities of Ref. 1 for these two lines by a factor of two.

*A*-values quoted here for a number of transitions involving an electron jump of the type 2*s*–2*p*, 3*s*–3*p*, or 3*p*–3*d* were taken from the work of Pokleba and Safronova,[3] who used wavefunctions calculated by a charge-expansion perturbation theory approach with allowance for mixing of configurations in which a single 2*s* or 2*p* electron is excited to an $n=3$ orbital but with no inclusion of configurations in which an electron occupies the $n=4$ shell. In cases where better wavelength data were available, these transition probabilities were first converted to line strengths, which were then reconverted to $f$- and $A$-values by using the more accurate wavelengths. Transitions involving levels of the $2p^53p$ and $2p^53d$ configurations which are indicated by Fawcett[4] (in Ti XII) or by Jupen and Litzen[5] (in Ti XII or Fe XVII) to be of low to moderate purity in *LS* coupling are excluded here, as are very weak lines. The pattern of levels within the $2s2p^63d$ configuration in the isoelectronic ions Fe XVII and Ni XIX resulting from the scaled Thomas-Fermi calculations of Loulergue and Nussbaumer[6] with extensive allowance for correlation is entirely different from that determined by Vainshtein and Safronova, whose energy levels were apparently used by Pokleba and Safronova in their transition probability calculations. We have thus excluded transitions out of these levels from our tabulation.

## References


[1]L. A. Vainshtein and U. I. Safronova, *Spektroskopicheskie Konstanty Atomov*, 5-122 (Ed. V. B. Belyanin, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Nauch. Sov. Spektrosk., Moscow, 1977).

[2]P. Shorer, Phys. Rev. A **20**, 642 (1979).

[3]A. K. Pokleba and U. I. Safronova, Preprint No. 11, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Inst. Spektrosk. (Moscow, 1981).

[4]B. C. Fawcett, private communication, as quoted in E. Träbert, Z. Phys. A **319**, 25 (1984).

[5]C. Jupen and U. Litzen, Phys. Scr. **30**, 112 (1984).

[6]M. Loulergue and H. Nussbaumer, Astron. Astrophys. **45**, 125 (1975).


Cr XV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5(^2P^\circ_{3/2})3s-2s2p^63s$ | $(^3/_2,^1/_2)^\circ-{}^3S$ | | | | | | | | | | | |
| | | | 102.18 | 4713200 | 5691900 | 5 | 3 | 700 | 0.065 | 0.11 | −0.49 | D | 3 |
| 2. | $2s^22p^5(^2P^\circ_{1/2})3s-2s2p^63s$ | $(^1/_2,^1/_2)^\circ-{}^3S$ | | | | | | | | | | | |
| | | | 111.27 | 4793200 | 5691900 | 3 | 3 | 170 | 0.031 | 0.034 | −1.03 | D | 3 |
| 3. | $2s^22p^53p-2s2p^63p$ | $^3S-{}^3P^\circ$ | | | | | | | | | | | |
| | | | [102] | | | 3 | 3 | 160 | 0.025 | 0.025 | −1.13 | E | 3 |
| | | | [103] | | | 3 | 1 | 380 | 0.020 | 0.020 | −1.22 | D | 3 |
| 4. | | $^3D-{}^3P^\circ$ | | | | | | | | | | | |
| | | | [105] | | | 7 | 5 | 530 | 0.063 | 0.15 | −0.36 | D | 3 |
| 5. | $2p^6-2p^5(^2P^\circ_{3/2})3s$ | $^1S-(^3/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 21.153 | 0 | 4727500 | 1 | 3 | 5600 | 0.11 | 0.0078 | −0.95 | C− | 1*n* |
| 6. | $2p^6-2p^5(^2P^\circ_{1/2})3s$ | $^1S-(^1/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 20.863 | 0 | 4793200 | 1 | 3 | 6000 | 0.12 | 0.0081 | −0.93 | C− | 1*n* |
| 7. | $2p^6-2p^53d$ | $^1S-{}^3P^\circ$ | | | | | | | | | | | |
| | | | 19.015 | 0 | 5259000 | 1 | 3 | 630 | 0.010 | 6.4(−4)[a] | −1.99 | E | 1 |
| 8. | | $^1S-{}^3D^\circ$ | | | | | | | | | | | |
| | | | 18.782 | 0 | 5324200 | 1 | 3 | 2.8(+4) | 0.44 | 0.027 | −0.35 | D | 1 |
| 9. | | $^1S-{}^1P^\circ$ | 18.497 | 0 | 5406300 | 1 | 3 | 1.62(+5) | 2.49 | 0.152 | 0.397 | C− | 1 |
| 10. | $2p^5(^2P^\circ_{3/2})3s-2p^53p$ | $(^3/_2,^1/_2)^\circ-{}^3S$ | | | | | | | | | | | |
| | | | [469] | | | 5 | 3 | 25 | 0.049 | 0.38 | −0.61 | D | 3 |

Cr XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11. | | $(^3/_2,^1/_2)^\circ$ - $^3$D | | | | | | | | | | | |
| | | | 405.127 | 4713200 | 4960000 | 5 | 7 | 44 | 0.15 | 1.0 | −0.13 | D | 3 |
| 12. | $2p^5(^2P^\circ_{1/2})3s$–$2p^53p$ | $(^1/_2,^1/_2)^\circ$ - $^3$S | | | | | | | | | | | |
| | | | [703] | | | 1 | 3 | 0.19 | 0.0042 | 0.0098 | −2.37 | E | 3 |
| 13. | $2p^53p$–$2p^53d$ | $^3$S - $^3$P° | *298* | | | 3 | 9 | 56 | 0.22 | 0.66 | −0.17 | E | 3 |
| | | | [293] | | | 3 | 5 | 42 | 0.090 | 0.26 | −0.57 | E | 3 |
| | | | [304] | | | 3 | 3 | 67 | 0.093 | 0.28 | −0.56 | D | 3 |
| | | | [309] | | | 3 | 1 | 79 | 0.038 | 0.12 | −0.95 | D | 3 |
| 14. | | $^3$D - $^3$P° | | | | | | | | | | | |
| | | | [327] | | | 7 | 5 | 3.5 | 0.0040 | 0.030 | −1.55 | E | 3 |
| 15. | | $^3$D - $^3$F° | | | | | | | | | | | |
| | | | 321.262 | 4960000 | 5271300 | 7 | 9 | 81 | 0.16 | 1.2 | 0.05 | D | 3 |
| 16. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | [417] | | | 1 | 3 | 1.7 | 0.013 | 0.018 | −1.88 | D− | 3 |
| 17. | | $^3$P - D° | | | | | | | | | | | |
| | | | [324] | | | 1 | 3 | 39 | 0.18 | 0.20 | −0.73 | D | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Cr XV

### Forbidden Transitions

The $A$-value for the single transition tabulated here is the result of the Hartree-Fock-Relativistic (HFR) calculations of Cowan.[1] The wavelength is the result of these same calculations and may be somewhat uncertain, as the energy of the $J = 0$ level has not been determined experimentally.

### Reference

[1]R. D. Cowan, Los Alamos Scientific Laboratory Informal Report LA-6679-MS (Jan. 1977).

Cr XV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^5(^2P^\circ_{3/2})3s$–$2p^5(^2P^\circ_{1/2})3s$ | $(^3/_2,^1/_2)^\circ$ - $(^1/_2,^1/_2)^\circ$ | | | | | | | | | | |
| | | | [1710] | | | 3 | 1 | M1 | 5200 | 0.96 | D+ | 1 |

# Cr XVI

F Isoelectronic Sequence

Ground State: $1s^22s^22p^5\ ^2P^\circ_{3/2}$

Ionization Energy: 1097 eV = 8850000 $cm^{-1}$

## Allowed Transitions

Oscillator strengths for lines of the multiplet $2s^22p^5\ ^2P^\circ - 2s2p^6\ ^2S$ are the results of the Dirac-Fock calculations of Cheng *et al.*,[1] which included a perturbative treatment of the Breit interaction and the Lamb shift.

For lines of the arrays $2p^5$–$2p^43s$ and $2p^5$–$2p^43d$, we quote the $f$-values calculated by Fawcett[2] using Cowan's Hartree-Fock-Relativistic (HFR) method and incorporating scaling of energy parameters on the basis of a least-squares fit to observed energies. Fawcett's calculations included fairly extensive allowance for configuration mixing in both odd- and even-parity states. Transitions involving levels which are indicated by Fawcett to be of low to moderate purity in $LS$ coupling in neighboring fluorinelike ions are excluded from this compilation, as are lines characterized by very small $f$-values.

The ratio of $A$-values for the two resonance lines out of the $2s2p^6\ ^2S_{1/2}$ level as given in Ref. 1 is in reasonably good agreement with the result of Stratton *et al.*[3] derived from relative-intensity measurements.

### References


[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2] B. C. Fawcett, At. Data Nucl. Data Tables **31**, 495 (1984).

[3] B. C. Stratton, H. W. Moos, S. Suckewer, U. Feldman, J. F. Seely, and A. K. Bhatia, Phys. Rev. A **31**, 2534 (1985).


Cr XVI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8\ s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5$–$2s2p^6$ | $^2P^\circ - {}^2S$ | *109.38* | *23631* | 937910 | 6 | 2 | 1050 | 0.0625 | 0.135 | −0.426 | C+ | 1 |
| | | | 106.62 | 0 | 937910 | 4 | 2 | 758 | 0.0646 | 0.0907 | −0.588 | C+ | 1 |
| | | | 115.33 | 70892 | 937910 | 2 | 2 | 295 | 0.0589 | 0.0447 | −0.929 | C+ | 1 |
| 2. | $2p^5$–$2p^4(^3P)3s$ | $^2P^\circ - {}^4P$ | | | | | | | | | | | |
| | | | 19.807 | 0 | 5048700 | 4 | 6 | 430 | 0.0038 | 9.9(−4)[a] | −1.82 | E | 2 |
| 3. | | $^2P^\circ - {}^2P$ | | | | | | | | | | | |
| | | | 19.714 | 70892 | 5143500 | 2 | 2 | 1.1(+4) | 0.064 | 0.0083 | −0.89 | D | 2 |
| | | | 19.442 | 0 | 5143500 | 4 | 2 | 9900 | 0.028 | 0.0072 | −0.95 | D | 2 |
| 4. | $2p^5$–$2p^4(^1D)3s$ | $^2P^\circ - {}^2D$ | | | | | | | | | | | |
| | | | 19.255 | 0 | 5193500 | 4 | 6 | 7700 | 0.064 | 0.016 | −0.59 | D | 2 |
| | | | 19.511 | 70892 | 5196200 | 2 | 4 | 8800 | 0.10 | 0.013 | −0.70 | D | 2 |
| 5. | $2p^5$–$2p^4(^1S)3s$ | $^2P^\circ - {}^2S$ | *18.868* | *23631* | 5323600 | 6 | 2 | 9200 | 0.016 | 0.0061 | −1.01 | E | 2 |
| | | | 18.775 | 0 | 5323600 | 4 | 2 | 2600 | 0.0068 | 0.0017 | −1.57 | E | 2 |
| | | | 19.038 | 70892 | 5323600 | 2 | 2 | 6400 | 0.035 | 0.0044 | −1.15 | D | 2 |
| 6. | $2p^5$–$2p^4(^1D)3d$ | $^2P^\circ - {}^2S$ | *17.510* | *23631* | 5734600 | 6 | 2 | 1.2(+5) | 0.19 | 0.066 | 0.06 | D | 2 |
| | | | 17.438 | 0 | 5734600 | 4 | 2 | 1.1(+5) | 0.24 | 0.055 | −0.02 | D | 2 |
| | | | [17.656] | 70892 | 5734600 | 2 | 2 | 2.0(+4) | 0.094 | 0.011 | −0.73 | D | 2 |

Cr XVI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7. | | $^2P^\circ$ - $^2P$ | | | | | | | | | | | |
| | | | [17.372] | 0 | 5756300 | 4 | 4 | 1.4(+5) | 0.62 | 0.14 | 0.39 | E | 2 |
| | | | 17.587 | 70892 | 5756300 | 2 | 4 | 2.0(+4) | 0.19 | 0.022 | −0.42 | E | 2 |
| 8. | | $^2P^\circ$ - $^2D$ | | | | | | | | | | | |
| | | | 17.514 | 70892 | 5780600 | 2 | 4 | 1.1(+5) | 0.97 | 0.11 | 0.29 | E | 2 |
| | | | [17.299] | 0 | 5780600 | 4 | 4 | 2.5(+4) | 0.11 | 0.025 | −0.36 | E | 2 |
| 9. | $2p^5$-$2p^4(^1S)3d$ | $^2P^\circ$ - $^2D$ | *17.126* | *23631* | *5862600* | 6 | 10 | 4.0(+4) | 0.30 | 0.10 | 0.25 | E | 2 |
| | | | 17.073 | 0 | 5857200 | 4 | 6 | 1.2(+4) | 0.077 | 0.017 | −0.51 | D | 2 |
| | | | 17.242 | 70892 | 5870700 | 2 | 4 | 8.6(+4) | 0.77 | 0.087 | 0.19 | D | 2 |
| | | | [17.034] | 0 | 5870700 | 4 | 4 | 990 | 0.0043 | 9.6(−4) | −1.76 | E | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XVI

## Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $2p^5$ configuration are the results of the Dirac-Fock calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor $^2/_3$ which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

Cr XVI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^5$-$2p^5$ | $^2P^\circ$ - $^2P^\circ$ | | | | | | | | | | |
| | | | 1410.60 | 0 | 70892 | 4 | 2 | M1 | 6390 | 1.33 | B | 1 |
| | | | " | " | " | 4 | 2 | E2 | 0.45 | 0.0030 | D | 1 |

# Cr XVII

O Isoelectronic Sequence

Ground State: $1s^22s^22p^4\ ^3P_2$

Ionization Energy: 1185 eV = 9560000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 16.11 | 29 | 16.80 | 19 | 18.088 | 12 | 101.91 | 4 |
| 16.27 | 27 | 16.81 | 25 | 18.12 | 15 | 116.53 | 1 |
| 16.31 | 31 | 16.97 | 18,19 | 18.219 | 11 | 117.20 | 6 |
| 16.32 | 24 | 17.19 | 20 | 18.226 | 11 | 120.84 | 1 |
| 16.37 | 28 | 17.59 | 14 | 18.336 | 10,13 | 122.91 | 1 |
| 16.44 | 22,27 | 17.77 | 14 | 18.389 | 17 | 125.00 | 1 |
| 16.59 | 23 | 17.87 | 14 | 18.52 | 9 | 125.35 | 1 |
| 16.62 | 21 | 17.892 | 12 | 18.531 | 10 | 129.78 | 8 |
| 16.64 | 30 | 17.90 | 14 | 18.73 | 9 | 132.76 | 1 |
| 16.65 | 30 | 17.957 | 11 | 89.572 | 2 | 147.40 | 3 |
| 16.66 | 32 | 17.968 | 16 | 94.49 | 2 | 168.08 | 5 |
| 16.68 | 26 | 18.01 | 15 | 94.69 | 2 | | |
| 16.78 | 21 | 18.020 | 11 | 97.20 | 7 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^4$–$2s2p^5$ and $2s2p^5$–$2p^6$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. The results should be quite accurate, except in the case of weak lines. (The $2s^22p^4\ ^1D_2 - 2s2p^5\ ^3P_1^\circ$ transition has been omitted from this tabulation, because its $f$-value as reported in Ref. 1 is extremely small, and thus very uncertain.)

Transition probabilities for lines of the $2s^22p^4$–$2s2p^5$ array were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis set included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these two sources are in reasonably good agreement, particularly for the stronger transitions.

$A$-values for lines of the $2p^4\ ^3P - 2p^3(^4S^\circ)3s\ ^5S^\circ$ multiplet are taken from the scaled Thomas-Fermi approach of Kastner *et al.*[3] with configuration interaction and relativistic effects. For all other lines of the $2p^4$–$2p^33s$ array, and for lines of the $2p^4$–$2p^33d$ array, we quote the $f$-values calculated by Fawcett[4] using Cowan's Hartree-Fock-Relativistic (HFR) method and incorporating scaling of energy parameters on the basis of a least-squares fit to observed energies. Fawcett's calculations included fairly extensive allowance for configuration mixing in both odd- and even-parity states. The weakest lines were not reported, and thus are not tabulated here. Transitions involving levels which are indicated by Fawcett to be of low to moderate purity in $LS$ coupling in neighboring oxygenlike ions are excluded from this compilation.

## References

[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2] C. Froese Fischer and H. P. Saha, J. Phys. B **17**, 943 (1984).
[3] S. O. Kastner, A. K. Bhatia, and L. Cohen, Phys. Scr. **15**, 259 (1977).
[4] B. C. Fawcett, At. Data Nucl. Data Tables **34**, 215 (1986).

Cr XVII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^4–2s2p^5$ | $^3P – ^3P°$ | *123.44* | *26590* | *836710* | 9 | 9 | 450 | 0.10 | 0.38 | −0.03 | C | 1 |
| | | | 122.91 | 0 | 813600 | 5 | 5 | 330 | 0.074 | 0.15 | −0.43 | C | 1 |
| | | | 125.35 | 60380 | 858150 | 3 | 3 | 109 | 0.0257 | 0.0318 | −1.113 | C | 1 |
| | | | 116.53 | 0 | 858150 | 5 | 3 | 244 | 0.0298 | 0.057 | −0.83 | C | 1 |
| | | | 120.84 | 60380 | 887920 | 3 | 1 | 499 | 0.0364 | 0.0434 | −0.96 | C | 1 |
| | | | 132.76 | 60380 | 813600 | 3 | 5 | 93 | 0.0409 | 0.054 | −0.91 | C | 1 |
| | | | 125.00 | 58150 | 858150 | 1 | 3 | 140 | 0.096 | 0.040 | −1.02 | C | 1 |
| 2. | | $^3P – ^1P°$ | | | | | | | | | | | |
| | | | [89.572] | 0 | 1116420 | 5 | 3 | 85 | 0.0061 | 0.0090 | −1.52 | E | 1 |
| | | | 94.69 | 60380 | 1116420 | 3 | 3 | 4.8 | 6.5(−4)[a] | 6.1(−4) | −2.71 | E | 1 |
| | | | 94.49 | 58150 | 1116420 | 1 | 3 | 9.5 | 0.0038 | 0.0012 | −2.42 | E | 1 |
| 3. | | $^1D – ^3P°$ | | | | | | | | | | | |
| | | | 147.40 | 135160 | 813600 | 5 | 5 | 14 | 0.0047 | 0.011 | −1.63 | E | 1 |
| 4. | | $^1D – ^1P°$ | 101.91 | 135160 | 1116420 | 5 | 3 | 1320 | 0.123 | 0.206 | −0.211 | C | 1 |
| 5. | | $^1S – ^3P°$ | | | | | | | | | | | |
| | | | [168.08] | 263180 | 858150 | 1 | 3 | 5.0 | 0.0064 | 0.0035 | −2.19 | E | 1 |
| 6. | | $^1S – ^1P°$ | 117.20 | 263180 | 1116420 | 1 | 3 | 96 | 0.059 | 0.023 | −1.23 | C | 1 |
| 7. | $2s2p^5–2p^6$ | $^3P° – ^1S$ | | | | | | | | | | | |
| | | | 97.20 | 858150 | 1886950 | 3 | 1 | 59 | 0.0028 | 0.0027 | −2.08 | E | 1 |
| 8. | | $^1P° – ^1S$ | 129.78 | 1116420 | 1886950 | 3 | 1 | 1400 | 0.118 | 0.151 | −0.451 | C | 1 |
| 9. | $2p^4–2p^3(^4S°)3s$ | $^3P – ^5S°$ | | | | | | | | | | | |
| | | | [18.52] | | | 5 | 5 | 160 | 8.2(−4) | 2.5(−4) | −2.39 | E | 3 |
| | | | [18.73] | | | 3 | 5 | 12 | 1.1(−4) | 1.9(−5) | −3.50 | E | 3 |
| 10. | $2p^4–2p^3(^4S°)3s$ | $^3P – ^3S°$ | *18.426* | *26590* | 5453800 | 9 | 3 | 2.7(+4) | 0.046 | 0.025 | −0.38 | C− | 4 |
| | | | 18.336 | 0 | 5453800 | 5 | 3 | 1.7(+4) | 0.052 | 0.016 | −0.59 | C− | 4 |
| | | | 18.531 | 60380 | 5453800 | 3 | 3 | 5800 | 0.030 | 0.0055 | −1.05 | C− | 4 |
| | | | 18.531 | 58150 | 5453800 | 1 | 3 | 3200 | 0.050 | 0.0031 | −1.30 | C− | 4 |
| 11. | $2p^4–2p^3(^2D°)3s$ | $^3P – ^3D°$ | | | | | | | | | | | |
| | | | 17.957 | 0 | 5568900 | 5 | 7 | 7800 | 0.053 | 0.016 | −0.58 | C | 4 |
| | | | 18.219 | 60380 | 5549400 | 3 | 5 | 2000 | 0.017 | 0.0031 | −1.29 | D | 4 |
| | | | 18.219 | 58150 | 5547000 | 1 | 3 | 1700 | 0.026 | 0.0016 | −1.59 | D | 4 |
| | | | 18.020 | 0 | 5549400 | 5 | 5 | 6400 | 0.031 | 0.0092 | −0.81 | D | 4 |
| | | | [18.226] | 60380 | 5547000 | 3 | 3 | 7000 | 0.035 | 0.0063 | −0.98 | D | 4 |
| 12. | | $^3P – ^1D°$ | | | | | | | | | | | |
| | | | [17.892] | 0 | 5589000 | 5 | 5 | 960 | 0.0046 | 0.0014 | −1.64 | E | 4 |
| | | | [18.088] | 60380 | 5589000 | 3 | 5 | 1700 | 0.014 | 0.0025 | −1.38 | E | 4 |
| 13. | | $^1D – ^1D°$ | 18.336 | 135160 | 5589000 | 5 | 5 | 1.6(+4) | 0.081 | 0.024 | −0.39 | D | 4 |

Cr XVII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14. | $2p^4 - 2p^3(^2P^\circ)3s$ | $^3P - ^3P^\circ$ | | | | | | | | | | | |
| | | | [17.59] | | | 5 | 5 | 1300 | 0.0060 | 0.0017 | −1.52 | D− | 4 |
| | | | [17.90] | | | 3 | 1 | 7500 | 0.012 | 0.0021 | −1.44 | C | 4 |
| | | | [17.77] | | | 3 | 5 | 4400 | 0.035 | 0.0061 | −0.98 | D | 4 |
| | | | [17.87] | | | 1 | 3 | 4900 | 0.071 | 0.0042 | −1.15 | D | 4 |
| 15. | | $^1D - ^3P^\circ$ | | | | | | | | | | | |
| | | | [18.01] | | | 5 | 5 | 4300 | 0.021 | 0.0062 | −0.98 | E | 4 |
| | | | [18.12] | | | 5 | 3 | 2900 | 0.0086 | 0.0026 | −1.37 | E | 4 |
| 16. | | $^1D - ^1P^\circ$ | 17.968 | 135160 | 5701200 | 5 | 3 | 8600 | 0.025 | 0.0074 | −0.90 | D | 4 |
| 17. | | $^1S - ^1P^\circ$ | 18.389 | 263180 | 5701200 | 1 | 3 | 9200 | 0.14 | 0.0085 | −0.85 | D | 4 |
| 18. | $2p^4 - 2p^3(^4S^\circ)3d$ | $^3P - ^5D^\circ$ | | | | | | | | | | | |
| | | | [16.97] | | | 5 | 5 | 1100 | 0.0046 | 0.0013 | −1.64 | E | 4 |
| 19. | $2p^4 - 2p^3(^4S^\circ)3d$ | $^3P - ^3D^\circ$ | | | | | | | | | | | |
| | | | [16.80] | | | 5 | 7 | 4.4(+4) | 0.26 | 0.072 | 0.11 | D | 4 |
| | | | [16.97] | | | 1 | 3 | 2.63(+4) | 0.341 | 0.0191 | −0.467 | C− | 4 |
| | | | [16.97] | | | 3 | 3 | 1.5(+4) | 0.066 | 0.011 | −0.70 | C− | 4 |
| | | | [16.80] | | | 5 | 3 | 1800 | 0.0046 | 0.0013 | −1.64 | D | 4 |
| 20. | | $^1D - ^3D^\circ$ | | | | | | | | | | | |
| | | | [17.19] | | | 5 | 7 | 680 | 0.0042 | 0.0012 | −1.68 | E | 4 |
| 21. | $2p^4 - 2p^3(^2D^\circ)3d$ | $^3P - ^3F^\circ$ | | | | | | | | | | | |
| | | | [16.78] | | | 3 | 5 | 3600 | 0.025 | 0.0041 | −1.12 | E | 4 |
| | | | [16.62] | | | 5 | 5 | 5600 | 0.023 | 0.0063 | −0.94 | E | 4 |
| 22. | $2p^4 - 2p^3(^2D^\circ)3d$ | $^3P - ^3D^\circ$ | | | | | | | | | | | |
| | | | [16.44] | | | 5 | 7 | 1.3(+5) | 0.74 | 0.20 | 0.57 | D | 4 |
| 23. | | $^3P - ^3P^\circ$ | | | | | | | | | | | |
| | | | [16.59] | | | 3 | 1 | 5.7(+4) | 0.078 | 0.013 | −0.63 | D | 4 |
| 24. | | $^3P - ^1F^\circ$ | | | | | | | | | | | |
| | | | [16.32] | | | 5 | 7 | 3.2(+4) | 0.18 | 0.048 | −0.05 | E | 4 |
| 25. | | $^1D - ^3D^\circ$ | | | | | | | | | | | |
| | | | [16.81] | | | 5 | 7 | 2000 | 0.012 | 0.0033 | −1.22 | E | 4 |
| 26. | | $^1D - ^1F^\circ$ | [16.68] | | | 5 | 7 | 6.8(+4) | 0.40 | 0.11 | 0.30 | D | 4 |
| 27. | $2p^4 - 2p^3(^2D^\circ)3d$ | $^3P - ^3F^\circ$ | | | | | | | | | | | |
| | | | [16.27] | | | 5 | 7 | 5400 | 0.030 | 0.0080 | −0.82 | E | 4 |
| | | | [16.44] | | | 3 | 5 | 5800 | 0.039 | 0.0063 | −0.93 | E | 4 |
| 28. | | $^3P - ^3P^\circ$ | | | | | | | | | | | |
| | | | [16.37] | | | 3 | 1 | 9.7(+4) | 0.13 | 0.021 | −0.41 | D | 4 |

Cr XVII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | | $^3P$ - $^1P^o$ | | | | | | | | | | | |
| | | | [16.11] | | | 3 | 3 | 3900 | 0.015 | 0.0024 | −1.35 | E | 4 |
| 30. | | $^1D$ - $^3F^o$ | | | | | | | | | | | |
| | | | [16.64] | | | 5 | 7 | 5200 | 0.030 | 0.0082 | −0.66 | E | 4 |
| | | | [16.65] | | | 5 | 5 | 1.1(+4) | 0.046 | 0.013 | −0.99 | E | 4 |
| 31. | | $^1D$ - $^1P^o$ | [16.31] | | | 5 | 3 | 9600 | 0.023 | 0.0062 | −0.94 | D | 4 |
| 32. | | $^1S$ - $^1P^o$ | [16.66] | | | 1 | 3 | 1.8(+5) | 2.3 | 0.13 | 0.36 | D | 4 |

[a]The number in parenthesis following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Cr XVII

### Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^4$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

Transition probabilities for these same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these data are in quite good agreement with the data of Cheng *et al*. For this ion of the oxygen isoelectronic sequence, correlation effects due to mixing with configurations outside the complex were found by Froese Fischer and Saha to be rather small, as shown by a comparison of the results of their calculations employing an extensive basis to those derived by the same technique but limited to configurations within the $n=2$ complex.

The weakest lines are excluded from this compilation, as their transition probabilities are considered to be very uncertain.

### References


[1]K. T. Cheng, Y.-K Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).


Cr XVII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | S (at. u.) | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^4$–$2p^4$ | $^3P$ - $^3P$ | | | | | | | | | | |
| | | | 1656.3 | 0 | 60380 | 5 | 3 | M1 | 4590 | 2.32 | C+ | 1 |
| | | | ″ | ″ | ″ | 5 | 3 | E2 | 0.13 | 0.0029 | E | 1 |
| | | | [1720] | 0 | 58150 | 5 | 1 | E2 | 0.19 | 0.0017 | E | 1 |
| 2. | | $^3P$ - $^1D$ | | | | | | | | | | |
| | | | 740.75 | 0 | 135160 | 5 | 5 | M1 | 6600 | 0.50 | D | 1 |
| | | | ″ | ″ | ″ | 5 | 5 | E2 | 2.3 | 0.0015 | E | 1 |
| | | | 1340.7 | 60380 | 135160 | 3 | 5 | M1 | 400 | 0.18 | D | 1 |

Cr XVII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | 493.8 | 60380 | 263180 | 3 | 1 | M1 | 6.5(+4)[a] | 0.29 | D | 1 |
| 4. | | $^1$D - $^1$S | [781.13] | 135160 | 263180 | 5 | 1 | E2 | 28 | 0.0049 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XVIII

N Isoelectronic Sequence

Ground State: $1s^22s^22p^3\ ^4S^\circ_{3/2}$

Ionization Energy: 1299 eV = 10480000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 90.63 | 4 | 108.37 | 2 | 129.53 | 6 | 157.40 | 16 |
| 92.508 | 13 | 110.41 | 12 | 133.08 | 15 | 164.89 | 5 |
| 93.36 | 13 | 112.27 | 14 | 136.52 | 1 | 169.81 | 5 |
| 94.16 | 3 | 113.99 | 12 | 139.87 | 1 | 175.90 | 16 |
| 95.77 | 8 | 119.21 | 12 | 140.82 | 16 | 184.67 | 5 |
| 97.680 | 13 | 119.62 | 11 | 143.53 | 10 | 193.51 | 5 |
| 99.383 | 13 | 122.56 | 14 | 147.79 | 15 | 197.48 | 9 |
| 102.32 | 8 | 123.87 | 14 | 149.80 | 1 | 222.00 | 9 |
| 104.98 | 8 | 125.38 | 11 | 149.94 | 10 | 248.10 | 9 |
| 105.92 | 12 | 125.51 | 6 | 151.90 | 10 | | |
| 106.84 | 7 | 128.10 | 6 | 155.46 | 16 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^3$–$2s2p^4$ and $2s2p^4$–$2p^5$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

### Reference

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

Cr XVIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^3$–$2s2p^4$ | $^4$S° - $^4$P | *144.05* | 0 | *694180* | 4 | 12 | 140 | 0.13 | 0.24 | −0.30 | C | 1 |
| | | | 149.80 | 0 | 667560 | 4 | 6 | 120 | 0.059 | 0.12 | −0.63 | C | 1 |
| | | | 139.87 | 0 | 714950 | 4 | 4 | 149 | 0.0437 | 0.080 | −0.76 | C | 1 |
| | | | 136.52 | 0 | 732490 | 4 | 2 | 166 | 0.0232 | 0.0417 | −1.032 | C | 1 |

Cr XVIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | | $^4S° - ^2D$ | | | | | | | | | | | |
| | | | 108.37 | 0 | 922800 | 4 | 4 | 6.2 | 0.0011 | 0.0016 | −2.36 | E | 1 |
| 3. | | $^4S° - ^2S$ | | | | | | | | | | | |
| | | | 94.16 | 0 | 1062060 | 4 | 2 | 9.2 | 6.1(−4)[a] | 7.6(−4) | −2.61 | E | 1 |
| 4. | | $^4S° - ^2P$ | | | | | | | | | | | |
| | | | 90.63 | 0 | 1103370 | 4 | 4 | 24 | 0.0030 | 0.0036 | −1.92 | E | 1 |
| 5. | | $^2D° - ^4P$ | | | | | | | | | | | |
| | | | [193.51] | 150800 | 667560 | 6 | 6 | 1.4 | 8.0(−4) | 0.0031 | −2.32 | E | 1 |
| | | | [169.81] | 126040 | 714950 | 4 | 4 | 0.42 | 1.8(−4) | 4.0(−4) | −3.14 | E | 1 |
| | | | [164.89] | 126040 | 732490 | 4 | 2 | 1.3 | 2.6(−4) | 5.6(−4) | −2.98 | E | 1 |
| | | | [184.67] | 126040 | 667560 | 4 | 6 | 2.6 | 0.0020 | 0.0049 | −2.10 | E | 1 |
| 6. | | $^2D° - ^2D$ | | | | | | | | | | | |
| | | | 128.10 | 150800 | 931420 | 6 | 6 | 280 | 0.068 | 0.17 | −0.39 | C | 1 |
| | | | 125.51 | 126040 | 922800 | 4 | 4 | 340 | 0.081 | 0.13 | −0.49 | C | 1 |
| | | | [129.53] | 150800 | 922800 | 6 | 4 | 2.9 | 4.9(−4) | 0.0013 | −2.53 | E | 1 |
| 7. | | $^2D° - ^2S$ | | | | | | | | | | | |
| | | | 106.84 | 126040 | 1062060 | 4 | 2 | 340 | 0.029 | 0.041 | −0.94 | E | 1 |
| 8. | | $^2D° - ^2P$ | *101.55* | *140900* | *1125650* | 10 | 6 | 840 | 0.078 | 0.26 | −0.11 | C | 1 |
| | | | 104.98 | 150800 | 1103370 | 6 | 4 | 870 | 0.096 | 0.20 | −0.24 | C | 1 |
| | | | 95.77 | 126040 | 1170210 | 4 | 2 | 308 | 0.0212 | 0.0267 | −1.072 | C | 1 |
| | | | 102.32 | 126040 | 1103370 | 4 | 4 | 154 | 0.0242 | 0.0326 | −1.014 | C | 1 |
| 9. | | $^2P° - ^4P$ | | | | | | | | | | | |
| | | | [248.10] | 264490 | 667560 | 4 | 6 | 0.23 | 3.2(−4) | 0.0010 | −2.89 | E | 1 |
| | | | [222.00] | 264490 | 714950 | 4 | 4 | 1.1 | 8.4(−4) | 0.0025 | −2.47 | E | 1 |
| | | | [197.48] | 226100 | 732490 | 2 | 2 | 1.0 | 5.9(−4) | 7.7(−4) | −2.93 | E | 1 |
| 10. | | $^2P° - ^2D$ | *147.87* | *251690* | *927970* | 6 | 10 | 46 | 0.025 | 0.074 | −0.82 | C− | 1 |
| | | | 149.94 | 264490 | 931420 | 4 | 6 | 53 | 0.0270 | 0.053 | −0.97 | C | 1 |
| | | | 143.53 | 226100 | 922800 | 2 | 4 | 28.5 | 0.0176 | 0.0166 | −1.453 | C | 1 |
| | | | [151.90] | 264490 | 922800 | 4 | 4 | 6.1 | 0.0021 | 0.0042 | −2.08 | D | 1 |
| 11. | | $^2P° - ^2S$ | *123.40* | *251690* | 1062060 | 6 | 2 | 350 | 0.026 | 0.064 | −0.80 | C− | 1 |
| | | | 125.38 | 264490 | 1062060 | 4 | 2 | 53 | 0.0063 | 0.010 | −1.60 | D | 1 |
| | | | 119.62 | 226100 | 1062060 | 2 | 2 | 320 | 0.068 | 0.054 | −0.87 | C | 1 |
| 12. | | $^2P° - ^2P$ | *114.42* | *251690* | *1125650* | 6 | 6 | 360 | 0.071 | 0.16 | −0.37 | C− | 1 |
| | | | 119.21 | 264490 | 1103370 | 4 | 4 | 89 | 0.0190 | 0.0298 | −1.119 | C | 1 |
| | | | 105.92 | 226100 | 1170210 | 2 | 2 | 49 | 0.0083 | 0.0058 | −1.78 | D | 1 |
| | | | 110.41 | 264490 | 1170210 | 4 | 2 | 790 | 0.072 | 0.10 | −0.54 | C | 1 |
| | | | 113.99 | 226100 | 1103370 | 2 | 4 | 70 | 0.0274 | 0.0206 | −1.261 | C | 1 |

Cr XVIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13. | $2s2p^4$-$2p^5$ | $^4P$ - $^2P°$ | | | | | | | | | | | |
| | | | 93.36 | 667560 | 1738700 | 6 | 4 | 17 | 0.0015 | 0.0028 | −2.05 | E | 1 |
| | | | [97.680] | 714950 | 1738700 | 4 | 4 | 7.0 | 0.0010 | 0.0013 | −2.40 | E | 1 |
| | | | [92.508] | 732490 | 1813480 | 2 | 2 | 5.5 | 7.1(−4) | 4.3(−4) | −2.85 | E | 1 |
| | | | [99.383] | 732490 | 1738700 | 2 | 4 | 2.5 | 7.3(−4) | 4.8(−4) | −2.84 | E | 1 |
| 14. | | $^2D$ - $^2P°$ | *119.67* | *927970* | *1763630* | 10 | 6 | 490 | 0.063 | 0.25 | −0.20 | C | 1 |
| | | | 123.87 | 931420 | 1738700 | 6 | 4 | 390 | 0.060 | 0.15 | −0.44 | C | 1 |
| | | | 112.27 | 922800 | 1813480 | 4 | 2 | 424 | 0.0401 | 0.059 | −0.79 | C | 1 |
| | | | 122.56 | 922800 | 1738700 | 4 | 4 | 124 | 0.0280 | 0.0452 | −0.95 | C | 1 |
| 15. | | $^2S$ - $^2P°$ | *142.54* | 1062060 | *1763630* | 2 | 6 | 56 | 0.051 | 0.0476 | −0.99 | C− | 1 |
| | | | 147.79 | 1062060 | 1738700 | 2 | 4 | 72 | 0.0469 | 0.0456 | −1.028 | C | 1 |
| | | | [133.08] | 1062060 | 1813480 | 2 | 2 | 8.7 | 0.0023 | 0.0020 | −2.34 | D | 1 |
| 16. | | $^2P$ - $^2P°$ | *156.74* | *1125650* | *1763630* | 6 | 6 | 367 | 0.135 | 0.418 | −0.091 | C | 1 |
| | | | 157.40 | 1103370 | 1738700 | 4 | 4 | 283 | 0.105 | 0.218 | −0.377 | C | 1 |
| | | | 155.46 | 1170210 | 1813480 | 2 | 2 | 284 | 0.103 | 0.105 | −0.69 | C | 1 |
| | | | [140.82] | 1103370 | 1813480 | 4 | 2 | 266 | 0.0396 | 0.073 | −0.80 | C | 1 |
| | | | [175.90] | 1170210 | 1738700 | 2 | 4 | 20.5 | 0.0190 | 0.0220 | −1.420 | C | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XVIII

## Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^3$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. The weakest lines are excluded from this compilation, as their strengths are considered to be very uncertain.

*A*-values for the M1 and E2 components of the single transition within the $2p^5$ configuration were obtained by applying *Z*-expansion formulas published by Oboladze and Safronova.[2] Their values for the magnetic dipole contribution to this line are in very good agreement with the results of the scaled Thomas-Fermi calculations of Bhatia *et al.*[3] and Bhatia[4] for nitrogenlike Ti and Mn, respectively. It is not clear whether Oboladze and Safronova incorporated configuration interaction into their calculations. Thus the *A*-value for the E2 contribution should be considered rather uncertain.

### References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]N. S. Oboladze and U. I. Safronova, Opt. Spectrosc. (USSR) **48**, 469 (1980).

[3]A. K. Bhatia, U. Feldman, and G. A. Doschek, J. Appl. Phys. **51**, 1464 (1980).

[4]A. K. Bhatia, J. Appl. Phys. **53**, 59 (1982).

Cr XVIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^3$–$2p^3$ | $^4S°$ - $^2D°$ | | | | | | | | | | |
| | | | 663.1 | 0 | 150800 | 4 | 6 | M1 | 320 | 0.021 | D− | 1 |
| | | | 793.3 | 0 | 126040 | 4 | 4 | M1 | 6100 | 0.45 | D | 1 |
| 2. | | $^4S°$ - $^2P°$ | | | | | | | | | | |
| | | | 378.0 | 0 | 264490 | 4 | 4 | M1 | 1.6(+4)[a] | 0.13 | D | 1 |
| | | | 442.1 | 0 | 226100 | 4 | 2 | M1 | 1.3(+4) | 0.084 | D− | 1 |
| 3. | | $^2D°$ - $^2D°$ | | | | | | | | | | |
| | | | 4039 | 126040 | 150800 | 4 | 6 | M1 | 127 | 1.86 | C+ | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 6 | E2 | 4.9(−4) | 0.0019 | E | 1 |
| 4. | | $^2D°$ - $^2P°$ | | | | | | | | | | |
| | | | [1328] | 150800 | 226100 | 6 | 2 | E2 | 0.63 | 0.0031 | E | 1 |
| | | | [879.58] | 150800 | 264490 | 6 | 4 | M1 | 5200 | 0.52 | D | 1 |
| | | | 〃 | 〃 | 〃 | 6 | 4 | E2 | 6.3 | 0.0079 | E | 1 |
| | | | [999.40] | 126040 | 226100 | 4 | 2 | M1 | 3400 | 0.25 | D | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 2 | E2 | 3.0 | 0.0036 | E | 1 |
| | | | 722.1 | 126040 | 264490 | 4 | 4 | M1 | 1.6(+4) | 0.87 | D | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 4 | E2 | 3.0 | 0.0014 | E | 1 |
| 5. | | $^2P°$ - $^2P°$ | | | | | | | | | | |
| | | | 2606.4 | 226100 | 264490 | 2 | 4 | M1 | 382 | 1.00 | C | 1 |
| 6. | $2p^5$–$2p^5$ | $^2P°$ - $^2P°$ | | | | | | | | | | |
| | | | [1337] | 1738700 | 1813480 | 4 | 2 | M1 | 7600 | 1.3 | C+ | 2 |
| | | | 〃 | 〃 | 〃 | 4 | 2 | E2 | 0.53 | 0.0027 | E | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XIX

C Isoelectronic Sequence

Ground State: $1s^22s^22p^2\ ^3P_0$

Ionization Energy: 1396 eV = 11260000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 14.73 | 30 | 107.70 | 5 | 118.83 | 17 | 129.00 | 9 |
| 14.80 | 29 | 109.33 | 18 | 120.86 | 23 | 130.99 | 17 |
| 14.81 | 30 | 109.64 | 4 | 125.93 | 3 | 132.11 | 3 |
| 14.84 | 29 | 110.37 | 11 | 126.24 | 20 | 133.99 | 3 |
| 90.102 | 16 | 111.18 | 18 | 126.30 | 15 | 134.89 | 3 |
| 95.62 | 16 | 111.88 | 5 | 126.33 | 10 | 137.89 | 19 |
| 95.88 | 6 | 113.97 | 4 | 127.95 | 20 | 138.15 | 19 |
| 100.69 | 21 | 118.31 | 17 | 128.43 | 17 | 138.45 | 3 |
| 104.18 | 4 | 118.67 | 17 | 128.63 | 17 | 140.51 | 3 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 140.92 | 19 | 161.29 | 8 | 185.87 | 24 | 236.11 | 26 |
| 143.57 | 28 | 163.94 | 25 | 199.16 | 7 | 267.55 | 12 |
| 148.64 | 2 | 164.09 | 8 | 201.82 | 27 | 278.21 | 26 |
| 151.32 | 14 | 165.46 | 2 | 201.97 | 13 | 280.37 | 1 |
| 152.42 | 19 | 169.40 | 2 | 203.94 | 22 | 310.54 | 1 |
| 154.92 | 19 | 169.73 | 2 | 204.89 | 7 | | |
| 160.01 | 2 | 179.18 | 22 | 205.38 | 7 | | |
| 160.30 | 2 | 180.37 | 22 | 211.00 | 24 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^2$–$2s2p^3$ and $2s2p^3$–$2p^4$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

Transition probabilities for lines of the $2s^22p^2$–$2s2p^3$ array were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these two sources are in reasonably good agreement, particularly for the stronger transitions.

Data for a few lines of the $2p^2$–$2p3d$ array were interpolated from the HX (Hartree-Fock with statistical allowance for exchange) $f$-values of Bromage and Fawcett[3] for the isoelectronic ions Ca XV and Fe XXI.

## References

[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2] C. Froese Fischer and H. P. Saha, Phys. Scr. **32**, 181 (1985).
[3] G. E. Bromage and B. C. Fawcett, Mon. Not. R. Astron. Soc. **178**, 605 (1977).

Cr XIX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm⁻¹) | $E_k$ (cm⁻¹) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s⁻¹) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^2$–$2s2p^3$ | $^3$P - $^5$S° | | | | | | | | | | | |
| | | | [310.54] | 82420 | 404440 | 5 | 5 | 0.17 | 2.5(−4)[a] | 0.0013 | −2.90 | E | 1 |
| | | | [280.37] | 47770 | 404440 | 3 | 5 | 0.15 | 2.9(−4) | 8.0(−4) | −3.06 | E | 1 |
| 2. | | $^3$P - $^3$D° | *162.02* | *61710* | *678920* | 9 | 15 | 72 | 0.0473 | 0.227 | −0.371 | C− | 1 |
| | | | 165.46 | 82420 | 686810 | 5 | 7 | 59 | 0.0339 | 0.092 | −0.77 | C | 1 |
| | | | 160.30 | 47770 | 671590 | 3 | 5 | 83 | 0.053 | 0.084 | −0.80 | C | 1 |
| | | | 148.64 | 0 | 672750 | 1 | 3 | 90 | 0.089 | 0.044 | −1.05 | C | 1 |
| | | | 169.73 | 82420 | 671590 | 5 | 5 | 0.095 | 4.1(−5) | 1.1(−4) | −3.69 | E | 1 |
| | | | 160.01 | 47770 | 672750 | 3 | 3 | 11 | 0.0041 | 0.0065 | −1.91 | D | 1 |
| | | | [169.40] | 82420 | 672750 | 5 | 3 | 0.26 | 6.7(−5) | 1.9(−4) | −3.47 | E | 1 |
| 3. | | $^3$P - $^3$P° | *135.55* | *61710* | *799430* | 9 | 9 | 190 | 0.052 | 0.210 | −0.327 | C− | 1 |
| | | | 138.45 | 82420 | 804690 | 5 | 5 | 171 | 0.0491 | 0.112 | −0.61 | C | 1 |
| | | | 133.99 | 47770 | 794120 | 3 | 3 | 121 | 0.0325 | 0.0430 | −1.011 | C | 1 |
| | | | 140.51 | 82420 | 794120 | 5 | 3 | 35 | 0.0063 | 0.015 | −1.50 | D | 1 |
| | | | 134.89 | 47770 | 789100 | 3 | 1 | 198 | 0.0180 | 0.0240 | −1.268 | C | 1 |
| | | | 132.11 | 47770 | 804690 | 3 | 5 | 7.1 | 0.0031 | 0.0040 | −2.03 | D | 1 |
| | | | 125.93 | 0 | 794120 | 1 | 3 | 40.5 | 0.0289 | 0.0120 | −1.54 | C | 1 |
| 4. | | $^3$P - $^3$S° | *111.34* | *61710* | 959860 | 9 | 3 | 880 | 0.055 | 0.18 | −0.31 | C | 1 |
| | | | 113.97 | 82420 | 959860 | 5 | 3 | 550 | 0.064 | 0.12 | −0.49 | C | 1 |
| | | | 109.64 | 47770 | 959860 | 3 | 3 | 246 | 0.0444 | 0.0481 | −0.88 | C | 1 |
| | | | 104.18 | 0 | 959860 | 1 | 3 | 90 | 0.0438 | 0.0150 | −1.359 | C | 1 |

Cr XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5. | | $^3$P - $^1$D° | | | | | | | | | | | |
| | | | 111.88 | 82420 | 976270 | 5 | 5 | 53 | 0.010 | 0.018 | −1.30 | E | 1 |
| | | | [107.70] | 47770 | 976270 | 3 | 5 | 2.4 | 7.1(−4) | 7.6(−4) | −2.67 | E | 1 |
| 6. | | $^3$P - $^1$P° | | | | | | | | | | | |
| | | | 95.88 | 47770 | 1090760 | 3 | 3 | 36 | 0.0049 | 0.0046 | −1.83 | E | 1 |
| 7. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [199.16] | 184690 | 686810 | 5 | 7 | 6.2 | 0.0052 | 0.017 | −1.59 | E | 1 |
| | | | [205.38] | 184690 | 671590 | 5 | 5 | 0.33 | 2.1(−4) | 7.1(−4) | −2.98 | E | 1 |
| | | | [204.89] | 184690 | 672750 | 5 | 3 | 1.2 | 4.6(−4) | 0.0016 | −2.64 | E | 1 |
| 8. | | $^1$D - $^3$P° | | | | | | | | | | | |
| | | | [161.29] | 184690 | 804690 | 5 | 5 | 1.9 | 7.6(−4) | 0.0020 | −2.42 | E | 1 |
| | | | [164.09] | 184690 | 794120 | 5 | 3 | 2.8 | 6.7(−4) | 0.0018 | −2.47 | E | 1 |
| 9. | | $^1$D - $^3$S° | [129.00] | 184690 | 959860 | 5 | 3 | 0.73 | 1.1(−4) | 2.3(−4) | −3.26 | E | 1 |
| 10. | | $^1$D - $^1$D° | 126.33 | 184690 | 976270 | 5 | 5 | 435 | 0.104 | 0.216 | −0.284 | C | 1 |
| 11. | | $^1$D - $^1$P° | 110.37 | 184690 | 1090760 | 5 | 3 | 600 | 0.066 | 0.12 | −0.48 | C | 1 |
| 12. | | $^1$S - $^3$D° | | | | | | | | | | | |
| | | | [267.55] | 298990 | 672750 | 1 | 3 | 0.37 | 0.0012 | 0.0011 | −2.92 | E | 1 |
| 13. | | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [201.97] | 298990 | 794120 | 1 | 3 | 1.1 | 0.0020 | 0.0013 | −2.70 | E | 1 |
| 14. | | $^1$S - $^3$S° | [151.32] | 298990 | 959860 | 1 | 3 | 4.2 | 0.0043 | 0.0021 | −2.37 | E | 1 |
| 15. | | $^1$S - $^1$P° | 126.30 | 298990 | 1090760 | 1 | 3 | 156 | 0.112 | 0.0466 | −0.95 | C | 1 |
| 16. | $2s2p^3$–$2p^4$ | $^5$S° - $^3$P | | | | | | | | | | | |
| | | | 95.62 | 404440 | 1450200 | 5 | 5 | 7.2 | 9.9(−4) | 0.0016 | −2.31 | E | 1 |
| | | | [90.102] | 404440 | 1514290 | 5 | 3 | 1.8 | 1.3(−4) | 1.9(−4) | −3.19 | E | 1 |
| 17. | | $^3$D° - $^3$P | *124.97* | *678920* | *1479090* | 15 | 9 | 400 | 0.057 | 0.35 | −0.07 | C− | 1 |
| | | | 130.99 | 686810 | 1450200 | 7 | 5 | 290 | 0.053 | 0.16 | −0.43 | C | 1 |
| | | | 118.67 | 671590 | 1514290 | 5 | 3 | 210 | 0.0266 | 0.052 | −0.88 | C | 1 |
| | | | 118.31 | 672750 | 1517960 | 3 | 1 | 329 | 0.0230 | 0.0269 | −1.161 | C | 1 |
| | | | 128.43 | 671590 | 1450200 | 5 | 5 | 119 | 0.0295 | 0.062 | −0.83 | C | 1 |
| | | | 118.83 | 672750 | 1514290 | 3 | 3 | 135 | 0.0286 | 0.0336 | −1.067 | C | 1 |
| | | | 128.63 | 672750 | 1450200 | 3 | 5 | 23 | 0.0097 | 0.012 | −1.54 | D | 1 |
| 18. | | $^3$D° - $^1$D | | | | | | | | | | | |
| | | | 111.18 | 686810 | 1586250 | 7 | 5 | 37 | 0.0049 | 0.013 | −1.46 | E | 1 |
| | | | [109.33] | 671590 | 1586250 | 5 | 5 | 5.5 | 9.8(−4) | 0.0018 | −2.31 | E | 1 |

Cr XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19. | | $^3P^o - {}^3P$ | | | | | | | | | | | |
| | | | 154.92 | 804690 | 1450200 | 5 | 5 | 35.3 | 0.0127 | 0.0324 | −1.197 | C | 1 |
| | | | 140.92 | 804690 | 1514290 | 5 | 3 | 138 | 0.0247 | 0.057 | −0.91 | C | 1 |
| | | | 138.15 | 794120 | 1517960 | 3 | 1 | 175 | 0.0167 | 0.0228 | −1.300 | C | 1 |
| | | | 152.42 | 794120 | 1450200 | 3 | 5 | 32.7 | 0.0190 | 0.0286 | −1.244 | C | 1 |
| | | | 137.89 | 789100 | 1514290 | 1 | 3 | 41.6 | 0.0356 | 0.0162 | −1.449 | C | 1 |
| 20. | | $^3P^o - {}^1D$ | | | | | | | | | | | |
| | | | 127.95 | 804690 | 1586250 | 5 | 5 | 10 | 0.0025 | 0.0053 | −1.90 | E | 1 |
| | | | [126.24] | 794120 | 1586250 | 3 | 5 | 7.0 | 0.0028 | 0.0035 | −2.08 | E | 1 |
| 21. | | $^3P^o - {}^1S$ | | | | | | | | | | | |
| | | | [100.69] | 794120 | 1787280 | 3 | 1 | 26 | 0.0013 | 0.0013 | −2.41 | E | 1 |
| 22. | | $^3S^o - {}^3P$ | *192.59* | 959860 | *1479090* | 3 | 9 | 85 | 0.14 | 0.27 | −0.37 | C | 1 |
| | | | [203.94] | 959860 | 1450200 | 3 | 5 | 63 | 0.065 | 0.13 | −0.71 | C | 1 |
| | | | 180.37 | 959860 | 1514290 | 3 | 3 | 110 | 0.054 | 0.096 | −0.79 | C | 1 |
| | | | 179.18 | 959860 | 1517960 | 3 | 1 | 145 | 0.0232 | 0.0411 | −1.157 | C | 1 |
| 23. | | $^3S^o - {}^1S$ | [120.86] | 959860 | 1787280 | 3 | 1 | 45 | 0.0033 | 0.0039 | −2.00 | E | 1 |
| 24. | | $^1D^o - {}^3P$ | | | | | | | | | | | |
| | | | [211.00] | 976270 | 1450200 | 5 | 5 | 6.3 | 0.0042 | 0.015 | −1.68 | E | 1 |
| | | | [185.87] | 976270 | 1514290 | 5 | 3 | 1.4 | 4.5(−4) | 0.0014 | −2.65 | E | 1 |
| 25. | | $^1D^o - {}^1D$ | 163.94 | 976270 | 1586250 | 5 | 5 | 310 | 0.125 | 0.337 | −0.204 | C | 1 |
| 26. | | $^1P^o - {}^3P$ | | | | | | | | | | | |
| | | | [278.21] | 1090760 | 1450200 | 3 | 5 | 0.88 | 0.0017 | 0.0047 | −2.29 | E | 1 |
| | | | [236.11] | 1090760 | 1514290 | 3 | 3 | 4.7 | 0.0039 | 0.0091 | −1.93 | E | 1 |
| 27. | | $^1P^o - {}^1D$ | 201.82 | 1090760 | 1586250 | 3 | 5 | 41.6 | 0.0423 | 0.084 | −0.90 | C | 1 |
| 28. | | $^1P^o - {}^1S$ | 143.57 | 1090760 | 1787280 | 3 | 1 | 720 | 0.074 | 0.10 | −0.65 | C | 1 |
| 29. | $2p^2$–$2p3d$ | $^3P - {}^3D^o$ | | | | | | | | | | | |
| | | | [14.84] | | | 5 | 7 | 1.3(+5) | 0.61 | 0.15 | 0.48 | E | *interp.* |
| | | | [14.80] | | | 1 | 3 | 1.3(+5) | 1.3 | 0.063 | 0.11 | D | *interp.* |
| 30. | | $^3P - {}^3P^o$ | | | | | | | | | | | |
| | | | [14.73] | | | 3 | 3 | 7.1(+4) | 0.23 | 0.033 | −0.16 | E | *interp.* |
| | | | [14.81] | | | 5 | 3 | 3.4(+4) | 0.068 | 0.017 | −0.47 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XIX

## Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^2$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor $^2/_3$ which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. The weakest lines are excluded from this compilation, as their strengths are considered to be very uncertain.

Transition probabilities for these same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these data are in good agreement with the data of Cheng *et al.*

### References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Scr. **32**, 181 (1985).

Cr XIX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^2$–$2p^2$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | 2885.4 | 47770 | 82420 | 3 | 5 | M1 | 469 | 2.09 | C+ | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.0035 | 0.0021 | E | 1 |
| | | | 2090.9 | 0 | 47770 | 1 | 3 | M1 | 1810 | 1.84 | C+ | 1 |
| | | | [1213] | 0 | 82420 | 1 | 5 | E2 | 0.18 | 0.0014 | E | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | 979.0 | 82420 | 184690 | 5 | 5 | M1 | 5700 | 1.0 | C | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.90 | 0.0024 | E | 1 |
| | | | 731.1 | 47770 | 184690 | 3 | 5 | M1 | 5700 | 0.41 | D | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | 398.4 | 47770 | 298990 | 3 | 1 | M1 | 6.4(+4)[a] | 0.15 | D | 1 |
| 4. | | $^1$D - $^1$S | [874.89] | 184690 | 298990 | 5 | 1 | E2 | 13 | 0.0041 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XX

B Isoelectronic Sequence

Ground State: $1s^22s^22p\ ^2P^\circ_{1/2}$

Ionization Energy: 1496 eV = 12070000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 14.13 | 14 | 128.42 | 3 | 164.63 | 8 | 216.99 | 7 |
| 14.26 | 14 | 129.26 | 9 | 167.97 | 8 | 258.57 | 11 |
| 97.494 | 6 | 131.31 | 9 | 169.87 | 8 | 271.72 | 11 |
| 97.729 | 6 | 133.82 | 4 | 173.42 | 8 | 281.99 | 1 |
| 101.63 | 6 | 135.26 | 9 | 175.42 | 2 | 287.63 | 1 |
| 116.05 | 3 | 140.75 | 4 | 179.21 | 2 | 368.20 | 1 |
| 119.29 | 5 | 148.99 | 4 | 180.85 | 12 | 416.34 | 10 |
| 122.29 | 5 | 156.00 | 2 | 192.82 | 12 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p$–$2s2p^2$ and $2s2p^2$–$2p^3$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

According to several sources (see, e.g., introduction to Fe XXII), the two levels $2s2p^2\ ^2P_{1/2}$ and $^2S_{1/2}$ "cross" at about V XIX or Cr XX. Transitions to these levels in Cr XX have been omitted from this compilation, since the precise location of the level crossing, and thus the correct designations of the levels, are uncertain.

The Hartree-Fock results of Shamey[2] for the isoelectronic ions Ar XIV and Fe XXII, which allowed for limited configuration interaction, were interpolated to provide $f$-values for the $2p$–$3s$, $2p$–$3d$, and $2p$–$4d$ transitions.

### References


[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2] L. J. Shamey, J. Opt. Soc. Am. **61**, 942 (1971).


Cr XX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p$–$2s2p^2$ | $^2P^\circ$ – $^4P$ | | | | | | | | | | | |
| | | | [287.63] | 83030 | 430700 | 4 | 6 | 0.33 | 6.1(−4)[a] | 0.0023 | −2.61 | E | 1 |
| | | | [281.99] | 0 | 354620 | 2 | 2 | 0.42 | 5.0(−4) | 9.3(−4) | −3.00 | E | 1 |
| | | | [368.20] | 83030 | 354620 | 4 | 2 | 0.11 | 1.1(−4) | 5.3(−4) | −3.36 | E | 1 |
| 2. | | $^2P^\circ$ – $^2D$ | *168.66* | *55350* | *648270* | 6 | 10 | 63 | 0.045 | 0.15 | −0.57 | D | 1 |
| | | | 175.42 | 83030 | 653090 | 4 | 6 | 53 | 0.0368 | 0.085 | −0.83 | C | 1 |
| | | | 156.00 | 0 | 641030 | 2 | 4 | 84 | 0.061 | 0.063 | −0.91 | C | 1 |
| | | | 179.21 | 83030 | 641030 | 4 | 4 | 1.1 | 5.4(−4) | 0.0013 | −2.67 | E | 1 |
| 3. | | $^2P^\circ$ – $^2P$ | | | | | | | | | | | |
| | | | 128.42 | 83030 | 861700 | 4 | 4 | 380 | 0.093 | 0.16 | −0.43 | C | 1 |
| | | | 116.05 | 0 | 861700 | 2 | 4 | 57 | 0.0230 | 0.0176 | −1.337 | C | 1 |

Cr XX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | $2s2p^2–2p^3$ | $^4$P – $^4$S° | *143.48* | *404920* | 1101890 | 12 | 4 | 389 | 0.0400 | 0.227 | −0.318 | C | 1 |
| | | | 148.99 | 430700 | 1101890 | 6 | 4 | 175 | 0.0388 | 0.114 | −0.63 | C | 1 |
| | | | 140.75 | 391410 | 1101890 | 4 | 4 | 135 | 0.0400 | 0.074 | −0.80 | C | 1 |
| | | | 133.82 | 354620 | 1101890 | 2 | 4 | 83 | 0.0445 | 0.0392 | −1.051 | C | 1 |
| 5. | | $^4$P – $^2$D° | | | | | | | | | | | |
| | | | 122.29 | 430700 | 1248440 | 6 | 6 | 9.8 | 0.0022 | 0.0053 | −1.88 | E | 1 |
| | | | [119.29] | 391410 | 1229720 | 4 | 4 | 9.8 | 0.0021 | 0.0033 | −2.08 | E | 1 |
| 6. | | $^4$P – $^2$P° | | | | | | | | | | | |
| | | | [101.63] | 430700 | 1414650 | 6 | 4 | 1.1 | 1.1(−4) | 2.2(−4) | −3.18 | E | 1 |
| | | | [97.729] | 391410 | 1414650 | 4 | 4 | 2.0 | 2.8(−4) | 3.6(−4) | −2.95 | E | 1 |
| | | | [97.494] | 354620 | 1380320 | 2 | 2 | 1.5 | 2.1(−4) | 1.3(−4) | −3.38 | E | 1 |
| 7. | | $^2$D – $^4$S° | | | | | | | | | | | |
| | | | [216.99] | 641030 | 1101890 | 4 | 4 | 0.42 | 3.0(−4) | 8.6(−4) | −2.92 | E | 1 |
| 8. | | $^2$D – $^2$D° | *168.73* | *648270* | *1240950* | 10 | 10 | 126 | 0.054 | 0.298 | −0.270 | C | 1 |
| | | | 167.97 | 653090 | 1248440 | 6 | 6 | 112 | 0.0474 | 0.157 | −0.55 | C | 1 |
| | | | 169.87 | 641030 | 1229720 | 4 | 4 | 71 | 0.0306 | 0.068 | −0.91 | C | 1 |
| | | | 173.42 | 653090 | 1229720 | 6 | 4 | 40.3 | 0.0121 | 0.0414 | −1.139 | C | 1 |
| | | | 164.63 | 641030 | 1248440 | 4 | 6 | 24.1 | 0.0147 | 0.0319 | −1.231 | C | 1 |
| 9. | | $^2$D – $^2$P° | *132.46* | *648270* | *1403210* | 10 | 6 | 195 | 0.0307 | 0.134 | −0.51 | C | 1 |
| | | | 131.31 | 653090 | 1414650 | 6 | 4 | 127 | 0.0219 | 0.057 | −0.88 | C | 1 |
| | | | 135.26 | 641030 | 1380320 | 4 | 2 | 241 | 0.0331 | 0.059 | −0.88 | C | 1 |
| | | | 129.26 | 641030 | 1414650 | 4 | 4 | 42.7 | 0.0107 | 0.0182 | −1.369 | C | 1 |
| 10. | | $^2$P – $^4$S° | | | | | | | | | | | |
| | | | [416.34] | 861700 | 1101890 | 4 | 4 | 0.19 | 5.0(−4) | 0.0027 | −2.70 | E | 1 |
| 11. | | $^2$P – $^2$D° | | | | | | | | | | | |
| | | | [258.57] | 861700 | 1248440 | 4 | 6 | 29.8 | 0.0448 | 0.153 | −0.75 | C | 1 |
| | | | 271.72 | 861700 | 1229720 | 4 | 4 | 0.54 | 6.0(−4) | 0.0021 | −2.62 | E | 1 |
| 12. | | $^2$P – $^2$P° | | | | | | | | | | | |
| | | | 180.85 | 861700 | 1414650 | 4 | 4 | 160 | 0.077 | 0.18 | −0.51 | C | 1 |
| | | | 192.82 | 861700 | 1380320 | 4 | 2 | 23 | 0.0065 | 0.017 | −1.59 | D | 1 |
| 13. | $2p–3s$ | $^2$P° – $^2$S | | | | | | | | | | | |
| | | | | | | 4 | 2 | | 0.019 | | −1.12 | E | *interp.* |
| | | | | | | 2 | 2 | | 0.020 | | −1.40 | E | *interp.* |
| 14. | $2p–3d$ | $^2$P° – $^2$D | | | | | | | | | | | |
| | | | [14.26] | | | 4 | 6 | 1.3(+5) | 0.58 | 0.11 | 0.37 | D | *interp.* |
| | | | [14.13] | | | 2 | 4 | 1.1(+5) | 0.65 | 0.060 | 0.11 | D | *interp.* |
| | | | | | | 4 | 4 | | 0.064 | | −0.59 | D | *interp.* |

Cr XX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | $2p$–$4d$ | $^2$P° - $^2$D | | | | | | | | | | | |
| | | | | | | 4 | 6 | | 0.11 | | −0.36 | D | *interp.* |
| | | | | | | 2 | 4 | | 0.12 | | −0.62 | E | *interp.* |
| | | | | | | 4 | 4 | | 0.012 | | −1.32 | D | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XX

## Forbidden Transitions

The line strengths tabulated for the single magnetic dipole and single electric quadrupole transition within the $2s^22p$ ground state configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing is limited to the $n=2$ complex. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 in order to bring this value into conformance with the definition of the quadrupole strength used in the NBS tables.

Transition probabilities for the same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their orbital basis includes many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. The line strengths for both the M1 and E2 transitions, derived from these data by interpolation between appropriately spaced ions of the B sequence, are in very good agreement with the data of Cheng *et al.*[1]

### References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).

Cr XX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p$–$2p$ | $^2$P° - $^2$P° | | | | | | | | | | |
| | | | 1205.9 | 0 | 82926 | 2 | 4 | M1 | 5110 | 1.33 | B | 1 |
| | | | " | " | " | 2 | 4 | E2 | 0.336 | 0.00204 | C | 1 |

# Cr XXI

Be Isoelectronic Sequence

Ground State: $1s^22s^2\ {}^1S_0$

Ionization Energy: 1634 eV = 13180000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 12.87 | 11 | 13.60 | 12,29 | 13.99 | 28 | 140.72 | 4 |
| 12.97 | 11 | 13.65 | 24 | 14.00 | 19 | 149.90 | 2 |
| 12.98 | 10,11 | 13.66 | 29 | 14.04 | 19,25 | 154.62 | 4 |
| 13.01 | 10 | 13.67 | 24 | 14.12 | 30 | 165.03 | 3 |
| 13.02 | 10 | 13.68 | 29 | 14.17 | 19,21 | 168.62 | 3 |
| 13.08 | 9 | 13.75 | 29 | 14.20 | 31 | 170.16 | 7 |
| 13.12 | 8 | 13.76 | 27 | 14.23 | 21 | 175.45 | 3 |
| 13.13 | 10 | 13.78 | 27 | 14.24 | 35 | 184.48 | 3 |
| 13.22 | 16 | 13.84 | 27,33,34 | 14.25 | 21 | 190.98 | 3 |
| 13.34 | 15 | 13.87 | 27 | 14.32 | 21 | 197.61 | 3 |
| 13.44 | 14 | 13.91 | 27 | 14.35 | 21 | 259.94 | 6 |
| 13.49 | 24 | 13.92 | 28 | 14.38 | 22 | 293.11 | 1 |
| 13.53 | 24 | 13.93 | 26 | 14.39 | 21 | 357.12 | 5 |
| 13.55 | 24 | 13.94 | 27 | 14.58 | 20 | 409.80 | 5 |
| 13.59 | 13 | 13.95 | 32 | 14.81 | 23 | 505.89 | 5 |

Oscillator strengths for transitions of the arrays $2s^2$–$2s2p$ and $2s2p$–$2p^2$ are taken from the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include the configuration interaction most relevant for the states of these configurations, as well as a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except for the weakest intercombination lines. (The ${}^3P_1^\circ$ - ${}^1S_0$ transition of the $2s2p$–$2p^2$ array has been omitted here, since the $f$-value is considerably smaller than those of the other lines of this array.)

A number of sources of reliable data, from other relativistic calculations, are available for the $2s$–$2p$ transitions. However, with the exception of some of the weaker lines, they all agree well with the results of Cheng *et al.*[1] The latter are quoted exclusively here since they provide data from a single set of comprehensive calculations, all done at a uniform and reasonably accurate level of approximation, for the valence shell $2s$–$2p$ transitions for all ions of the isoelectronic sequence.

The $f$-values for the $2s^2$–$2s3p$, $2s2p$–$2p3p$, $2s2p$–$2s3s$, $2p^2$–$2p3s$, $2s2p$–$2s3d$, and $2p^2$–$2p3d$ arrays of transitions are taken from the work of Fawcett,[2] who used Cowan's version of the relativistic Hartree-Fock method with intermediate coupling and configuration interaction. This work provides a comprehensive set of data for the entire isoelectronic sequence, calculated at a uniform level of approximation. Some of these transitions, for some ions of this sequence, have also been calculated by Bhatia *et al.*[3] using the program SUPERSTRUCTURE, which includes configuration interaction and intermediate coupling. Where they overlap, these two sets of calculations agree to within the uncertainties assigned here. Transitions involving the $J=1$ levels of $2p3p$ ${}^3S$ and ${}^3P$ have been omitted because of erratic behavior of the $f$-values along the sequence.

Oscillator strengths for the transition array $2s^2$–$2s4p$ have been interpolated from the relativistic random phase approximation (RRPA) calculations along the isoelectronic sequence by Lin and Johnson.[4]

A few multiplet $f$-values for transitions involving the outer electron alone, $2s3s$–$2s3p$ and $2s3p$–$2s3d$, have been interpolated along the isoelectronic sequence and assigned a low accuracy.

## References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]B. C. Fawcett, At. Data Nucl. Data Tables **30**, 1 (1984); **33**, 479 (1985).

[3]A. K. Bhatia, U. Feldman, and J. F. Seely, At. Data Nucl. Data Tables **35**, 449 (1986).

[4]C. D. Lin and W. R. Johnson, Phys. Rev. A **15**, 1046 (1977).

Cr XXI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^2$–$2s2p$ | $^1S$ – $^3P°$ | | | | | | | | | | | |
| | | | [293.11] | 0 | 341170 | 1 | 3 | 0.26 | 0.0010 | 9.6(−4)[a] | −3.00 | D | 1 |
| 2. | | $^1S$ – $^1P°$ | [149.90] | 0 | 667110 | 1 | 3 | 162 | 0.164 | 0.0809 | −0.785 | B | 1 |
| 3. | $2s2p$–$2p^2$ | $^3P°$ – $^3P$ | *181.20* | *374100* | *925980* | 9 | 9 | 117 | 0.0576 | 0.309 | −0.286 | B | 1 |
| | | | [184.48] | 405070 | 947130 | 5 | 5 | 73.7 | 0.0376 | 0.114 | −0.726 | B | 1 |
| | | | [175.45] | 341170 | 911130 | 3 | 3 | 34.2 | 0.0158 | 0.0274 | −1.324 | B | 1 |
| | | | [197.61] | 405070 | 911130 | 5 | 3 | 40.1 | 0.0141 | 0.0459 | −1.152 | B | 1 |
| | | | [190.98] | 341170 | 864780 | 3 | 1 | 109 | 0.0199 | 0.0375 | −1.224 | B | 1 |
| | | | [165.03] | 341170 | 947130 | 3 | 5 | 42.8 | 0.0291 | 0.0474 | −1.059 | B | 1 |
| | | | [168.62] | 318080 | 911130 | 1 | 3 | 52.4 | 0.0670 | 0.0372 | −1.174 | B | 1 |
| 4. | | $^3P°$ – $^1D$ | | | | | | | | | | | |
| | | | [154.62] | 405070 | 1051810 | 5 | 5 | 28.2 | 0.0101 | 0.0257 | −1.297 | C | 1 |
| | | | [140.72] | 341170 | 1051810 | 3 | 5 | 2.4 | 0.0012 | 0.0017 | −2.44 | D | 1 |
| 5. | | $^1P°$ – $^3P$ | | | | | | | | | | | |
| | | | [357.12] | 667110 | 947130 | 3 | 5 | 2.1 | 0.0066 | 0.023 | −1.70 | D | 1 |
| | | | [409.80] | 667110 | 911130 | 3 | 3 | 0.040 | 1.0(−4) | 4.0(−4) | −3.52 | E | 1 |
| | | | [505.89] | 667110 | 864780 | 3 | 1 | 0.19 | 2.4(−4) | 0.0012 | −3.14 | E | 1 |
| 6. | | $^1P°$ – $^1D$ | [259.94] | 667110 | 1051810 | 3 | 5 | 36.5 | 0.0616 | 0.158 | −0.733 | B | 1 |
| 7. | | $^1P°$ – $^1S$ | [170.16] | 667110 | 1254790 | 3 | 1 | 271 | 0.0392 | 0.0659 | −0.930 | B | 1 |
| 8. | $2s^2$–$2s3p$ | $^1S$ – $^3P°$ | | | | | | | | | | | |
| | | | [13.12] | 0 | 7620000 | 1 | 3 | 3.7(+4) | 0.29 | 0.013 | −0.54 | C− | 2 |
| 9. | | $^1S$ – $^1P°$ | [13.08] | 0 | [7648000] | 1 | 3 | 5.2(+4) | 0.40 | 0.017 | −0.40 | C− | 2 |
| 10. | $2s2p$–$2p3p$ | $^3P°$ – $^3D$ | | | | | | | | | | | |
| | | | [13.02] | 405070 | 8087000 | 5 | 7 | 3.9(+4) | 0.14 | 0.030 | −0.15 | C− | 2 |
| | | | [13.02] | 341170 | [8023000] | 3 | 5 | 3.8(+4) | 0.16 | 0.021 | −0.32 | C− | 2 |
| | | | [12.98] | 318080 | [8025000] | 1 | 3 | 1.1(+4) | 0.082 | 0.0035 | −1.09 | D | 2 |
| | | | [13.13] | 405070 | [8023000] | 5 | 5 | 1900 | 0.0050 | 0.0011 | −1.60 | D | 2 |
| | | | [13.01] | 341170 | [8025000] | 3 | 3 | 1.9(+4) | 0.047 | 0.0060 | −0.85 | D | 2 |
| 11. | | $^3P°$ – $^3P$ | | | | | | | | | | | |
| | | | [12.98] | 405070 | 8109000 | 5 | 5 | 3.9(+4) | 0.098 | 0.021 | −0.31 | C− | 2 |
| | | | [12.97] | 341170 | [8049000] | 3 | 1 | 4.8(+4) | 0.040 | 0.0051 | −0.92 | D | 2 |
| | | | [12.87] | 341170 | 8109000 | 3 | 5 | 2700 | 0.011 | 0.0014 | −1.48 | D | 2 |
| 12. | | $^1P°$ – $^1P$ | [13.60] | 667110 | 8022000 | 3 | 3 | 1.6(+4) | 0.043 | 0.0058 | −0.89 | D | 2 |
| 13. | | $^1P°$ – $^3D$ | | | | | | | | | | | |
| | | | [13.59] | 667110 | [8025000] | 3 | 3 | 1.2(+4) | 0.033 | 0.0044 | −1.00 | D | 2 |
| 14. | | $^1P°$ – $^3P$ | | | | | | | | | | | |
| | | | [13.44] | 667110 | 8109000 | 3 | 5 | 1.2(+4) | 0.053 | 0.0070 | −0.80 | D | 2 |
| | | | [13.44] | 667110 | [8109000] | 3 | 3 | 2.5(+4) | 0.067 | 0.0089 | −0.70 | C− | 2 |

Cr XXI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | | $^1$P° - $^1$D | [13.34] | 667110 | [8161000] | 3 | 5 | 5.2(+4) | 0.23 | 0.030 | −0.16 | C− | 2 |
| 16. | | $^1$P° - $^1$S | [13.22] | 667110 | [8231000] | 3 | 1 | 4.6(+4) | 0.040 | 0.0052 | −0.92 | D | 2 |
| 17. | $2s^2$–$2s4p$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | | | | 1 | 3 | | 0.020 | | −1.70 | D | *interp.* |
| 18. | | $^1$S - $^1$P° | | | | 1 | 3 | | 0.16 | | −0.80 | D | *interp.* |
| 19. | $2s2p$–$2s3s$ | $^3$P° - $^3$S | *14.11* | *374100* | 7463000 | 9 | 3 | 2.6(+4) | 0.026 | 0.011 | −0.63 | D | 2 |
| | | | [14.17] | 405070 | 7463000 | 5 | 3 | 1.4(+4) | 0.026 | 0.0061 | −0.89 | D | 2 |
| | | | [14.04] | 341170 | 7463000 | 3 | 3 | 9100 | 0.027 | 0.0037 | −1.09 | D | 2 |
| | | | [14.00] | 318080 | 7463000 | 1 | 3 | 3200 | 0.028 | 0.0013 | −1.55 | D | 2 |
| 20. | | $^1$P° - $^1$S | [14.58] | 667110 | [7526000] | 3 | 1 | 9400 | 0.010 | 0.0014 | −1.52 | D | 2 |
| 21. | $2p^2$–$2p3s$ | $^3$P - $^3$P° | *14.27* | *925980* | *[7933000]* | 9 | 9 | 1.8(+4) | 0.054 | 0.023 | −0.31 | D | 2 |
| | | | [14.25] | 947130 | [7966000] | 5 | 5 | 1.2(+4) | 0.038 | 0.0089 | −0.72 | D | 2 |
| | | | [14.32] | 911130 | [7894000] | 3 | 3 | 3600 | 0.011 | 0.0016 | −1.48 | D | 2 |
| | | | [14.39] | 947130 | [7894000] | 5 | 3 | 8100 | 0.015 | 0.0036 | −1.12 | D | 2 |
| | | | [14.35] | 911130 | [7881000] | 3 | 1 | 1.7(+4) | 0.017 | 0.0024 | −1.29 | D | 2 |
| | | | [14.17] | 911130 | [7966000] | 3 | 5 | 6000 | 0.030 | 0.0042 | −1.05 | D | 2 |
| | | | [14.23] | 864780 | [7894000] | 1 | 3 | 6100 | 0.056 | 0.0026 | −1.25 | D | 2 |
| 22. | | $^1$D - $^1$P° | [14.38] | 1051810 | [8008000] | 5 | 3 | 1.5(+4) | 0.028 | 0.0066 | −0.85 | D | 2 |
| 23. | | $^1$S - $^1$P° | [14.81] | 1254790 | [8008000] | 1 | 3 | 5800 | 0.057 | 0.0028 | −1.24 | D | 2 |
| 24. | $2s2p$–$2s3d$ | $^3$P° - $^3$D | *13.60* | *374100* | *[7728000]* | 9 | 15 | 1.6(+5) | 0.72 | 0.29 | 0.81 | C− | 2 |
| | | | [13.65] | 405070 | 7733000 | 5 | 7 | 1.5(+5) | 0.60 | 0.13 | 0.48 | C− | 2 |
| | | | [13.55] | 341170 | 7721000 | 3 | 5 | 1.2(+5) | 0.55 | 0.074 | 0.22 | C− | 2 |
| | | | [13.49] | 318080 | [7730000] | 1 | 3 | 9.0(+4) | 0.74 | 0.033 | −0.13 | C− | 2 |
| | | | [13.67] | 405070 | 7721000 | 5 | 5 | 3.9(+4) | 0.11 | 0.025 | −0.26 | C− | 2 |
| | | | [13.53] | 341170 | [7730000] | 3 | 3 | 6.6(+4) | 0.18 | 0.024 | −0.27 | C− | 2 |
| | | | [13.65] | 405070 | [7730000] | 5 | 3 | 4300 | 0.0072 | 0.0016 | −1.44 | C− | 2 |
| 25. | | $^1$P° - $^1$D | [14.04] | 667110 | [7792000] | 3 | 5 | 1.2(+5) | 0.61 | 0.085 | 0.26 | C− | 2 |
| 26. | $2p^2$–$2p3d$ | $^3$P - $^3$F° | | | | | | | | | | | |
| | | | [13.93] | 947130 | [8124000] | 5 | 7 | 4.2(+4) | 0.17 | 0.039 | −0.07 | C− | 2 |
| 27. | | $^3$P - $^3$D° | *13.82* | *925980* | *8162000* | 9 | 15 | 1.5(+5) | 0.71 | 0.29 | 0.80 | C− | 2 |
| | | | [13.78] | 947130 | 8204000 | 5 | 7 | 1.7(+5) | 0.68 | 0.15 | 0.53 | C− | 2 |
| | | | [13.87] | 911130 | 8121000 | 3 | 5 | 8.5(+4) | 0.407 | 0.056 | 0.087 | C− | 2 |
| | | | [13.76] | 864780 | 8134000 | 1 | 3 | 1.51(+5) | 1.29 | 0.058 | 0.111 | C− | 2 |
| | | | [13.94] | 947130 | 8121000 | 5 | 5 | 1.1(+4) | 0.032 | 0.0073 | −0.80 | D | 2 |
| | | | [13.84] | 911130 | 8134000 | 3 | 3 | 3.5(+4) | 0.10 | 0.014 | −0.52 | C− | 2 |
| | | | [13.91] | 947130 | 8134000 | 5 | 3 | 1000 | 0.0018 | 4.1(−4) | −2.05 | D | 2 |
| 28. | | $^3$P - $^1$D° | | | | | | | | | | | |
| | | | [13.99] | 947130 | [8093000] | 5 | 5 | 8200 | 0.024 | 0.0055 | −0.92 | C− | 2 |
| | | | [13.92] | 911130 | [8093000] | 3 | 5 | 8.5(+4) | 0.41 | 0.056 | 0.09 | D | 2 |

Cr XXI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ (10$^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | | $^3$P - $^3$P° | *13.71* | *925980* | *[8220000]* | 9 | 9 | 1.15(+5) | 0.325 | 0.132 | 0.466 | C− | 2 |
| | | | [13.75] | 947130 | 8219000 | 5 | 5 | 9.5(+4) | 0.270 | 0.061 | 0.130 | C− | 2 |
| | | | [13.68] | 911130 | 8219000 | 3 | 3 | 8.2(+4) | 0.23 | 0.031 | −0.16 | C− | 2 |
| | | | [13.75] | 947130 | 8219000 | 5 | 3 | 4.5(+4) | 0.076 | 0.017 | −0.42 | C− | 2 |
| | | | [13.66] | 911130 | [8231000] | 3 | 1 | 1.2(+5) | 0.11 | 0.015 | −0.48 | C− | 2 |
| | | | [13.68] | 911130 | 8219000 | 3 | 5 | 1.2(+4) | 0.057 | 0.0077 | −0.77 | D | 2 |
| | | | [13.60] | 864780 | 8219000 | 1 | 3 | 610 | 0.0051 | 2.3(−4) | −2.29 | D | 2 |
| 30. | | $^1$D - $^3$F° | | | | | | | | | | | |
| | | | [14.12] | 1051810 | [8132000] | 5 | 5 | 7400 | 0.022 | 0.0051 | −0.96 | D | 2 |
| 31. | | $^1$D - $^1$D° | [14.20] | 1051810 | [8093000] | 5 | 5 | 1.7(+4) | 0.050 | 0.012 | −0.60 | C− | 2 |
| 32. | | $^1$D - $^3$P° | | | | | | | | | | | |
| | | | [13.95] | 1051810 | 8219000 | 5 | 5 | 3.8(+4) | 0.11 | 0.025 | −0.26 | C− | 2 |
| 33. | | $^1$D - $^1$P° | [13.84] | 1051810 | 8275000 | 5 | 3 | 8700 | 0.015 | 0.0034 | −1.12 | D | 2 |
| 34. | | $^1$D - $^1$F° | [13.84] | 1051810 | 8275000 | 5 | 7 | 2.59(+5) | 1.04 | 0.237 | 0.72 | C− | 2 |
| 35. | | $^1$S - $^1$P° | [14.24] | 1254790 | 8275000 | 1 | 3 | 1.41(+5) | 1.29 | 0.060 | 0.111 | C− | 2 |
| 36. | $2s3s$–$2s3p$ | $^3$S - $^3$P° | | | | 3 | 9 | | 0.13 | | −0.41 | D | *interp.* |
| 37. | | $^1$S - $^1$P° | | | | 1 | 3 | | 0.056 | | −1.25 | E | *interp.* |
| 38. | $2s3p$–$2s3d$ | $^3$P° - $^3$D | | | | 9 | 15 | | 0.029 | | −0.58 | E | *interp.* |
| 39. | | $^1$P° - $^1$D | | | | 3 | 5 | | 0.052 | | −0.81 | E | *interp.* |

[a]The number in parentheses following the tabulated vlaue indicates the power of ten by which this value has to be multiplied.

# Cr XXI

## Forbidden Transitions

Transition probabilities for magnetic dipole and electric quadrupole transitions within the $2s2p$ and $2p^2$ configurations were calculated by Feldman *et al.*[1] using scaled Thomas-Fermi wavefunctions with allowance for configuration interaction and relativistic effects. We modified their transition probability data by the application of experimental wavelengths, i.e., we first converted their $A$-values into line strength data utilizing their theoretical transition energies and then reconverted the line strengths into $A$-values with wavelengths derived from experimental data. This approach should normally yield transition probabilities that are more accurate than those based on theoretically determined wavelengths.

The one E2 transition listed, which is relatively strong compared to other E2 transitions, has been taken from the multiconfiguration relativistic Hartree-Fock calculations of Anderson and Anderson,[2] and has been included to indicate the small magnitude of the E2 line strengths.

### References

[1]U. Feldman, G. A. Doschek, Ch.-Ch. Cheng, and A. K. Bhatia, J. Appl. Phys. **51**, 190 (1980).
[2]E. K. Anderson and E. M. Anderson, Opt. Spectrosc. (USSR) **52**, 478 (1982).

Cr XXI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s2p-2s2p$ | $^3P^o - ^3P^o$ | | | | | | | | | | |
| | | | 1566.4 | 341170 | 405070 | 3 | 5 | M1 | 3450 | 2.46 | C+ | 1 |
| | | | [4329.7] | 318080 | 341170 | 1 | 3 | M1 | 218 | 1.97 | C+ | 1 |
| 2. | | $^3P^o - ^1P^o$ | | | | | | | | | | |
| | | | [381.62] | 405070 | 667110 | 5 | 3 | M1 | 6000 | 0.037 | D | 1 |
| | | | [306.80] | 341170 | 667110 | 3 | 3 | M1 | 6800 | 0.022 | D− | 1 |
| | | | " | " | " | 3 | 3 | E2 | 23 | 1.1(−4)[a] | D− | 2 |
| | | | [286.51] | 318080 | 667110 | 1 | 3 | M1 | 1.1(+4) | 0.030 | D | 1 |
| 3. | $2p^2-2p^2$ | $^3P - ^3P$ | | | | | | | | | | |
| | | | [2777.0] | 911130 | 947130 | 3 | 5 | M1 | 520 | 2.07 | C | 1 |
| | | | [2156.8] | 864780 | 911130 | 1 | 3 | M1 | 1720 | 1.92 | C | 1 |
| 4. | | $^3P - ^1D$ | | | | | | | | | | |
| | | | [955.29] | 947130 | 1051810 | 5 | 5 | M1 | 6800 | 1.1 | D+ | 1 |
| | | | [710.83] | 911130 | 1051810 | 3 | 5 | M1 | 6300 | 0.42 | D+ | 1 |
| 5. | | $^3P - ^1S$ | | | | | | | | | | |
| | | | [290.99] | 911130 | 1254790 | 3 | 1 | M1 | 9.2(+4) | 0.084 | D | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XXII

Li Isoelectronic Sequence

Ground State: $1s^22s\ ^2S_{1/2}$

Ionization Energy: 1721.4 eV = 13882000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2.190 | 5 | 8.04 | 17 | 9.493 | 8 | 36.8 | 18 |
| 2.191 | 2 | 8.07 | 10 | 9.809 | 14 | 37.5 | 22 |
| 2.196 | 1 | 8.10 | 17 | 9.865 | 14 | 37.7 | 22 |
| 2.198 | 4 | 8.30 | 16 | 12.623 | 7 | 38.0 | 22 |
| 2.199 | 1,3,4 | 8.37 | 16 | 12.664 | 7 | 222.98 | 6 |
| 2.202 | 3 | 8.52 | 9 | 13.149 | 13 | 279.74 | 6 |
| 2.203 | 4 | 8.78 | 15 | 13.292 | 13 | | |
| 7.82 | 11 | 8.85 | 15 | 13.308 | 13 | | |

Transition probabilities for the strongest inner-shell transitions to doubly excited $n = 2$ states are taken from the multiconfiguration Dirac-Fock (MCDF) calculations of Hata and Grant.[1] Their results are in good agreement with the $Z$-expansion perturbation calculations of Vainshtein and Safronova,[2] who included relativistic corrections at the level of the Pauli approximation.

Oscillator strengths for lines of the principal ($2s$–$2p$) resonance multiplet are the results of the MCDF calculations of Cheng *et al.*,[3] which include a perturbative treatment of the Breit interaction and the Lamb shift. The results of the MCDF calculations of Armstrong *et al.*[4] were interpolated to provide $f$-values for the $2p$–$3d$ transitions.

The $f$-value for the $3d$–$4f$ transition was taken from a study of systematic trends along isoelectronic sequences by Smith and Wiese.[5] The tabulated data for many additional transitions were taken from the theoretical analysis of Martin and Wiese,[6] which was based on a generalized study of systematic trends for several spectral series of the lithium isoelectronic sequence.

Results of the relativistic Hartree-Fock calculations of Kim and Desclaux[7] for several ions of the Li sequence were incorporated into the data of Ref. 6 for the $2s$–$3p$ transitions. For all other transitions for which the results of Ref. 6 are quoted here, no relativistic calculations were available. However, the relativistic calculations of Younger and Weiss[8] for the hydrogen isoelectronic sequence provide a means of assessing the magnitude of relativistic corrections since the Li sequence is very similar in structure to the H sequence. For those transitions for which relativistic effects were estimated to be significant (specifically, whenever the ratio of the weighted relativistic hydrogenic $f$-values $g_i f_{ik}$ of any two lines within a multiplet was found to deviate from the corresponding $LS$-coupling linestrength ratio by more than 5% for the appropriate value of the nuclear charge $Z$), the $f$-values were excluded from the compilation. A more detailed discussion of this comparison is given in Ref. 6.

Although the $2p$–$3s$ multiplet did not satisfy the criterion described in the paragraph above, we have nevertheless quoted the multiplet $f$-value obtained by Onello[9] using a $Z$-expansion technique based on a variational calculation for O VI That allowed for large-scale configuration interaction. The resulting multiplet oscillator strengths for Fe XXIV and Ni XXVI are in very good agreement with data derived from the results of calculations that included relativistic effects.[10,11] We thus felt that the results of Ref. 9 should be sufficiently accurate for inclusion in this compilation.

Transition probability data are available for numerous transitions involving doubly excited states with the spectator electron occupying the $n=3$ shell, or higher.[12] These have not been tabulated, however, since they belong to, or are very close to belonging to, the unresolved satellites of the helium-like ion.

### References


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Cr XXII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^22s$–$1s(^2S)2s2p(^3P^\circ)$ | $^2S$ - $^2P^\circ$ | *2.196* | | | 2 | 6 | 4.1(+5)[a] | 0.090 | 0.0013 | −0.75 | D | 1 |
| | | | [2.196] | | | 2 | 4 | 3.4(+4) | 0.0049 | 7.1(−5) | −2.01 | D | 1 |
| | | | [2.199] | | | 2 | 2 | 1.1(+6) | 0.080 | 0.0012 | −0.80 | C | 1 |
| 2. | $1s^22s$–$1s(^2S)2s2p(^1P^\circ)$ | $^2S$ - $^2P^\circ$ | | | | | | | | | | | |
| | | | [2.191] | | | 2 | 2 | 2.5(+6) | 0.18 | 0.0026 | −0.44 | C | 1 |
| 3. | $1s^22p$–$1s2p^2$ | $^2P^\circ$ - $^2D$ | | | | | | | | | | | |
| | | | [2.202] | | | 4 | 6 | 1.6(+6) | 0.17 | 0.0051 | −0.16 | C | 1 |
| | | | [2.199] | | | 2 | 4 | 2.3(+6) | 0.33 | 0.0048 | −0.18 | C | 1 |

Cr XXII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^2P^\circ - ^2P$ | | | | | | | | | | | |
| | | | [2.198] | | | 4 | 4 | 4.5(+6) | 0.33 | 0.0094 | 0.12 | C | 1 |
| | | | [2.199] | | | 2 | 2 | 3.9(+6) | 0.28 | 0.0041 | −0.25 | C | 1 |
| | | | [2.203] | | | 4 | 2 | 1.3(+6) | 0.047 | 0.0014 | −0.72 | C | 1 |
| 5. | | $^2P^\circ - ^2S$ | | | | | | | | | | | |
| | | | [2.190] | | | 4 | 2 | 1.7(+6) | 0.061 | 0.0018 | −0.61 | C | 1 |
| 6. | 2*s*–2*p* | $^2S - ^2P^\circ$ | *239.15* | 0 | *418140* | 2 | 6 | 26.4 | 0.0680 | 0.107 | −0.867 | B+ | 3 |
| | | | 222.98 | 0 | 448470 | 2 | 4 | 32.9 | 0.0490 | 0.0719 | −1.009 | B+ | 3 |
| | | | 279.74 | 0 | 357470 | 2 | 2 | 16.5 | 0.0193 | 0.0355 | −1.413 | B+ | 3 |
| 7. | 2*s*–3*p* | $^2S - ^2P^\circ$ | *12.637* | 0 | *7913500* | 2 | 6 | 5.19(+4) | 0.373 | 0.0310 | −0.128 | B | 6 |
| | | | 12.623 | 0 | 7922000 | 2 | 4 | 5.13(+4) | 0.245 | 0.0204 | −0.310 | B | 6 |
| | | | 12.664 | 0 | 7896400 | 2 | 2 | 5.28(+4) | 0.127 | 0.0106 | −0.595 | B | 6 |
| 8. | 2*s*–4*p* | $^2S - ^2P^\circ$ | 9.493 | 0 | 10530000 | 2 | 6 | 2.5(+4) | 0.10 | 0.0063 | −0.70 | C+ | 6 |
| 9. | 2*s*–5*p* | $^2S - ^2P^\circ$ | [8.52] | | | 2 | 6 | 1.2(+4) | 0.040 | 0.0022 | −1.10 | C+ | 6 |
| 10. | 2*s*–6*p* | $^2S - ^2P^\circ$ | [8.07] | | | 2 | 6 | 7240 | 0.0212 | 0.00113 | −1.373 | C+ | 6 |
| 11. | 2*s*–7*p* | $^2S - ^2P^\circ$ | [7.82] | | | 2 | 6 | 4510 | 0.0124 | 6.38(−4) | −1.606 | C+ | 6 |
| 12. | 2*p*–3*s* | $^2P^\circ - ^2S$ | *13.54* | *418140* | 7805000 | 6 | 2 | 1.9(+4) | 0.017 | 0.0045 | −0.99 | D | 9 |
| 13. | 2*p*–3*d* | $^2P^\circ - ^2D$ | *13.245* | *418140* | *7968100* | 6 | 10 | 1.54(+5) | 0.677 | 0.177 | 0.608 | B | *interp.* |
| | | | 13.292 | 448470 | 7971800 | 4 | 6 | 1.54(+5) | 0.611 | 0.107 | 0.388 | B | *interp.* |
| | | | 13.149 | 357470 | 7962600 | 2 | 4 | 1.29(+5) | 0.671 | 0.0581 | 0.128 | B | *interp.* |
| | | | [13.308] | 448470 | 7962600 | 4 | 4 | 2.6(+4) | 0.068 | 0.012 | −0.57 | B | *interp.* |
| 14. | 2*p*–4*d* | $^2P^\circ - ^2D$ | *9.852* | *418140* | *10570000* | 6 | 10 | 4.9(+4) | 0.12 | 0.023 | −0.14 | B | 6 |
| | | | 9.865 | 448470 | 10590000 | 4 | 6 | 4.9(+4) | 0.11 | 0.014 | −0.37 | B | *ls* |
| | | | 9.809 | 357470 | 10550000 | 2 | 4 | 4.1(+4) | 0.12 | 0.0077 | −0.62 | B | *ls* |
| | | | 9.865 | 448470 | 10550000 | 4 | 4 | 7900 | 0.012 | 0.0015 | −1.34 | C+ | *ls* |
| 15. | 2*p*–5*d* | $^2P^\circ - ^2D$ | *8.83* | | | 6 | 10 | 2.31(+4) | 0.0450 | 0.00785 | −0.569 | C+ | 6 |
| | | | [8.85] | | | 4 | 6 | 2.29(+4) | 0.0404 | 0.00471 | −0.791 | C+ | *ls* |
| | | | [8.78] | | | 2 | 4 | 1.96(+4) | 0.0453 | 0.00262 | −1.043 | C+ | *ls* |
| | | | [8.85] | | | 4 | 4 | 3800 | 0.0045 | 5.2(−4) | −1.75 | D | *ls* |
| 16. | 2*p*–6*d* | $^2P^\circ - ^2D$ | *8.35* | | | 6 | 10 | 1.26(+4) | 0.0220 | 0.00363 | −0.879 | C+ | 6 |
| | | | [8.37] | | | 4 | 6 | 1.26(+4) | 0.0198 | 0.00218 | −1.102 | C+ | *ls* |
| | | | [8.30] | | | 2 | 4 | 1.07(+4) | 0.0221 | 0.00121 | −1.354 | C+ | *ls* |
| | | | [8.37] | | | 4 | 4 | 2100 | 0.0022 | 2.4(−4) | −2.06 | D | *ls* |
| 17. | 2*p*–7*d* | $^2P^\circ - ^2D$ | *8.08* | | | 6 | 10 | 7720 | 0.0126 | 0.00201 | −1.121 | C+ | 6 |
| | | | [8.10] | | | 4 | 6 | 7690 | 0.0113 | 0.00121 | −1.343 | C+ | *ls* |
| | | | [8.04] | | | 2 | 4 | 6530 | 0.0127 | 6.70(−4) | −1.597 | C+ | *ls* |
| | | | [8.10] | | | 4 | 4 | 1200 | 0.0012 | 1.3(−4) | −2.31 | D | *ls* |
| 18. | 3*s*–4*p* | $^2S - ^2P^\circ$ | [36.8] | 7805000 | 10530000 | 2 | 6 | 7100 | 0.43 | 0.10 | −0.07 | C | 6 |

Cr XXII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19. | $3s$–$5p$ | $^2$S - $^2$P° | | | | 2 | 6 | | 0.107 | | −0.67 | C | 6 |
| 20. | $3s$–$6p$ | $^2$S - $^2$P° | | | | 2 | 6 | | 0.047 | | −1.03 | C | 6 |
| 21. | $3s$–$7p$ | $^2$S - $^2$P° | | | | 2 | 6 | | 0.0249 | | −1.303 | C | 6 |
| 22. | $3p$–$4d$ | $^2$P° - $^2$D | *37.6* | *7913500* | *10570000* | 6 | 10 | 1.7(+4) | 0.59 | 0.44 | 0.55 | B | 6 |
| | | | [37.5] | 7922000 | 10590000 | 4 | 6 | 1.7(+4) | 0.53 | 0.26 | 0.32 | B | *ls* |
| | | | [37.7] | 7896400 | 10550000 | 2 | 4 | 1.4(+4) | 0.60 | 0.15 | 0.08 | B | *ls* |
| | | | [38.0] | 7922000 | 10550000 | 4 | 4 | 2700 | 0.058 | 0.029 | −0.63 | C+ | *ls* |
| 23. | $3p$–$5d$ | $^2$P° - $^2$D | | | | 6 | 10 | | 0.138 | | −0.082 | C+ | 6 |
| 24. | $3p$–$6d$ | $^2$P° - $^2$D | | | | 6 | 10 | | 0.0558 | | −0.475 | C+ | 6 |
| 25. | $3p$–$7s$ | $^2$P° - $^2$S | | | | 6 | 2 | | 0.0018 | | −1.97 | C− | 6 |
| 26. | $3p$–$7d$ | $^2$P° - $^2$D | | | | 6 | 10 | | 0.0289 | | −0.761 | C+ | 6 |
| 27. | $3d$–$4f$ | $^2$D - $^2$F° | | | | 10 | 14 | | 1.00 | | 1.000 | B | 5 |
| 28. | $4s$–$5p$ | $^2$S - $^2$P° | | | | 2 | 6 | | 0.473 | | −0.024 | C | 6 |
| 29. | $4s$–$6p$ | $^2$S - $^2$P° | | | | 2 | 6 | | 0.128 | | −0.59 | C | 6 |
| 30. | $4s$–$7p$ | $^2$S - $^2$P° | | | | 2 | 6 | | 0.056 | | −0.95 | C | 6 |
| 31. | $4p$–$5d$ | $^2$P° - $^2$D | | | | 6 | 10 | | 0.583 | | 0.544 | C+ | 6 |
| 32. | $4p$–$6d$ | $^2$P° - $^2$D | | | | 6 | 10 | | 0.141 | | −0.073 | C+ | 6 |
| 33. | $4p$–$7s$ | $^2$P° - $^2$S | | | | 6 | 2 | | 0.0060 | | −1.44 | C− | 6 |
| 34. | $4p$–$7d$ | $^2$P° - $^2$D | | | | 6 | 10 | | 0.0616 | | −0.432 | C+ | 6 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XXII

## Forbidden Transitions

The single magnetic dipole transition within the $1s^22p$ configuration has the line strength of 1.33 in the absence of relativistic effects in the wavefunctions.[1] It is estimated that these effects are negligible, since comprehensive relativistic calculations by Cheng *et al.*[2] for the analogous transition in the $1s^22s^22p$ configuration of the boron sequence show that such relativistic corrections are negligible until much more highly charged ions.

The listed transition probability data are also expected to be quite accurate since the energy levels are derived from experimental data.

An electric quadrupole transition at the same wavelength is estimated to be of negligible strength, as calculated by Bhatia[3] for this transition in the case of Mn XXIII. (He obtains a ratio of about $10^{-3}$ for the ratio of E2 to M1 line strengths).

### References

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Cr XXII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p$–$2p$ | $^2P^\circ$ – $^2P^\circ$ | | | | | | | | | | |
| | | | [1098.9] | 357470 | 448470 | 2 | 4 | M1 | 6760 | 1.33 | B | *interp.* |

# Cr XXIII

He Isoelectronic Sequence

Ground State: $1s^2\ ^1S_0$

Ionization Energy: 7481.8 eV = 60344000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 1.7235 | 17 | 2.107 | 3,7,10 | 9.0513 | 31 | 35.722 | 45 |
| 1.7238 | 16 | 2.109 | 7 | 9.2126 | 32 | 74.234 | 55 |
| 1.7632 | 15 | 2.113 | 9 | 11.852 | 21 | 74.878 | 56 |
| 1.7640 | 14 | 2.119 | 5 | 12.093 | 22 | 76.447 | 58 |
| 1.8557 | 13 | 2.129 | 6 | 12.271 | 27 | 77.226 | 59 |
| 1.8578 | 12 | 2.1818 | 2 | 12.512 | 28 | 225.3 | 19 |
| 2.095 | 11 | 2.1923 | 1 | 23.553 | 41 | 326.3 | 18 |
| 2.101 | 4,8 | 7.9233 | 25 | 23.820 | 42 | 442.9 | 18 |
| 2.102 | 3 | 8.0619 | 26 | 23.979 | 48 | 467.5 | 20 |
| 2.103 | 7 | 8.0762 | 35 | 24.265 | 49 | 471.0 | 18 |
| 2.104 | 7 | 8.2126 | 36 | 34.193 | 39 | | |
| 2.105 | 7 | 8.8497 | 23 | 34.609 | 40 | | |
| 2.106 | 3 | 9.0127 | 24 | 35.256 | 44 | | |

Oscillator strengths for transitions of the $1s^2$–$1s2p$ array are taken from the results of Drake,[1] who incorporated accurate nonrelativistic matrix elements and Dirac hydrogenic matrix elements into a $Z$-expansion technique in order to provide $f$-values which would accurately reflect correlation effects for low-$Z$ ions and relativistic effects for high-$Z$ ions of the helium isoelectronic sequence. The $f$-values for the $1s^2\ ^1S$ - $1snp\ ^3P°$ ($n=3$–5) transitions were interpolated from results of the relativistic random phase approximation (RRPA) calculations of Johnson and Lin.[2] Data for other $s$–$p$ and $p$–$s$ transitions were interpolated from the RRPA results of Lin *et al.*,[3] with the exception of the $2s$–$2p$ transitions, where we tabulate the actual published RRPA $A$-values of these same authors.[4]

The charge expansion results of Laughlin[5] are given for various $p$–$d$ and $d$–$p$ transitions, as well as transitions between $4d$ and $4f$ levels. For those multiplets involving no change in principal quantum number ($3p$–$3d$, $4p$–$4d$, $4d$–$4f$) the $f$-values should be considered rather uncertain, since they are sensitive to energy differences. Oscillator strengths for the $2p$–$3d$ transitions, and for $1s3p\ ^3P°$ - $1s3d\ ^3D$, were interpolated from the variational calculations of Weiss.[6] Both of these calculations indicate that, unlike the triplets, the $nd\ ^1D$ energy levels ($n=3,4$) lie below the $np\ ^1P°$ levels, and the $4f\ ^1F°$ lies below the $4d\ ^1D$.

Brown and Cortez[7] have provided $f$-values for numerous $d$–$f$ and $f$–$d$ transitions for the isoelectronic sequence by fitting $Z$-expansion formulas to the results of variational calculations for the low-$Z$ ions. Their results for transitions between the lower-lying D and F° terms are tabulated here.

Transition probabilities for the stronger transitions involving the doubly excited $n=2$ states are taken from the comprehensive, charge expansion perturbation theory calculations of Vainshtein and Safronova.[8] Numerous data are also available for transitions involving doubly excited states where the spectator electron has principal quantum number $n=3$.[9] However, these data are not tabulated here since most of the transitions are very close to belonging to the unresolved satellites of the H-like ions, if they do not in fact do so.

## References


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[9] L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **25**, 311 (1980).

Cr XXIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2$–$1s2p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [2.1923] | 0 | [45614900] | 1 | 3 | 2.34(+5)[a] | 0.0505 | 3.64(−4) | −1.297 | B | 1 |
| 2. | | $^1$S – $^1$P° | [2.1818] | 0 | [45832900] | 1 | 3 | 3.37(+6) | 0.721 | 0.00518 | −0.142 | B | 1 |
| 3. | $1s2s$–$2s2p$ | $^3$S – $^3$P° | *2.104* | [45389100] | [*92920000*] | 3 | 9 | 2.1(+6) | 0.41 | 0.0085 | 0.09 | C | 8 |
| | | | [2.102] | [45389100] | [92960000] | 3 | 5 | 2.1(+6) | 0.23 | 0.0048 | −0.16 | C | 8 |
| | | | [2.106] | [45389100] | [92870000] | 3 | 3 | 2.0(+6) | 0.13 | 0.0028 | −0.40 | C | 8 |
| | | | [2.107] | [45389100] | [92850000] | 3 | 1 | 2.0(+6) | 0.044 | 9.2(−4) | −0.88 | C | 8 |
| 4. | | $^1$S – $^1$P° | [2.101] | [45619000] | [93220000] | 1 | 3 | 2.0(+6) | 0.40 | 0.0027 | −0.40 | C | 8 |
| 5. | $1s2p$–$2s^2$ | $^3$P° – $^1$S | | | | | | | | | | | |
| | | | [2.119] | [45614900] | [92800000] | 3 | 1 | 2.7(+5) | 0.0061 | 1.3(−4) | −1.74 | D | 8 |
| 6. | | $^1$P° – $^1$S | [2.129] | [45832900] | [92800000] | 3 | 1 | 5.1(+5) | 0.012 | 2.4(−4) | −1.46 | D | 8 |
| 7. | $1s2p$–$2p^2$ | $^3$P° – $^3$P | *2.106* | [*45658200*] | [*93140000*] | 9 | 9 | 3.9(+6) | 0.26 | 0.016 | 0.36 | D+ | 8 |
| | | | [2.107] | [45695600] | [93160000] | 5 | 5 | 2.3(+6) | 0.15 | 0.0053 | −0.12 | C | 8 |
| | | | [2.105] | [45614900] | [93130000] | 3 | 3 | 9.6(+5) | 0.064 | 0.0013 | −0.72 | D | 8 |
| | | | [2.109] | [45695600] | [93130000] | 5 | 3 | 1.7(+6) | 0.068 | 0.0024 | −0.47 | C | 8 |
| | | | [2.107] | [45614900] | [93070000] | 3 | 1 | 3.8(+6) | 0.084 | 0.0018 | −0.60 | C | 8 |
| | | | [2.103] | [45614900] | [93160000] | 3 | 5 | 1.2(+6) | 0.13 | 0.0028 | −0.40 | C | 8 |
| | | | [2.104] | [45601400] | [93130000] | 1 | 3 | 1.4(+6) | 0.28 | 0.0019 | −0.55 | C | 8 |
| 8. | | $^3$P° – $^1$D | | | | | | | | | | | |
| | | | [2.101] | [45695600] | [93290000] | 5 | 5 | 7.9(+5) | 0.052 | 0.0018 | −0.58 | D | 8 |
| 9. | | $^1$P° – $^3$P | | | | | | | | | | | |
| | | | [2.113] | [45832900] | [93160000] | 3 | 5 | 5.9(+5) | 0.066 | 0.0014 | −0.70 | D | 8 |
| 10. | | $^1$P° – $^1$D | [2.107] | [45832900] | [93290000] | 3 | 5 | 3.3(+6) | 0.37 | 0.0076 | 0.04 | C | 8 |
| 11. | | $^1$P° – $^1$S | [2.095] | [45832900] | [93560000] | 3 | 1 | 3.5(+6) | 0.077 | 0.0016 | −0.64 | C | 8 |
| 12. | $1s^2$–$1s3p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [1.8578] | 0 | [53826600] | 1 | 3 | 8.4(+4) | 0.013 | 8.0(−5) | −1.89 | E | *interp* |
| 13. | | $^1$S – $^1$P° | [1.8557] | 0 | [53888200] | 1 | 3 | 8.97(+5) | 0.139 | 8.49(−4) | −0.857 | C+ | *interp* |
| 14. | $1s^2$–$1s4p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [1.7640] | 0 | [56688900] | 1 | 3 | 3.2(+4) | 0.0045 | 2.6(−5) | −2.35 | E | *inter* |
| 15. | | $^1$S – $^1$P° | [1.7632] | 0 | [56714400] | 1 | 3 | 3.68(+5) | 0.0514 | 2.98(−4) | −1.289 | C+ | *inter* |
| 16. | $1s^2$–$1s4p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [1.7238] | 0 | [58010100] | 1 | 3 | 1.6(+4) | 0.0022 | 1.2(−5) | −2.66 | E | *inte* |

Cr XXIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59. | | $^1$P° – $^1$S | [77.226] | [56714400] | [58009300] | 3 | 1 | 1800 | 0.055 | 0.042 | −0.78 | C | *interp.* |
| 60. | $1s4d$–$1s4p$ | $^1$D – $^1$P° | | | | 5 | 3 | | 0.0034 | | −1.77 | E | 5 |
| 61. | $1s4d$–$1s4f$ | $^3$D – $^3$F° | | | | 15 | 21 | | 8.5(−4) | | −1.89 | E | 5 |
| 62. | $1s4d$–$1s5f$ | $^3$D – $^3$F° | | | | 15 | 21 | | 0.89 | | 1.13 | B | 7 |
| 63. | | $^1$D – $^1$F° | | | | 5 | 7 | | 0.89 | | 0.65 | B | 7 |
| 64. | $1s4f$–$1s4d$ | $^1$F° – $^1$D | | | | 7 | 5 | | 4.5(−4) | | −2.50 | E | 5 |
| 65. | $1s4f$–$1s5d$ | $^3$F° – $^3$D | | | | 21 | 15 | | 0.0089 | | −0.73 | C | 7 |
| 66. | | $^1$F° – $^1$D | | | | 7 | 5 | | 0.0089 | | −1.21 | C | 7 |
| 67. | $1s5s$–$1s5p$ | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.031 | | −1.03 | E | *interp.* |
| 68. | | $^1$S – $^1$P° | | | | 1 | 3 | | 0.10 | | −1.00 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XXIII

## Forbidden Transitions

The results of multi-configuration Dirac-Fock calculations by Hata and Grant[1] have been selected for this tabulation. Their work includes both a very detailed consideration of configuration interaction—with configurational wavefunction sets containing as many as 51 interacting states—as well as a fully relativistic treatment based on the Dirac Hamiltonian. Their calculated wavelengths are in very close agreement with experiment, and the agreement between an experimentally determined lifetime[2] for the $2p$ $^3P_2^\circ$ state and the theoretical result is excellent, the difference being only 5%. A comprehensive comparison table containing all experimental data on these He-sequence transitions is given in the introduction to the forbidden lines of Ti XXI.

### References


[1]J. Hata and I. P. Grant, Mon. Not. R. Astr. Soc. **211**, 549 (1984).
[2]H. D. Dohmann, R. Mann, and E. Pfeng, Z. Phys. A **309**, 101 (1982).


Cr XXIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2$–$1s2s$ | $^1$S – $^3$S | [2.2034] | 0 | [45383500] | 1 | 3 | M1 | 9.37(+7)[a] | 1.11(−4) | B | 1 |
| 2. | $1s^2$–$1s2p$ | $^1$S – $^3$P° | | | | | | | | | | |
| | | | [2.1886] | 0 | [45691370] | 1 | 5 | M2 | 3.45(+9) | 0.131 | B | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Cr XXIV

H Isoelectronic Sequence

Ground State: $1s\ ^2S_{1/2}$

Ionization Energy: 7894.87 eV = 63675900 cm$^{-1}$

## Allowed Transitions

Electric dipole transition probability data for this hydrogen-like ion can be obtained directly, in a non-relativistic approximation, from the data for neutral hydrogen.[1] The oscillator strength is independent of $Z$ along the entire isoelectronic sequence and is therefore identical to the value for the hydrogen atom. Line strengths scale as $Z^{-2}$ and transition probabilities scale as $Z^4$, i.e.,

$$S_Z = Z^{-2} S_H, \qquad A_Z = Z^4 A_H.$$

For higher nuclear charges in this sequence, relativistic corrections will cause these values to deviate increasingly from the non-relativistic ones. The first effect of relativity will be to alter the transition energies, or wavelengths, from the non-relativistic, even though the line strength itself is still well approximated by the non-relativistic value. In this case, experimental energies should be used in the standard conversion formulas, given in the general introduction to this volume, to calculate the most accurate values of $f$ and $A$. It should be noted that the relativistic removal of the $j$-degeneracy introduces dipole transitions which do not occur in the non-relativistic theory, e.g., $2s_{1/2} - 2p_{3/2}$.

For very high $Z$, it is necessary to use the four-component Dirac spinors rather than two-component Schroedinger functions in theoretical calculations, and this introduces relativistic corrections to the line strengths themselves. Several recent systematic studies of the problem[2,3] indicate that these corrections are not large for stages of ionization in the range 20–30. Corrections for $Z = 30$ are usually no larger than 5–10% and generally substantially less than 5%. If an accuracy greater than this is required, the reader is referred to these papers[2,3] for a more detailed error analysis.

## References


[1] W. L. Wiese, M. W. Smith, and B. M. Glennon, Atomic Transition Probabilities – Hydrogen through Neon (A Critical Data Compilation), Vol. I, 157 pp., Nat. Stand. Ref. Data Ser., Nat. Bur. Stand. (U.S.), 4 (May 1966).

[2] S. M. Younger and A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **79**, 629 (1975).

[3] S. J. Rose, Rutherford Appleton Laboratory Report RL–82–114 (December 1982).

# Manganese

## Mn I

Ground State: $1s^22s^22p^63s^23p^63d^54s^2\ ^6S_{5/2}$

Ionization Energy: 7.43408 eV = 59959.4 cm$^{-1}$

### Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2794.82 | 4 | 3146.32 | 33 | 3273.02 | 91 | 3601.27 | 155 |
| 2798.27 | 4 | 3148.18 | 17 | 3278.06 | 91 | 3607.53 | 9 |
| 2801.08 | 4 | 3148.86 | 92 | 3278.55 | 12 | 3608.49 | 9 |
| 3007.65 | 40 | 3149.93 | 27 | 3290.97 | 11 | 3610.30 | 9 |
| 3011.17 | 40 | 3151.42 | 113 | 3296.88 | 12 | 3615.38 | 86 |
| 3011.38 | 40 | 3152.25 | 156 | 3298.23 | 47 | 3623.78 | 9 |
| 3016.45 | 40 | 3155.78 | 113 | 3300.94 | 46 | 3626.30 | 85 |
| 3041.22 | 39 | 3159.95 | 26 | 3303.28 | 47 | 3629.74 | 9 |
| 3043.14 | 39 | 3160.16 | 112 | 3307.00 | 47 | 3635.70 | 154 |
| 3043.36 | 39 | 3161.05 | 17 | 3308.78 | 11 | 3639.15 | 8 |
| 3044.57 | 14 | 3167.83 | 26 | 3311.90 | 12 | 3643.02 | 84 |
| 3045.59 | 39 | 3169.36 | 156 | 3330.66 | 12 | 3646.71 | 8 |
| 3045.80 | 39 | 3170.43 | 92 | 3334.56 | 46 | 3648.70 | 133 |
| 3046.59 | 114 | 3175.36 | 73 | 3343.72 | 12 | 3652.29 | 106 |
| 3047.03 | 39 | 3175.58 | 112 | 3350.41 | 72 | 3653.51 | 8 |
| 3048.86 | 39 | 3175.71 | 111 | 3351.66 | 25 | 3657.91 | 83 |
| 3054.36 | 14 | 3177.04 | 26 | 3355.48 | 72 | 3660.40 | 133 |
| 3062.12 | 14 | 3177.62 | 26 | 3360.68 | 59 | 3663.37 | 133 |
| 3066.02 | 14 | 3178.50 | 17 | 3364.19 | 59 | 3667.71 | 133 |
| 3070.27 | 14 | 3189.96 | 112 | 3365.14 | 90 | 3668.20 | 153 |
| 3073.18 | 14 | 3192.24 | 111 | 3376.53 | 107 | 3668.55 | 134 |
| 3079.64 | 14 | 3201.11 | 112 | 3410.80 | 89 | 3669.20 | 8 |
| 3081.34 | 14 | 3202.21 | 111 | 3418.28 | 58 | 3669.84 | 8 |
| 3082.71 | 93 | 3203.13 | 110 | 3420.79 | 88 | 3670.51 | 8 |
| 3091.10 | 62 | 3206.91 | 13 | 3428.78 | 56 | 3675.67 | 134 |
| 3093.35 | 93 | 3212.89 | 13 | 3429.16 | 137 | 3676.96 | 133 |
| 3097.76 | 94 | 3216.95 | 3 | 3429.74 | 136 | 3678.47 | 8 |
| 3098.09 | 51 | 3224.76 | 3 | 3440.04 | 60 | 3680.15 | 132 |
| 3103.28 | 49 | 3226.05 | 13 | 3446.82 | 87 | 3682.09 | 133 |
| 3106.75 | 94 | 3227.04 | 110 | 3450.61 | 88 | 3684.87 | 133 |
| 3108.63 | 49 | 3228.09 | 13 | 3451.48 | 56 | 3685.22 | 8 |
| 3110.68 | 50 | 3230.23 | 108 | 3458.84 | 57 | 3685.56 | 83 |
| 3113.12 | 49 | 3230.72 | 13 | 3463.66 | 138 | 3692.82 | 8 |
| 3113.36 | 94 | 3238.72 | 108 | 3470.01 | 138 | 3696.55 | 23 |
| 3113.80 | 93 | 3240.41 | 12 | 3488.31 | 10 | 3700.30 | 45 |
| 3114.12 | 48 | 3240.61 | 13 | 3491.55 | 10 | 3701.73 | 8 |
| 3115.46 | 49 | 3240.88 | 109 | 3494.86 | 137 | 3706.08 | 82 |
| 3115.75 | 61 | 3243.78 | 13 | 3503.73 | 10 | 3706.66 | 45 |
| 3116.82 | 93 | 3249.89 | 108 | 3505.86 | 10 | 3708.87 | 132 |
| 3117.51 | 61 | 3251.13 | 13 | 3507.54 | 16 | 3709.83 | 163 |
| 3118.10 | 61 | 3252.95 | 13 | 3509.07 | 10 | 3710.75 | 55 |
| 3121.07 | 94 | 3254.04 | 12 | 3511.19 | 10 | 3711.59 | 55 |
| 3122.88 | 93 | 3255.51 | 108 | 3511.83 | 135 | 3713.79 | 105 |
| 3126.85 | 94 | 3256.14 | 13 | 3523.53 | 10 | 3715.53 | 119 |
| 3132.28 | 113 | 3258.41 | 13 | 3535.30 | 135 | 3718.13 | 119 |
| 3132.79 | 93 | 3260.24 | 13 | 3538.00 | 135 | 3718.92 | 82 |
| 3135.19 | 32 | 3263.04 | 91 | 3559.81 | 135 | 3720.91 | 82 |
| 3136.96 | 48 | 3264.71 | 12 | 3577.87 | 9 | 3726.95 | 23 |
| 3138.22 | 27 | 3267.79 | 91 | 3583.68 | 24 | 3727.99 | 55 |
| 3141.82 | 27 | 3268.72 | 72 | 3591.81 | 24 | 3728.89 | 23 |
| 3142.67 | 26 | 3270.35 | 91 | 3595.11 | 9 | 3729.52 | 105 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 3731.01 | 81 | 3931.52 | 152 | 4090.62 | 99 | 4388.09 | 143 |
| 3731.94 | 82 | 3935.54 | 80 | 4092.39 | 98 | 4408.08 | 115 |
| 3746.62 | 81 | 3936.77 | 80 | 4094.07 | 166 | 4410.49 | 67 |
| 3750.77 | 23 | 3937.76 | 80 | 4096.68 | 127 | 4411.87 | 142 |
| 3752.55 | 81 | 3942.88 | 63 | 4099.40 | 166 | 4414.89 | 20 |
| 3753.30 | 162 | 3951.98 | 70 | 4105.37 | 96 | 4419.77 | 142 |
| 3754.22 | 65 | 3952.84 | 68 | 4107.87 | 117 | 4433.72 | 142 |
| 3756.64 | 81 | 3954.58 | 150 | 4113.88 | 96 | 4434.14 | 158 |
| 3763.37 | 23 | 3975.88 | 71 | 4114.38 | 97 | 4436.36 | 20 |
| 3766.05 | 65 | 3977.08 | 69 | 4116.60 | 127 | 4451.58 | 20 |
| 3767.70 | 81 | 3978.78 | 78 | 4119.01 | 42 | 4452.53 | 115 |
| 3768.18 | 104 | 3980.14 | 167 | 4122.37 | 96 | 4453.01 | 20 |
| 3771.44 | 173 | 3982.16 | 68 | 4122.76 | 96 | 4455.82 | 29 |
| 3772.96 | 65 | 3982.58 | 37 | 4123.28 | 96 | 4457.04 | 29 |
| 3773.86 | 173 | 3982.90 | 170 | 4123.54 | 42 | 4457.55 | 29 |
| 3774.67 | 65 | 3984.17 | 37 | 4125.81 | 165 | 4458.26 | 29 |
| 3776.29 | 169 | 3985.24 | 37 | 4132.28 | 174 | 4461.09 | 29 |
| 3776.54 | 7 | 3986.82 | 37 | 4135.03 | 75 | 4462.03 | 29 |
| 3785.42 | 65 | 3987.09 | 37 | 4137.27 | 42 | 4464.68 | 20 |
| 3786.84 | 118 | 3987.46 | 37 | 4141.06 | 75 | 4470.14 | 20 |
| 3790.21 | 7 | 3989.95 | 37 | 4147.53 | 42 | 4472.79 | 20 |
| 3791.08 | 162 | 3990.74 | 54 | 4148.80 | 75 | 4479.40 | 164 |
| 3799.26 | 7 | 3991.60 | 54 | 4151.66 | 126 | 4490.08 | 20 |
| 3800.55 | 65 | 3993.86 | 54 | 4152.57 | 165 | 4496.64 | 121 |
| 3801.90 | 38 | 3996.10 | 71 | 4154.22 | 125 | 4498.90 | 20 |
| 3803.07 | 103 | 3999.57 | 77 | 4155.53 | 42 | 4502.22 | 20 |
| 3804.02 | 38 | 4001.19 | 54 | 4158.69 | 139 | 4503.87 | 120 |
| 3806.72 | 7 | 4002.17 | 54 | 4164.98 | 139 | 4523.40 | 121 |
| 3808.51 | 38 | 4003.26 | 128 | 4166.21 | 125 | 4529.80 | 157 |
| 3809.59 | 7 | 4007.04 | 54 | 4167.20 | 126 | 4544.42 | 157 |
| 3810.68 | 38 | 4008.02 | 54 | 4176.61 | 74 | 4605.37 | 140 |
| 3811.66 | 38 | 4011.54 | 68 | 4182.25 | 149 | 4626.54 | 140 |
| 3816.75 | 7 | 4011.91 | 167 | 4189.99 | 74 | 4642.80 | 141 |
| 3823.51 | 7 | 4016.67 | 100 | 4201.78 | 74 | 4671.69 | 19 |
| 3823.89 | 7 | 4018.11 | 6 | 4203.11 | 116 | 4701.15 | 19 |
| 3826.62 | 31 | 4020.07 | 53 | 4220.61 | 67 | 4709.71 | 19 |
| 3829.68 | 7 | 4021.35 | 53 | 4221.56 | 124 | 4727.46 | 19 |
| 3833.87 | 7 | 4025.94 | 53 | 4224.34 | 148 | 4739.11 | 19 |
| 3834.37 | 7 | 4026.44 | 36 | 4225.08 | 66 | 4754.05 | 15 |
| 3839.78 | 7 | 4028.60 | 36 | 4230.14 | 22 | 4761.53 | 19 |
| 3841.07 | 7 | 4030.76 | 2 | 4235.30 | 21 | 4762.38 | 19 |
| 3843.99 | 7 | 4031.79 | 36 | 4239.74 | 21 | 4765.86 | 19 |
| 3845.01 | 102 | 4033.07 | 2 | 4257.67 | 21 | 4766.43 | 19 |
| 3855.11 | 70 | 4034.49 | 2 | 4258.37 | 148 | 4783.43 | 15 |
| 3870.82 | 130 | 4038.73 | 53 | 4259.35 | 123 | 4823.53 | 15 |
| 3871.67 | 44 | 4041.36 | 6 | 4261.30 | 146 | 4942.40 | 18 |
| 3872.13 | 131 | 4048.75 | 6 | 4265.93 | 21 | 4965.86 | 18 |
| 3873.20 | 131 | 4052.48 | 101 | 4278.68 | 148 | 4987.07 | 18 |
| 3876.71 | 102 | 4055.55 | 6 | 4279.55 | 147 | 5004.89 | 18 |
| 3888.84 | 130 | 4058.94 | 6 | 4281.10 | 21 | 5029.78 | 18 |
| 3889.46 | 127 | 4059.39 | 30 | 4284.08 | 21 | 5042.57 | 18 |
| 3891.62 | 79 | 4061.74 | 30 | 4290.11 | 123 | 5117.94 | 35 |
| 3894.71 | 43 | 4063.53 | 6 | 4300.19 | 122 | 5149.16 | 35 |
| 3898.37 | 70 | 4065.08 | 76 | 4305.67 | 123 | 5150.94 | 35 |
| 3899.34 | 70 | 4066.24 | 166 | 4312.55 | 21 | 5196.60 | 35 |
| 3911.14 | 64 | 4068.01 | 6 | 4326.18 | 122 | 5197.23 | 35 |
| 3912.75 | 70 | 4070.28 | 6 | 4326.75 | 145 | 5255.33 | 35 |
| 3914.21 | 63 | 4073.98 | 68 | 4327.95 | 160 | 5260.77 | 35 |
| 3919.33 | 168 | 4075.25 | 98 | 4328.68 | 95 | 5292.87 | 41 |
| 3920.66 | 129 | 4079.42 | 6 | 4329.43 | 145 | 5317.08 | 41 |
| 3923.33 | 80 | 4082.95 | 6 | 4337.41 | 67 | 5334.87 | 41 |
| 3924.08 | 64 | 4083.63 | 6 | 4359.64 | 122 | 5348.08 | 41 |
| 3926.48 | 64 | 4085.48 | 161 | 4359.82 | 143 | 5388.54 | 41 |
| 3928.31 | 151 | 4088.57 | 171 | 4368.88 | 144 | 5394.68 | 1 |
| 3929.66 | 80 | 4089.94 | 76 | 4381.70 | 159 | 5407.43 | 5 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 5420.37 | 5 | 5516.78 | 5 | 6349.80 | 52 | 6413.95 | 52 |
| 5432.56 | 1 | 6013.48 | 28 | 6378.97 | 52 | 6443.51 | 52 |
| 5504.22 | 34 | 6021.79 | 28 | 6382.20 | 52 | 6491.70 | 52 |
| 5510.19 | 34 | 6344.13 | 52 | 6384.69 | 52 | 6519.38 | 52 |

For this compilation, we have chosen a variety of experiments which contain fairly accurate transition probability data. The sources providing a reliable *absolute* scale include an atomic-beam absorption experiment by Bell *et al.*[11]; and lifetime measurements performed by Marek[3] and by Becker *et al.*,[7] both of whom used dye lasers to selectively populate the various upper levels via stepwise excitation, and utilized the delayed coincidence technique for detection. Another source providing lifetime data is by Marek and Richter,[12] who employed the phase-shift method. References providing reliable *relative* oscillator strengths include work by Booth *et al.*,[1] and Blackwell and Collins,[4] who obtained data in absorption with an advanced King-type furnace; Ostrovskii and Penkin,[2] who used the anomalous dispersion (hook) method; Woodgate,[5] who measured relative intensities in emission with a vortex-stabilized arc; and Greenlee and Whaling,[6] who measured emission branching ratios from a hollow-cathode light source.

In their papers, the authors of Refs. 1, 2, 4, 5, and 6 tabulated *absolute* $f$-values, i.e., they normalized their own relative data as follows: Booth *et al.* used published lifetime data, principally those of Becker *et al.*; Ostrovskii and Penkin relied on a vapor-pressure formula taken from Kelley *et al.*[9]; Blackwell and Collins normalized their data directly to Bell *et al.*; Woodgate adjusted his scale to agree with that of Ostrovskii and Penkin; and Greenlee and Whaling normalized their branching ratios to their own beam-foil lifetimes.

Despite the different normalization procedures used, the agreement among Refs. 1, 2, 3, 4, and 5 is generally quite good, particularly for strong lines. For five lines in which the $f$-value data of Refs. 2 and 4 overlap, the agreement is within 18 percent. Refs. 4 and 5 have provided data for seven common lines, and with the exception of the 4048.75 Å line, the agreement is within 15 percent. For the 4030.76 Å line, the only line investigated by Bell *et al.*, the agreement between Refs. 1 and 11 and Refs. 2 and 11 is excellent: the results differ by only seven percent, which is clearly within the mutually estimated error limits. More importantly, the measurement by Bell *et al.* independently confirms the absolute scale adopted by Booth *et al.* As a further consistency check, the transition probability data of Refs. 1, 2, 4, and 11 are in very close agreement (within 6 percent) with Marek's measured lifetime for the $z\ ^6P^\circ_{7/2}$ level. In completing these branching ratios, we utilized the tables of Kurucz and Peytremann,[8] who supplied log $gf$-values for a few weak, infrared lines.

The reference providing the most reliable relative data for this spectrum is that of Booth *et al.*[1] These authors measured highly accurate relative oscillator strengths in absorption by using the well-known Oxford furnace, as developed by Blackwell and co-workers. Their $f$-values were normalized to lifetime data of Becker *et al.*,[7] or, when not available, Marek,[3] or Marek and Richter.[12] We have preferred the lifetime data of Ref. 7, since these authors measured radiative lifetimes of individual levels by selective laser excitation and achieved accuracies of typically $\pm 5\%$ through careful measurements. We have therefore assigned a high accuracy rating ("B") to lines measured by Booth *et al.*, who, in addition, normalized their branching ratios to the lifetimes of Becker *et al.* Our next choice for normalization was the work by Marek,[3] who also utilized selective laser excitation for his lifetime measurements.

Another reliable data source is the paper by Greenlee and Whaling.[6] These authors have used the combination of branching-ratio measurements with beam-foil lifetime data. The lifetimes of Ref. 6, however, are about six percent longer than those measured by Becker *et al.*, probably because of small cascade effects. Therefore, in this compilation, we have normalized the branching ratios of Greenlee and Whaling to the lifetimes of Ref. 7.

The source providing the largest quantity of $f$-value data is that of Woodgate.[5] In this work, the author generated the Mn I line spectrum with a vortex-stabilized, high-current arc (50—80 Å). He struck the arc for short time periods ($\approx$15s) through a rapidly rotating, narrow sintered tube, which consisted of $Mn_3O_4$ and some carrier material ($SiO_2$), so that the tube gradually evaporated. The spectra were recorded photographically from end-on observations. Time-resolved spectra showed weak fluctuations, indicating a fairly quiescent source.

Since Refs. 1 and 5 have 41 lines in common, it is possible to assess the accuracy of Woodgate's data. We found that for very strong lines (log $gf > 0$), Woodgate's data agreed fairly well (within 50%) with those of Booth *et al.* This finding was also confirmed by good agreement between Woodgate's branching ratios and lifetimes of fine-structure levels of the $e\ ^6D$ and $e\ ^8S$ terms, as measured by either Marek or by Becker *et al.* However, for weaker lines, there is severe scatter in Woodgate's data; for several lines, the $A$-values of Refs. 1 and 5 disagree by factors of two or more. We also detected a possible energy-level dependent systematic error in Woodgate's data—the worst cases of disagreement occur for upper energy levels ($E_k$) greater than 44000

$cm^{-1}$. In this compilation, we have included those data of Ref. 5 not covered by Refs. 1, 2, 4, and 6, but have lowered the accuracies of weaker lines (log $gf < 0$) to "E."

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Mn I: Allowed transitions

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $a\ ^6S - z\ ^8P^\circ$ (1) | | | | | | | | | | | |
| | | 5394.68 | 0 | 18532 | 6 | 8 | 9.00(−5)[a] | 5.23(−5) | 0.00558 | −3.503 | C+ | 1 |
| | | 5432.56 | 0 | 18402 | 6 | 6 | 6.04(−5) | 2.67(−5) | 0.00287 | −3.795 | C+ | 1 |
| 2. | $a\ ^6S - z\ ^6P^\circ$ (2) | *4032.4* | 0 | *24792* | 6 | 18 | 0.17 | 0.12 | 9.8 | −0.13 | C+ | 1 |
| | | 4030.76 | 0 | 24802 | 6 | 8 | 0.17 | 0.056 | 4.5 | −0.47 | C+ | 1 |
| | | 4033.07 | 0 | 24788 | 6 | 6 | 0.165 | 0.0402 | 3.20 | −0.618 | C+ | 1 |
| | | 4034.49 | 0 | 24779 | 6 | 4 | 0.158 | 0.0258 | 2.05 | −0.811 | C+ | 1 |
| 3. | $a\ ^6S - z\ ^4P^\circ$ (3) | | | | | | | | | | | |
| | | 3224.76 | 0 | 31001 | 6 | 6 | 0.00378 | 5.89(−4) | 0.0375 | −2.452 | C+ | 1 |
| | | 3216.95 | 0 | 31076 | 6 | 4 | 0.00245 | 2.53(−4) | 0.0161 | −2.818 | C+ | 1 |
| 4. | $a\ ^6S - y\ ^6P^\circ$ (uv 1) | *2797.3* | 0 | *35738* | 6 | 18 | 3.7 | 1.3 | 77 | 0.89 | C | 2 |
| | | 2794.82 | 0 | 35770 | 6 | 8 | 3.7 | 0.57 | 32 | 0.53 | C | 2 |
| | | 2798.27 | 0 | 35726 | 6 | 6 | 3.6 | 0.42 | 23 | 0.40 | C | 2 |
| | | 2801.08 | 0 | 35690 | 6 | 4 | 3.7 | 0.29 | 16 | 0.24 | C | 2 |
| 5. | $a\ ^6D - y\ ^6P^\circ$ (4) | | | | | | | | | | | |
| | | 5420.37 | 17282 | 35726 | 8 | 6 | 0.0131 | 0.00431 | 0.616 | −1.462 | C+ | 1 |
| | | 5407.43 | 17282 | 35770 | 8 | 8 | 0.00515 | 0.00226 | 0.322 | −1.743 | C+ | 1 |
| | | 5516.78 | 17568 | 35690 | 4 | 4 | 0.00779 | 0.00356 | 0.258 | −1.847 | C+ | 1 |
| 6. | $a\ ^6D - z\ ^6D^\circ$ (5) | | | | | | | | | | | |
| | | 4041.36 | 17052 | 41789 | 10 | 10 | 0.787 | 0.193 | 25.6 | 0.285 | C+ | 1 |
| | | 4055.55 | 17282 | 41933 | 8 | 8 | 0.431 | 0.106 | 11.4 | −0.070 | C+ | 1 |
| | | 4063.53 | 17452 | 42054 | 6 | 6 | 0.169 | 0.0418 | 3.35 | −0.601 | C+ | 1 |
| | | 4068.01 | 17568 | 42144 | 4 | 4 | 0.014 | 0.0035 | 0.18 | −1.86 | E | 5 |
| | | 4070.28 | 17637 | 42199 | 2 | 2 | 0.23 | 0.056 | 1.5 | −0.95 | C+ | 4 |
| | | 4018.11 | 17052 | 41933 | 10 | 8 | 0.254 | 0.0491 | 6.49 | −0.309 | C+ | 1 |
| | | 4048.75 | 17452 | 42144 | 6 | 4 | 0.75 | 0.12 | 9.9 | −0.13 | C+ | 4 |
| | | 4058.94 | 17568 | 42199 | 4 | 2 | 0.725 | 0.0895 | 4.79 | −0.446 | C+ | 1 |
| | | 4083.63 | 17452 | 41933 | 6 | 8 | 0.28 | 0.094 | 7.6 | −0.25 | C+ | 4 |
| | | 4082.95 | 17568 | 42054 | 4 | 6 | 0.295 | 0.111 | 5.95 | −0.354 | C+ | 1 |
| | | 4079.42 | 17637 | 42144 | 2 | 4 | 0.38 | 0.19 | 5.1 | −0.42 | C+ | 4 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7. | $a\ ^6D - z\ ^6F°$ (6) | *3820.2* | *17301* | *43470* | 30 | 42 | 0.58 | 0.18 | 67 | 0.73 | B | 1,6*n* |
| | | 3806.72 | 17052 | 43314 | 10 | 12 | 0.59 | 0.15 | 19 | 0.19 | B | 1 |
| | | 3823.51 | 17282 | 43429 | 8 | 10 | 0.521 | 0.143 | 14.4 | 0.058 | B | 1 |
| | | 3834.37 | 17452 | 43524 | 6 | 8 | 0.429 | 0.126 | 9.55 | −0.121 | B | 1 |
| | | 3841.07 | 17568 | 43596 | 4 | 6 | 0.33 | 0.11 | 5.5 | −0.36 | C | 6*n* |
| | | 3843.99 | 17637 | 43644 | 2 | 4 | 0.211 | 0.0935 | 2.37 | −0.728 | B | 1 |
| | | 3790.21 | 17052 | 43429 | 10 | 10 | 0.0565 | 0.0122 | 1.52 | −0.915 | B | 1 |
| | | 3809.59 | 17282 | 43524 | 8 | 8 | 0.143 | 0.0312 | 3.13 | −0.603 | B | 1 |
| | | 3823.89 | 17452 | 43596 | 6 | 6 | 0.231 | 0.0506 | 3.82 | −0.518 | B | 1 |
| | | 3833.87 | 17568 | 43644 | 4 | 4 | 0.314 | 0.0692 | 3.49 | −0.558 | B | 1 |
| | | 3839.78 | 17637 | 43673 | 2 | 2 | 0.464 | 0.103 | 2.59 | −0.688 | B | 1 |
| | | 3776.54 | 17052 | 43524 | 10 | 8 | 0.0019 | 3.3(−4) | 0.040 | −2.49 | C | 6*n* |
| | | 3799.26 | 17282 | 43596 | 8 | 6 | 0.0135 | 0.00220 | 0.220 | −1.755 | B | 1 |
| | | 3816.75 | 17452 | 43644 | 6 | 4 | 0.0419 | 0.00611 | 0.460 | −1.436 | B | 1 |
| | | 3829.68 | 17568 | 43673 | 4 | 2 | 0.103 | 0.0113 | 0.572 | −1.343 | B | 1 |
| 8. | $a\ ^6D - z\ ^4F°$ (7) | | | | | | | | | | | |
| | | 3670.51 | 17052 | 44289 | 10 | 10 | 0.0059 | 0.0012 | 0.14 | −1.92 | C | 6*n* |
| | | 3669.84 | 17282 | 44523 | 8 | 8 | 0.0063 | 0.0013 | 0.12 | −1.99 | C | 6*n* |
| | | 3669.20 | 17568 | 44815 | 4 | 4 | 0.0010 | 2.0(−4) | 0.0098 | −3.09 | C | 6*n* |
| | | 3639.15 | 17052 | 44523 | 10 | 8 | 3.9(−4) | 6.2(−5) | 0.0074 | −3.21 | C | 6*n* |
| | | 3646.71 | 17282 | 44696 | 8 | 6 | 5.1(−4) | 7.6(−5) | 0.0073 | −3.21 | C | 6*n* |
| | | 3653.51 | 17452 | 44815 | 6 | 4 | 7.5(−4) | 1.0(−4) | 0.0072 | −3.22 | C | 6*n* |
| | | 3701.73 | 17282 | 44289 | 8 | 10 | 0.0086 | 0.0022 | 0.22 | −1.75 | C | 6*n* |
| | | 3692.82 | 17452 | 44523 | 6 | 8 | 0.0046 | 0.0013 | 0.091 | −2.12 | C | 6*n* |
| | | 3685.22 | 17568 | 44696 | 4 | 6 | 0.0021 | 6.4(−4) | 0.031 | −2.59 | C | 6*n* |
| | | 3678.47 | 17637 | 44815 | 2 | 4 | 9.6(−4) | 3.9(−4) | 0.0094 | −3.11 | C | 6*n* |
| 9. | $a\ ^6D - x\ ^6P°$ (8) | | | | | | | | | | | |
| | | 3577.87 | 17052 | 44994 | 10 | 8 | 0.94 | 0.14 | 17 | 0.16 | D− | 5 |
| | | 3595.11 | 17452 | 45259 | 6 | 4 | 0.18 | 0.023 | 1.6 | −0.86 | E | 5 |
| | | 3607.53 | 17282 | 44994 | 8 | 8 | 0.23 | 0.045 | 4.3 | −0.44 | E | 5 |
| | | 3608.49 | 17452 | 45156 | 6 | 6 | 0.36 | 0.071 | 5.1 | −0.37 | E | 5 |
| | | 3610.30 | 17568 | 45259 | 4 | 4 | 0.42 | 0.083 | 3.9 | −0.48 | E | 5 |
| | | 3629.74 | 17452 | 44994 | 6 | 8 | 0.028 | 0.0074 | 0.53 | −1.35 | E | 5 |
| | | 3623.78 | 17568 | 45156 | 4 | 6 | 0.097 | 0.029 | 1.4 | −0.94 | E | 5 |
| 10. | $a\ ^6D - z\ ^4D°$ | | | | | | | | | | | |
| | | 3488.31 | 17282 | 45941 | 8 | 6 | 6.0(−4) | 8.2(−5) | 0.0075 | −3.18 | C | 6*n* |
| | | 3491.55 | 17452 | 46084 | 6 | 4 | 1.2(−4) | 1.5(−5) | 0.0010 | −4.06 | C | 6*n* |
| | | 3511.19 | 17282 | 45754 | 8 | 8 | 2.9(−4) | 5.4(−5) | 0.0050 | −3.37 | C | 6*n* |
| | | 3509.07 | 17452 | 45941 | 6 | 6 | 6.2(−4) | 1.2(−4) | 0.0080 | −3.16 | E | 5 |
| | | 3505.86 | 17568 | 46084 | 4 | 4 | 2.8(−4) | 5.2(−5) | 0.0024 | −3.69 | C | 6*n* |
| | | 3503.73 | 17637 | 46170 | 2 | 2 | 0.0036 | 6.6(−4) | 0.015 | −2.88 | C | 6*n* |
| | | 3523.53 | 17568 | 45941 | 4 | 6 | 2.8(−4) | 7.8(−5) | 0.0036 | −3.50 | C | 6*n* |
| 11. | $a\ ^6D - w\ ^6P°$ | | | | | | | | | | | |
| | | 3290.97 | 17282 | 47660 | 8 | 6 | 0.0021 | 2.6(−4) | 0.022 | −2.69 | E | 5 |
| | | 3308.78 | 17568 | 47782 | 4 | 4 | 0.0049 | 8.1(−4) | 0.035 | −2.49 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | $a\,^6$D – $y\,^6$D° | | | | | | | | | | | |
| | | 3240.41 | 17052 | 47904 | 10 | 10 | 0.064 | 0.010 | 1.1 | −1.00 | E | 5 |
| | | 3278.55 | 17282 | 47775 | 8 | 8 | 0.0091 | 0.0015 | 0.13 | −1.93 | E | 5 |
| | | 3343.72 | 17568 | 47467 | 4 | 4 | 0.0086 | 0.0014 | 0.063 | −2.24 | E | 5 |
| | | 3254.04 | 17052 | 47775 | 10 | 8 | 0.017 | 0.0021 | 0.23 | −1.67 | E | 5 |
| | | 3330.66 | 17452 | 47467 | 6 | 4 | 0.074 | 0.0082 | 0.54 | −1.31 | E | 5 |
| | | 3264.71 | 17282 | 47904 | 8 | 10 | 0.14 | 0.029 | 2.5 | −0.64 | E | 5 |
| | | 3296.88 | 17452 | 47775 | 6 | 8 | 0.015 | 0.0032 | 0.21 | −1.72 | E | 5 |
| | | 3311.90 | 17568 | 47754 | 4 | 6 | 0.020 | 0.0049 | 0.21 | −1.71 | E | 5 |
| 13. | $a\,^6$D – $y\,^6$F° (14) | | | | | | | | | | | |
| | | 3228.09 | 17052 | 48021 | 10 | 12 | 0.64 | 0.12 | 13 | 0.08 | D− | 5 |
| | | 3256.14 | 17568 | 48271 | 4 | 6 | 0.50 | 0.12 | 5.1 | −0.32 | E | 5 |
| | | 3260.24 | 17637 | 48301 | 2 | 4 | 0.38 | 0.12 | 2.6 | −0.62 | E | 5 |
| | | 3212.89 | 17052 | 48168 | 10 | 10 | 0.16 | 0.025 | 2.7 | −0.60 | E | 5 |
| | | 3230.72 | 17282 | 48226 | 8 | 8 | 0.35 | 0.055 | 4.6 | −0.36 | E | 5 |
| | | 3243.78 | 17452 | 48271 | 6 | 6 | 0.53 | 0.084 | 5.4 | −0.30 | E | 5 |
| | | 3252.95 | 17568 | 48301 | 4 | 4 | 0.18 | 0.028 | 1.2 | −0.95 | E | 5 |
| | | 3258.41 | 17637 | 48318 | 2 | 2 | 0.97 | 0.15 | 3.3 | −0.51 | E | 5 |
| | | 3206.91 | 17052 | 48226 | 10 | 8 | 0.010 | 0.0013 | 0.14 | −1.89 | E | 5 |
| | | 3226.05 | 17282 | 48271 | 8 | 6 | 0.049 | 0.0057 | 0.49 | −1.34 | E | 5 |
| | | 3240.61 | 17452 | 48301 | 6 | 4 | 0.098 | 0.010 | 0.66 | −1.21 | E | 5 |
| | | 3251.13 | 17568 | 48318 | 4 | 2 | 0.23 | 0.019 | 0.79 | −1.13 | E | 5 |
| 14. | $a\,^6$D – $v\,^6$P° (15) | | | | | | | | | | | |
| | | 3044.57 | 17052 | 49888 | 10 | 8 | 0.57 | 0.063 | 6.3 | −0.20 | E | 5 |
| | | 3054.36 | 17282 | 50013 | 8 | 6 | 0.46 | 0.049 | 3.9 | −0.41 | E | 5 |
| | | 3062.12 | 17452 | 50099 | 6 | 4 | 0.13 | 0.012 | 0.73 | −1.14 | E | 5 |
| | | 3066.02 | 17282 | 49888 | 8 | 8 | 0.16 | 0.023 | 1.8 | −0.74 | E | 5 |
| | | 3070.27 | 17452 | 50013 | 6 | 6 | 0.19 | 0.026 | 1.6 | −0.80 | E | 5 |
| | | 3073.18 | 17568 | 50099 | 4 | 4 | 0.37 | 0.052 | 2.1 | −0.68 | E | 5 |
| | | 3081.34 | 17568 | 50013 | 4 | 6 | 0.030 | 0.0064 | 0.26 | −1.59 | E | 5 |
| | | 3079.64 | 17637 | 50099 | 2 | 4 | 0.16 | 0.047 | 0.95 | −1.03 | E | 5 |
| 15. | $z\,^8$P° – $e\,^8$S (16) | *4792.8* | *18572* | 39431 | 24 | 8 | 1.20 | 0.138 | 52.2 | 0.520 | B | 1 |
| | | 4823.53 | 18705 | 39431 | 10 | 8 | 0.499 | 0.139 | 22.1 | 0.144 | B | 1 |
| | | 4783.43 | 18532 | 39431 | 8 | 8 | 0.401 | 0.138 | 17.3 | 0.042 | B | 1 |
| | | 4754.05 | 18402 | 39431 | 6 | 8 | 0.303 | 0.137 | 12.8 | −0.086 | B | 1 |
| 16. | $z\,^8$P° – $e\,^6$D | | | | | | | | | | | |
| | | 3507.54 | 18705 | 47207 | 10 | 10 | 5.9(−4) | 1.1(−4) | 0.013 | −2.96 | E | 5 |
| 17. | $z\,^8$P° – $f\,^8$S (19) | *3165.0* | *18572* | 50158 | 24 | 8 | 0.18 | 0.0088 | 2.2 | −0.68 | E | 5 |
| | | 3178.50 | 18705 | 50158 | 10 | 8 | 0.037 | 0.0045 | 0.47 | −1.35 | E | 5 |
| | | 3161.05 | 18532 | 50158 | 8 | 8 | 0.048 | 0.0072 | 0.60 | −1.24 | E | 5 |
| | | 3148.18 | 18402 | 50158 | 6 | 8 | 0.088 | 0.017 | 1.1 | −0.98 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18. | $a\,^4D - z\,^6F°$ (20) | | | | | | | | | | | |
| | | 4965.86 | 23297 | 43429 | 8 | 10 | 0.011 | 0.0051 | 0.66 | −1.39 | C | 6*n* |
| | | 5004.89 | 23549 | 43524 | 6 | 8 | 0.0078 | 0.0039 | 0.39 | −1.63 | C | 6*n* |
| | | 5029.78 | 23720 | 43596 | 4 | 6 | 0.0056 | 0.0032 | 0.21 | −1.89 | C | 6*n* |
| | | 5042.57 | 23819 | 43644 | 2 | 4 | 0.0026 | 0.0020 | 0.066 | −2.40 | C | 6*n* |
| | | 4942.40 | 23297 | 43524 | 8 | 8 | 5.5(−4) | 2.0(−4) | 0.026 | −2.79 | C | 6*n* |
| | | 4987.07 | 23549 | 43596 | 6 | 6 | 4.1(−4) | 1.5(−4) | 0.015 | −3.04 | C | 6*n* |
| 19. | $a\,^4D - z\,^4F°$ (21) | *4758.5* | *23509* | *44518* | 20 | 28 | 0.698 | 0.332 | 104 | 0.822 | C+ | 1,6*n* |
| | | 4762.38 | 23297 | 44289 | 8 | 10 | 0.783 | 0.333 | 41.7 | 0.425 | B | 1 |
| | | 4766.43 | 23549 | 44523 | 6 | 8 | 0.46 | 0.21 | 20 | 0.10 | C | 6*n* |
| | | 4765.86 | 23720 | 44696 | 4 | 6 | 0.41 | 0.21 | 13 | −0.08 | C | 6*n* |
| | | 4761.53 | 23819 | 44815 | 2 | 4 | 0.535 | 0.364 | 11.4 | −0.138 | B | 1 |
| | | 4709.71 | 23297 | 44523 | 8 | 8 | 0.172 | 0.0571 | 7.09 | −0.340 | B | 1 |
| | | 4727.46 | 23549 | 44696 | 6 | 6 | 0.17 | 0.057 | 5.3 | −0.47 | C | 6*n* |
| | | 4739.11 | 23720 | 44815 | 4 | 4 | 0.240 | 0.0809 | 5.05 | −0.490 | B | 1 |
| | | 4671.69 | 23297 | 44696 | 8 | 6 | 0.011 | 0.0027 | 0.33 | −1.67 | C | 6*n* |
| | | 4701.15 | 23549 | 44815 | 6 | 4 | 0.017 | 0.0038 | 0.35 | −1.65 | C | 6*n* |
| 20. | $a\,^4D - z\,^4D°$ (22) | *4461.2* | *23509* | *45918* | 20 | 20 | 0.982 | 0.293 | 86.1 | 0.768 | B | 1 |
| | | 4451.58 | 23297 | 45754 | 8 | 8 | 0.798 | 0.237 | 27.8 | 0.278 | B | 1 |
| | | 4464.68 | 23549 | 45941 | 6 | 6 | 0.439 | 0.131 | 11.6 | −0.104 | B | 1 |
| | | 4470.14 | 23720 | 46084 | 4 | 4 | 0.300 | 0.0899 | 5.29 | −0.444 | B | 1 |
| | | 4472.79 | 23819 | 46170 | 2 | 2 | 0.435 | 0.131 | 3.85 | −0.583 | B | 1 |
| | | 4414.89 | 23297 | 45941 | 8 | 6 | 0.293 | 0.0641 | 7.45 | −0.290 | B | 1 |
| | | 4436.36 | 23549 | 46084 | 6 | 4 | 0.437 | 0.0859 | 7.52 | −0.288 | B | 1 |
| | | 4453.01 | 23720 | 46170 | 4 | 2 | 0.544 | 0.0809 | 4.74 | −0.490 | B | 1 |
| | | 4502.22 | 23549 | 45754 | 6 | 8 | 0.186 | 0.0753 | 6.70 | −0.345 | B | 1 |
| | | 4498.90 | 23720 | 45941 | 4 | 6 | 0.249 | 0.0113 | 6.72 | −0.343 | B | 1 |
| | | 4490.08 | 23819 | 46084 | 2 | 4 | 0.249 | 0.150 | 4.44 | −0.522 | B | 1 |
| 21. | $a\,^4D - y\,^4P°$ (23) | | | | | | | | | | | |
| | | 4235.30 | 23297 | 46901 | 8 | 6 | 0.917 | 0.185 | 20.6 | 0.170 | C+ | 1 |
| | | 4239.74 | 23720 | 47299 | 4 | 2 | 0.39 | 0.052 | 2.9 | −0.68 | E | 5 |
| | | 4281.10 | 23549 | 46901 | 6 | 6 | 0.23 | 0.063 | 5.4 | −0.42 | E | 5 |
| | | 4265.93 | 23720 | 47155 | 4 | 4 | 0.492 | 0.134 | 7.54 | −0.270 | C+ | 1 |
| | | 4257.67 | 23819 | 47299 | 2 | 2 | 0.37 | 0.10 | 2.8 | −0.70 | E | 5 |
| | | 4312.55 | 23720 | 46901 | 4 | 6 | 0.0501 | 0.0209 | 1.19 | −1.077 | C+ | 1 |
| | | 4284.08 | 23819 | 47155 | 2 | 4 | 0.0892 | 0.0491 | 1.38 | −1.008 | C+ | 1 |
| 22. | $a\,^4D - y\,^6D°$ | | | | | | | | | | | |
| | | 4230.14 | 23819 | 47452 | 2 | 2 | 0.017 | 0.0045 | 0.12 | −2.05 | E | 5 |
| 23. | $a\,^4D - y\,^4F°$ (24) | | | | | | | | | | | |
| | | 3696.55 | 23297 | 50341 | 8 | 10 | 0.0786 | 0.0201 | 1.96 | −0.793 | C+ | 1 |
| | | 3728.89 | 23549 | 50359 | 6 | 8 | 0.0578 | 0.0161 | 1.18 | −1.016 | C+ | 1 |
| | | 3750.77 | 23720 | 50373 | 4 | 6 | 0.030 | 0.0095 | 0.47 | −1.42 | E | 5 |
| | | 3763.37 | 23819 | 50383 | 2 | 4 | 0.039 | 0.017 | 0.41 | −1.48 | E | 5 |
| | | 3726.95 | 23549 | 50373 | 6 | 6 | 0.013 | 0.0026 | 0.19 | −1.80 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24. | $a\,^4D - x\,^4P°$ (25) | | | | | | | | | | | |
| | | 3583.68 | 23549 | 51446 | 6 | 4 | 0.035 | 0.0045 | 0.32 | −1.57 | E | 5 |
| | | 3591.81 | 23720 | 51553 | 4 | 2 | 0.022 | 0.0021 | 0.098 | −2.08 | E | 5 |
| 25. | $a\,^4D - y\,^4D°$ | | | | | | | | | | | |
| | | 3351.66 | 23297 | 53124 | 8 | 8 | 0.0080 | 0.0013 | 0.12 | −1.97 | C− | 5 |
| 26. | $a\,^4D - x\,^4D°$ | | | | | | | | | | | |
| | | 3142.67 | 23297 | 55108 | 8 | 8 | 0.041 | 0.0061 | 0.51 | −1.31 | E | 5 |
| | | 3159.95 | 23549 | 55186 | 6 | 6 | 0.031 | 0.0047 | 0.29 | −1.55 | E | 5 |
| | | 3167.83 | 23549 | 55108 | 6 | 8 | 0.0072 | 0.0015 | 0.091 | −2.06 | E | 5 |
| | | 3177.04 | 23720 | 55186 | 4 | 6 | 0.011 | 0.0025 | 0.10 | −2.00 | E | 5 |
| | | 3177.62 | 23819 | 55280 | 2 | 4 | 0.012 | 0.0037 | 0.078 | −2.13 | E | 5 |
| 27. | $a\,^4D - w\,^4P°$ | | | | | | | | | | | |
| | | 3141.82 | 23549 | 55369 | 6 | 4 | 0.0067 | 6.6(−4) | 0.041 | −2.40 | E | 5 |
| | | 3149.93 | 23720 | 55457 | 4 | 2 | 0.019 | 0.0014 | 0.060 | −2.24 | E | 5 |
| | | 3138.22 | 23549 | 55405 | 6 | 6 | 0.011 | 0.0016 | 0.10 | −2.01 | E | 5 |
| 28. | $z\,^6P° - e\,^6S$ (27) | | | | | | | | | | | |
| | | 6021.79 | 24802 | 41404 | 8 | 6 | 0.332 | 0.135 | 21.4 | 0.034 | C+ | 1 |
| | | 6013.48 | 24779 | 41404 | 4 | 6 | 0.172 | 0.140 | 11.1 | −0.251 | C+ | 1 |
| 29. | $z\,^6P° - e\,^6D$ (28) | | | | | | | | | | | |
| | | 4462.03 | 24802 | 47207 | 8 | 10 | 0.700 | 0.261 | 30.7 | 0.320 | C+ | 1 |
| | | 4458.26 | 24788 | 47212 | 6 | 8 | 0.462 | 0.184 | 16.2 | 0.042 | C+ | 1 |
| | | 4455.82 | 24779 | 47216 | 4 | 6 | 0.17 | 0.077 | 4.5 | −0.51 | E | 5 |
| | | 4461.09 | 24802 | 47212 | 8 | 8 | 0.17 | 0.052 | 6.1 | −0.38 | E | 5 |
| | | 4457.55 | 24788 | 47216 | 6 | 6 | 0.427 | 0.127 | 11.2 | −0.117 | C+ | 1 |
| | | 4457.04 | 24788 | 47218 | 6 | 4 | 0.234 | 0.0464 | 4.09 | −0.555 | C+ | 1 |
| 30. | $z\,^6P° - f\,^6S$ (29) | | | | | | | | | | | |
| | | 4061.74 | 24802 | 49415 | 8 | 6 | 0.19 | 0.034 | 3.7 | −0.56 | E | 5 |
| | | 4059.39 | 24788 | 49415 | 6 | 6 | 0.14 | 0.034 | 2.7 | −0.69 | E | 5 |
| 31. | $z\,^6P° - g\,^6S$ | | | | | | | | | | | |
| | | 3826.62 | 24779 | 50905 | 4 | 6 | 0.0033 | 0.0011 | 0.055 | −2.36 | E | 5 |
| 32. | $z\,^6P° - i\,^6D$ | | | | | | | | | | | |
| | | 3135.19 | 24779 | 56666 | 4 | 2 | 0.028 | 0.0021 | 0.086 | −2.08 | E | 5 |
| 33. | $z\,^6P° - e\,^4D$ | | | | | | | | | | | |
| | | 3146.32 | 24788 | 56562 | 6 | 6 | 0.0050 | 7.4(−4) | 0.046 | −2.35 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34. | $a\,^4G - z\,^6F^\circ$ (31) | | | | | | | | | | | |
| | | 5504.22 | 25266 | 43429 | 12 | 10 | 6.3(−4) | 2.4(−4) | 0.052 | −2.54 | C | 6n |
| | | 5510.19 | 25285 | 43429 | 10 | 10 | 8.0(−5) | 3.6(−5) | 0.0066 | −3.44 | C | 6n |
| 35. | $a\,^4G - z\,^4F^\circ$ (32) | | | | | | | | | | | |
| | | 5255.33 | 25266 | 44289 | 12 | 10 | 0.0417 | 0.0144 | 2.99 | −0.763 | B | 1 |
| | | 5196.60 | 25285 | 44523 | 10 | 8 | 0.036 | 0.012 | 2.0 | −0.93 | C | 6n |
| | | 5150.94 | 25288 | 44696 | 8 | 6 | 0.039 | 0.012 | 1.6 | −1.03 | C | 6n |
| | | 5117.94 | 25281 | 44815 | 6 | 4 | 0.046 | 0.012 | 1.2 | −1.14 | C | 6n |
| | | 5260.77 | 25285 | 44289 | 10 | 10 | 0.0026 | 0.0011 | 0.19 | −1.97 | C | 6n |
| | | 5197.23 | 25288 | 44523 | 8 | 8 | 0.0048 | 0.0019 | 0.27 | −1.81 | C | 6n |
| | | 5149.16 | 25281 | 44696 | 6 | 6 | 0.0053 | 0.0021 | 0.21 | −1.90 | C | 6n |
| 36. | $a\,^4G - z\,^4H^\circ$ | | | | | | | | | | | |
| | | 4026.44 | 25266 | 50095 | 12 | 14 | 0.089 | 0.025 | 4.0 | −0.52 | E | 5 |
| | | 4031.79 | 25285 | 50081 | 10 | 12 | 0.073 | 0.021 | 2.8 | −0.67 | E | 5 |
| | | 4028.60 | 25266 | 50081 | 12 | 12 | 0.0038 | 9.1(−4) | 0.15 | −1.96 | E | 5 |
| 37. | $a\,^4G - y\,^4F^\circ$ (33) | | | | | | | | | | | |
| | | 3986.82 | 25266 | 50341 | 12 | 10 | 0.11 | 0.021 | 3.3 | −0.60 | E | 5 |
| | | 3987.09 | 25285 | 50359 | 10 | 8 | 0.10 | 0.019 | 2.5 | −0.72 | E | 5 |
| | | 3985.24 | 25288 | 50373 | 8 | 6 | 0.097 | 0.017 | 1.8 | −0.86 | E | 5 |
| | | 3982.58 | 25281 | 50383 | 6 | 4 | 0.23 | 0.036 | 2.9 | −0.66 | E | 5 |
| | | 3989.95 | 25285 | 50341 | 10 | 10 | 0.015 | 0.0036 | 0.48 | −1.44 | E | 5 |
| | | 3987.46 | 25288 | 50359 | 8 | 8 | 0.018 | 0.0042 | 0.44 | −1.47 | E | 5 |
| | | 3984.17 | 25281 | 50373 | 6 | 6 | 0.023 | 0.0054 | 0.42 | −1.49 | E | 5 |
| 38. | $a\,^4G - z\,^4G^\circ$ | | | | | | | | | | | |
| | | 3801.90 | 25266 | 51561 | 12 | 12 | 0.064 | 0.014 | 2.1 | −0.78 | E | 5 |
| | | 3810.68 | 25281 | 51516 | 6 | 6 | 0.053 | 0.012 | 0.87 | −1.16 | E | 5 |
| | | 3804.02 | 25266 | 51546 | 12 | 10 | 0.0028 | 5.0(−4) | 0.075 | −2.22 | E | 5 |
| | | 3811.66 | 25288 | 51516 | 8 | 6 | 0.0038 | 6.3(−4) | 0.063 | −2.30 | E | 5 |
| | | 3808.51 | 25281 | 51531 | 6 | 8 | 0.0057 | 0.0017 | 0.13 | −2.00 | E | 5 |
| 39. | $a\,^4G - y\,^4G^\circ$ | | | | | | | | | | | |
| | | 3047.03 | 25266 | 58075 | 12 | 12 | 0.61 | 0.085 | 10 | 0.01 | D− | 5 |
| | | 3045.59 | 25285 | 58110 | 10 | 10 | 0.67 | 0.093 | 9.4 | −0.03 | E | 5 |
| | | 3043.36 | 25288 | 58137 | 8 | 8 | 0.59 | 0.083 | 6.6 | −0.18 | E | 5 |
| | | 3043.14 | 25285 | 58137 | 10 | 8 | 0.14 | 0.015 | 1.6 | −0.81 | E | 5 |
| | | 3041.22 | 25288 | 58160 | 8 | 6 | 0.11 | 0.012 | 0.93 | −1.03 | E | 5 |
| | | 3048.86 | 25285 | 58075 | 10 | 12 | 0.091 | 0.015 | 1.5 | −0.82 | E | 5 |
| | | 3045.80 | 25288 | 58110 | 8 | 10 | 0.17 | 0.030 | 2.4 | −0.62 | E | 5 |
| 40. | $a\,^4G - y\,^4H^\circ$ | | | | | | | | | | | |
| | | 3016.45 | 25285 | 58427 | 10 | 12 | 0.29 | 0.047 | 4.6 | −0.33 | E | 5 |
| | | 3011.38 | 25288 | 58486 | 8 | 10 | 0.31 | 0.053 | 4.2 | −0.37 | E | 5 |
| | | 3007.65 | 25281 | 58520 | 6 | 8 | 0.18 | 0.033 | 2.0 | −0.70 | E | 5 |
| | | 3011.17 | 25285 | 58486 | 10 | 10 | 0.11 | 0.014 | 1.4 | −0.84 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41. | $a\ ^4P - z\ ^4D°$ (36) | | | | | | | | | | | |
| | | 5388.54 | 27202 | 45754 | 6 | 8 | 0.0059 | 0.0034 | 0.36 | −1.69 | C | 6*n* |
| | | 5348.08 | 27248 | 45941 | 4 | 6 | 0.0065 | 0.0042 | 0.29 | −1.78 | C | 6*n* |
| | | 5317.08 | 27282 | 46084 | 2 | 4 | 0.0035 | 0.0030 | 0.10 | −2.23 | C | 6*n* |
| | | 5334.87 | 27202 | 45941 | 6 | 6 | 5.4(−4) | 2.3(−4) | 0.024 | −2.86 | C | 6*n* |
| | | 5292.87 | 27282 | 46170 | 2 | 2 | 0.0015 | 6.3(−4) | 0.022 | −2.90 | C | 6*n* |
| 42. | $a\ ^4P - x\ ^4P°$ (37) | | | | | | | | | | | |
| | | 4147.53 | 27202 | 51305 | 6 | 6 | 0.066 | 0.017 | 1.4 | −0.99 | E | 5 |
| | | 4119.01 | 27282 | 51553 | 2 | 2 | 0.011 | 0.0029 | 0.078 | −2.24 | E | 5 |
| | | 4123.54 | 27202 | 51446 | 6 | 4 | 0.038 | 0.0065 | 0.53 | −1.41 | E | 5 |
| | | 4155.53 | 27248 | 51305 | 4 | 6 | 0.021 | 0.0081 | 0.44 | −1.49 | E | 5 |
| | | 4137.27 | 27282 | 51446 | 2 | 4 | 0.031 | 0.016 | 0.43 | −1.50 | E | 5 |
| 43. | $a\ ^4P - x\ ^6D°$ | | | | | | | | | | | |
| | | 3894.71 | 27202 | 52870 | 6 | 8 | 0.025 | 0.0076 | 0.59 | −1.34 | E | 5 |
| 44. | $a\ ^4P - y\ ^4D°$ | | | | | | | | | | | |
| | | 3871.67 | 27282 | 53103 | 2 | 4 | 0.0097 | 0.0044 | 0.11 | −2.06 | E | 5 |
| 45. | $a\ ^4P - z\ ^4S°$ | | | | | | | | | | | |
| | | 3700.30 | 27202 | 54219 | 6 | 4 | 0.095 | 0.013 | 0.95 | −1.11 | E | 5 |
| | | 3706.66 | 27248 | 54219 | 4 | 4 | 0.027 | 0.0055 | 0.27 | −1.66 | E | 5 |
| 46. | $a\ ^4P - v\ ^4P°$ | | | | | | | | | | | |
| | | 3300.94 | 27202 | 57487 | 6 | 6 | 0.0097 | 0.0016 | 0.10 | −2.02 | E | 5 |
| | | 3334.56 | 27248 | 57228 | 4 | 2 | 0.024 | 0.0020 | 0.089 | −2.09 | E | 5 |
| 47. | $a\ ^4P - y\ ^4S°$ | *3301.5* | *27231* | 57512 | 12 | 4 | 0.58 | 0.031 | 4.1 | −0.42 | E | 5 |
| | | 3298.23 | 27202 | 57512 | 6 | 4 | 0.28 | 0.030 | 2.0 | −0.74 | E | 5 |
| | | 3303.28 | 27248 | 57512 | 4 | 4 | 0.19 | 0.031 | 1.4 | −0.90 | E | 5 |
| | | 3307.00 | 27282 | 57512 | 2 | 4 | 0.094 | 0.031 | 0.67 | −1.21 | E | 5 |
| 48. | $a\ ^4P - u\ ^4P°$ | | | | | | | | | | | |
| | | 3136.96 | 27248 | 59117 | 4 | 6 | 0.040 | 0.0089 | 0.37 | −1.45 | E | 5 |
| | | 3114.12 | 27282 | 59384 | 2 | 4 | 0.041 | 0.012 | 0.25 | −1.62 | E | 5 |
| 49. | $a\ ^4P - x\ ^4F°$ (38) | | | | | | | | | | | |
| | | 3115.46 | 27202 | 59290 | 6 | 8 | 0.14 | 0.026 | 1.6 | −0.80 | E | 5 |
| | | 3113.12 | 27248 | 59361 | 4 | 6 | 0.051 | 0.011 | 0.46 | −1.35 | E | 5 |
| | | 3108.63 | 27202 | 59361 | 6 | 6 | 0.055 | 0.0080 | 0.49 | −1.32 | E | 5 |
| | | 3103.28 | 27202 | 59416 | 6 | 4 | 0.063 | 0.0061 | 0.37 | −1.44 | E | 5 |
| 50. | $a\ ^4P - \ ^4D°$ | | | | | | | | | | | |
| | | 3110.68 | 27202 | 59340 | 6 | 8 | 0.27 | 0.052 | 3.2 | −0.51 | E | 5 |
| 51. | $a\ ^4P - \ ^4D°$ | | | | | | | | | | | |
| | | 3098.09 | 27202 | 59470 | 6 | 8 | 0.020 | 0.0038 | 0.23 | −1.64 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 52. | $b\ ^4D - z\ ^4D°$ (39) | | | | | | | | | | | |
| | | 6491.70 | 30354 | 45754 | 8 | 8 | 0.018 | 0.011 | 1.9 | −1.04 | C | 6*n* |
| | | 6384.69 | 30426 | 46084 | 4 | 4 | 0.012 | 0.0073 | 0.62 | −1.53 | C | 6*n* |
| | | 6344.13 | 30412 | 46170 | 2 | 2 | 0.013 | 0.0078 | 0.33 | −1.80 | C | 6*n* |
| | | 6413.95 | 30354 | 45941 | 8 | 6 | 0.0033 | 0.0015 | 0.26 | −1.91 | C | 6*n* |
| | | 6382.20 | 30420 | 46084 | 6 | 4 | 0.0065 | 0.0026 | 0.33 | −1.80 | C | 6*n* |
| | | 6349.80 | 30426 | 46170 | 4 | 2 | 0.012 | 0.0036 | 0.30 | −1.84 | C | 6*n* |
| | | 6519.38 | 30420 | 45754 | 6 | 8 | 0.011 | 0.0093 | 1.2 | −1.25 | C | 6*n* |
| | | 6443.51 | 30426 | 45941 | 4 | 6 | 0.0047 | 0.0044 | 0.37 | −1.76 | C | 6*n* |
| | | 6378.97 | 30412 | 46084 | 2 | 4 | 0.0060 | 0.0073 | 0.31 | −1.83 | C | 6*n* |
| 53. | $b\ ^4D - x\ ^4D°$ | | | | | | | | | | | |
| | | 4038.73 | 30354 | 55108 | 8 | 8 | 0.047 | 0.011 | 1.2 | −1.04 | E | 5 |
| | | 4025.94 | 30354 | 55186 | 8 | 6 | 0.019 | 0.0035 | 0.37 | −1.55 | E | 5 |
| | | 4021.35 | 30420 | 55280 | 6 | 4 | 0.014 | 0.0022 | 0.17 | −1.88 | E | 5 |
| | | 4020.07 | 30412 | 55280 | 2 | 4 | 0.049 | 0.024 | 0.63 | −1.32 | E | 5 |
| 54. | $b\ ^4D - w\ ^4P°$ | | | | | | | | | | | |
| | | 3990.74 | 30354 | 55405 | 8 | 6 | 0.0043 | 7.7(−4) | 0.081 | −2.21 | E | 5 |
| | | 4007.04 | 30420 | 55369 | 6 | 4 | 0.022 | 0.0036 | 0.28 | −1.67 | E | 5 |
| | | 3993.86 | 30426 | 55457 | 4 | 2 | 0.044 | 0.0052 | 0.27 | −1.68 | E | 5 |
| | | 4001.19 | 30420 | 55405 | 6 | 6 | 0.024 | 0.0058 | 0.46 | −1.46 | E | 5 |
| | | 4008.02 | 30426 | 55369 | 4 | 4 | 0.046 | 0.011 | 0.59 | −1.35 | E | 5 |
| | | 3991.60 | 30412 | 55457 | 2 | 2 | 0.21 | 0.050 | 1.3 | −1.00 | E | 5 |
| | | 4002.17 | 30426 | 55405 | 4 | 6 | 0.036 | 0.013 | 0.68 | −1.29 | E | 5 |
| 55. | $b\ ^4D - v\ ^4P°$ | | | | | | | | | | | |
| | | 3710.75 | 30420 | 57361 | 6 | 4 | 0.033 | 0.0045 | 0.33 | −1.57 | E | 5 |
| | | 3711.59 | 30426 | 57361 | 4 | 4 | 0.031 | 0.0064 | 0.31 | −1.59 | E | 5 |
| | | 3727.99 | 30412 | 57228 | 2 | 2 | 0.033 | 0.0069 | 0.17 | −1.86 | E | 5 |
| 56. | $b\ ^4D - u\ ^4P°$ | | | | | | | | | | | |
| | | 3451.48 | 30420 | 59384 | 6 | 4 | 0.086 | 0.010 | 0.70 | −1.21 | E | 5 |
| | | 3428.78 | 30412 | 59568 | 2 | 2 | 0.053 | 0.0093 | 0.21 | −1.73 | E | 5 |
| 57. | $b\ ^4D - x\ ^4F°$ (41) | | | | | | | | | | | |
| | | 3458.84 | 30354 | 59257 | 8 | 10 | 0.0093 | 0.0021 | 0.19 | −1.78 | E | 5 |
| 58. | $b\ ^4D - ^4D°$ | | | | | | | | | | | |
| | | 3418.28 | 30354 | 59600 | 8 | 6 | 0.024 | 0.0031 | 0.28 | −1.60 | E | 5 |
| 59. | $b\ ^4D - ^4D°$ | | | | | | | | | | | |
| | | 3360.68 | 30354 | 60102 | 8 | 6 | 0.022 | 0.0027 | 0.24 | −1.66 | E | 5 |
| | | 3364.19 | 30426 | 60142 | 4 | 2 | 0.032 | 0.0027 | 0.12 | −1.97 | E | 5 |
| 60. | $b\ ^4D - ^2D°$ | | | | | | | | | | | |
| | | 3440.04 | 30420 | 59481 | 6 | 6 | 0.029 | 0.0052 | 0.35 | −1.51 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 61. | $b\,^4D - v\,^4F°$ | | | | | | | | | | | |
| | | 3115.75 | 30420 | 62505 | 6 | 8 | 0.12 | 0.024 | 1.4 | −0.85 | E | 5 |
| | | 3118.10 | 30426 | 62487 | 4 | 6 | 0.17 | 0.036 | 1.5 | −0.84 | E | 5 |
| | | 3117.51 | 30420 | 62487 | 6 | 6 | 0.10 | 0.015 | 0.94 | −1.04 | E | 5 |
| 62. | $b\,^4D - ^6F°$ | | | | | | | | | | | |
| | | 3091.10 | 30420 | 62761 | 6 | 6 | 0.0079 | 0.0011 | 0.069 | −2.17 | E | 5 |
| 63. | $z\,^4P° - i\,^6D$ | | | | | | | | | | | |
| | | 3942.88 | 31001 | 56356 | 6 | 8 | 0.018 | 0.0055 | 0.43 | −1.48 | E | 5 |
| | | 3914.21 | 31125 | 56666 | 2 | 2 | 0.012 | 0.0027 | 0.071 | −2.26 | E | 5 |
| 64. | $z\,^4P° - e\,^4D$ | | | | | | | | | | | |
| | | 3926.48 | 31001 | 56462 | 6 | 8 | 0.54 | 0.17 | 13 | 0.00 | D− | 5 |
| | | 3924.08 | 31125 | 56602 | 2 | 4 | 0.94 | 0.44 | 11 | −0.06 | E | 5 |
| | | 3911.14 | 31001 | 56562 | 6 | 6 | 0.13 | 0.030 | 2.3 | −0.75 | E | 5 |
| 65. | $z\,^4P° - f\,^4D$ (45) | | | | | | | | | | | |
| | | 3800.55 | 31001 | 57306 | 6 | 8 | 0.27 | 0.078 | 5.9 | −0.33 | E | 5 |
| | | 3785.42 | 31076 | 57486 | 4 | 6 | 0.098 | 0.031 | 1.6 | −0.90 | E | 5 |
| | | 3772.96 | 31125 | 57622 | 2 | 4 | 0.064 | 0.027 | 0.68 | −1.26 | E | 5 |
| | | 3774.67 | 31001 | 57486 | 6 | 6 | 0.053 | 0.011 | 0.84 | −1.17 | E | 5 |
| | | 3766.05 | 31076 | 57622 | 4 | 4 | 0.045 | 0.0095 | 0.47 | −1.42 | E | 5 |
| | | 3754.22 | 31076 | 57706 | 4 | 2 | 0.14 | 0.014 | 0.71 | −1.24 | E | 5 |
| 66. | $b\,^4P - v\,^4P°$ | | | | | | | | | | | |
| | | 4225.08 | 33825 | 57487 | 6 | 6 | 0.0034 | 9.2(−4) | 0.076 | −2.26 | E | 5 |
| 67. | $b\,^4P - y\,^4S°$ | *4289.9* | *34208* | 57512 | 12 | 4 | 0.23 | 0.021 | 3.6 | −0.59 | E | 5 |
| | | 4220.61 | 33825 | 57512 | 6 | 4 | 0.16 | 0.028 | 2.3 | −0.78 | E | 5 |
| | | 4337.41 | 34463 | 57512 | 4 | 4 | 0.069 | 0.019 | 1.1 | −1.11 | E | 5 |
| | | 4410.49 | 34845 | 57512 | 2 | 4 | 0.011 | 0.0063 | 0.18 | −1.90 | E | 5 |
| 68. | $b\,^4P - u\,^4P°$ | | | | | | | | | | | |
| | | 3952.84 | 33825 | 59117 | 6 | 6 | 0.41 | 0.096 | 7.5 | −0.24 | E | 5 |
| | | 4011.54 | 34463 | 59384 | 4 | 4 | 0.082 | 0.020 | 1.0 | −1.10 | E | 5 |
| | | 3982.16 | 34463 | 59568 | 4 | 2 | 0.35 | 0.041 | 2.2 | −0.78 | E | 5 |
| | | 4073.98 | 34845 | 59384 | 2 | 4 | 0.058 | 0.029 | 0.77 | −1.24 | E | 5 |
| 69. | $b\,^4P - ^4D°$ | | | | | | | | | | | |
| | | 3977.08 | 34463 | 59600 | 4 | 6 | 0.16 | 0.059 | 3.1 | −0.63 | E | 5 |
| 70. | $b\,^4P - ^4D°$ | | | | | | | | | | | |
| | | 3898.37 | 33825 | 59470 | 6 | 8 | 0.17 | 0.052 | 4.0 | −0.51 | E | 5 |
| | | 3899.34 | 34463 | 60102 | 4 | 6 | 0.24 | 0.081 | 4.2 | −0.49 | E | 5 |
| | | 3912.75 | 34845 | 60396 | 2 | 4 | 0.042 | 0.019 | 0.50 | −1.41 | E | 5 |
| | | 3855.11 | 34463 | 60396 | 4 | 4 | 0.032 | 0.0072 | 0.37 | −1.54 | E | 5 |
| | | 3951.98 | 34845 | 60142 | 2 | 2 | 0.31 | 0.072 | 1.9 | −0.84 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71. | $b\,^4P - ^2D°$ | | | | | | | | | | | |
| | | 3996.10 | 34463 | 59481 | 4 | 6 | 0.041 | 0.015 | 0.77 | −1.23 | E | 5 |
| | | 3975.88 | 34845 | 59990 | 2 | 4 | 0.18 | 0.087 | 2.3 | −0.76 | E | 5 |
| 72. | $b\,^4P - u\,^4D°$ | | | | | | | | | | | |
| | | 3268.72 | 33825 | 64410 | 6 | 8 | 0.33 | 0.069 | 4.5 | −0.38 | E | 5 |
| | | 3350.41 | 34845 | 64684 | 2 | 4 | 0.0026 | 8.7(−4) | 0.019 | −2.76 | E | 5 |
| | | 3355.48 | 34845 | 64639 | 2 | 2 | 0.12 | 0.021 | 0.46 | −1.38 | E | 5 |
| 73. | $b\,^4P - ^4D°$ | | | | | | | | | | | |
| | | 3175.36 | 34463 | 65947 | 4 | 6 | 0.065 | 0.015 | 0.62 | −1.23 | E | 5 |
| 74. | $a\,^4H - y\,^4G°$ | | | | | | | | | | | |
| | | 4176.61 | 34139 | 58075 | 14 | 12 | 0.24 | 0.054 | 10 | −0.12 | E | 5 |
| | | 4189.99 | 34251 | 58110 | 12 | 10 | 0.20 | 0.045 | 7.4 | −0.27 | E | 5 |
| | | 4201.78 | 34344 | 58137 | 10 | 8 | 0.23 | 0.048 | 6.6 | −0.32 | E | 5 |
| 75. | $a\,^4H - y\,^4H°$ | | | | | | | | | | | |
| | | 4135.03 | 34251 | 58427 | 12 | 12 | 0.30 | 0.078 | 13 | −0.03 | E | 5 |
| | | 4141.06 | 34344 | 58486 | 10 | 10 | 0.26 | 0.066 | 9.0 | −0.18 | E | 5 |
| | | 4148.80 | 34423 | 58520 | 8 | 8 | 0.23 | 0.060 | 6.5 | −0.32 | E | 5 |
| 76. | $a\,^4H - z\,^4I°$ | | | | | | | | | | | |
| | | 4065.08 | 34251 | 58834 | 12 | 14 | 0.25 | 0.073 | 12 | −0.06 | E | 5 |
| | | 4089.94 | 34423 | 58867 | 8 | 10 | 0.17 | 0.053 | 5.7 | −0.37 | E | 5 |
| 77. | $a\,^4H - ^4D°$ | | | | | | | | | | | |
| | | 3999.57 | 34344 | 59340 | 10 | 8 | 0.0039 | 7.4(−4) | 0.098 | −2.13 | E | 5 |
| 78. | $a\,^4H - ^4D°$ | | | | | | | | | | | |
| | | 3978.78 | 34344 | 59470 | 10 | 8 | 0.0074 | 0.0014 | 0.19 | −1.85 | E | 5 |
| 79. | $a\,^4H - z\,^2I°$ | | | | | | | | | | | |
| | | 3891.62 | 34139 | 59828 | 14 | 12 | 0.011 | 0.0021 | 0.37 | −1.54 | E | 5 |
| 80. | $a\,^4H - x\,^4G°$ | | | | | | | | | | | |
| | | 3923.33 | 34251 | 59732 | 12 | 10 | 0.13 | 0.025 | 3.9 | −0.52 | E | 5 |
| | | 3929.66 | 34344 | 59784 | 10 | 8 | 0.092 | 0.017 | 2.2 | −0.77 | E | 5 |
| | | 3936.77 | 34423 | 59818 | 8 | 6 | 0.12 | 0.022 | 2.3 | −0.76 | E | 5 |
| | | 3935.54 | 34251 | 59653 | 12 | 12 | 0.024 | 0.0056 | 0.88 | −1.17 | E | 5 |
| | | 3937.76 | 34344 | 59732 | 10 | 10 | 0.030 | 0.0069 | 0.90 | −1.16 | E | 5 |
| 81. | $a\,^4H - x\,^4H°$ | | | | | | | | | | | |
| | | 3746.62 | 34251 | 60934 | 12 | 12 | 0.16 | 0.034 | 5.0 | −0.39 | E | 5 |
| | | 3756.64 | 34344 | 60956 | 10 | 10 | 0.14 | 0.030 | 3.7 | −0.52 | E | 5 |
| | | 3767.70 | 34423 | 60957 | 8 | 8 | 0.14 | 0.029 | 2.9 | −0.63 | E | 5 |
| | | 3731.01 | 34139 | 60934 | 14 | 12 | 0.035 | 0.0062 | 1.1 | −1.06 | E | 5 |
| | | 3752.55 | 34251 | 60891 | 12 | 14 | 0.012 | 0.0029 | 0.43 | −1.46 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 82. | $a\ ^4H - y\ ^4I°$ | | | | | | | | | | | |
| | | 3706.08 | 34251 | 61226 | 12 | 14 | 1.4 | 0.33 | 49 | 0.60 | D− | 5 |
| | | 3718.92 | 34344 | 61226 | 10 | 12 | 0.96 | 0.24 | 29 | 0.38 | D− | 5 |
| | | 3731.94 | 34423 | 61211 | 8 | 10 | 1.0 | 0.27 | 26 | 0.33 | D− | 5 |
| | | 3720.91 | 34344 | 61211 | 10 | 10 | 0.025 | 0.0051 | 0.63 | −1.29 | E | 5 |
| 83. | $a\ ^4H - {}^2H°$ | | | | | | | | | | | |
| | | 3657.91 | 34139 | 61469 | 14 | 12 | 0.055 | 0.0094 | 1.6 | −0.88 | E | 5 |
| | | 3685.56 | 34344 | 61469 | 10 | 12 | 0.024 | 0.0059 | 0.71 | −1.23 | E | 5 |
| 84. | $a\ ^4H - {}^2G°$ | | | | | | | | | | | |
| | | 3643.02 | 34344 | 61786 | 10 | 8 | 0.020 | 0.0032 | 0.38 | −1.50 | E | 5 |
| 85. | $a\ ^4H - y\ ^2I°$ | | | | | | | | | | | |
| | | 3626.30 | 34251 | 61819 | 12 | 12 | 0.016 | 0.0032 | 0.45 | −1.42 | E | 5 |
| 86. | $a\ ^4H - {}^4G°$ | | | | | | | | | | | |
| | | 3615.38 | 34423 | 62075 | 8 | 6 | 0.13 | 0.018 | 1.8 | −0.83 | E | 5 |
| 87. | $a\ ^4H - {}^4G°$ | | | | | | | | | | | |
| | | 3446.82 | 34344 | 63348 | 10 | 10 | 0.032 | 0.0058 | 0.65 | −1.24 | E | 5 |
| 88. | $a\ ^4H - w\ ^4H°$ | | | | | | | | | | | |
| | | 3420.79 | 34139 | 63364 | 14 | 14 | 0.12 | 0.021 | 3.3 | −0.53 | E | 5 |
| | | 3450.61 | 34423 | 63395 | 8 | 8 | 0.11 | 0.020 | 1.8 | −0.80 | E | 5 |
| 89. | $a\ ^4H - {}^2H°$ | | | | | | | | | | | |
| | | 3410.80 | 34139 | 63449 | 14 | 12 | 0.015 | 0.0023 | 0.36 | −1.50 | E | 5 |
| 90. | $a\ ^4H - x\ ^2H°$ | | | | | | | | | | | |
| | | 3365.14 | 34344 | 64052 | 10 | 12 | 0.042 | 0.0085 | 0.94 | −1.07 | E | 5 |
| 91. | $a\ ^4H - v\ ^4H°$ | | | | | | | | | | | |
| | | 3267.79 | 34139 | 64732 | 14 | 14 | 0.35 | 0.057 | 8.5 | −0.10 | E | 5 |
| | | 3270.35 | 34251 | 64820 | 12 | 12 | 0.26 | 0.042 | 5.4 | −0.30 | E | 5 |
| | | 3273.02 | 34344 | 64888 | 10 | 10 | 0.27 | 0.044 | 4.7 | −0.36 | E | 5 |
| | | 3278.06 | 34423 | 64920 | 8 | 8 | 0.11 | 0.018 | 1.5 | −0.85 | E | 5 |
| | | 3263.04 | 34251 | 64888 | 12 | 10 | 0.014 | 0.0018 | 0.24 | −1.66 | E | 5 |
| 92. | $a\ ^4H - v\ ^4G°$ | | | | | | | | | | | |
| | | 3148.86 | 34139 | 65887 | 14 | 12 | 0.089 | 0.011 | 1.6 | −0.80 | E | 5 |
| | | 3170.43 | 34344 | 65876 | 10 | 8 | 0.037 | 0.0045 | 0.47 | −1.35 | E | 5 |
| 93. | $a\ ^4H - u\ ^4H°$ | | | | | | | | | | | |
| | | 3082.71 | 34139 | 66569 | 14 | 14 | 0.29 | 0.041 | 5.8 | −0.24 | E | 5 |
| | | 3122.88 | 34344 | 66356 | 10 | 10 | 0.19 | 0.028 | 2.8 | −0.56 | E | 5 |
| | | 3132.79 | 34423 | 66334 | 8 | 8 | 0.27 | 0.040 | 3.3 | −0.50 | E | 5 |
| | | 3113.80 | 34251 | 66356 | 12 | 10 | 0.26 | 0.032 | 3.9 | −0.42 | E | 5 |
| | | 3093.35 | 34251 | 66569 | 12 | 14 | 0.028 | 0.0047 | 0.57 | −1.25 | E | 5 |
| | | 3116.82 | 34344 | 66419 | 10 | 12 | 0.031 | 0.0055 | 0.56 | −1.26 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 94. | $a\ ^4H - u\ ^4G°$ | | | | | | | | | | | |
| | | 3097.76 | 34251 | 66523 | 12 | 10 | 0.056 | 0.0068 | 0.83 | −1.09 | E | 5 |
| | | 3113.36 | 34344 | 66454 | 10 | 8 | 0.088 | 0.010 | 1.0 | −0.99 | E | 5 |
| | | 3126.85 | 34423 | 66395 | 8 | 6 | 0.23 | 0.025 | 2.1 | −0.70 | E | 5 |
| | | 3106.75 | 34344 | 66523 | 10 | 10 | 0.093 | 0.013 | 1.4 | −0.87 | E | 5 |
| | | 3121.07 | 34423 | 66454 | 8 | 8 | 0.11 | 0.016 | 1.3 | −0.90 | E | 5 |
| 95. | $a\ ^4F - y\ ^4G°$ | | | | | | | | | | | |
| | | 4328.68 | 35041 | 58137 | 8 | 8 | 0.0029 | 8.1(−4) | 0.092 | −2.19 | E | 5 |
| 96. | $a\ ^4F - x\ ^4F°$ (47) | | | | | | | | | | | |
| | | 4122.76 | 35041 | 59290 | 8 | 8 | 0.058 | 0.015 | 1.6 | −0.93 | E | 5 |
| | | 4123.28 | 35115 | 59361 | 6 | 6 | 0.090 | 0.023 | 1.9 | −0.86 | E | 5 |
| | | 4122.37 | 35165 | 59416 | 4 | 4 | 0.13 | 0.033 | 1.8 | −0.88 | E | 5 |
| | | 4105.37 | 34939 | 59290 | 10 | 8 | 0.17 | 0.034 | 4.6 | −0.47 | E | 5 |
| | | 4113.88 | 35115 | 59416 | 6 | 4 | 0.15 | 0.026 | 2.1 | −0.81 | E | 5 |
| 97. | $a\ ^4F - ^4D°$ | | | | | | | | | | | |
| | | 4114.38 | 35041 | 59340 | 8 | 8 | 0.15 | 0.038 | 4.1 | −0.52 | E | 5 |
| 98. | $a\ ^4F - ^4D°$ | | | | | | | | | | | |
| | | 4075.25 | 34939 | 59470 | 10 | 8 | 0.069 | 0.014 | 1.9 | −0.86 | E | 5 |
| | | 4092.39 | 35041 | 59470 | 8 | 8 | 0.14 | 0.036 | 3.9 | −0.54 | E | 5 |
| 99. | $a\ ^4F - ^2D°$ | | | | | | | | | | | |
| | | 4090.62 | 35041 | 59481 | 8 | 6 | 0.058 | 0.011 | 1.2 | −1.06 | E | 5 |
| 100. | $a\ ^4F - z\ ^2I°$ | | | | | | | | | | | |
| | | 4016.67 | 34939 | 59828 | 10 | 12 | 0.024 | 0.0069 | 0.91 | −1.16 | E | 5 |
| 101. | $a\ ^4F - x\ ^4G°$ (48) | | | | | | | | | | | |
| | | 4052.48 | 35115 | 59784 | 6 | 8 | 0.38 | 0.12 | 9.9 | −0.13 | E | 5 |
| 102. | $a\ ^4F - w\ ^4F°$ | | | | | | | | | | | |
| | | 3845.01 | 34939 | 60939 | 10 | 10 | 0.034 | 0.0076 | 0.96 | −1.12 | E | 5 |
| | | 3876.71 | 35115 | 60903 | 6 | 8 | 0.0099 | 0.0030 | 0.23 | −1.75 | E | 5 |
| 103. | $a\ ^4F - y\ ^4I°$ | | | | | | | | | | | |
| | | 3803.07 | 34939 | 61226 | 10 | 12 | 0.0060 | 0.0015 | 0.19 | −1.81 | E | 5 |
| 104. | $a\ ^4F - ^2H°$ | | | | | | | | | | | |
| | | 3768.18 | 34939 | 61469 | 10 | 12 | 0.071 | 0.018 | 2.3 | −0.74 | E | 5 |
| 105. | $a\ ^4F - ^4G°$ | | | | | | | | | | | |
| | | 3729.52 | 34939 | 61744 | 10 | 12 | 0.066 | 0.017 | 2.0 | −0.78 | E | 5 |
| | | 3713.79 | 35115 | 62034 | 6 | 8 | 0.045 | 0.012 | 0.91 | −1.13 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 106. | $a\ ^4F - v\ ^4F°$ | | | | | | | | | | | |
| | | 3652.29 | 35115 | 62487 | 6 | 6 | 0.074 | 0.015 | 1.1 | −1.05 | E | 5 |
| 107. | $a\ ^4F - ^4F°$ | | | | | | | | | | | |
| | | 3376.53 | 35041 | 64649 | 8 | 8 | 0.023 | 0.0039 | 0.34 | −1.51 | E | 5 |
| 108. | $a\ ^4F - v\ ^4G°$ | | | | | | | | | | | |
| | | 3230.23 | 34939 | 65887 | 10 | 12 | 0.19 | 0.036 | 3.9 | −0.44 | E | 5 |
| | | 3238.72 | 35041 | 65909 | 8 | 10 | 0.12 | 0.023 | 2.0 | −0.73 | E | 5 |
| | | 3249.89 | 35115 | 65876 | 6 | 8 | 0.081 | 0.017 | 1.1 | −0.99 | E | 5 |
| | | 3255.51 | 35165 | 65873 | 4 | 6 | 0.10 | 0.024 | 1.0 | −1.02 | E | 5 |
| 109. | $a\ ^4F - ^4D°$ | | | | | | | | | | | |
| | | 3240.88 | 35115 | 65962 | 6 | 4 | 0.22 | 0.024 | 1.5 | −0.85 | E | 5 |
| 110. | $a\ ^4F - u\ ^2F°$ | | | | | | | | | | | |
| | | 3203.13 | 34939 | 66149 | 10 | 8 | 0.037 | 0.0046 | 0.48 | −1.34 | E | 5 |
| | | 3227.04 | 35041 | 66021 | 8 | 6 | 0.10 | 0.012 | 0.99 | −1.03 | E | 5 |
| 111. | $a\ ^4F - u\ ^4H°$ | | | | | | | | | | | |
| | | 3175.71 | 34939 | 66419 | 10 | 12 | 0.12 | 0.022 | 2.3 | −0.66 | E | 5 |
| | | 3192.24 | 35041 | 66356 | 8 | 10 | 0.070 | 0.013 | 1.1 | −0.97 | E | 5 |
| | | 3202.21 | 35115 | 66334 | 6 | 8 | 0.045 | 0.0092 | 0.58 | −1.26 | E | 5 |
| 112. | $a\ ^4F - u\ ^4G°$ | | | | | | | | | | | |
| | | 3160.16 | 34939 | 66574 | 10 | 12 | 0.14 | 0.025 | 2.6 | −0.60 | E | 5 |
| | | 3175.58 | 35041 | 66523 | 8 | 10 | 0.18 | 0.034 | 2.8 | −0.57 | E | 5 |
| | | 3189.96 | 35115 | 66454 | 6 | 8 | 0.16 | 0.033 | 2.1 | −0.70 | E | 5 |
| | | 3201.11 | 35165 | 66395 | 4 | 6 | 0.22 | 0.050 | 2.1 | −0.70 | E | 5 |
| 113. | $a\ ^4F - u\ ^4F°$ | | | | | | | | | | | |
| | | 3132.28 | 34939 | 66855 | 10 | 10 | 0.21 | 0.032 | 3.3 | −0.50 | E | 5 |
| | | 3151.42 | 35115 | 66838 | 6 | 6 | 0.10 | 0.015 | 0.92 | −1.05 | E | 5 |
| | | 3155.78 | 35165 | 66844 | 4 | 4 | 0.16 | 0.023 | 0.97 | −1.03 | E | 5 |
| 114. | $a\ ^4F - t\ ^4G°$ | | | | | | | | | | | |
| | | 3046.59 | 34939 | 67753 | 10 | 12 | 0.13 | 0.022 | 2.2 | −0.65 | E | 5 |
| 115. | $a\ ^2I - z\ ^2I°$ | | | | | | | | | | | |
| | | 4452.53 | 37164 | 59617 | 14 | 14 | 0.059 | 0.018 | 3.6 | −0.61 | E | 5 |
| | | 4408.08 | 37149 | 59828 | 12 | 12 | 0.034 | 0.010 | 1.7 | −0.92 | E | 5 |
| 116. | $a\ ^2I - x\ ^4H°$ | | | | | | | | | | | |
| | | 4203.11 | 37149 | 60934 | 12 | 12 | 0.0095 | 0.0025 | 0.42 | −1.52 | E | 5 |
| 117. | $a\ ^2I - ^2G°$ | | | | | | | | | | | |
| | | 4107.87 | 37149 | 61485 | 12 | 10 | 0.097 | 0.020 | 3.3 | −0.61 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 118. | $a\ ^2I - ^2H^\circ$ | | | | | | | | | | | |
| | | 3786.84 | 37149 | 63548 | 12 | 10 | 0.035 | 0.0063 | 0.95 | −1.12 | E | 5 |
| 119. | $a\ ^2I - x\ ^2H^\circ$ | | | | | | | | | | | |
| | | 3718.13 | 37164 | 64052 | 14 | 12 | 0.025 | 0.0044 | 0.75 | −1.21 | E | 5 |
| | | 3715.53 | 37149 | 64055 | 12 | 10 | 0.024 | 0.0042 | 0.61 | −1.30 | E | 5 |
| 120. | $b\ ^4G - z\ ^2I^\circ$ | | | | | | | | | | | |
| | | 4503.87 | 37420 | 59617 | 12 | 14 | 0.083 | 0.030 | 5.3 | −0.45 | E | 5 |
| 121. | $b\ ^4G - x\ ^4G^\circ$ | | | | | | | | | | | |
| | | 4496.64 | 37420 | 59653 | 12 | 12 | 0.036 | 0.011 | 2.0 | −0.88 | E | 5 |
| | | 4523.40 | 37631 | 59732 | 10 | 10 | 0.014 | 0.0044 | 0.65 | −1.36 | E | 5 |
| 122. | $b\ ^4G - z\ ^2G^\circ$ | | | | | | | | | | | |
| | | 4300.19 | 37420 | 60668 | 12 | 10 | 0.087 | 0.020 | 3.4 | −0.62 | E | 5 |
| | | 4326.18 | 37631 | 60739 | 10 | 8 | 0.011 | 0.0025 | 0.36 | −1.60 | E | 5 |
| | | 4359.64 | 37737 | 60668 | 8 | 10 | 0.0099 | 0.0035 | 0.40 | −1.55 | E | 5 |
| 123. | $b\ ^4G - x\ ^4H^\circ$ | | | | | | | | | | | |
| | | 4259.35 | 37420 | 60891 | 12 | 14 | 0.019 | 0.0059 | 0.99 | −1.15 | E | 5 |
| | | 4290.11 | 37631 | 60934 | 10 | 12 | 0.034 | 0.011 | 1.6 | −0.95 | E | 5 |
| | | 4305.67 | 37737 | 60956 | 8 | 10 | 0.034 | 0.012 | 1.4 | −1.02 | E | 5 |
| 124. | $b\ ^4G - ^2F^\circ$ | | | | | | | | | | | |
| | | 4221.56 | 37790 | 61471 | 6 | 6 | 0.026 | 0.0069 | 0.58 | −1.38 | E | 5 |
| 125. | $b\ ^4G - ^2G^\circ$ | | | | | | | | | | | |
| | | 4154.22 | 37420 | 61485 | 12 | 10 | 0.0035 | 7.6(−4) | 0.12 | −2.04 | E | 5 |
| | | 4166.21 | 37790 | 61786 | 6 | 8 | 0.024 | 0.0082 | 0.67 | −1.31 | E | 5 |
| 126. | $b\ ^4G - ^4F^\circ$ | | | | | | | | | | | |
| | | 4151.66 | 37631 | 61711 | 10 | 8 | 0.024 | 0.0049 | 0.67 | −1.31 | E | 5 |
| | | 4167.20 | 37737 | 61727 | 8 | 6 | 0.019 | 0.0038 | 0.41 | −1.52 | E | 5 |
| 127. | $b\ ^4G - ^4G^\circ$ | | | | | | | | | | | |
| | | 4096.68 | 37631 | 62034 | 10 | 8 | 0.025 | 0.0050 | 0.68 | −1.30 | E | 5 |
| | | 4116.60 | 37790 | 62075 | 6 | 6 | 0.12 | 0.030 | 2.4 | −0.75 | E | 5 |
| 128. | $b\ ^4G - v\ ^4F^\circ$ | | | | | | | | | | | |
| | | 4003.26 | 37420 | 62393 | 12 | 10 | 0.11 | 0.022 | 3.5 | −0.58 | E | 5 |
| 129. | $b\ ^4G - ^4G^\circ$ | | | | | | | | | | | |
| | | 3920.66 | 37790 | 63289 | 6 | 8 | 0.027 | 0.0084 | 0.65 | −1.30 | E | 5 |
| 130. | $b\ ^4G - w\ ^4H^\circ$ | | | | | | | | | | | |
| | | 3870.82 | 37631 | 63458 | 10 | 12 | 0.021 | 0.0056 | 0.72 | −1.25 | E | 5 |
| | | 3888.84 | 37737 | 63445 | 8 | 10 | 0.042 | 0.012 | 1.2 | −1.02 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131. | $b\ ^4G - ^2H^\circ$ | | | | | | | | | | | |
| | | 3872.13 | 37631 | 63449 | 10 | 12 | 0.077 | 0.021 | 2.7 | −0.68 | E | 5 |
| | | 3873.20 | 37737 | 63548 | 8 | 10 | 0.11 | 0.031 | 3.2 | −0.60 | E | 5 |
| 132. | $b\ ^4G - ^4F^\circ$ | | | | | | | | | | | |
| | | 3680.15 | 37420 | 64585 | 12 | 10 | 0.19 | 0.032 | 4.7 | −0.41 | E | 5 |
| | | 3708.87 | 37631 | 64585 | 10 | 10 | 0.052 | 0.011 | 1.3 | −0.97 | E | 5 |
| 133. | $b\ ^4G - v\ ^4H^\circ$ | | | | | | | | | | | |
| | | 3660.40 | 37420 | 64732 | 12 | 14 | 0.91 | 0.21 | 31 | 0.41 | D− | 5 |
| | | 3676.96 | 37631 | 64820 | 10 | 12 | 0.73 | 0.18 | 22 | 0.25 | D− | 5 |
| | | 3682.09 | 37737 | 64888 | 8 | 10 | 0.76 | 0.19 | 19 | 0.19 | D− | 5 |
| | | 3684.87 | 37790 | 64920 | 6 | 8 | 0.26 | 0.069 | 5.1 | −0.38 | E | 5 |
| | | 3648.70 | 37420 | 64820 | 12 | 12 | 0.043 | 0.0085 | 1.2 | −0.99 | E | 5 |
| | | 3667.71 | 37631 | 64888 | 10 | 10 | 0.073 | 0.015 | 1.8 | −0.83 | E | 5 |
| | | 3663.37 | 37631 | 64920 | 10 | 8 | 0.050 | 0.0081 | 0.98 | −1.09 | E | 5 |
| 134. | $b\ ^4G - w\ ^2F^\circ$ | | | | | | | | | | | |
| | | 3668.55 | 37737 | 64988 | 8 | 8 | 0.015 | 0.0029 | 0.28 | −1.63 | E | 5 |
| | | 3675.67 | 37790 | 64988 | 6 | 8 | 0.22 | 0.061 | 4.4 | −0.44 | E | 5 |
| 135. | $b\ ^4G - v\ ^4G^\circ$ | | | | | | | | | | | |
| | | 3511.83 | 37420 | 65887 | 12 | 12 | 0.27 | 0.050 | 7.0 | −0.22 | E | 5 |
| | | 3535.30 | 37631 | 65909 | 10 | 10 | 0.17 | 0.032 | 3.7 | −0.50 | E | 5 |
| | | 3559.81 | 37790 | 65873 | 6 | 6 | 0.21 | 0.039 | 2.7 | −0.63 | E | 5 |
| | | 3538.00 | 37631 | 65887 | 10 | 12 | 0.040 | 0.0091 | 1.1 | −1.04 | E | 5 |
| 136. | $b\ ^4G - u\ ^4H^\circ$ | | | | | | | | | | | |
| | | 3429.74 | 37420 | 66569 | 12 | 14 | 0.015 | 0.0030 | 0.41 | −1.44 | E | 5 |
| 137. | $b\ ^4G - u\ ^4G^\circ$ | | | | | | | | | | | |
| | | 3429.16 | 37420 | 66574 | 12 | 12 | 0.051 | 0.0089 | 1.2 | −0.97 | E | 5 |
| | | 3494.86 | 37790 | 66395 | 6 | 6 | 0.032 | 0.0059 | 0.41 | −1.45 | E | 5 |
| 138. | $b\ ^4G - (\ ^\circ)^b$ | | | | | | | | | | | |
| | | 3463.66 | 37737 | 66600 | 8 | 8 | 0.32 | 0.057 | 5.2 | −0.34 | E | 5 |
| | | 3470.01 | 37790 | 66600 | 6 | 8 | 0.24 | 0.058 | 4.0 | −0.46 | E | 5 |
| 139. | $a\ ^2P - z\ ^2P^\circ$ | | | | | | | | | | | |
| | | 4158.69 | 38352 | 62391 | 2 | 2 | 0.16 | 0.043 | 1.2 | −1.07 | E | 5 |
| | | 4164.98 | 38352 | 62355 | 2 | 4 | 0.11 | 0.055 | 1.5 | −0.96 | E | 5 |
| 140. | $a\ ^2H - z\ ^2I^\circ$ | | | | | | | | | | | |
| | | 4626.54 | 38009 | 59617 | 12 | 14 | 0.36 | 0.14 | 25 | 0.21 | D− | 5 |
| | | 4605.37 | 38120 | 59828 | 10 | 12 | 0.36 | 0.14 | 21 | 0.14 | D− | 5 |
| 141. | $a\ ^2H - x\ ^4G^\circ$ | | | | | | | | | | | |
| | | 4642.80 | 38120 | 59653 | 10 | 12 | 0.0096 | 0.0037 | 0.57 | −1.43 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 142. | $a\ ^2$H - $z\ ^2$G° | *4415.5* | *38059* | *60700* | 22 | 18 | 0.25 | 0.059 | 19 | 0.12 | D− | 5 |
| | | 4411.87 | 38009 | 60668 | 12 | 10 | 0.26 | 0.063 | 11 | −0.12 | E | 5 |
| | | 4419.77 | 38120 | 60739 | 10 | 8 | 0.21 | 0.050 | 7.3 | −0.30 | E | 5 |
| | | 4433.72 | 38120 | 60668 | 10 | 10 | 0.0073 | 0.0021 | 0.31 | −1.67 | E | 5 |
| 143. | $a\ ^2$H - $w\ ^4$F° | | | | | | | | | | | |
| | | 4359.82 | 38009 | 60939 | 12 | 10 | 0.0072 | 0.0017 | 0.29 | −1.69 | E | 5 |
| | | 4388.09 | 38120 | 60903 | 10 | 8 | 0.024 | 0.0056 | 0.81 | −1.25 | E | 5 |
| 144. | $a\ ^2$H - $x\ ^4$H° | | | | | | | | | | | |
| | | 4368.88 | 38009 | 60891 | 12 | 14 | 0.0060 | 0.0020 | 0.35 | −1.62 | E | 5 |
| 145. | $a\ ^2$H - $y\ ^4$I° | | | | | | | | | | | |
| | | 4326.75 | 38120 | 61226 | 10 | 12 | 0.0046 | 0.0015 | 0.22 | −1.81 | E | 5 |
| | | 4329.43 | 38120 | 61211 | 10 | 10 | 0.0047 | 0.0013 | 0.19 | −1.88 | E | 5 |
| 146. | $a\ ^2$H - $^2$H° | | | | | | | | | | | |
| | | 4261.30 | 38009 | 61469 | 12 | 12 | 0.081 | 0.022 | 3.7 | −0.58 | E | 5 |
| 147. | $a\ ^2$H - $^2$F° | | | | | | | | | | | |
| | | 4279.55 | 38120 | 61481 | 10 | 8 | 0.029 | 0.0063 | 0.89 | −1.20 | E | 5 |
| 148. | $a\ ^2$H - $^2$G° | *4243.3* | *38059* | *61619* | 22 | 18 | 0.057 | 0.013 | 3.9 | −0.55 | E | 5 |
| | | 4258.37 | 38009 | 61485 | 12 | 10 | 0.025 | 0.0056 | 0.95 | −1.17 | E | 5 |
| | | 4224.34 | 38120 | 61786 | 10 | 8 | 0.011 | 0.0025 | 0.34 | −1.61 | E | 5 |
| | | 4278.68 | 38120 | 61485 | 10 | 10 | 0.068 | 0.019 | 2.6 | −0.73 | E | 5 |
| 149. | $a\ ^2$H - $y\ ^2$I° | | | | | | | | | | | |
| | | 4182.25 | 38009 | 61913 | 12 | 14 | 0.092 | 0.028 | 4.7 | −0.47 | E | 5 |
| 150. | $a\ ^2$H - $^4$G° | | | | | | | | | | | |
| | | 3954.58 | 38009 | 63289 | 12 | 12 | 0.046 | 0.011 | 1.7 | −0.89 | E | 5 |
| 151. | $a\ ^2$H - $w\ ^4$H° | | | | | | | | | | | |
| | | 3928.31 | 38009 | 63458 | 12 | 12 | 0.039 | 0.0091 | 1.4 | −0.96 | E | 5 |
| 152. | $a\ ^2$H - $^2$H° | | | | | | | | | | | |
| | | 3931.52 | 38120 | 63548 | 10 | 10 | 0.082 | 0.019 | 2.5 | −0.72 | E | 5 |
| 153. | $a\ ^2$H - $w\ ^2$G° | | | | | | | | | | | |
| | | 3668.20 | 38009 | 65262 | 12 | 10 | 0.010 | 0.0017 | 0.25 | −1.69 | E | 5 |
| 154. | $a\ ^2$H - $v\ ^2$F° | | | | | | | | | | | |
| | | 3635.70 | 38120 | 65617 | 10 | 8 | 0.21 | 0.033 | 4.0 | −0.48 | E | 5 |
| 155. | $a\ ^2$H - $^2$G° | | | | | | | | | | | |
| | | 3601.27 | 38009 | 65769 | 12 | 10 | 0.23 | 0.037 | 5.3 | −0.35 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 156. | $a\ ^2H - v\ ^2H°$ | | | | | | | | | | | |
| | | 3152.25 | 38009 | 69723 | 12 | 12 | 0.081 | 0.012 | 1.5 | −0.84 | E | 5 |
| | | 3169.36 | 38120 | 69663? | 10 | 10 | 0.075 | 0.011 | 1.2 | −0.95 | E | 5 |
| 157. | $a\ ^2F - z\ ^2G°$ | | | | | | | | | | | |
| | | 4544.42 | 38670 | 60668 | 8 | 10 | 0.030 | 0.012 | 1.4 | −1.03 | E | 5 |
| | | 4529.80 | 38670 | 60739 | 8 | 8 | 0.019 | 0.0057 | 0.68 | −1.34 | E | 5 |
| 158. | $a\ ^2F - {}^2F°$ | | | | | | | | | | | |
| | | 4434.14 | 38935 | 61481 | 6 | 8 | 0.015 | 0.0059 | 0.52 | −1.45 | E | 5 |
| 159. | $a\ ^2F - {}^2G°$ | | | | | | | | | | | |
| | | 4381.70 | 38670 | 61485 | 8 | 10 | 0.14 | 0.050 | 5.7 | −0.40 | E | 5 |
| 160. | $a\ ^2F - {}^4G°$ | | | | | | | | | | | |
| | | 4327.95 | 38935 | 62034 | 6 | 8 | 0.027 | 0.010 | 0.88 | −1.21 | E | 5 |
| 161. | $a\ ^2F - {}^4G°$ | | | | | | | | | | | |
| | | 4085.48 | 38670 | 63140 | 8 | 6 | 0.015 | 0.0028 | 0.30 | −1.65 | E | 5 |
| 162. | $a\ ^2F - w\ ^2G°$ | | | | | | | | | | | |
| | | 3791.08 | 38935 | 65305 | 6 | 8 | 0.027 | 0.0078 | 0.58 | −1.33 | E | 5 |
| | | 3753.30 | 38670 | 65305 | 8 | 8 | 0.011 | 0.0023 | 0.22 | −1.74 | E | 5 |
| 163. | $a\ ^2F - v\ ^2F°$ | | | | | | | | | | | |
| | | 3709.83 | 38670 | 65617 | 8 | 8 | 0.068 | 0.014 | 1.4 | −0.95 | E | 5 |
| 164. | $a\ ^2G - {}^2H°$ | | | | | | | | | | | |
| | | 4479.40 | 41230 | 63548 | 8 | 10 | 0.34 | 0.13 | 15 | 0.01 | D− | 5 |
| 165. | $a\ ^2G - w\ ^2G°$ | | | | | | | | | | | |
| | | 4125.81 | 41031 | 65262 | 10 | 10 | 0.070 | 0.018 | 2.4 | −0.75 | E | 5 |
| | | 4152.57 | 41230 | 65305 | 8 | 8 | 0.011 | 0.0029 | 0.32 | −1.63 | E | 5 |
| 166. | $a\ ^2G - v\ ^2F°$ | *4078.5* | *41119* | *65631* | 18 | 14 | 0.21 | 0.041 | 10 | −0.13 | E | 5 |
| | | 4066.24 | 41031 | 65617 | 10 | 8 | 0.22 | 0.044 | 5.8 | −0.36 | E | 5 |
| | | 4094.07 | 41230 | 65649? | 8 | 6 | 0.076 | 0.014 | 1.5 | −0.94 | E | 5 |
| | | 4099.40 | 41230 | 65617 | 8 | 8 | 0.11 | 0.029 | 3.1 | −0.64 | E | 5 |
| 167. | $a\ ^2G - u\ ^2F°$ | | | | | | | | | | | |
| | | 3980.14 | 41031 | 66149 | 10 | 8 | 0.13 | 0.025 | 3.2 | −0.61 | E | 5 |
| | | 4011.91 | 41230 | 66149 | 8 | 8 | 0.23 | 0.055 | 5.8 | −0.36 | E | 5 |
| 168. | $a\ ^2G - v\ ^2G°$ | | | | | | | | | | | |
| | | 3919.33 | 41230 | 66738 | 8 | 8 | 0.088 | 0.020 | 2.1 | −0.79 | E | 5 |
| 169. | $a\ ^2G - w\ ^2H°$ | | | | | | | | | | | |
| | | 3776.29 | 41031 | 67505 | 10 | 12 | 0.050 | 0.013 | 1.6 | −0.89 | E | 5 |

Mn I: Allowed transitions — Continued

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 170. | $e\ ^6S - {^4S^\circ}$ | | | | | | | | | | | |
| | | 3982.90 | 41404 | 66504 | 6 | 4 | 0.55 | 0.087 | 6.9 | −0.28 | E | 5 |
| 171. | $b\ ^2I - w\ ^2H^\circ$ | | | | | | | | | | | |
| | | 4088.57 | 43053 | 67505 | 14 | 12 | 0.046 | 0.0099 | 1.9 | −0.86 | E | 5 |
| 172. | $b\ ^2I - z\ ^2K^\circ$ | | | | | | | | | | | |
| | | 3889.46 | 43139 | 68843? | 12 | 14 | 0.31 | 0.081 | 13 | −0.01 | E | 5 |
| 173. | $b\ ^2I - x\ ^2I^\circ$ | | | | | | | | | | | |
| | | 3771.44 | 43053 | 69561? | 14 | 14 | 0.19 | 0.041 | 7.1 | −0.24 | E | 5 |
| | | 3773.86 | 43139 | 69630? | 12 | 12 | 0.25 | 0.053 | 7.8 | −0.20 | E | 5 |
| 174. | $z\ ^4F^\circ - f\ ^4G$ | | | | | | | | | | | |
| | | 4132.28 | 44523 | 68716 | 8 | 10 | 0.15 | 0.049 | 5.3 | −0.41 | E | 5 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.
[b]The term designation for the 66600 cm$^{-1}$ level was not provided by Corliss and Sugar in their energy level compilation (J. Phys. Chem. Ref. Data 6, 1253 (1977)), so we have accordingly omitted it from this work.

# Mn I

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 4197.2 | 2 | 5862.7 | 1 | 16172 | 3 | 16716 | 3 |
| 5668.3 | 1 | 15950 | 3 | 16253 | 3 | 17104 | 3 |
| 5690.4 | 1 | 15952 | 3 | 16395 | 3 | 395890 | 4 |
| 5728.6 | 1 | 15995 | 3 | 16436 | 3 | 586970 | 4 |
| 5784.8 | 1 | 16010 | 3 | 16621 | 3 | 1006000 | 4 |

For this spectrum, we chose the work of Nussbaumer and Swings,[1] who calculated M1 and E2 transition probabilities for lines connecting the $3d^54s^2$ (ground) configuration to the $3d^64s$ configuration. These authors also provided M1 data for lines within the $3d^64s$ configuration. The calculations include the effects of spin-orbit interaction and limited configuration interaction. As is usually the case, $A$-values for electric quadrupole transitions are expected to be less accurate than those for M1 transitions.

For the $a\ ^6S - a\ ^4D$ multiplet, we have not tabulated data for three lines which were considered in Ref. 1. Each of these lines emits a combination of M1 and E2 radiation, and the radiation types could not be separated. The total transition probabilities are as follows: for the 4291.25 Å line, $A_{ki} = 8.2 \times 10^{-5}$ s$^{-1}$; for the 4245.23 Å line, $A_{ki} = 2.7 \times 10^{-4}$ s$^{-1}$; for the 4214.75 Å line, $A_{ki} = 1.7 \times 10^{-4}$ s$^{-1}$. However, the $a\ ^6S_{5/2} - a\ ^4D_{1/2}$ transition is strictly electric quadrupole, so we have included it in this compilation.

### Reference

[1]H. Nussbaumer and J. P. Swings, Astrophys. J. **172**, 121 (1972).

Mn I: Forbidden transitions

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $a\ ^6S - a\ ^6D$ | | | | | | | | | | |
| | | [5862.7] | 0 | 17052 | 6 | 10 | E2 | 0.29 | 12 | E | 1 |
| | | [5784.8] | 0 | 17282 | 6 | 8 | E2 | 0.31 | 9.6 | E | 1 |
| | | [5728.6] | 0 | 17452 | 6 | 6 | E2 | 0.33 | 7.3 | E | 1 |
| | | [5690.4] | 0 | 17568 | 6 | 4 | E2 | 0.34 | 4.8 | E | 1 |
| | | [5668.3] | 0 | 17637 | 6 | 2 | E2 | 0.35 | 2.4 | E | 1 |
| 2. | $a\ ^6S - a\ ^4D$ | | | | | | | | | | |
| | | [4197.2] | 0 | 23819 | 6 | 2 | E2 | 2.3(−5)[a] | 3.6(−5) | E | 1 |
| 3. | $a\ ^6D - a\ ^4D$ | | | | | | | | | | |
| | | [16010] | 17052 | 23297 | 10 | 8 | M1 | 8.8(−4) | 0.0011 | D | 1 |
| | | [15952] | 17282 | 23549 | 8 | 6 | M1 | 8.7(−5) | 7.9(−5) | D | 1 |
| | | [15950] | 17452 | 23720 | 6 | 4 | M1 | 8.3(−6) | 5.0(−6) | D | 1 |
| | | [15995] | 17568 | 23819 | 4 | 2 | M1 | 1.3(−4) | 3.9(−5) | D | 1 |
| | | [16621] | 17282 | 23297 | 8 | 8 | M1 | 2.6(−4) | 3.5(−4) | D | 1 |
| | | [16395] | 17452 | 23549 | 6 | 6 | M1 | 4.1(−4) | 4.0(−4) | D | 1 |
| | | [16253] | 17568 | 23720 | 4 | 4 | M1 | 5.1(−4) | 3.2(−4) | D | 1 |
| | | [16172] | 17637 | 23819 | 2 | 2 | M1 | 6.9(−4) | 2.2(−4) | D | 1 |
| | | [17104] | 17452 | 23297 | 6 | 8 | M1 | 1.5(−4) | 2.2(−4) | D | 1 |
| | | [16716] | 17568 | 23549 | 4 | 6 | M1 | 2.3(−4) | 2.4(−4) | D | 1 |
| | | [16436] | 17637 | 23720 | 2 | 4 | M1 | 2.2(−4) | 1.4(−4) | D | 1 |
| 4. | $a\ ^4D - a\ ^4D$ | | | | | | | | | | |
| | | [395890] | 23297 | 23549 | 8 | 6 | M1 | 5.0(−4) | 6.9 | C+ | 1 |
| | | [586970] | 23549 | 23720 | 6 | 4 | M1 | 2.8(−4) | 8.4 | C+ | 1 |
| | | [1006000] | 23720 | 23819 | 4 | 2 | M1 | 7.9(−5) | 6.0 | C+ | 1 |

[a] The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn II

Cr Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s\ ^7S_3$

Ionization Energy: 15.64011 eV = 126145.0 cm$^{-1}$

## Allowed Transitions

For this spectrum, we have chosen experimental data from the following three sources: Kwiatkowski *et al.*,[1] who measured radiative lifetimes via selective dye-laser excitation; Woodgate,[2] who measured relative oscillator strengths in emission with a vortex-stabilized arc (discussed in detail in the Mn I introduction); and Martinson *et al.*,[3] who determined absolute $f$-values by measuring beam-foil lifetimes in conjunction with branching ratios obtained from a hollow-cathode discharge.

Kwiatkowski *et al.* have tabulated absolute log $gf$-values for five lines. They were able to convert lifetimes for the $z\ ^7P_2^\circ$ and $z\ ^7P_3^\circ$ levels directly to absolute $f$-values, since in each case there is only one principal mode of decay—down to the $a\ ^7S_3$ ground level. As stated in Ref. 1, the contributions of all other competing downward transitions are estimated to be less than one percent of the total sum, $\Sigma A_{ki}$. For the remaining three lines tabulated in Ref. 1, the authors normalized branching ratios of Ref. 3 to their own laser lifetimes. The data of Refs. 1 and 3 are estimated to contain uncertainties not exceeding 25 percent. The data of Refs. 2 and 3 overlap for five lines—the agreement being within 20 percent for three lines and 32 percent for the remaining two lines.

Recently, Wujec and Weniger[4] used a wall-stabilized arc to measure emission oscillator strengths for 326 lines of Mn II. We tested these data, specifically the scatter of the individual line values and the accuracy of the absolute scale, by comparing them to the data of Refs. 1 and 3 and to the semiempirical calculations of Kurucz and Peytremann.[5] We found that for a few lines arising from levels of low excitation ($E_k < 44000\ \mathrm{cm}^{-1}$), the $f$-values of Refs. 1, 3, 4, and 5 agree quite well with one another. However, the absolute scales formed by the majority of lines tabulated in Refs. 4 and 5 disagree by almost a factor of three, and the scatter is disconcertingly large. For these reasons, we have not included the data of Refs. 4 and 5 in this compilation.

## References


[1]M. Kwiatkowski, G. Micali, K. Werner, and P. Zimmermann, J. Phys. B **15**, 4357 (1982).

[2]B. Woodgate, Mon. Not. R. Astron. Soc. **134**, 287 (1966).

[3]I. Martinson, L. J. Curtis, P. L. Smith, and E. Biemont, Phys. Scr. **16**, 35 (1977).

[4]T. Wujec and S. Weniger, J. Quant. Spectrosc. Radiat. Transfer **28**, 113 (1982).

[5]R. L. Kurucz and E. Peytremann, Smithsonian Astrophysical Observatory Special Report 362 (1975).


Mn II: Allowed transitions

| No. | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $a\ ^7S - z\ ^7P°$ (uv 1) | | | | | | | | | | | |
| | | 2593.72 | 0 | 38543 | 7 | 7 | 2.6 | 0.27 | 16 | 0.27 | C+ | 1 |
| | | 2605.68 | 0 | 38366 | 7 | 5 | 2.7 | 0.20 | 12 | 0.14 | C+ | 1 |
| 2. | $a\ ^5S - z\ ^7P°$ (1) | | | | | | | | | | | |
| | | 3438.97 | 9473 | 38543 | 5 | 7 | 0.0041 | 0.0010 | 0.058 | −2.29 | D | 2 |
| 3. | $a\ ^5S - z\ ^5P°$ (uv 5) | *2942.7* | 9473 | *43446* | 5 | 15 | 1.9 | 0.72 | 35 | 0.56 | C+ | 1 |
| | | 2949.20 | 9473 | 43371 | 5 | 7 | 1.9 | 0.34 | 16 | 0.23 | C+ | 1 |
| | | 2939.31 | 9473 | 43485 | 5 | 5 | 1.9 | 0.24 | 12 | 0.08 | C+ | 1 |
| | | 2933.05 | 9473 | 43557 | 5 | 3 | 2.0 | 0.15 | 7.3 | −0.12 | C+ | 1 |
| 4. | $a\ ^5D - z\ ^5P°$ (3) | *3464.0* | *14586* | *43446* | 25 | 15 | 0.55 | 0.060 | 17 | 0.17 | C | 3 |
| | | 3441.99 | 14326 | 43371 | 9 | 7 | 0.43 | 0.060 | 6.1 | −0.27 | C | 3 |
| | | 3460.32 | 14594 | 43485 | 7 | 5 | 0.32 | 0.041 | 3.3 | −0.54 | C | 3 |
| | | 3474.13 | 14781 | 43557 | 5 | 3 | 0.15 | 0.017 | 0.95 | −1.08 | C | 3 |
| | | 3474.04 | 14594 | 43371 | 7 | 7 | 0.079 | 0.014 | 1.1 | −1.00 | C | 3 |
| | | 3482.90 | 14781 | 43485 | 5 | 5 | 0.20 | 0.036 | 2.1 | −0.74 | C | 3 |
| | | 3488.68 | 14901 | 43557 | 3 | 3 | 0.25 | 0.046 | 1.6 | −0.86 | C | 3 |
| | | 3496.81 | 14781 | 43371 | 5 | 7 | 0.016 | 0.0041 | 0.24 | −1.69 | C− | 3 |
| | | 3497.53 | 14901 | 43485 | 3 | 5 | 0.051 | 0.016 | 0.54 | −1.33 | C− | 3 |
| | | 3495.83 | 14960 | 43557 | 1 | 3 | 0.11 | 0.063 | 0.73 | −1.20 | C− | 3 |

# Mn V

Sc Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3\ ^4F_{3/2}$

Ionization Energy: 72.4 eV = 584000 $cm^{-1}$

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 1591.0 | 8 | 2525.2 | 7 | 4564.7 | 25 | 12138 | 11 |
| 1597.2 | 8 | 2529.2 | 20 | 5620.1 | 19 | 12379 | 11 |
| 1600.1 | 8 | 2562.6 | 7 | 5672.0 | 19 | 12442 | 11 |
| 1606.4 | 8 | 2615.4 | 22 | 5692.0 | 3 | 13117 | 11 |
| 1612.4 | 8 | 2632.3 | 22 | 5701.8 | 3 | 13187 | 11 |
| 1618.8 | 8 | 2635.1 | 22 | 5711.2 | 19 | 14116 | 15 |
| 1634.1 | 8 | 2656.4 | 24 | 5861.0 | 3 | 14416 | 15 |
| 2153.6 | 13 | 4052.3 | 5 | 5885.4 | 3 | 15039 | 10 |
| 2161.1 | 13 | 4058.9 | 5 | 5990.1 | 2 | 15203 | 15 |
| 2165.0 | 13 | 4112.1 | 5 | 6024.4 | 2 | 15416 | 10 |
| 2172.6 | 13 | 4119.0 | 5 | 6066.2 | 3 | 15808 | 10 |
| 2182.5 | 13 | 4195.4 | 12 | 6083.3 | 2 | 17031 | 10 |
| 2194.2 | 13 | 4201.4 | 5 | 6157.6 | 2 | 57072 | 18 |
| 2223.5 | 17 | 4242.8 | 6 | 6166.0 | 2 | 58423 | 18 |
| 2235.7 | 17 | 4362.0 | 4 | 6218.3 | 21 | 62919 | 18 |
| 2261.3 | 17 | 4381.9 | 16 | 6219.1 | 2 | 173200 | 1 |
| 2455.8 | 7 | 4431.4 | 4 | 6234.0 | 21 | 197400 | 14 |
| 2477.7 | 7 | 4437.1 | 16 | 6330.0 | 21 | 210000 | 1 |
| 2495.2 | 7 | 4457.0 | 25 | 6343.6 | 2 | 220200 | 9 |
| 2503.3 | 20 | 4506.3 | 25 | 6354.6 | 23 | 278500 | 1 |
| 2507.3 | 7 | 4514.1 | 25 | 6393.6 | 2 | | |
| 2513.6 | 20 | 4527.0 | 4 | 6471.3 | 23 | | |
| 2518.8 | 20 | 4539.1 | 16 | 6625.3 | 23 | | |

For this spectrum, we have chosen the work of Pasternack,[1] who calculated M1 and E2 transition probabilities within the $3d^3$ configuration by using the central-field approximation without consideration of configuration interaction. However, the $3d^3$ configuration is well-separated from the next configuration—$3d^2 4s$. For electric quadrupole transitions, we modified the data of Ref. 1 by applying correction factors suggested by Garstang.[2] These factors were introduced because of the availability of better wavefunctions. In the case of Fe VI, which is isoelectronic to Mn V, we compared the $A$-values of Ref. 1 to those of Nussbaumer and Storey,[3] who could utilize, in their much later work, modern theoretical and computational techniques. The agreement between Refs. 1 and 3 is surprisingly good—generally within 50 percent—even for the E2 transitions (after undergoing Garstang's correction). Weak lines are subject to greater uncertainties, so we have omitted lines having $A$-values less than 0.001 $s^{-1}$.

## References

[1] S. Pasternack, Astrophys. J. **92**, 129 (1940).
[2] R. H. Garstang, J. Res. Nat. Bur. Stand., Sect. A **68**, 61 (1964).
[3] H. Nussbaumer and P. J. Storey, Astron. Astrophys. **70**, 37 (1978).

Mn V: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^3$–$3d^3$ | $^4$F - $^4$F | | | | | | | | | | |
| | | | [173200] | 835.1 | 1412.2 | 8 | 10 | M1 | 0.0052 | 10 | C | 1 |
| | | | [210000] | 359.0 | 835.1 | 6 | 8 | M1 | 0.0047 | 13 | C | 1 |
| | | | [278500] | 0.0 | 359.0 | 4 | 6 | M1 | 0.0018 | 8.6 | C | 1 |
| 2. | | $^4$F - $^4$P (1F) | | | | | | | | | | |
| | | | [6393.6] | 1412.2 | 17049 | 10 | 6 | E2 | 0.041 | 1.6 | E | 1*n* |
| | | | [6343.6] | 835.1 | 16595 | 8 | 4 | E2 | 0.031 | 0.76 | E | 1*n* |
| | | | [6219.1] | 359.0 | 16434 | 6 | 2 | E2 | 0.026 | 0.29 | E | 1*n* |
| | | | [6166.0] | 835.1 | 17049 | 8 | 6 | E2 | 0.016 | 0.51 | E | 1*n* |
| | | | [6157.6] | 359.0 | 16595 | 6 | 4 | E2 | 0.026 | 0.55 | E | 1*n* |
| | | | [6083.3] | 0.0 | 16434 | 4 | 2 | E2 | 0.044 | 0.44 | E | 1*n* |
| | | | [5990.1] | 359.0 | 17049 | 6 | 6 | E2 | 0.0041 | 0.11 | E | 1*n* |
| | | | [6024.4] | 0.0 | 16595 | 4 | 4 | E2 | 0.0093 | 0.18 | E | 1*n* |
| 3. | | $^4$F - $^2$G (2F) | | | | | | | | | | |
| | | | [5885.4] | 1412.2 | 18399 | 10 | 10 | M1 | 0.24 | 0.018 | E | 1 |
| | | | [5861.0] | 835.1 | 17892 | 8 | 8 | M1 | 0.096 | 0.0057 | E | 1 |
| | | | [6066.2] | 1412.2 | 17892 | 10 | 8 | M1 | 0.0059 | 3.9(−4)[a] | E | 1 |
| | | | [5692.0] | 835.1 | 18399 | 8 | 10 | M1 | 0.096 | 0.0066 | E | 1 |
| | | | [5701.8] | 359.0 | 17892 | 6 | 8 | M1 | 0.088 | 0.0048 | E | 1 |
| 4. | | $^4$F - $^2$P (3F) | | | | | | | | | | |
| | | | [4527.0] | 835.1 | 22919 | 8 | 4 | E2 | 0.0020 | 0.0091 | E | 1*n* |
| | | | [4431.4] | 359.0 | 22919 | 6 | 4 | M1 | 0.17 | 0.0022 | E | 1 |
| | | | " | " | " | 6 | 4 | E2 | 0.0013 | 0.0053 | E | 1*n* |
| | | | [4362.0] | 0.0 | 22919 | 4 | 4 | M1 | 0.11 | 0.0014 | E | 1 |
| 5. | | $^4$F - $^2$D2 (4F) | | | | | | | | | | |
| | | | [4201.4] | 385.1 | 24630 | 8 | 6 | M1 | 0.42 | 0.0069 | E | 1 |
| | | | [4112.1] | 359.0 | 24671 | 6 | 4 | M1 | 0.32 | 0.0033 | E | 1 |
| | | | [4119.0] | 359.0 | 24630 | 6 | 6 | M1 | 0.053 | 8.2(−4) | E | 1 |
| | | | [4052.3] | 0.0 | 24671 | 4 | 4 | M1 | 0.17 | 0.0017 | E | 1 |
| | | | [4058.9] | 0.0 | 24630 | 4 | 6 | M1 | 0.019 | 2.8(−4) | E | 1 |
| 6. | | $^4$F - $^2$H | | | | | | | | | | |
| | | | [4242.8] | 1412.2 | 24975 | 10 | 10 | M1 | 0.0015 | 4.2(−5) | E | 1 |
| 7. | | $^4$F - $^2$F | | | | | | | | | | |
| | | | [2562.6] | 1412.2 | 40423 | 10 | 8 | M1 | 0.092 | 4.6(−4) | D | 1 |
| | | | " | " | " | 10 | 8 | E2 | 0.0024 | 0.0013 | E | 1*n* |
| | | | [2507.3] | 835.1 | 40707 | 8 | 6 | M1 | 0.015 | 5.3(−5) | D | 1 |
| | | | [2525.2] | 835.1 | 40423 | 8 | 8 | M1 | 0.0085 | 4.1(−5) | D | 1 |
| | | | [2477.7] | 359.0 | 40707 | 6 | 6 | M1 | 0.013 | 4.4(−5) | D | 1 |
| | | | [2495.2] | 359.0 | 40423 | 6 | 8 | M1 | 0.037 | 1.7(−4) | D | 1 |
| | | | [2455.8] | 0.0 | 40707 | 4 | 6 | M1 | 0.084 | 2.8(−4) | D | 1 |
| | | | " | " | " | 4 | 6 | E2 | 0.0022 | 7.0(−4) | E | 1*n* |

Mn V: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^4$F - $^2$D1 | | | | | | | | | | |
| | | | [1634.1] | 1412.2 | 62608 | 10 | 6 | E2 | 0.035 | 0.0015 | E | 1$n$ |
| | | | [1612.4] | 835.1 | 62854 | 8 | 4 | E2 | 0.0085 | 2.2(−4) | E | 1$n$ |
| | | | [1618.8] | 835.1 | 62608 | 8 | 6 | M1 | 0.12 | 1.1(−4) | E | 1 |
| | | | 〃 | 〃 | 〃 | 8 | 6 | E2 | 0.0024 | 9.5(−5) | E | 1$n$ |
| | | | [1600.1] | 359.0 | 62854 | 6 | 4 | M1 | 0.13 | 7.9(−5) | E | 1 |
| | | | [1606.4] | 359.0 | 62608 | 6 | 6 | M1 | 0.011 | 1.0(−5) | E | 1 |
| | | | 〃 | 〃 | 〃 | 6 | 6 | E2 | 0.0018 | 6.9(−5) | E | 1$n$ |
| | | | [1591.0] | 0.0 | 62854 | 4 | 4 | M1 | 0.067 | 4.0(−5) | E | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 4 | E2 | 0.0030 | 7.3(−5) | E | 1$n$ |
| | | | [1597.2] | 0.0 | 62608 | 4 | 6 | M1 | 0.0043 | 3.9(−6) | E | 1 |
| 9. | | $^4$P - $^4$P | | | | | | | | | | |
| | | | [220200] | 16595 | 17049 | 4 | 6 | M1 | 0.0015 | 3.6 | C | 1 |
| 10. | | $^4$P - $^2$P | | | | | | | | | | |
| | | | [17031] | 17049 | 22919 | 6 | 4 | M1 | 0.047 | 0.034 | D | 1 |
| | | | [15808] | 16595 | 22919 | 4 | 4 | M1 | 0.080 | 0.047 | D | 1 |
| | | | [15039] | 16434 | 23082 | 2 | 2 | M1 | 0.14 | 0.035 | D | 1 |
| | | | [15416] | 16434 | 22919 | 2 | 4 | M1 | 0.036 | 0.020 | D | 1 |
| 11. | | $^4$P - $^2$D2 | | | | | | | | | | |
| | | | [13187] | 17049 | 24630 | 6 | 6 | M1 | 0.021 | 0.011 | E | 1 |
| | | | [12379] | 16595 | 24671 | 4 | 4 | M1 | 0.0028 | 7.9(−4) | E | 1 |
| | | | [13117] | 17049 | 24671 | 6 | 4 | M1 | 0.057 | 0.019 | E | 1 |
| | | | [12442] | 16595 | 24630 | 4 | 6 | M1 | 0.0011 | 4.7(−4) | E | 1 |
| | | | [12138] | 16434 | 24671 | 2 | 4 | M1 | 0.0049 | 0.0013 | E | 1 |
| 12. | | $^4$P - $^2$F | | | | | | | | | | |
| | | | [4195.4] | 16595 | 40423 | 4 | 8 | E2 | 0.0011 | 0.0068 | E | 1$n$ |
| 13. | | $^4$P - $^2$D1 | | | | | | | | | | |
| | | | [2194.2] | 17049 | 62608 | 6 | 6 | M1 | 0.62 | 0.0015 | E | 1 |
| | | | [2161.1] | 16595 | 62854 | 4 | 4 | M1 | 0.24 | 3.6(−4) | E | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 4 | E2 | 0.052 | 0.0058 | E | 1$n$ |
| | | | [2182.5] | 17049 | 62854 | 6 | 4 | M1 | 0.055 | 8.5(−5) | E | 1 |
| | | | [2172.6] | 16595 | 62608 | 4 | 6 | M1 | 0.11 | 2.5(−4) | E | 1 |
| | | | 〃 | 〃 | 〃 | 4 | 6 | E2 | 0.052 | 0.0090 | E | 1$n$ |
| | | | [2153.6] | 16434 | 62854 | 2 | 4 | M1 | 0.062 | 9.2(−5) | E | 1 |
| | | | 〃 | 〃 | 〃 | 2 | 4 | E2 | 0.017 | 0.0019 | E | 1$n$ |
| | | | [2165.0] | 16434 | 62608 | 2 | 6 | E2 | 0.0050 | 8.5(−4) | E | 1$n$ |
| 14. | | $^2$G - $^2$G | | | | | | | | | | |
| | | | [197400] | 17892 | 18399 | 8 | 10 | M1 | 0.0015 | 4.3 | C | 1 |
| 15. | | $^2$G - $^2$H | | | | | | | | | | |
| | | | [14416] | 18399 | 25334 | 10 | 12 | M1 | 0.043 | 0.057 | E | 1 |
| | | | [14116] | 17892 | 24975 | 8 | 10 | M1 | 0.045 | 0.047 | E | 1 |
| | | | [15203] | 18399 | 24975 | 10 | 10 | M1 | 0.081 | 0.11 | E | 1 |

Mn V: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16. | | $^2G - ^2F$ | | | | | | | | | | |
| | | | [4539.1] | 18399 | 40423 | 10 | 8 | M1 | 0.049 | 0.0014 | E | 1 |
| | | | " | " | " | 10 | 8 | E2 | 0.11 | 1.0 | E | 1*n* |
| | | | [4381.9] | 17892 | 40707 | 8 | 6 | M1 | 0.059 | 0.0011 | E | 1 |
| | | | " | " | " | 8 | 6 | E2 | 0.12 | 0.69 | E | 1*n* |
| | | | [4437.1] | 17892 | 40423 | 8 | 8 | M1 | 0.10 | 0.0026 | E | 1 |
| | | | " | " | " | 8 | 8 | E2 | 0.011 | 0.090 | E | 1*n* |
| 17. | | $^2G - ^2D1$ | | | | | | | | | | |
| | | | [2261.3] | 18399 | 62608 | 10 | 6 | E2 | 11 | 2.3 | E | 1*n* |
| | | | [2223.5] | 17892 | 62854 | 8 | 4 | E2 | 12 | 1.6 | E | 1*n* |
| | | | [2235.7] | 17892 | 62608 | 8 | 6 | E2 | 0.93 | 0.19 | E | 1*n* |
| 18. | | $^2P - ^2D2$ | | | | | | | | | | |
| | | | [58423] | 22919 | 24630 | 4 | 6 | M1 | 0.019 | 0.84 | E | 1 |
| | | | [62919] | 23082 | 24671 | 2 | 4 | M1 | 0.012 | 0.44 | E | 1 |
| | | | [57072] | 22919 | 24671 | 4 | 4 | M1 | 0.036 | 0.99 | E | 1 |
| 19. | | $^2P - ^2F$ | | | | | | | | | | |
| | | | [5711.2] | 22919 | 40423 | 4 | 8 | E2 | 0.020 | 0.58 | E | 1*n* |
| | | | [5672.0] | 23082 | 40707 | 2 | 6 | E2 | 0.012 | 0.25 | E | 1*n* |
| | | | [5620.1] | 22919 | 40707 | 4 | 6 | M1 | 0.0017 | 6.7(−5) | E | 1 |
| | | | " | " | " | 4 | 6 | E2 | 0.0072 | 0.14 | E | 1*n* |
| 20. | | $^2P - ^2D1$ | | | | | | | | | | |
| | | | [2529.2] | 23082 | 62608 | 2 | 6 | E2 | 0.67 | 0.25 | E | 1*n* |
| | | | [2518.8] | 22919 | 62608 | 4 | 6 | M1 | 0.13 | 4.6(−4) | E | 1 |
| | | | " | " | " | 4 | 6 | E2 | 0.89 | 0.32 | E | 1*n* |
| | | | [2513.6] | 23082 | 62854 | 2 | 4 | E2 | 1.6 | 0.38 | E | 1*n* |
| | | | [2503.3] | 22919 | 62854 | 4 | 4 | M1 | 0.0011 | 2.6(−6) | E | 1 |
| | | | " | " | " | 4 | 4 | E2 | 2.6 | 0.61 | E | 1*n* |
| 21. | | $^2D2 - ^2F$ | | | | | | | | | | |
| | | | [6330.0] | 24630 | 40423 | 6 | 8 | M1 | 0.0037 | 2.8(−4) | E | 1 |
| | | | " | " | " | 6 | 8 | E2 | 0.033 | 1.6 | E | 1*n* |
| | | | [6234.0] | 24671 | 40707 | 4 | 6 | M1 | 0.0024 | 1.3(−4) | E | 1 |
| | | | " | " | " | 4 | 6 | E2 | 0.026 | 0.87 | E | 1*n* |
| | | | [6218.3] | 24630 | 40707 | 6 | 6 | M1 | 0.010 | 5.3(−4) | E | 1 |
| | | | " | " | " | 6 | 6 | E2 | 0.0080 | 0.27 | E | 1*n* |
| 22. | | $^2D2 - ^2D1$ | | | | | | | | | | |
| | | | [2632.3] | 24630 | 62608 | 6 | 6 | E2 | 0.91 | 0.41 | E | 1*n* |
| | | | [2615.4] | 24630 | 62854 | 6 | 4 | M1 | 0.39 | 0.0010 | D | 1 |
| | | | " | " | " | 6 | 4 | E2 | 0.11 | 0.032 | E | 1*n* |
| | | | [2635.1] | 24671 | 62608 | 4 | 6 | M1 | 0.15 | 6.1(−4) | D | 1 |
| | | | " | " | " | 4 | 6 | E2 | 1.6 | 0.73 | E | 1*n* |
| 23. | | $^2H - ^2F$ | | | | | | | | | | |
| | | | [6625.3] | 25334 | 40423 | 12 | 8 | E2 | 0.048 | 2.9 | E | 1*n* |
| | | | [6354.6] | 24975 | 40707 | 10 | 6 | E2 | 0.057 | 2.1 | E | 1*n* |
| | | | [6471.3] | 24975 | 40423 | 10 | 8 | E2 | 0.0012 | 0.065 | E | 1*n* |

Mn VI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | | $^1$D - $^1$F° | 1285.10 | 255240 | 333055 | 5 | 7 | 11 | 0.38 | 8.1 | 0.28 | D− | 1 |
| 13. | | $^1$D - $^1$P° | 1236.23 | 255240 | 336131 | 5 | 3 | 13 | 0.17 | 3.5 | −0.06 | D− | 1 |

## Mn VI

### Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 391.79 | 12 | 422.63 | 16 | 510.27 | 20 | 5894.9 | 3 |
| 392.94 | 12 | 423.61 | 13 | 522.84 | 19 | 6518.8 | 2 |
| 394.37 | 12 | 425.19 | 13 | 1687.3 | 5 | 6852.1 | 2 |
| 397.77 | 11 | 425.97 | 13 | 2275.7 | 8 | 7314.9 | 2 |
| 398.95 | 11 | 428.55 | 15 | 2426.0 | 10 | 9825.3 | 7 |
| 399.16 | 11 | 429.60 | 15 | 2460.1 | 10 | 30370 | 6 |
| 399.85 | 11 | 429.65 | 15 | 3918.8 | 4 | 36740 | 6 |
| 400.35 | 11 | 430.16 | 15 | 4036.8 | 4 | 108000 | 1 |
| 400.43 | 11 | 430.96 | 15 | 4193.1 | 4 | 134000 | 1 |
| 401.04 | 11 | 431.22 | 15 | 5366.8 | 3 | 175000 | 9 |
| 401.84 | 11 | 432.02 | 15 | 5536.5 | 3 | 364000 | 9 |
| 416.83 | 14 | 435.30 | 18 | 5590.7 | 3 | | |
| 421.13 | 16 | 442.69 | 17 | 5622.1 | 3 | | |
| 421.62 | 16 | 444.41 | 17 | 5775.1 | 3 | | |

For this ion, we selected the work of Warner and Kirkpatrick,[1] who used a single-configuration approximation and calculated radial integrals with scaled Thomas-Fermi wavefunctions. We have tabulated M1 and E2 transition probabilities for 23 lines within the $3d^2$ (ground) configuration and E2 data for 30 lines in the $3d^2$–$3d4s$ transition array. For long-wavelength lines within the $3d^2$ $^3$F and $3d^2$ $^3$P terms, we have recalculated Warner and Kirkpatrick's $A$-values by using observed energy-level information instead of theoretically derived values.

For lines within the $3d^2$ configuration, calculated $A$-values by Garstang[2] are also available. The $A$-values for M1 transitions from Refs. 1 and 2 are in almost perfect agreement. For E2 transitions, the data agree within 40 percent. In this compilation, we tabulated only the $A$-values of Ref. 1, since it is the more comprehensive work and includes the $3d^2$–$3d4s$ transition array. For other spectra, we found that the electric quadrupole data of Warner and Kirkpatrick agree reasonably well with other recent calculations.

### References

[1]B. Warner and R. C. Kirkpatrick, Mon. Not. R. Astron. Soc. **144**, 397 (1969).

[2]R. H. Garstang, J. Res. Nat. Bur. Stand., Sect. A **68**, 61 (1964).

Mn VI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3d^2$-$3d^2$ | $^3$F - $^3$F | | | | | | | | | | |
| | | | [108000] | 746 | 1669 | 7 | 9 | M1 | 0.016 | 6.8 | C | 1$n$ |
| | | | [134000] | 0 | 746 | 5 | 7 | M1 | 0.011 | 7.1 | C | 1$n$ |
| 2. | | $^3$F - $^1$D (1F) | | | | | | | | | | |
| | | | [7314.9] | 1669 | 15336 | 9 | 5 | E2 | 6.5(−4)[a] | 0.041 | E | 1 |
| | | | [6852.1] | 746 | 15336 | 7 | 5 | M1 | 0.24 | 0.014 | E | 1 |
| | | | ″ | ″ | ″ | 7 | 5 | E2 | 1.7(−4) | 0.0076 | E | 1 |
| | | | [6518.8] | 0 | 15336 | 5 | 5 | M1 | 0.14 | 0.0072 | E | 1 |
| | | | ″ | ″ | ″ | 5 | 5 | E2 | 1.2(−4) | 0.0042 | E | 1 |
| 3. | | $^3$F - $^3$P (2F) | | | | | | | | | | |
| | | | [5894.9] | 1669 | 18628 | 9 | 5 | E2 | 0.037 | 0.78 | E | 1 |
| | | | [5775.1] | 746 | 18057 | 7 | 3 | E2 | 0.037 | 0.42 | E | 1 |
| | | | [5622.1] | 0 | 17782 | 5 | 1 | E2 | 0.064 | 0.21 | E | 1 |
| | | | [5590.7] | 746 | 18628 | 7 | 5 | M1 | 0.013 | 4.2(−4) | E | 1 |
| | | | ″ | ″ | ″ | 7 | 5 | E2 | 0.013 | 0.21 | E | 1 |
| | | | [5536.5] | 0 | 18057 | 5 | 3 | M1 | 3.8(−4) | 7.2(−6) | E | 1 |
| | | | ″ | ″ | ″ | 5 | 3 | E2 | 0.023 | 0.21 | E | 1 |
| | | | [5366.8] | 0 | 18628 | 5 | 5 | M1 | 0.0035 | 1.0(−4) | E | 1 |
| | | | ″ | ″ | ″ | 5 | 5 | E2 | 0.0021 | 0.028 | E | 1 |
| 4. | | $^3$F - $^1$G (3F) | | | | | | | | | | |
| | | | [4193.1] | 1669 | 25511 | 9 | 9 | M1 | 0.17 | 0.0042 | E | 1 |
| | | | ″ | ″ | ″ | 9 | 9 | E2 | 8.3(−5) | 5.8(−4) | E | 1 |
| | | | [4036.8] | 746 | 25511 | 7 | 9 | M1 | 0.12 | 0.0026 | E | 1 |
| | | | [3918.8] | 0 | 25511 | 5 | 9 | E2 | 1.8(−4) | 8.9(−4) | E | 1 |
| 5. | | $^3$F - $^1$S | | | | | | | | | | |
| | | | [1687.3] | 0 | 59265 | 5 | 1 | E2 | 0.049 | 4.0(−4) | E | 1 |
| 6. | | $^1$D - $^3$P | | | | | | | | | | |
| | | | [30370] | 15336 | 18628 | 5 | 5 | M1 | 0.059 | 0.31 | E | 1 |
| | | | [36740] | 15336 | 18057 | 5 | 3 | M1 | 0.019 | 0.10 | E | 1 |
| 7. | | $^1$D - $^1$G | [9825.3] | 15336 | 25511 | 5 | 9 | E2 | 7.5(−4) | 0.37 | E | 1 |
| 8. | | $^1$D - $^1$S | [2275.7] | 15336 | 59265 | 5 | 1 | E2 | 12 | 0.44 | E | 1 |
| 9. | | $^3$P - $^3$P | | | | | | | | | | |
| | | | [175000] | 18057 | 18628 | 3 | 5 | M1 | 0.00201 | 2.00 | C | 1$n$ |
| | | | [364000] | 17782 | 18057 | 1 | 3 | M1 | 4.19(−4) | 2.25 | C | 1$n$ |
| 10. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [2460.1] | 18628 | 59265 | 5 | 1 | E2 | 0.43 | 0.023 | E | 1 |
| | | | [2426.0] | 18057 | 59265 | 3 | 1 | M1 | 2.8 | 0.0015 | E | 1 |

Mn VI: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11. | $3d^2$–$3d4s$ | $^3$F - $^3$D | | | | | | | | | | |
| | | | [401.84] | 1669 | 250527 | 9 | 5 | E2 | 1.1(+4) | 0.34 | E | 1 |
| | | | [401.04] | 746 | 250097 | 7 | 3 | E2 | 1.8(+4) | 0.33 | E | 1 |
| | | | [400.43] | 1669 | 251403 | 9 | 7 | E2 | 4.0(+4) | 1.7 | E | 1 |
| | | | [400.35] | 746 | 250527 | 7 | 5 | E2 | 2.6(+4) | 0.80 | E | 1 |
| | | | [399.85] | 0 | 250097 | 5 | 3 | E2 | 3.5(+4) | 0.64 | E | 1 |
| | | | [398.95] | 746 | 251403 | 7 | 7 | E2 | 1.2(+4) | 0.51 | E | 1 |
| | | | [399.16] | 0 | 250527 | 5 | 5 | E2 | 1.5(+4) | 0.45 | E | 1 |
| | | | [397.77] | 0 | 251403 | 5 | 7 | E2 | 1100 | 0.046 | E | 1 |
| 12. | | $^3$F - $^1$D | | | | | | | | | | |
| | | | [394.37] | 1669 | 255240 | 9 | 5 | E2 | 97 | 0.0028 | E | 1 |
| | | | [392.94] | 746 | 255240 | 7 | 5 | E2 | 540 | 0.015 | E | 1 |
| | | | [391.79] | 0 | 255240 | 5 | 5 | E2 | 67 | 0.0018 | E | 1 |
| 13. | | $^1$D - $^3$D | | | | | | | | | | |
| | | | [423.61] | 15336 | 251403 | 5 | 7 | E2 | 550 | 0.031 | E | 1 |
| | | | [425.19] | 15336 | 250527 | 5 | 5 | E2 | 1400 | 0.058 | E | 1 |
| | | | [425.97] | 15336 | 250097 | 5 | 3 | E2 | 430 | 0.011 | E | 1 |
| 14. | | $^1$D - $^1$D | [416.83] | 15336 | 255240 | 5 | 5 | E2 | 2.8(+4) | 1.0 | E | 1 |
| 15. | | $^3$P - $^3$D | | | | | | | | | | |
| | | | [428.55] | 18057 | 251403 | 3 | 7 | E2 | 5400 | 0.33 | E | 1 |
| | | | [429.65] | 17782 | 250527 | 1 | 5 | E2 | 5200 | 0.23 | E | 1 |
| | | | [429.60] | 18628 | 251403 | 5 | 7 | E2 | 1.0(+4) | 0.61 | E | 1 |
| | | | [430.16] | 18057 | 250527 | 3 | 5 | E2 | 1300 | 0.057 | E | 1 |
| | | | [431.22] | 18628 | 250527 | 5 | 5 | E2 | 7900 | 0.35 | E | 1 |
| | | | [430.96] | 18057 | 250097 | 3 | 3 | E2 | 1.2(+4) | 0.32 | E | 1 |
| | | | [432.02] | 18628 | 250097 | 5 | 3 | E2 | 3500 | 0.094 | E | 1 |
| 16. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [422.63] | 18628 | 255240 | 5 | 5 | E2 | 2300 | 0.092 | E | 1 |
| | | | [421.62] | 18057 | 255240 | 3 | 5 | E2 | 27 | 0.0011 | E | 1 |
| | | | [421.13] | 17782 | 255240 | 1 | 5 | E2 | 69 | 0.0027 | E | 1 |
| 17. | | $^1$G - $^3$D | | | | | | | | | | |
| | | | [444.41] | 25511 | 250527 | 9 | 5 | E2 | 660 | 0.034 | E | 1 |
| | | | [442.69] | 25511 | 251403 | 9 | 7 | E2 | 9.2 | 6.5(−4) | E | 1 |
| 18. | | $^1$G - $^1$D | [435.30] | 25511 | 255240 | 9 | 5 | E2 | 4.4(+4) | 2.0 | E | 1 |
| 19. | | $^1$S - $^3$D | | | | | | | | | | |
| | | | [522.84] | 59265 | 250527 | 1 | 5 | E2 | 24 | 0.0028 | E | 1 |
| 20. | | $^1$S - $^1$D | [510.27] | 59265 | 255240 | 1 | 5 | E2 | 2300 | 0.24 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn VII

K Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^63d\ ^2D_{3/2}$

Ionization Energy: 119.204 eV = 961440 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 133.636 | 8 | 141.757 | 6 | 183.708 | 5 | 239.381 | 2 |
| 133.655 | 8 | 142.028 | 6 | 184.161 | 5 | 244.766 | 2 |
| 133.875 | 8 | 142.615 | 6 | 184.538 | 5 | 244.935 | 1 |
| 134.190 | 9 | 182.499 | 4 | 202.840 | 3 | 245.739 | 1 |
| 138.441 | 7 | 182.692 | 4 | 204.117 | 3 | 247.473 | 1 |
| 138.697 | 7 | 182.945 | 4 | 204.675 | 3 | | |
| 139.595 | 7 | 183.141 | 4 | 238.617 | 2 | | |

For this spectrum, we have chosen the data of Tiwary,[1,2] who calculated absolute multiplet oscillator strengths for the $3p^63d$–$3p^53d^2$ and $3p^63d$–$3p^53d4s$ arrays by using configuration interaction wavefunctions. For the $3p^63d$–$3p^53d4s$ array, the *LS*-coupling line strengths generally agree quite well with the intermediate coupling calculations of Cowan.[3] Where this agreement is not good (worse than ±50%), we have omitted the lines from this compilation. Within this transition array, we have normalized Cowan's line strengths to the multiplet strengths of Ref. 2.

For lines within the $3p^63d$–$3p^53d^2$ transition array, we have obtained line strengths from Tiwary's multiplet strengths by applying *LS*-coupling rules. We estimate these data to be accurate within fifty percent for stronger lines.

### References


[1] S. N. Tiwary, Chem. Phys. Lett. **93**, 47 (1982).
[2] S. N. Tiwary, Astrophys. J. **269**, 803 (1983).
[3] R. D. Cowan, Astrophys. J. **147**, 377 (1967).


Mn VII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^63d$–$3p^5(^2P^\circ)3d^2(^1D)$ | $^2D$ – $^2P^\circ$ | *246.26* | *803* | *406877* | 10 | 6 | 38 | 0.021 | 0.17 | −0.68 | D− | 1 |
| | | | 245.739 | 1338 | 408273 | 6 | 4 | 34 | 0.021 | 0.10 | −0.91 | D− | *ls* |
| | | | 247.473 | 0 | 404085 | 4 | 2 | 38 | 0.017 | 0.057 | −1.16 | D− | *ls* |
| | | | 244.935 | 0 | 408273 | 4 | 4 | 3.8 | 0.0034 | 0.011 | −1.87 | E | *ls* |
| 2. | | $^2D$ – $^2F^\circ$ | *242.11* | *803* | *413830* | 10 | 14 | 33 | 0.040 | 0.32 | −0.40 | D− | 1 |
| | | | 244.766 | 1338 | 409891 | 6 | 8 | 31 | 0.037 | 0.18 | −0.65 | D− | *ls* |
| | | | 238.617 | 0 | 419081 | 4 | 6 | 32 | 0.041 | 0.13 | −0.78 | D− | *ls* |
| | | | 239.381 | 1338 | 419081 | 6 | 6 | 2.2 | 0.0019 | 0.0091 | −1.94 | E | *ls* |
| 3. | $3p^63d$–$3p^5(^2P^\circ)3d^2(^3F)$ | $^2D$ – $^2F^\circ$ | *203.40* | *803* | *492442* | 10 | 14 | 910 | 0.79 | 5.3 | 0.90 | D− | 1 |
| | | | 202.840 | 1338 | 494337 | 6 | 8 | 910 | 0.75 | 3.0 | 0.65 | D− | *ls* |
| | | | 204.117 | 0 | 489916 | 4 | 6 | 830 | 0.78 | 2.1 | 0.49 | D− | *ls* |
| | | | 204.675 | 1338 | 489916 | 6 | 6 | 59 | 0.037 | 0.15 | −0.65 | E | *ls* |

Mn VII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. | | $^2$D - $^2$D° | *182.88* | *803* | *547600* | 10 | 10 | 3000 | 1.5 | 9.0 | 1.18 | D− | 1 |
| | | | 183.141 | 1338 | 547367 | 6 | 6 | 2700 | 1.4 | 5.0 | 0.92 | D− | *ls* |
| | | | 182.499 | 0 | 547949 | 4 | 4 | 2700 | 1.3 | 3.2 | 0.73 | D− | *ls* |
| | | | 182.945 | 1338 | 547949 | 6 | 4 | 300 | 0.10 | 0.36 | −0.22 | E | *ls* |
| | | | 182.692 | 0 | 547367 | 4 | 6 | 200 | 0.15 | 0.36 | −0.22 | E | *ls* |
| 5. | $3p^63d-$ $3p^5(^2P°)3d^2(^3P)$ | $^2$D - $^2$P° | *184.26* | *803* | *543526* | 10 | 6 | 2100 | 0.65 | 3.9 | 0.81 | D− | 1 |
| | | | 184.161 | 1338 | 544342 | 6 | 4 | 1900 | 0.63 | 2.3 | 0.58 | D− | *ls* |
| | | | 184.538 | 0 | 541894 | 4 | 2 | 2100 | 0.53 | 1.3 | 0.33 | D− | *ls* |
| | | | 183.708 | 0 | 544342 | 4 | 4 | 210 | 0.11 | 0.26 | −0.37 | E | *ls* |
| 6. | $3p^63d-$ $3p^53d(^3P°)4s$ | $^2$D - $^2$P° | *142.21* | *803* | *704013* | 10 | 6 | 200 | 0.037 | 0.17 | −0.43 | D | 2 |
| | | | 142.028 | 1338 | 705425 | 6 | 4 | 170 | 0.034 | 0.096 | −0.69 | D | 3*n* |
| | | | 142.615 | 0 | 701189 | 4 | 2 | 200 | 0.031 | 0.058 | −0.91 | D | 3*n* |
| | | | 141.757 | 0 | 705425 | 4 | 4 | 28 | 0.0086 | 0.016 | −1.46 | E | 3*n* |
| 7. | $3p^63d-$ $3p^53d(^3F°)4s$ | $^2$D - $^2$F° | *139.11* | *803* | *719682* | 10 | 14 | 300 | 0.12 | 0.55 | 0.08 | D | 2 |
| | | | 139.595 | 1338 | 717696 | 6 | 8 | 260 | 0.10 | 0.28 | −0.22 | D | 3*n* |
| | | | 138.441 | 0 | 722331 | 4 | 6 | 330 | 0.14 | 0.26 | −0.24 | D | 3*n* |
| | | | 138.697 | 1338 | 722331 | 6 | 6 | 18 | 0.0051 | 0.014 | −1.51 | E | 3*n* |
| 8. | $3p^63d-$ $3p^53d(^3D°)4s$ | $^2$D - $^2$D° | *133.65* | *803* | *749040* | 10 | 10 | 310 | 0.083 | 0.37 | −0.08 | D | 2 |
| | | | 133.655 | 1338 | 749532 | 6 | 6 | 270 | 0.072 | 0.19 | −0.36 | D | 3*n* |
| | | | 133.636 | 0 | 748302 | 4 | 4 | 250 | 0.068 | 0.12 | −0.56 | D | 3*n* |
| | | | 133.875 | 1338 | 748302 | 6 | 4 | 59 | 0.011 | 0.028 | −1.20 | E | 3*n* |
| 9. | $3p^63d-$ $3p^53d(^1F°)4s$ | $^2$D - $^2$F° | *134.61* | *803* | *743713* | 10 | 14 | 110 | 0.041 | 0.18 | −0.39 | D | 2 |
| | | | 134.190 | 1338 | 746550 | 6 | 8 | 120 | 0.042 | 0.11 | −0.60 | D | 3*n* |

# Mn VIII

Ar Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^6\ ^1S_0$

Ionization Energy: 194.5 eV = 1569000 cm$^{-1}$

## Allowed Transitions

The line strength for the $3p^6$–$3p^53d$ resonance transition of this argon-like ion was interpolated from the superposition-of-configurations (SOC) calculations of Weiss,[1] which are expected to be fairly accurate.

Oscillator strengths for transitions of the $3p^6$–$3p^54s$ array were interpolated from the Dirac-Hartree-Fock data of Lin *et al.*,[2] who included correlation only in the lower state. Their results for lines of the $3p^6$–$3p^54d$ array in nearby Ar-like species have not been interpolated to provide $f$-values for Mn VIII, since cancellation effects at or near V VI—one of the ions treated—introduce considerable uncertainty into the results at the low-$Z$ end of the Ar sequence.

### References


[1]A. W. Weiss, private communication.

[2]D. L. Lin, W. Fielder, Jr., and L. Armstrong, Jr., Phys. Rev. A **16**, 589 (1977).


Mn VIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^6$–$3p^53d$ | $^1S$ - $^1P^\circ$ | 185.455 | 0 | 539214 | 1 | 3 | 1850 | 2.87 | 1.75 | 0.457 | C | *interp.* |
| 2. | $3p^6$–$3p^5(^2P^\circ_{3/2})4s$ | $^1S$ - $(^3/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 124.055 | 0 | 806094 | 1 | 3 | 200 | 0.14 | 0.057 | −0.85 | D | *interp.* |
| 3. | $3p^6$–$3p^5(^2P^\circ_{1/2})4s$ | $^1S$ - $(^1/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 122.168 | 0 | 818545 | 1 | 3 | 400 | 0.27 | 0.11 | −0.57 | D | *interp.* |

# Mn IX

Cl Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^5\ ^2P^\circ_{3/2}$

Ionization Energy: 221.8 eV = 1789000 cm$^{-1}$

## Allowed Transitions

Line strengths for transitions of the arrays $3s^23p^5$–$3s3p^6$ and $3p^5$–$3p^43d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang *et al.*[1] These relativistic calculations include a perturbative treatment of the Breit interaction and the Lamb shift. Configuration mixing was limited to some configurations within the $n=3$ complex. Those configurations which were assumed to lie far above $3p^5$ or $3p^43d$ in energy were excluded, as were all configurations outside the complex.

According to the semi-empirical HX (Hartree-Fock with statistical allowance for exchange) calculations of Bromage *et al.*[2] for Fe X, some levels of the $3p^43d$ con figuration are strongly mixed in the $LS$ basis, and in a few cases the *LS* designations given in Ref. 2 differed from those of Huang *et al*. The level designations used in this compilation are in accord with the theoretical results of Refs. 1 and 2 for Fe X. Percentage compositions published by Bromage[3] for the levels of the $3p^4 3d$ configuration in V VII and Ni XII indicate that the designations for the iron ion are appropriate for the neighboring ions of the chlorine isoelectronic sequence. Transitions involving highly mixed levels have been excluded, as have the very weak transitions.

The calculated wavelengths of Huang *et al*. differ appreciably from the observed ones found in the literature. Thus the available experimentally determined wavelengths were used in making the conversion from line strengths to *f*- and *A*-values. (Otherwise, the calculated wavelengths of Huang *et al*. were used, but they provide only a rough idea of the spectral-line positions.) Bromage *et al*. indicate that it was necessary to scale down some configuration-interaction parameters by a greater amount than usual in order to fit their calculated energy levels for Fe X to the experimental data. This could be an indication that neglecting to take configuration interaction into account on a larger scale yields significant errors in the energy levels and/or *f*-values.

## References


[1]K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables **28**, 355 (1983).

[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Phys. Scr. **15**, 177 (1977).

[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).


Mn IX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^2 3p^5 – 3s 3p^6$ | $^2P^\circ - {}^2S$ | *382.81* | *4182* | 265408 | 6 | 2 | 47.9 | 0.0350 | 0.265 | −0.68 | C− | 1 |
| | | | 376.778 | 0 | 265408 | 4 | 2 | 33.3 | 0.0355 | 0.176 | −0.85 | C− | 1 |
| | | | 395.473 | 12546 | 265408 | 2 | 2 | 15 | 0.034 | 0.089 | −1.17 | C− | 1 |
| 2. | $3p^5 – 3p^4(^3P)3d$ | $^2P^\circ - {}^4F$ | | | | | | | | | | | |
| | | | [243] | | | 4 | 6 | 0.15 | 1.9(−4)[a] | 6.2(−4) | −3.11 | E | 1 |
| | | | [249] | | | 2 | 4 | 0.14 | 2.6(−4) | 4.2(−4) | −3.29 | E | 1 |
| 3. | | $^2P^\circ - {}^4P$ | | | | | | | | | | | |
| | | | [244] | | | 2 | 4 | 0.15 | 2.7(−4) | 4.4(−4) | −3.26 | E | 1 |
| | | | [237] | | | 4 | 4 | 0.25 | 2.1(−4) | 6.6(−4) | −3.07 | E | 1 |
| | | | [246] | | | 2 | 2 | 0.39 | 3.6(−4) | 5.8(−4) | −3.14 | E | 1 |
| | | | [239] | | | 4 | 2 | 1.5 | 6.4(−4) | 0.0020 | −2.59 | E | 1 |
| 4. | | $^2P^\circ - {}^2D$ | *188.46* | *4182* | *534790* | 6 | 10 | 1700 | 1.5 | 5.5 | 0.95 | C− | 1 |
| | | | 188.48 | 0 | 530560 | 4 | 6 | 1660 | 1.33 | 3.30 | 0.73 | C | 1 |
| | | | 189.16 | 12546 | 541130 | 2 | 4 | 1590 | 1.70 | 2.12 | 0.53 | C | 1 |
| | | | 184.80 | 0 | 541130 | 4 | 4 | 61 | 0.031 | 0.076 | −0.90 | D | 1 |
| 5. | $3p^5 – 3p^4(^1D)3d$ | $^2P^\circ - {}^2F$ | | | | | | | | | | | |
| | | | [214] | | | 4 | 6 | 0.86 | 8.9(−4) | 0.0025 | −2.45 | E | 1 |
| 6. | | $^2P^\circ - {}^2S$ | *200.99* | *4182* | 501710 | 6 | 2 | 1450 | 0.292 | 1.16 | 0.244 | C− | 1 |
| | | | 199.32 | 0 | 501710 | 4 | 2 | 1100 | 0.32 | 0.83 | 0.10 | C− | 1 |
| | | | 204.43 | 12546 | 501710 | 2 | 2 | 395 | 0.247 | 0.333 | −0.306 | C− | 1 |
| 7. | $3p^5 – 3p^4(^1S)3d$ | $^2P^\circ - {}^2D$ | *200* | | | 6 | 10 | 3.3 | 0.0033 | 0.013 | −1.70 | E | 1 |
| | | | [198] | | | 4 | 6 | 0.23 | 2.0(−4) | 5.2(−4) | −3.10 | E | 1 |
| | | | [205] | | | 2 | 4 | 6.5 | 0.0081 | 0.011 | −1.79 | E | 1 |
| | | | [200] | | | 4 | 4 | 1.1 | 6.8(−4) | 0.0018 | −2.56 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn IX

## Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $3p^5$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for mixing among odd-parity configurations was limited to the set $3s^23p^5$, $3s3p^53d$, $3p^53d^2$, and $3s^23p^33d^2$. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K.-N. Huang, Y.-K. Kim, K. T. Cheng, and J. P. Desclaux, At. Data Nucl. Data Tables **28**, 355 (1983).

Mn IX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^5$–$3p^5$ | $^2P^\circ$ - $^2P^\circ$ | | | | | | | | | | |
| | | | [7968.5] | 0 | 12546 | 4 | 2 | M1 | 35.5 | 1.33 | B | 1 |
| | | | " | " | " | 4 | 2 | E2 | 0.0071 | 0.27 | D− | 1 |

# Mn X

S Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^4\ ^3P_2$

Ionization Energy: 248.3 eV = 2003000 cm$^{-1}$

## Allowed Transitions

Oscillator strengths for a few transitions of the arrays $3s^23p^4$–$3s3p^5$ and $3p^4$–$3p^33d$ were interpolated from the results of Bromage[1] for V VIII and those of Mason[2] and Bromage *et al.*[3] for Fe XI. The term designations used here are in accord with the results of Refs. 1 and 3.

### References

[1]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).
[2]H. E. Mason, Mon. Not. R. Astron. Soc. **170**, 651 (1975).
[3]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Phys. Scr. **15**, 177 (1977).

Mn X: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p^4$–$3s3p^5$ | $^3P$ - $^3P^\circ$ | | | | | | | | | | | |
| | | | 383.036 | 0 | 261072 | 5 | 5 | 15 | 0.034 | 0.21 | −0.77 | E | *interp.* |

Mn XI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^3$–$3p^3$ | $^4S°$ - $^2D°$ | | | | | | | | | | |
| | | | [2341.0] | 0 | 42703 | 4 | 6 | M1 | 0.74 | 0.0021 | E | 1 |
| | | | ″ | ″ | ″ | 4 | 6 | E2 | 0.064 | 0.016 | E | 1 |
| | | | [2538.0] | 0 | 39389 | 4 | 4 | M1 | 24 | 0.059 | D | 1 |
| | | | ″ | ″ | ″ | 4 | 4 | E2 | 0.029 | 0.0072 | E | 1 |
| 2. | | $^4S°$ - $^2P°$ | | | | | | | | | | |
| | | | 1359.59 | 0 | 73552 | 4 | 4 | M1 | 200 | 0.074 | D | 1 |
| | | | [1450.4] | 0 | 68945 | 4 | 2 | M1 | 100 | 0.023 | D | 1 |
| 3. | | $^2D°$ - $^2D°$ | | | | | | | | | | |
| | | | [30170] | 39389 | 42703 | 4 | 6 | M1 | 0.354 | 2.16 | C+ | 1 |
| | | | ″ | ″ | ″ | 4 | 6 | E2 | 9.7(−7)[a] | 0.087 | E | 1 |
| 4. | | $^2D°$ - $^2P°$ | | | | | | | | | | |
| | | | [3809.6] | 42703 | 68945 | 6 | 2 | E2 | 0.27 | 0.26 | D− | 1 |
| | | | [3240.7] | 42703 | 73552 | 6 | 4 | M1 | 48 | 0.24 | C | 1 |
| | | | ″ | ″ | ″ | 6 | 4 | E2 | 0.95 | 0.81 | D− | 1 |
| | | | [3382.4] | 39389 | 68945 | 4 | 2 | M1 | 45 | 0.13 | C | 1 |
| | | | ″ | ″ | ″ | 4 | 2 | E2 | 0.68 | 0.36 | D− | 1 |
| | | | [2926.3] | 39389 | 73552 | 4 | 4 | M1 | 110 | 0.42 | C | 1 |
| | | | ″ | ″ | ″ | 4 | 4 | E2 | 0.47 | 0.24 | D− | 1 |
| 5. | | $^2P°$ - $^2P°$ | | | | | | | | | | |
| | | | [21700] | 68945 | 73552 | 2 | 4 | M1 | 0.78 | 1.18 | C+ | 1 |
| | | | ″ | ″ | ″ | 2 | 4 | E2 | 3.0(−6) | 0.034 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XII

Si Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p^2\ ^3P_0$

Ionization Energy: 314.4 eV = 2536000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 184 | 9 | 232.34 | 11 | 336.95 | 2 | 388.58 | 1 |
| 199.06 | 8 | 251 | 5 | 337.29 | 2 | 397.46 | 1 |
| 210.43 | 12 | 253 | 5 | 346.04 | 2 | 400 | 1 |
| 215 | 6 | 278 | 10 | 346.38 | 2 | 400.72 | 1 |
| 218.56 | 7 | 329.28 | 2 | 377 | 1 | 445.49 | 3 |
| 223.56 | 13 | 336 | 2 | 388 | 1 | 457 | 4 |

Line strengths for transitions of the arrays $3s^2 3p^2$–$3s 3p^3$ and $3p^2$–$3p 3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published neither an energy-level diagram nor percentage compositions for levels of the $3s^2 3p^2$, $3s 3p^3$, and $3s^2 3p 3d$ configurations in Mn XII. We have used the percentages given by Bromage *et al.*[2] for Fe XIII, and by Bromage[3] for V X and Ni XV, as a guide to naming the levels; their values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to a partial set of configurations within the $n=3$ complex. Whenever the term designation of a level in Fe XIII, as given in Ref. 1, is different from that indicated in Ref. 2, all transitions involving the corresponding level in Mn XII are omitted from this compilation.

Transitions involving levels which are indicated to be of low purity in *LS* coupling are omitted here. Lines which are characterized by very small *f*-values are assigned lower accuracy ratings; the weakest lines have been excluded.

## References


[1]K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985).

[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).

[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).


Mn XII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^2 3p^2$–$3s 3p^3$ | $^3$P – $^3$D° | *392* | | | 9 | 15 | 12 | 0.046 | 0.54 | −0.38 | D− | 1 |
| | | | 397.46 | 14990 | 266590 | 5 | 7 | 11 | 0.037 | 0.24 | −0.74 | D | 1 |
| | | | 388.58 | 7190 | 264540 | 3 | 5 | 12 | 0.047 | 0.18 | −0.85 | D | 1 |
| | | | [377] | | | 1 | 3 | 10 | 0.066 | 0.082 | −1.18 | D | 1 |
| | | | [400.72] | 14990 | 264540 | 5 | 5 | 0.63 | 0.0015 | 0.010 | −2.12 | D− | 1 |
| | | | [388] | | | 3 | 3 | 3.2 | 0.0073 | 0.028 | −1.66 | D− | 1 |
| | | | [400] | | | 5 | 3 | 0.098 | 1.4(−4)[a] | 9.3(−4) | −3.15 | E | 1 |
| 2. | | $^3$P – $^3$P° | *341* | | | 9 | 9 | 33 | 0.057 | 0.58 | −0.29 | D | 1 |
| | | | 346.04 | 14990 | 303970 | 5 | 5 | 27 | 0.049 | 0.28 | −0.61 | D | 1 |
| | | | 337.29 | 7190 | 303690 | 3 | 3 | 15 | 0.026 | 0.085 | −1.12 | D | 1 |
| | | | [346.38] | 14990 | 303690 | 5 | 3 | 8.6 | 0.0093 | 0.053 | −1.33 | D− | 1 |
| | | | [336] | | | 3 | 1 | 36 | 0.020 | 0.067 | −1.22 | C− | 1 |
| | | | [336.95] | 7190 | 303970 | 3 | 5 | 4.2 | 0.012 | 0.040 | −1.44 | D | 1 |
| | | | 329.28 | 0 | 303690 | 1 | 3 | 11 | 0.054 | 0.058 | −1.27 | D | 1 |
| 3. | | $^1$D – $^3$D° | | | | | | | | | | | |
| | | | [445.49] | 42120 | 266590 | 5 | 7 | 0.52 | 0.0022 | 0.016 | −1.96 | E | 1 |
| 4. | | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [457] | | | 1 | 3 | 0.14 | 0.0013 | 0.0020 | −2.88 | E | 1 |
| 5. | $3p^2$–$3p 3d$ | $^3$P – $^3$F° | | | | | | | | | | | |
| | | | [253] | | | 5 | 7 | 2.0 | 0.0026 | 0.011 | −1.88 | E | 1 |
| | | | [251] | | | 3 | 5 | 0.69 | 0.0011 | 0.0027 | −2.49 | E | 1 |
| 6. | | $^3$P – $^3$P° | | | | | | | | | | | |
| | | | [215] | | | 3 | 1 | 450 | 0.10 | 0.22 | −0.51 | D | 1 |
| 7. | | $^3$P – $^3$D° | | | | | | | | | | | |
| | | | 218.56 | 14990 | 472530 | 5 | 7 | 610 | 0.61 | 2.2 | 0.49 | D | 1 |
| 8. | | $^3$P – $^1$F° | | | | | | | | | | | |
| | | | [199.06] | 14990 | 517340 | 5 | 7 | 21 | 0.017 | 0.056 | −1.07 | E | 1 |

Mn XII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9. | | $^3P - ^1P^o$ | | | | | | | | | | | |
| | | | [184] | | | 1 | 3 | 3.7 | 0.0056 | 0.0034 | −2.25 | E | 1 |
| 10. | | $^1D - ^3F^o$ | | | | | | | | | | | |
| | | | [278] | | | 5 | 5 | 2.3 | 0.0026 | 0.012 | −1.88 | E | 1 |
| 11. | | $^1D - ^3D^o$ | | | | | | | | | | | |
| | | | [232.34] | 42120 | 472530 | 5 | 7 | 15 | 0.017 | 0.065 | −1.07 | E | 1 |
| 12. | | $^1D - ^1F^o$ | 210.43 | 42120 | 517340 | 5 | 7 | 640 | 0.60 | 2.07 | 0.475 | C | 1 |
| 13. | | $^1S - ^1P^o$ | 223.56 | | | 1 | 3 | 520 | 1.2 | 0.86 | 0.07 | D | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XII

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 480 | 10 | 1300 | 5 | 2500 | 8 | 3685.5 | 2 |
| 485.58 | 11 | 1320 | 3 | 2540 | 8 | 6669 | 1 |
| 650 | 9 | 1400 | 5 | 2554 | 8 | 12800 | 1 |
| 660 | 9 | 1470 | 3 | 2674 | 8 | 13900 | 1 |
| 690 | 9 | 2400 | 8 | 2690 | 8 | 47000 | 7 |
| 880 | 6 | 2450 | 4 | 2862 | 2 | 48800 | 7 |

Line strengths for magnetic dipole and electric quadrupole transitions are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration interaction encompassed all configurations within the $n=3$ complex. Huang calculated line strengths for transitions within the $3p^2$ configuration, as well as for transitions between pairs of odd-parity levels whose lower level is one of the four lowest-lying odd-parity levels in the $n=3$ complex. Transitions involving odd-parity levels which are indicated by Bromage *et al.*[2] (for Fe XIII) or Bromage[3] (for V X and Ni XV) to be of low purity in *LS* coupling in Fe-group species are omitted here, as are lines whose strengths are very small. The strength of the magnetic dipole contribution to the $3s3p^3\ ^3D_1^o$ - $3s3p^3\ ^3D_2^o$ transition is excluded from the tabulation, because its wavelength uncertainty is unacceptably large. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

### References


[1]K.-N. Huang, At. Data Nucl. Data Tables **32**, 503 (1985) and private communication.

[2]G. E. Bromage, R. D. Cowan, and B. C. Fawcett, Mon. Not. R. Astron. Soc. **183**, 19 (1978).

[3]G. E. Bromage, Astron. Astrophys., Suppl. Ser. **41**, 79 (1980).

Mn XII: *Forbidden transitions*

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accu-racy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p^2$–$3p^2$ | ${}^3$P - ${}^3$P | | | | | | | | | | |
| | | | [12800] | 7190 | 14990 | 3 | 5 | M1 | 6.0 | 2.35 | C− | 1 |
| | | | " | " | " | 3 | 5 | E2 | 2.1(−4)[a] | 0.21 | D− | 1 |
| | | | [13900] | 0 | 7190 | 1 | 3 | M1 | 6.5 | 1.94 | C− | 1 |
| | | | [6669] | 0 | 14990 | 1 | 5 | E2 | 0.0028 | 0.11 | D− | 1 |
| 2. | | ${}^3$P - ${}^1$D | | | | | | | | | | |
| | | | 3685.5 | 14990 | 42120 | 5 | 5 | M1 | 44 | 0.41 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.042 | 0.086 | E | 1 |
| | | | [2862] | 7190 | 42120 | 3 | 5 | M1 | 35 | 0.15 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.023 | 0.013 | E | 1 |
| 3. | | ${}^3$P - ${}^1$S | | | | | | | | | | |
| | | | [1470] | | | 5 | 1 | E2 | 2.4 | 0.010 | E | 1 |
| | | | [1320] | | | 3 | 1 | M1 | 620 | 0.053 | E | 1 |
| 4. | | ${}^1$D - ${}^1$S | [2450] | | | 5 | 1 | E2 | 7.6 | 0.40 | D− | 1 |
| 5. | $3s3p^3$–$3s3p^3$ | ${}^5$S° - ${}^3$D° | | | | | | | | | | |
| | | | [1300] | | | 5 | 7 | E2 | 0.39 | 0.0060 | E | 1 |
| | | | [1400] | | | 5 | 5 | M1 | 17 | 0.0088 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 0.24 | 0.0039 | E | 1 |
| | | | [1400] | | | 5 | 3 | M1 | 5.2 | 0.0016 | E | 1 |
| | | | " | " | " | 5 | 3 | E2 | 0.10 | 0.0010 | E | 1 |
| 6. | | ${}^5$S° - ${}^3$P° | | | | | | | | | | |
| | | | [880] | | | 5 | 5 | M1 | 380 | 0.048 | E | 1 |
| | | | [880] | | | 5 | 3 | M1 | 220 | 0.017 | E | 1 |
| 7. | | ${}^3$D° - ${}^3$D° | | | | | | | | | | |
| | | | [48800] | 264540 | 266590 | 5 | 7 | M1 | 0.15 | 4.5 | D+ | 1 |
| | | | " | " | " | 5 | 7 | E2 | 3.9(−8) | 0.045 | E | 1 |
| | | | [47000] | | | 3 | 7 | E2 | 1.2(−8) | 0.011 | E | 1 |
| 8. | | ${}^3$D° - ${}^3$P° | | | | | | | | | | |
| | | | [2690] | 266590 | 303690 | 7 | 3 | E2 | 1.6 | 0.41 | D− | 1 |
| | | | [2500] | | | 5 | 1 | E2 | 4.6 | 0.27 | D− | 1 |
| | | | [2674] | 266590 | 303970 | 7 | 5 | M1 | 54 | 0.19 | E | 1 |
| | | | " | " | " | 7 | 5 | E2 | 1.8 | 0.75 | D− | 1 |
| | | | [2554] | 264540 | 303690 | 5 | 3 | E2 | 0.32 | 0.063 | E | 1 |
| | | | [2500] | | | 3 | 1 | M1 | 79 | 0.046 | E | 1 |
| | | | [2540] | 264540 | 303970 | 5 | 5 | M1 | 43 | 0.13 | E | 1 |
| | | | " | " | " | 5 | 5 | E2 | 1.4 | 0.44 | D− | 1 |
| | | | [2500] | | | 3 | 3 | M1 | 75 | 0.13 | E | 1 |
| | | | " | " | " | 3 | 3 | E2 | 2.1 | 0.36 | D− | 1 |
| | | | [2400] | | | 3 | 5 | M1 | 14 | 0.037 | E | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.59 | 0.14 | D− | 1 |
| 9. | $3s3p^3$–$3s^23p3d$ | ${}^3$D° - ${}^3$F° | | | | | | | | | | |
| | | | [650] | | | 5 | 9 | E2 | 9.7 | 0.0060 | E | 1 |
| | | | [690] | | | 3 | 7 | E2 | 4.1 | 0.0027 | E | 1 |
| | | | [660] | | | 7 | 9 | M1 | 650 | 0.062 | E | 1 |

Mn XII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | | $^3D^\circ - {}^3P^\circ$ | | | | | | | | | | |
| | | | [480] | | | 5 | 1 | E2 | 300 | 0.0046 | E | 1 |
| 11. | | $^3D^\circ - {}^3D^\circ$ | | | | | | | | | | |
| | | | [485.58] | 266590 | 472530 | 7 | 7 | M1 | 50 | 0.0015 | E | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XIII

Al Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^23p$ $^2P^\circ_{1/2}$

Ionization Energy: 343.6 eV = 2771000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 179 | 22 | 235 | 19,26 | 277.42 | 3 | 318 | 13 |
| 180 | 30 | 235.08 | 17 | 283.91 | 3 | 361.57 | 1 |
| 192 | 32 | 236 | 26,36 | 284 | 15 | 369 | 7 |
| 199 | 31 | 237 | 28 | 285 | 15 | 378 | 12 |
| 200 | 31 | 246 | 34 | 287 | 16 | 380.42 | 1 |
| 201 | 31 | 247 | 29 | 289.74 | 3 | 382.76 | 1 |
| 202 | 21,27 | 250 | 29 | 292 | 4 | 385 | 6 |
| 220 | 33 | 251 | 29 | 294.95 | 2 | 387 | 6,9 |
| 222 | 19 | 252 | 5 | 297 | 4 | 390 | 9 |
| 225 | 19,20 | 255 | 29 | 303 | 14 | 394 | 12 |
| 226.91 | 17 | 256 | 5 | 304 | 14 | 396 | 12 |
| 229 | 20,26 | 257 | 18 | 307 | 8,14 | 427 | 11 |
| 231 | 19 | 259 | 18 | 308.75 | 4 | 436 | 11 |
| 232 | 36 | 261 | 5 | 308.92 | 2 | 440 | 11 |
| 233 | 35 | 264 | 25 | 309 | 8 | 571 | 10 |
| 234 | 28 | 272.09 | 3 | 314 | 23 | | |
| 234.24 | 17 | 273 | 24 | 316 | 13 | | |

Line strengths for transitions of the arrays $3s^23p$–$3s3p^2$, $3s3p^2$–$3p^3$, $3s^23d$–$3s3p3d$, $3s^23p$–$3s^23d$, and $3s3p^2$–$3s3p3d$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction. Allowance for configuration mixing included all configurations within the $n=3$ complex.

Huang published neither an energy-level diagram nor percentage compositions for levels of the $3s^23p$, $3s3p^2$, $3s^23d$, $3p^3$, and $3s3p3d$ configurations in Mn XIII. We have used the percentages given by Fawcett[2] for the adjacent Al-like ions as a guide to naming the levels; the latter's values resulted from Hartree-Fock calculations with relativistic effects and statistical allowance for exchange (HXR), and incorporated correlation effects due to all configurations within the $n = 3$ complex.

Transitions involving levels which are indicated to be of low purity in *LS* coupling in one or both adjacent Al-like ions are omitted here. Lines which are characterized by very small *f*-values are assigned lower accuracy ratings; the weakest lines have been excluded. A few wavelengths computed by Huang for transitions in Cr XII differ significantly from those which resulted from the fitting and scaling procedure applied by Fawcett[2]; lines for which the wavelengths are in serious disagreement have been omitted in our tabulation for Mn XIII.

## References


[1]K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986) and private communication.

[2]B. C. Fawcett, At. Data Nucl. Data Tables **28**, 557 (1983).


Mn XIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^23p-3s3p^2$ | $^2P^\circ - ^2D$ | *374.07* | *10197* | *277530* | 6 | 10 | 18 | 0.062 | 0.46 | −0.43 | E | 1 |
| | | | 380.42 | 15295 | 278170 | 4 | 6 | 17 | 0.054 | 0.27 | −0.67 | D | 1 |
| | | | 361.57 | 0 | 276570 | 2 | 4 | 19 | 0.076 | 0.18 | −0.82 | D | 1 |
| | | | 382.76 | 15295 | 276570 | 4 | 4 | 0.86 | 0.0019 | 0.0095 | −2.12 | E | 1 |
| 2. | | $^2P^\circ - ^2S$ | *304.10* | *10197* | 339040 | 6 | 2 | 150 | 0.068 | 0.41 | −0.39 | D | 1 |
| | | | 308.92 | 15295 | 339040 | 4 | 2 | 16 | 0.012 | 0.048 | −1.33 | D | 1 |
| | | | 294.95 | 0 | 339040 | 2 | 2 | 140 | 0.19 | 0.36 | −0.43 | D | 1 |
| 3. | | $^2P^\circ - ^2P$ | *281.71* | *10197* | *365170* | 6 | 6 | 360 | 0.43 | 2.4 | 0.41 | D | 1 |
| | | | 283.91 | 15295 | 367530 | 4 | 4 | 308 | 0.372 | 1.39 | 0.172 | C− | 1 |
| | | | 277.42 | 0 | 360460 | 2 | 2 | 140 | 0.16 | 0.30 | −0.48 | D | 1 |
| | | | 289.74 | 15295 | 360460 | 4 | 2 | 190 | 0.12 | 0.45 | −0.33 | D | 1 |
| | | | 272.09 | 0 | 367530 | 2 | 4 | 68 | 0.150 | 0.269 | −0.52 | C− | 1 |
| 4. | $3s3p^2-3p^3$ | $^4P - ^4S^\circ$ | *302* | | | 12 | 4 | 330 | 0.15 | 1.8 | 0.26 | D | 1 |
| | | | 308.75 | | | 6 | 4 | 150 | 0.14 | 0.87 | −0.07 | D | 1 |
| | | | [297] | | | 4 | 4 | 110 | 0.15 | 0.59 | −0.22 | D | 1 |
| | | | [292] | | | 2 | 4 | 59 | 0.15 | 0.29 | −0.52 | D | 1 |
| 5. | | $^4P - ^2P^\circ$ | | | | | | | | | | | |
| | | | [261] | | | 6 | 4 | 1.6 | 0.0011 | 0.0057 | −2.18 | E | 1 |
| | | | [256] | | | 4 | 4 | 3.3 | 0.0033 | 0.011 | −1.88 | E | 1 |
| | | | [252] | | | 2 | 4 | 1.5 | 0.0028 | 0.0046 | −2.26 | E | 1 |
| 6. | | $^2D - ^2D^\circ$ | | | | | | | | | | | |
| | | | [387] | | | 6 | 6 | 27 | 0.060 | 0.46 | −0.44 | E | 1 |
| | | | [385] | | | 4 | 6 | 2.6 | 0.0087 | 0.044 | −1.46 | E | 1 |
| 7. | | $^2D - ^4S^\circ$ | | | | | | | | | | | |
| | | | [369] | | | 4 | 4 | 0.72 | 0.0015 | 0.0071 | −2.23 | E | 1 |
| 8. | | $^2D - ^2P^\circ$ | *309* | | | 10 | 6 | 110 | 0.093 | 0.95 | −0.03 | D | 1 |
| | | | [309] | | | 6 | 4 | 93 | 0.088 | 0.54 | −0.28 | D | 1 |
| | | | [309] | | | 4 | 2 | 120 | 0.084 | 0.34 | −0.48 | D | 1 |
| | | | [307] | | | 4 | 4 | 12 | 0.017 | 0.068 | −1.17 | D | 1 |
| 9. | | $^2S - ^2P^\circ$ | *388* | | | 2 | 6 | 12 | 0.078 | 0.20 | −0.81 | E | 1 |
| | | | [387] | | | 2 | 4 | 17 | 0.075 | 0.19 | −0.83 | D | 1 |
| | | | [390] | | | 2 | 2 | 2.0 | 0.0047 | 0.012 | −2.03 | E | 1 |

Mn XIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32. | | $^2$D - $^2$P° | | | | | | | | | | | |
| | | | [192] | | | 4 | 2 | 1.7 | 4.7(−4) | 0.0012 | −2.72 | E | 1 |
| 33. | | $^2$S - $^2$P° | | | | | | | | | | | |
| | | | [220] | | | 2 | 2 | 180 | 0.13 | 0.19 | −0.58 | D | 1 |
| 34. | | $^2$P - $^2$F° | | | | | | | | | | | |
| | | | [246] | | | 4 | 6 | 2.1 | 0.0029 | 0.0093 | −1.94 | E | 1 |
| 35. | | $^2$P - $^2$D° | | | | | | | | | | | |
| | | | [233] | | | 4 | 6 | 590 | 0.72 | 2.2 | 0.46 | E | 1 |
| 36. | | $^2$P - $^2$P° | | | | | | | | | | | |
| | | | [232] | | | 2 | 2 | 67 | 0.054 | 0.082 | −0.97 | D | 1 |
| | | | [236] | | | 4 | 2 | 85 | 0.0354 | 0.110 | −0.85 | C− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be mulitplied.

# Mn XIII

## Forbidden Transitions

Line strengths for magnetic dipole and electric quadrupole transitions within the $3s^23p$ $^2$P° and $3s3p^2$ $^4$P terms are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Huang.[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing included all configurations within the $n=3$ complex. Strengths of electric quadrupole transitions as reported in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1]K.-N. Huang, At. Data Nucl. Data Tables **34**, 1 (1986).

Mn XIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3p$–$3p$ | $^2$P° - $^2$P° | | | | | | | | | | |
| | | | 6536.3 | 0 | 15295 | 2 | 4 | M1 | 32.1 | 1.33 | C+ | 1 |
| | | | " | " | " | 2 | 4 | E2 | 0.0067 | 0.19 | D− | 1 |

Mn XIII: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ ($s^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | $3s3p^2$–$3s3p^2$ | $^4P$ - $^4P$ | | | | | | | | | | |
| | | | [12600] | | | 4 | 6 | M1 | 8.0 | 3.57 | C | 1 |
| | | | " | | | 4 | 6 | E2 | 2.5(−4)[a] | 0.28 | D− | 1 |
| | | | [16500] | | | 2 | 4 | M1 | 4.95 | 3.30 | C | 1 |
| | | | " | | | 2 | 4 | E2 | 7.9(−6) | 0.023 | E | 1 |
| | | | [7160] | | | 2 | 6 | E2 | 0.0031 | 0.21 | D− | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XIV

Mg Isoelectronic Sequence

Ground State: $1s^22s^22p^63s^2\ ^1S_0$

Ionization Energy: 403.0 eV = 3250000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 43.74 | 14 | 260.41 | 16 | 335 | 4 | 402.99 | 7 |
| 59.325 | 13 | 304.85 | 2 | 339.19 | 3 | 416.42 | 7 |
| 241.07 | 15 | 315.88 | 3 | 342.56 | 8 | 429.24 | 7 |
| 243.45 | 15 | 325.34 | 3 | 343.40 | 3 | 448 | 1 |
| 243.88 | 15 | 327.84 | 3 | 349 | 4 | 518.16 | 5 |
| 249.64 | 15 | 330.49 | 3 | 349.64 | 6 | | |

Oscillator strengths were interpolated from the results of theoretical calculations reported by various researchers for the neighboring magnesium-like ions Cr XIII and Fe XV. Data for the three transitions $3s^2\ ^1S_0$ – $3snp\ ^1P_1^\circ$ ($n=3$–5) were reported by Shorer *et al.*,[1] who applied the relativistic random phase approximation (RRPA) with allowance for correlation within the context of a frozen core. The source of $f$-values for most transitions of the arrays $3s3p$–$3p^2$, $3s3d$–$3p3d$, $3s3p$–$3s3d$, and $3p^2$–$3p3d$ is the work of Fawcett,[2] who performed Hartree-Fock calculations which included relativistic effects and statistical allowance for exchange (HXR); he incorporated correlation effects due to all configurations within the $n=3$ complex. The oscillator strength for the $3p3d\ ^1F^\circ$ - $3d^2\ ^1G$ transition was interpolated from results of the nonrelativistic multiconfiguration Hartree-Fock (MCHF) calculations of Froese Fischer and Godefroid[3]; their atomic model incorporated large-scale allowance for configuration interaction.

$A$-values for the three intercombination lines tabulated here were calculated for Mn XIV by Kastner and Bhatia[4] using a scaled Thomas-Fermi approach that allowed for correlation due to all configurations in the $n=3$ complex.

Transitions involving levels which are indicated in Ref. 2 to be of low purity in $LS$ coupling in neighboring Mg-like ions are omitted here. Lines which are characterized by very small $f$-values are assigned lower accuracy ratings.

## References


[1]P. Shorer, C. D. Lin, and W. R. Johnson, Phys. Rev. A **16**, 1109 (1977).
[2]B. C. Fawcett, At. Data Nucl. Data Tables **28**, 579 (1983).
[3]C. Froese Fischer and M. Godefroid, Nucl. Instrum. Methods **202**, 307 (1982).
[4]S. O. Kastner and A. K. Bhatia, J. Opt. Soc. Am. **69**, 1391 (1979).

Mn XIV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s^2$–$3s3p$ | $^1$S – $^3$P° | | | | | | | | | | | |
| | | | [448] | | | 1 | 3 | 0.27 | 0.0024 | 0.0036 | −2.61 | E | 4 |
| 2. | | $^1$S – $^1$P° | 304.85 | 0 | 328030 | 1 | 3 | 206 | 0.863 | 0.866 | −0.064 | C+ | *interp.* |
| 3. | $3s3p$–$3p^2$ | $^3$P° – $^3$P | *329.37* | | | 9 | 9 | 160 | 0.27 | 2.6 | 0.38 | D | *interp.* |
| | | | 327.84 | | | 5 | 5 | 110 | 0.18 | 0.97 | −0.05 | D− | *interp.* |
| | | | 330.49 | | | 3 | 3 | 45 | 0.073 | 0.24 | −0.66 | C | *interp.* |
| | | | 343.40 | | | 5 | 3 | 67 | 0.071 | 0.40 | −0.45 | C | *interp.* |
| | | | 339.19 | | | 3 | 1 | 170 | 0.095 | 0.32 | −0.55 | C− | *interp.* |
| | | | 315.88 | | | 3 | 5 | 39 | 0.096 | 0.30 | −0.54 | D− | *interp.* |
| | | | 325.34 | | | 1 | 3 | 63 | 0.30 | 0.32 | −0.52 | C | *interp.* |
| 4. | | $^3$P° – $^1$D | | | | | | | | | | | |
| | | | [349] | | | 5 | 5 | 16 | 0.029 | 0.17 | −0.84 | E | 4 |
| | | | [335] | | | 3 | 5 | 8.6 | 0.024 | 0.080 | −1.14 | E | 4 |
| 5. | | $^1$P° – $^1$D | 518.16 | 328030 | 521020 | 3 | 5 | 14 | 0.095 | 0.49 | −0.55 | E | *interp.* |
| 6. | | $^1$P° – $^1$S | 349.64 | 328030 | 614040 | 3 | 1 | 180 | 0.11 | 0.38 | −0.48 | C | *interp.* |
| 7. | $3s3d$–$3p3d$ | $^3$D – $^3$F° | | | | | | | | | | | |
| | | | 402.99 | | | 7 | 9 | 53 | 0.165 | 1.53 | 0.063 | C | *interp.* |
| | | | 416.42 | | | 5 | 7 | 38 | 0.14 | 0.96 | −0.15 | C− | *interp.* |
| | | | 429.24 | | | 3 | 5 | 30 | 0.14 | 0.59 | −0.38 | D− | *interp.* |
| | | | | | | 7 | 7 | | 0.022 | | −0.81 | C | *interp.* |
| | | | | | | 5 | 5 | | 0.022 | | −0.96 | D | *interp.* |
| | | | | | | 7 | 5 | | 2.4(−4)[a] | | −2.77 | E | *interp.* |
| 8. | | $^3$D – $^3$D° | | | | | | | | | | | |
| | | | 342.56 | | | 7 | 7 | 68 | 0.12 | 0.95 | −0.08 | C− | *interp.* |
| | | | | | | 5 | 7 | | 0.039 | | −0.71 | C | *interp.* |
| 9. | | $^3$D – $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 1 | | 0.057 | | −0.77 | C− | *interp.* |
| 10. | | $^1$D – $^1$D° | | | | 5 | 5 | | 0.034 | | −0.77 | D− | *interp.* |
| 11. | | $^1$D – $^1$F° | | | | 5 | 7 | | 0.45 | | 0.35 | D− | *interp.* |
| 12. | | $^1$D – $^1$P° | | | | 5 | 3 | | 0.12 | | −0.22 | D− | *interp.* |
| 13. | $3s^2$–$3s4p$ | $^1$S – $^1$P° | 59.325 | 0 | 1685600 | 1 | 3 | 2240 | 0.355 | 0.069 | −0.450 | C | *interp.* |
| 14. | $3s^2$–$3s5p$ | $^1$S – $^1$P° | 43.74 | 0 | 2286000 | 1 | 3 | 1300 | 0.112 | 0.0161 | −0.95 | C | *interp.* |
| 15. | $3s3p$–$3s3d$ | $^3$P° – $^3$D | | | | | | | | | | | |
| | | | 249.64 | | | 5 | 7 | 205 | 0.268 | 1.10 | 0.127 | C− | *interp.* |
| | | | 243.45 | | | 3 | 5 | 160 | 0.24 | 0.58 | −0.14 | C− | *interp.* |
| | | | 241.07 | | | 1 | 3 | 130 | 0.33 | 0.26 | −0.48 | C− | *interp.* |
| | | | | | | 5 | 5 | | 0.049 | | −0.61 | C− | *interp.* |
| | | | 243.88 | | | 3 | 3 | 91 | 0.081 | 0.20 | −0.61 | C− | *interp.* |
| | | | | | | 5 | 3 | | 0.0032 | | −1.80 | D− | *interp.* |

Mn XIV: Allowed transitions — *Continued*

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16. | | $^1P^o$ - $^1D$ | 260.41 | 328030 | 712040 | 3 | 5 | 380 | 0.65 | 1.7 | 0.29 | D− | *interp.* |
| 17. | $3p^2$–$3p3d$ | $^3P$ - $^3D^o$ | | | | | | | | | | | |
| | | | | | | 5 | 7 | | 0.31 | | 0.19 | E | *interp.* |
| 18. | | $^3P$ - $^3P^o$ | | | | | | | | | | | |
| | | | | | | 3 | 1 | | 0.060 | | −0.74 | C− | *interp.* |
| 19. | | $^1D$ - $^1D^o$ | | | | 5 | 5 | | 0.15 | | −0.12 | E | *interp.* |
| 20. | | $^1D$ - $^1P^o$ | | | | 5 | 3 | | 0.0013 | | −2.19 | E | *interp.* |
| 21. | | $^1S$ - $^1P^o$ | | | | 1 | 3 | | 0.68 | | −0.17 | C− | *interp.* |
| 22. | $3p3d$–$3d^2$ | $^1F^o$ - $^1G$ | | | | 7 | 9 | | 0.379 | | 0.424 | C− | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XV

Na Isoelectronic Sequence

Ground State: $1s^22s^22p^63s\ ^2S_{1/2}$

Ionization Energy: 435.166 eV = 3509820 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 32.230 | 6 | 41.185 | 3 | 53.032 | 21 | 82.163 | 39 |
| 33.635 | 5 | 41.243 | 3 | 53.039 | 21 | 82.183 | 39 |
| 35.04 | 17 | 42.152 | 25 | 55.661 | 20 | 83.619 | 49 |
| 35.23 | 17 | 42.185 | 25 | 55.708 | 20 | 83.689 | 49 |
| 35.25 | 17 | 42.191 | 25 | 55.766 | 20 | 84.46 | 38 |
| 36.099 | 4 | 42.706 | 24 | 56.270 | 2 | 84.96 | 38 |
| 36.119 | 4 | 42.746 | 24 | 56.484 | 2 | 86.73 | 54 |
| 36.577 | 15 | 44.820 | 11 | 60.720 | 9 | 86.81 | 54 |
| 36.803 | 15 | 45.154 | 11 | 61.319 | 9 | 87.291 | 18 |
| 36.807 | 15 | 45.167 | 11 | 61.361 | 9 | 87.47 | 18 |
| 37.12 | 14 | 45.659 | 23 | 69.682 | 32 | 87.80 | 18 |
| 37.4 | 14 | 45.700 | 23 | 74.40 | 41 | 90.695 | 30 |
| 39.287 | 13 | 45.706 | 23 | 74.74 | 41 | 90.827 | 30 |
| 39.547 | 13 | 46.757 | 22 | 74.79 | 41 | 91.149 | 48 |
| 39.552 | 13 | 46.792 | 22 | 75.182 | 19 | 91.208 | 48 |
| 40.285 | 12 | 46.806 | 22 | 75.286 | 19 | 91.233 | 48 |
| 40.466 | 26 | 47.270 | 10 | 75.307 | 19 | 93.782 | 47 |
| 40.502 | 26 | 47.666 | 10 | 76.599 | 31 | 93.870 | 47 |
| 40.572 | 12 | 52.977 | 21 | 81.733 | 39 | 96.628 | 37 |

List of tabulated lines — Continued

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 96.843 | 53 | 145 | 65 | 191.8 | 43 | 302.5 | 68 |
| 96.871 | 53 | 146 | 65 | 192.2 | 43 | 302.8 | 68 |
| 96.880 | 53 | 163.41 | 44 | 193.1 | 43 | 303.0 | 68 |
| 97.229 | 37 | 163.5 | 71 | 195.0 | 70 | 315.0 | 60 |
| 97.257 | 37 | 163.6 | 44,71 | 195.1 | 70 | 318.4 | 60 |
| 102.9 | 36 | 163.63 | 44 | 195.2 | 70 | 349.0 | 73 |
| 103.6 | 36 | 165.3 | 34 | 207.4 | 69 | 349.4 | 73 |
| 109.3 | 46 | 167.1 | 34 | 207.7 | 69 | 358.2 | 67 |
| 109.4 | 46 | 167.3 | 57 | 210.5 | 74 | 358.9 | 67 |
| 115.8 | 45 | 168 | 75 | 210.6 | 74 | 360.2 | 67 |
| 116.0 | 45 | 175.7 | 63 | 253.3 | 56 | 360.97 | 1 |
| 118.5 | 52 | 176.6 | 63 | 254.3 | 56 | 384.74 | 1 |
| 131.5 | 29 | 176.7 | 63 | 262.7 | 61 | 733.1 | 33 |
| 132.1 | 29 | 188.7 | 51 | 264.9 | 61 | 765.1 | 33 |
| 137.5 | 58 | 188.8 | 51 | 265.1 | 61 | 771.0 | 33 |
| 138.8 | 35 | 188.9 | 51 | 269.11 | 7 | 913.2 | 28 |
| 140.0 | 35 | 189 | 62 | 280.35 | 7 | 972.8 | 28 |
| 140.1 | 35 | 190 | 62 | 282.18 | 7 | | |

Strengths of the lines of the $3s$–$3p$ and $3p$–$3d$ transitions were taken from Edlén's interpolation formulae.[1] These were based on the results of Weiss' Hartree-Fock calculations,[2] in which ratios of relativistic Dirac to nonrelativistic line strengths in hydrogenic ions were applied as scaling factors to the nonrelativistic Hartree-Fock line strengths in the corresponding sodiumlike species. Oscillator strengths for the $4p$–$4d$ transitions were derived by Gruzdev and Sherstyuk[3] using the relativistic variant of their effective orbital quantum number method, which utilizes a Coulomb potential in conjunction with a semiempirical orbital quantum number which is determined from experimental energy levels. Strengths of the lines of the $3s$–$4p$ transition were interpolated from the results of the relativistic single-configuration Hartree-Fock calculations of Kim and Desclaux[4] for V XIII and Fe XVI.

Multiplet $f$-values calculated by Biemont[5] using a fully variational Hartree-Fock approach are quoted for numerous transitions $nl$–$n'l'$ ($3 \leqslant n \leqslant 5$; $4 \leqslant n' \leqslant 8$; $l,l'=s,p,d,f$). Data for additional transitions (namely, those for which $n > 5$, where $n$ is the principal quantum number of the lower state) can be found in Ref. 5. Whenever wavelengths of individual lines within a multiplet either were available directly or could be determined from the energy levels, the multiplet strength was distributed among the lines according to $LS$-coupling rules, except in cases where the wavelengths of all the lines in the multiplet are identical. The strength of the $3p\ ^2P^\circ - 4s\ ^2S$ multiplet was not distributed between the two lines in the multiplet, however, since the relativistic single-configuration Hartree-Fock calculations of Kim and Cheng[6] indicate that in the corresponding transition in sodiumlike iron the ratio of the two line strengths deviates somewhat from the value that would be obtained in the case of pure $LS$ coupling.

Transitions with small $f$-values were generally assigned lower accuracy ratings.

## References


[1] B. Edlén, Phys. Scr. **17**, 565 (1978).
[2] A. W. Weiss, J. Quant. Spectrosc. Radiat. Transfer **18**, 481 (1977).
[3] P. F. Gruzdev and A. I. Sherstyuk, Opt. Spectrosc. (USSR) **46**, 353 (1979).
[4] Y.-K. Kim and J.-P. Desclaux, Argonne National Laboratory Report ANL–76–88, Part I (1976).
[5] E. Biemont, Astron. Astrophys., Suppl. Ser. **31**, 285 (1978).
[6] Y.-K. Kim and K.-T. Cheng, J. Opt. Soc. Am. **68**, 836 (1978).


Mn XV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s$–$3p$ | $^2$S - $^2$P° | *368.55* | 0 | *271330* | 2 | 6 | 67.3 | 0.411 | 0.998 | −0.085 | B | 1 |
| | | | 360.97 | 0 | 277030 | 2 | 4 | 71.9 | 0.281 | 0.668 | −0.250 | B | 1 |
| | | | 384.74 | 0 | 259920 | 2 | 2 | 58.7 | 0.130 | 0.330 | −0.584 | B | 1 |

Mn XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | 3s–4p | $^2S - ^2P°$ | *56.341* | 0 | *1774900* | 2 | 6 | 1450 | 0.207 | 0.0769 | −0.382 | C+ | *interp.* |
| | | | 56.270 | 0 | 1777100 | 2 | 4 | 1420 | 0.135 | 0.0501 | −0.568 | C+ | *interp.* |
| | | | 56.484 | 0 | 1770400 | 2 | 2 | 1510 | 0.0721 | 0.0268 | −0.841 | C+ | *interp.* |
| 3. | 3s–5p | $^2S - ^2P°$ | *41.203* | 0 | *2427000* | 2 | 6 | 880 | 0.067 | 0.018 | −0.87 | C | 5 |
| | | | 41.185 | 0 | 2428100 | 2 | 4 | 870 | 0.044 | 0.012 | −1.05 | C | *ls* |
| | | | 41.243 | 0 | 2424700 | 2 | 2 | 870 | 0.022 | 0.0060 | −1.35 | C | *ls* |
| 4. | 3s–6p | $^2S - ^2P°$ | *36.105* | 0 | *2769700* | 2 | 6 | 520 | 0.0304 | 0.0072 | −1.216 | C | 5 |
| | | | 36.099 | 0 | 2770200 | 2 | 4 | 520 | 0.020 | 0.0048 | −1.39 | C | *ls* |
| | | | 36.119 | 0 | 2768600 | 2 | 2 | 520 | 0.010 | 0.0024 | −1.69 | C | *ls* |
| 5. | 3s–7p | $^2S - ^2P°$ | 33.635 | 0 | 2973100 | 2 | 6 | 328 | 0.0167 | 0.00370 | −1.476 | C | 5 |
| 6. | 3s–8p | $^2S - ^2P°$ | 32.230 | 0 | 3102700 | 2 | 6 | 220 | 0.0103 | 0.00219 | −1.69 | C | 5 |
| 7. | 3p–3d | $^2P° - ^2D$ | *276.61* | *271330* | *632850* | 6 | 10 | 158 | 0.302 | 1.65 | 0.258 | B | 1 |
| | | | 280.35 | 277030 | 633730 | 4 | 6 | 151 | 0.267 | 0.987 | 0.029 | B | 1 |
| | | | 269.11 | 259920 | 631520 | 2 | 4 | 143 | 0.310 | 0.549 | −0.208 | B | 1 |
| | | | 282.18 | 277030 | 631520 | 4 | 4 | 24.6 | 0.0293 | 0.109 | −0.931 | B | 1 |
| 8. | 3p–4s | $^2P° - ^2S$ | *71.618* | *271330* | 1667600 | 6 | 2 | 2500 | 0.064 | 0.091 | −0.42 | C | 5 |
| 9. | 3p–4d | $^2P° - ^2D$ | *61.121* | *271330* | *1907400* | 6 | 10 | 3170 | 0.296 | 0.357 | 0.249 | C | 5 |
| | | | 61.319 | 277030 | 1907800 | 4 | 6 | 3130 | 0.265 | 0.214 | 0.025 | C | *ls* |
| | | | 60.720 | 259920 | 1906800 | 2 | 4 | 2690 | 0.298 | 0.119 | −0.225 | C | *ls* |
| | | | 61.361 | 277030 | 1906800 | 4 | 4 | 530 | 0.030 | 0.024 | −0.93 | D | *ls* |
| 10. | 3p–5s | $^2P° - ^2S$ | *47.526* | *271330* | 2375400 | 6 | 2 | 1120 | 0.0126 | 0.0118 | −1.121 | C | 5 |
| | | | 47.666 | 277030 | 2375400 | 4 | 2 | 740 | 0.013 | 0.0079 | −1.30 | C | *ls* |
| | | | 47.270 | 259920 | 2375400 | 2 | 2 | 377 | 0.0126 | 0.00393 | −1.60 | C | *ls* |
| 11. | 3p–5d | $^2P° - ^2D$ | *45.043* | *271330* | *2491400* | 6 | 10 | 1900 | 0.095 | 0.085 | −0.24 | C | 5 |
| | | | 45.154 | 277030 | 2491600 | 4 | 6 | 1900 | 0.086 | 0.051 | −0.46 | C | *ls* |
| | | | 44.820 | 259920 | 2491000 | 2 | 4 | 1600 | 0.095 | 0.028 | −0.72 | C | *ls* |
| | | | [45.167] | 277030 | 2491000 | 4 | 4 | 310 | 0.0096 | 0.0057 | −1.42 | D | *ls* |
| 12. | 3p–6s | $^2P° - ^2S$ | *40.471* | *271330* | 2742200 | 6 | 2 | 600 | 0.0049 | 0.0039 | −1.53 | D | 5 |
| | | | 40.572 | 277030 | 2742200 | 4 | 2 | 390 | 0.0049 | 0.0026 | −1.71 | D | *ls* |
| | | | 40.285 | 259920 | 2742200 | 2 | 2 | 200 | 0.0049 | 0.0013 | −2.01 | D | *ls* |
| 13. | 3p–6d | $^2P° - ^2D$ | *39.460* | *271330* | *2805500* | 6 | 10 | 1120 | 0.0434 | 0.0338 | −0.58 | C | 5 |
| | | | 39.547 | 277030 | 2805600 | 4 | 6 | 1110 | 0.0390 | 0.0203 | −0.81 | C | *ls* |
| | | | 39.287 | 259920 | 2805300 | 2 | 4 | 940 | 0.0437 | 0.0113 | −1.059 | C | *ls* |
| | | | [39.552] | 277030 | 2805300 | 4 | 4 | 190 | 0.0044 | 0.0023 | −1.75 | D | *ls* |
| 14. | 3p–7s | $^2P° - ^2S$ | *37.27* | *271330* | 2954000 | 6 | 2 | 360 | 0.0025 | 0.0018 | −1.82 | D | 5 |
| | | | 37.4 | 277030 | 2954000 | 4 | 2 | 230 | 0.0024 | 0.0012 | −2.01 | D | *ls* |
| | | | 37.12 | 259920 | 2954000 | 2 | 2 | 120 | 0.0025 | 6.0(−4)[a] | −2.31 | D | *ls* |

Mn XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | 3p–7d | $^2P^\circ - {}^2D$ | *36.727* | *271330* | *2994100* | 6 | 10 | 710 | 0.0239 | 0.0173 | −0.84 | C | 5 |
| | | | 36.803 | 277030 | 2994200 | 4 | 6 | 700 | 0.0215 | 0.0104 | −1.066 | C | *ls* |
| | | | 36.577 | 259920 | 2993900 | 2 | 4 | 600 | 0.024 | 0.0058 | −1.32 | C | *ls* |
| | | | [36.807] | 277030 | 2993900 | 4 | 4 | 120 | 0.0025 | 0.0012 | −2.00 | D | *ls* |
| 16. | 3p–8s | $^2P^\circ - {}^2S$ | | | | 6 | 2 | | 0.0015 | | −2.05 | D | 5 |
| 17. | 3p–8d | $^2P^\circ - {}^2D$ | *35.16* | *271330* | *3115000* | 6 | 10 | 476 | 0.0147 | 0.0102 | −1.055 | C | 5 |
| | | | 35.23 | 277030 | 3115000 | 4 | 6 | 470 | 0.013 | 0.0061 | −1.28 | C | *ls* |
| | | | 35.04 | 259920 | 3114000 | 2 | 4 | 400 | 0.0147 | 0.00340 | −1.53 | C | *ls* |
| | | | [35.25] | 277030 | 3114000 | 4 | 4 | 79 | 0.0015 | 6.8(−4) | −2.23 | D | *ls* |
| 18. | 3d–4p | $^2D - {}^2P^\circ$ | *87.566* | *632850* | *1774900* | 10 | 6 | 610 | 0.0418 | 0.120 | −0.379 | C | 5 |
| | | | 87.47 | 633730 | 1777100 | 6 | 4 | 540 | 0.042 | 0.072 | −0.60 | C | *ls* |
| | | | 87.80 | 631520 | 1770400 | 4 | 2 | 600 | 0.0346 | 0.0400 | −0.86 | C | *ls* |
| | | | [87.291] | 631520 | 1777100 | 4 | 4 | 61 | 0.0070 | 0.0080 | −1.56 | D | *ls* |
| 19. | 3d–4f | $^2D - {}^2F^\circ$ | *75.250* | *632850* | *1961800* | 10 | 14 | 7700 | 0.92 | 2.3 | 0.96 | C | 5 |
| | | | 75.286 | 633730 | 1962000 | 6 | 8 | 7700 | 0.87 | 1.3 | 0.72 | C | *ls* |
| | | | 75.182 | 631520 | 1961600 | 4 | 6 | 7300 | 0.93 | 0.92 | 0.57 | C | *ls* |
| | | | [75.307] | 633730 | 1961600 | 6 | 6 | 520 | 0.044 | 0.066 | −0.57 | D | *ls* |
| 20. | 3d–5p | $^2D - {}^2P^\circ$ | *55.738* | *632850* | *2427000* | 10 | 6 | 240 | 0.0067 | 0.012 | −1.17 | D | 5 |
| | | | 55.708 | 633730 | 2428100 | 6 | 4 | 210 | 0.0065 | 0.0072 | −1.41 | D | *ls* |
| | | | [55.766] | 631520 | 2424700 | 4 | 2 | 230 | 0.0054 | 0.0040 | −1.66 | D | *ls* |
| | | | [55.661] | 631520 | 2428100 | 4 | 4 | 23 | 0.0011 | 8.0(−4) | −2.36 | E | *ls* |
| 21. | 3d–5f | $^2D - {}^2F^\circ$ | *53.011* | *632850* | *2519300* | 10 | 14 | 2880 | 0.170 | 0.297 | 0.230 | C | 5 |
| | | | 53.032 | 633730 | 2519400 | 6 | 8 | 2890 | 0.162 | 0.170 | −0.012 | C | *ls* |
| | | | 52.977 | 631520 | 2519100 | 4 | 6 | 2700 | 0.171 | 0.119 | −0.166 | C | *ls* |
| | | | [53.039] | 633730 | 2519100 | 6 | 6 | 190 | 0.0081 | 0.0085 | −1.31 | D | *ls* |
| 22. | 3d–6p | $^2D - {}^2P^\circ$ | *46.799* | *632850* | *2769700* | 10 | 6 | 120 | 0.0024 | 0.0037 | −1.62 | D | 5 |
| | | | [46.806] | 633730 | 2770200 | 6 | 4 | 110 | 0.0024 | 0.0022 | −1.85 | D | *ls* |
| | | | [46.792] | 631520 | 2768600 | 4 | 2 | 120 | 0.0019 | 0.0012 | −2.11 | D | *ls* |
| | | | [46.757] | 631520 | 2770200 | 4 | 4 | 12 | 4.1(−4) | 2.5(−4) | −2.79 | E | *ls* |
| 23. | 3d–6f | $^2D - {}^2F^\circ$ | *45.685* | *632850* | *2821800* | 10 | 14 | 1400 | 0.063 | 0.095 | −0.20 | C | 5 |
| | | | 45.700 | 633730 | 2821900 | 6 | 8 | 1400 | 0.060 | 0.054 | −0.44 | C | *ls* |
| | | | 45.659 | 631520 | 2821600 | 4 | 6 | 1300 | 0.063 | 0.038 | −0.60 | C | *ls* |
| | | | [45.706] | 633730 | 2821600 | 6 | 6 | 95 | 0.0030 | 0.0027 | −1.75 | D | *ls* |
| 24. | 3d–7p | $^2D - {}^2P^\circ$ | *42.731* | *632850* | 2973100 | 10 | 6 | 73 | 0.0012 | 0.0017 | −1.92 | D | 5 |
| | | | [42.746] | 633730 | 2973100 | 6 | 4 | 65 | 0.0012 | 0.0010 | −2.15 | D | *ls* |
| | | | [42.706] | 631520 | 2973100 | 4 | 2 | 74 | 0.0010 | 5.7(−4) | −2.39 | D | *ls* |
| | | | [42.706] | 631520 | 2973100 | 4 | 4 | 7.2 | 2.0(−4) | 1.1(−4) | −3.11 | E | *ls* |
| 25. | 3d–7f | $^2D - {}^2F^\circ$ | *42.173* | *632850* | *3004100* | 10 | 14 | 830 | 0.0310 | 0.0430 | −0.51 | C | 5 |
| | | | 42.185 | 633730 | 3004200 | 6 | 8 | 830 | 0.0295 | 0.0246 | −0.75 | C | *ls* |
| | | | 42.152 | 631520 | 3003900 | 4 | 6 | 780 | 0.0310 | 0.0172 | −0.91 | C | *ls* |
| | | | [42.191] | 633730 | 3003900 | 6 | 6 | 54 | 0.0014 | 0.0012 | −2.06 | D | *ls* |

Mn XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26. | 3d–8p | $^2$D – $^2$P° | *40.489* | *632850* | 3102700 | 10 | 6 | 45 | 6.7(–4) | 8.9(–4) | –2.17 | E | 5 |
| | | | [40.502] | 633730 | 3102700 | 6 | 4 | 40 | 6.6(–4) | 5.3(–4) | –2.40 | E | *ls* |
| | | | [40.466] | 631520 | 3102700 | 4 | 2 | 46 | 5.6(–4) | 3.0(–4) | –2.65 | E | *ls* |
| | | | [40.466] | 631520 | 3102700 | 4 | 4 | 4.5 | 1.1(–4) | 5.9(–5) | –3.35 | E | *ls* |
| 27. | 3d–8f | $^2$D – $^2$F° | | | | 10 | 14 | | 0.0179 | | –0.75 | C | 5 |
| 28. | 4s–4p | $^2$S – $^2$P° | *932.0* | 1667600 | *1774900* | 2 | 6 | 15 | 0.57 | 3.5 | 0.06 | C | 5 |
| | | | [913.2] | 1667600 | 1777100 | 2 | 4 | 15 | 0.38 | 2.3 | –0.12 | C | *ls* |
| | | | [972.8] | 1667600 | 1770400 | 2 | 2 | 13 | 0.19 | 1.2 | –0.43 | C | *ls* |
| 29. | 4s–5p | $^2$S – $^2$P° | *131.7* | 1667600 | *2427000* | 2 | 6 | 295 | 0.230 | 0.199 | –0.337 | C | 5 |
| | | | [131.5] | 1667600 | 2428100 | 2 | 4 | 296 | 0.154 | 0.133 | –0.51 | C | *ls* |
| | | | [132.1] | 1667600 | 2424700 | 2 | 2 | 290 | 0.076 | 0.066 | –0.82 | C | *ls* |
| 30. | 4s–6p | $^2$S – $^2$P° | *90.736* | 1667600 | *2769700* | 2 | 6 | 200 | 0.073 | 0.044 | –0.84 | C | 5 |
| | | | [90.695] | 1667600 | 2770200 | 2 | 4 | 200 | 0.049 | 0.029 | –1.01 | C | *ls* |
| | | | [90.827] | 1667600 | 2768600 | 2 | 2 | 200 | 0.025 | 0.015 | –1.30 | C | *ls* |
| 31. | 4s–7p | $^2$S – $^2$P° | [76.599] | 1667600 | 2973100 | 2 | 6 | 129 | 0.0341 | 0.0172 | –1.166 | C | 5 |
| 32. | 4s–8p | $^2$S – $^2$P° | [69.682] | 1667600 | 3102700 | 2 | 6 | 88 | 0.0192 | 0.0088 | –1.416 | C | 5 |
| 33. | 4p–4d | $^2$P° – $^2$D | *754.7* | *1774900* | *1907400* | 6 | 10 | 32 | 0.45 | 6.7 | 0.43 | C | 3 |
| | | | [765.1] | 1777100 | 1907800 | 4 | 6 | 30 | 0.40 | 4.0 | 0.20 | C | 3 |
| | | | [733.1] | 1770400 | 1906800 | 2 | 4 | 29 | 0.46 | 2.2 | –0.04 | C | 3 |
| | | | [771.0] | 1777100 | 1906800 | 4 | 4 | 4.9 | 0.044 | 0.45 | –0.75 | C | 3 |
| 34. | 4p–5s | $^2$P° – $^2$S | *166.5* | *1774900* | 2375400 | 6 | 2 | 790 | 0.110 | 0.362 | –0.180 | C | 5 |
| | | | [167.1] | 1777100 | 2375400 | 4 | 2 | 520 | 0.110 | 0.241 | –0.358 | C | *ls* |
| | | | [165.3] | 1770400 | 2375400 | 2 | 2 | 271 | 0.111 | 0.121 | –0.65 | C | *ls* |
| 35. | 4p–5d | $^2$P° – $^2$D | *139.6* | *1774900* | *2491400* | 6 | 10 | 520 | 0.254 | 0.70 | 0.183 | C | 5 |
| | | | [140.0] | 1777100 | 2491600 | 4 | 6 | 520 | 0.23 | 0.42 | –0.04 | C | *ls* |
| | | | [138.8] | 1770400 | 2491000 | 2 | 4 | 440 | 0.25 | 0.23 | –0.30 | C | *ls* |
| | | | [140.1] | 1777100 | 2491000 | 4 | 4 | 87 | 0.025 | 0.047 | –0.99 | D | *ls* |
| 36. | 4p–6s | $^2$P° – $^2$S | *103.4* | *1774900* | 2742200 | 6 | 2 | 404 | 0.0216 | 0.0441 | –0.89 | C | 5 |
| | | | [103.6] | 1777100 | 2742200 | 4 | 2 | 268 | 0.0216 | 0.0294 | –1.064 | C | *ls* |
| | | | [102.9] | 1770400 | 2742200 | 2 | 2 | 137 | 0.0217 | 0.0147 | –1.363 | C | *ls* |
| 37. | 4p–6d | $^2$P° – $^2$D | *97.031* | *1774900* | *2805500* | 6 | 10 | 370 | 0.087 | 0.17 | –0.28 | C | 5 |
| | | | [97.229] | 1777100 | 2805600 | 4 | 6 | 370 | 0.078 | 0.10 | –0.51 | C | *ls* |
| | | | [96.628] | 1770400 | 2805300 | 2 | 4 | 320 | 0.090 | 0.057 | –0.75 | C | *ls* |
| | | | [97.257] | 1777100 | 2805300 | 4 | 4 | 61 | 0.0086 | 0.011 | –1.46 | D | *ls* |
| 38. | 4p–7s | $^2$P° – $^2$S | *84.82* | *1774900* | 2954000 | 6 | 2 | 230 | 0.0084 | 0.014 | –1.30 | D | 5 |
| | | | [84.96] | 1777100 | 2954000 | 4 | 2 | 150 | 0.0083 | 0.0093 | –1.48 | D | *ls* |
| | | | [84.46] | 1770400 | 2954000 | 2 | 2 | 79 | 0.0085 | 0.0047 | –1.77 | D | *ls* |

Mn XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39. | $4p$–$7d$ | $^2P^\circ$ – $^2D$ | *82.021* | *1774900* | *2994100* | 6 | 10 | 249 | 0.0418 | 0.068 | −0.60 | C | 5 |
| | | | [82.163] | 1777100 | 2994200 | 4 | 6 | 250 | 0.038 | 0.041 | −0.82 | C | *ls* |
| | | | [81.733] | 1770400 | 2993900 | 2 | 4 | 210 | 0.043 | 0.023 | −1.07 | C | *ls* |
| | | | [82.183] | 1777100 | 2993900 | 4 | 4 | 41 | 0.0042 | 0.0045 | −1.78 | D | *ls* |
| 40. | $4p$–$8s$ | $^2P^\circ$ – $^2S$ | | | | 6 | 2 | | 0.0043 | | −1.59 | D | 5 |
| 41. | $4p$–$8d$ | $^2P^\circ$ – $^2D$ | *74.63* | *1774900* | *3115000* | 6 | 10 | 171 | 0.0238 | 0.0351 | −0.85 | C | 5 |
| | | | [74.74] | 1777100 | 3115000 | 4 | 6 | 171 | 0.0214 | 0.0211 | −1.067 | C | *ls* |
| | | | [74.40] | 1770400 | 3114000 | 2 | 4 | 144 | 0.0239 | 0.0117 | −1.321 | C | *ls* |
| | | | [74.79] | 1777100 | 3114000 | 4 | 4 | 28 | 0.0023 | 0.0023 | −2.03 | D | *ls* |
| 42. | $4d$–$4f$ | $^2D$ – $^2F^\circ$ | | | | 10 | 14 | | 0.118 | | 0.072 | C | 5 |
| 43. | $4d$–$5p$ | $^2D$ – $^2P^\circ$ | *192.5* | *1907400* | *2427000* | 10 | 6 | 280 | 0.093 | 0.59 | −0.03 | C | 5 |
| | | | [192.2] | 1907800 | 2428100 | 6 | 4 | 250 | 0.092 | 0.35 | −0.26 | C | *ls* |
| | | | [193.1] | 1906800 | 2424700 | 4 | 2 | 280 | 0.079 | 0.20 | −0.50 | C | *ls* |
| | | | [191.8] | 1906800 | 2428100 | 4 | 4 | 28 | 0.015 | 0.039 | −1.21 | D | *ls* |
| 44. | $4d$–$5f$ | $^2D$ – $^2F^\circ$ | *163.4* | *1907400* | *2519300* | 10 | 14 | 1300 | 0.72 | 3.9 | 0.86 | C | 5 |
| | | | 163.63 | 1907800 | 2519400 | 6 | 8 | 1300 | 0.68 | 2.2 | 0.61 | C | *ls* |
| | | | 163.41 | 1906800 | 2519100 | 4 | 6 | 1200 | 0.74 | 1.6 | 0.47 | C | *ls* |
| | | | [163.6] | 1907800 | 2519100 | 6 | 6 | 85 | 0.034 | 0.11 | −0.69 | D | *ls* |
| 45. | $4d$–$6p$ | $^2D$ – $^2P^\circ$ | *116.0* | *1907400* | *2769700* | 10 | 6 | 131 | 0.0158 | 0.060 | −0.80 | C | 5 |
| | | | [116.0] | 1907800 | 2770200 | 6 | 4 | 120 | 0.016 | 0.036 | −1.03 | C | *ls* |
| | | | [116.0] | 1906800 | 2768600 | 4 | 2 | 130 | 0.013 | 0.020 | −1.28 | C | *ls* |
| | | | [115.8] | 1906800 | 2770200 | 4 | 4 | 13 | 0.0026 | 0.0040 | −1.98 | D | *ls* |
| 46. | $4d$–$6f$ | $^2D$ – $^2F^\circ$ | *109.4* | *1907400* | *2821800* | 10 | 14 | 710 | 0.178 | 0.64 | 0.250 | C | 5 |
| | | | [109.4] | 1907800 | 2821900 | 6 | 8 | 720 | 0.17 | 0.37 | 0.01 | C | *ls* |
| | | | [109.3] | 1906800 | 2821600 | 4 | 6 | 670 | 0.18 | 0.26 | −0.14 | C | *ls* |
| | | | [109.4] | 1907800 | 2821600 | 6 | 6 | 46 | 0.0083 | 0.018 | −1.30 | D | *ls* |
| 47. | $4d$–$7p$ | $^2D$ – $^2P^\circ$ | *93.835* | *1907400* | 2973100 | 10 | 6 | 73 | 0.0058 | 0.018 | −1.24 | D | 5 |
| | | | [93.870] | 1907800 | 2973100 | 6 | 4 | 67 | 0.0059 | 0.011 | −1.45 | D | *ls* |
| | | | [93.782] | 1906800 | 2973100 | 4 | 2 | 74 | 0.0049 | 0.0060 | −1.71 | D | *ls* |
| | | | [93.782] | 1906800 | 2973100 | 4 | 4 | 7.4 | 9.7(−4) | 0.0012 | −2.41 | E | *ls* |
| 48. | $4d$–$7f$ | $^2D$ – $^2F^\circ$ | *91.183* | *1907400* | *3004100* | 10 | 14 | 420 | 0.074 | 0.22 | −0.13 | C | 5 |
| | | | [91.208] | 1907800 | 3004200 | 6 | 8 | 430 | 0.072 | 0.13 | −0.36 | C | *ls* |
| | | | [91.149] | 1906800 | 3003900 | 4 | 6 | 390 | 0.073 | 0.088 | −0.53 | C | *ls* |
| | | | [91.233] | 1907800 | 3003900 | 6 | 6 | 28 | 0.0035 | 0.0063 | −1.68 | D | *ls* |
| 49. | $4d$–$8p$ | $^2D$ – $^2P^\circ$ | *83.661* | *1907400* | 3102700 | 10 | 6 | 46 | 0.0029 | 0.0080 | −1.54 | D | 5 |
| | | | [83.689] | 1907800 | 3102700 | 6 | 4 | 41 | 0.0029 | 0.0048 | −1.76 | D | *ls* |
| | | | [83.619] | 1906800 | 3102700 | 4 | 2 | 47 | 0.0025 | 0.0027 | −2.01 | D | *ls* |
| | | | [83.619] | 1906800 | 3102700 | 4 | 4 | 4.6 | 4.8(−4) | 5.3(−4) | −2.72 | E | *ls* |
| 50. | $4d$–$8f$ | $^2D$ – $^2F^\circ$ | | | | 10 | 14 | | 0.0388 | | −0.411 | C | 5 |

Mn XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51. | 4f–5d | $^2F^o$ - $^2D$ | *188.8* | *1961800* | *2491400* | 14 | 10 | 51 | 0.0196 | 0.171 | −0.56 | C | 5 |
| | | | [188.8] | 1962000 | 2491600 | 8 | 6 | 49 | 0.020 | 0.098 | −0.80 | C | ls |
| | | | [188.9] | 1961600 | 2491000 | 6 | 4 | 51 | 0.018 | 0.068 | −0.96 | C | ls |
| | | | [188.7] | 1961600 | 2491600 | 6 | 6 | 2.5 | 0.0013 | 0.0049 | −2.10 | D | ls |
| 52. | 4f–6d | $^2F^o$ - $^2D$ | [118.5] | *1961800* | *2805500* | 14 | 10 | 22 | 0.0033 | 0.018 | −1.34 | D | 5 |
| 53. | 4f–7d | $^2F^o$ - $^2D$ | *96.871* | *1961800* | *2994100* | 14 | 10 | 12 | 0.0012 | 0.0054 | −1.77 | D | 5 |
| | | | [96.880] | 1962000 | 2994200 | 8 | 6 | 12 | 0.0012 | 0.0031 | −2.01 | D | ls |
| | | | [96.871] | 1961600 | 2993900 | 6 | 4 | 12 | 0.0011 | 0.0022 | −2.16 | D | ls |
| | | | [96.843] | 1961600 | 2994200 | 6 | 6 | 0.56 | 7.8(−5) | 1.5(−4) | −3.33 | E | ls |
| 54. | 4f–8d | $^2F^o$ - $^2D$ | *86.73* | *1961800* | *3115000* | 14 | 10 | 7.0 | 5.6(−4) | 0.0022 | −2.11 | E | 5 |
| | | | [86.73] | 1962000 | 3115000 | 8 | 6 | 6.7 | 5.7(−4) | 0.0013 | −2.34 | E | ls |
| | | | [86.81] | 1961600 | 3114000 | 6 | 4 | 6.8 | 5.1(−4) | 8.8(−4) | −2.51 | E | ls |
| | | | [86.73] | 1961600 | 3115000 | 6 | 6 | 0.33 | 3.7(−5) | 6.3(−5) | −3.66 | E | ls |
| 55. | 5s–5p | $^2S$ - $^2P^o$ | | | | 2 | 6 | | 0.74 | | 0.17 | C | 5 |
| 56. | 5s–6p | $^2S$ - $^2P^o$ | *253.6* | 2375400 | *2769700* | 2 | 6 | 86 | 0.248 | 0.414 | −0.305 | C | 5 |
| | | | [253.3] | 2375400 | 2770200 | 2 | 4 | 86 | 0.165 | 0.276 | −0.480 | C | ls |
| | | | [254.3] | 2375400 | 2768600 | 2 | 2 | 85 | 0.082 | 0.138 | −0.78 | C | ls |
| 57. | 5s–7p | $^2S$ - $^2P^o$ | [167.3] | 2375400 | 2973100 | 2 | 6 | 63 | 0.079 | 0.087 | −0.80 | C | 5 |
| 58. | 5s–8p | $^2S$ - $^2P^o$ | [137.5] | 2375400 | 3102700 | 2 | 6 | 44.1 | 0.0375 | 0.0339 | −1.125 | C | 5 |
| 59. | 5p–5d | $^2P^o$ - $^2D$ | | | | 6 | 10 | | 0.63 | | 0.58 | C | 5 |
| 60. | 5p–6s | $^2P^o$ - $^2S$ | *317.3* | *2427000* | 2742200 | 6 | 2 | 310 | 0.156 | 0.98 | −0.029 | C | 5 |
| | | | [318.4] | 2428100 | 2742200 | 4 | 2 | 200 | 0.16 | 0.65 | −0.21 | C | ls |
| | | | [315.0] | 2424700 | 2742200 | 2 | 2 | 110 | 0.16 | 0.33 | −0.50 | C | ls |
| 61. | 5p–6d | $^2P^o$ - $^2D$ | *264.2* | *2427000* | *2805500* | 6 | 10 | 136 | 0.237 | 1.24 | 0.153 | C | 5 |
| | | | [264.9] | 2428100 | 2805600 | 4 | 6 | 130 | 0.21 | 0.74 | −0.07 | C | ls |
| | | | [262.7] | 2424700 | 2805300 | 2 | 4 | 115 | 0.239 | 0.413 | −0.321 | C | ls |
| | | | [265.1] | 2428100 | 2805300 | 4 | 4 | 23 | 0.024 | 0.083 | −1.02 | D | ls |
| 62. | 5p–7s | $^2P^o$ - $^2S$ | *190* | *2427000* | 2954000 | 6 | 2 | 170 | 0.0306 | 0.115 | −0.74 | C | 5 |
| | | | [190] | 2428100 | 2954000 | 4 | 2 | 110 | 0.031 | 0.077 | −0.91 | C | ls |
| | | | [189] | 2424700 | 2954000 | 2 | 2 | 57 | 0.0308 | 0.0383 | −1.211 | C | ls |
| 63. | 5p–7d | $^2P^o$ - $^2D$ | *176.3* | *2427000* | *2994100* | 6 | 10 | 110 | 0.084 | 0.29 | −0.30 | C | 5 |
| | | | [176.6] | 2428100 | 2994200 | 4 | 6 | 100 | 0.073 | 0.17 | −0.53 | C | ls |
| | | | [175.7] | 2424700 | 2993900 | 2 | 4 | 91 | 0.084 | 0.097 | −0.78 | C | ls |
| | | | [176.7] | 2428100 | 2993900 | 4 | 4 | 17 | 0.0082 | 0.019 | −1.49 | D | ls |
| 64. | 5p–8s | $^2P^o$ - $^2S$ | | | | 6 | 2 | | 0.0120 | | −1.143 | C | 5 |
| 65. | 5p–8d | $^2P^o$ - $^2D$ | *145* | *2427000* | *3115000* | 6 | 10 | 78 | 0.0411 | 0.118 | −0.61 | C | 5 |
| | | | [146] | 2428100 | 3115000 | 4 | 6 | 77 | 0.037 | 0.071 | −0.83 | C | ls |
| | | | [145] | 2424700 | 3114000 | 2 | 4 | 65 | 0.0412 | 0.0393 | −1.084 | C | ls |
| | | | [146] | 2428100 | 3114000 | 4 | 4 | 13 | 0.0041 | 0.0079 | −1.78 | D | ls |

Mn XV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66. | $5d$–$5f$ | $^2$D - $^2$F° | | | | 10 | 14 | | 0.206 | | 0.314 | C | 5 |
| 67. | $5d$–$6p$ | $^2$D - $^2$P° | *359.3* | *2491400* | *2769700* | 10 | 6 | 128 | 0.149 | 1.76 | 0.173 | C | 5 |
| | | | [358.9] | 2491600 | 2770200 | 6 | 4 | 116 | 0.150 | 1.06 | −0.047 | C | *ls* |
| | | | [360.2] | 2491000 | 2768600 | 4 | 2 | 130 | 0.12 | 0.59 | −0.30 | C | *ls* |
| | | | [358.2] | 2491000 | 2770200 | 4 | 4 | 13 | 0.025 | 0.12 | −0.99 | D | *ls* |
| 68. | $5d$–$6f$ | $^2$D - $^2$F° | *302.7* | *2491400* | *2821800* | 10 | 14 | 330 | 0.64 | 6.4 | 0.81 | C | 5 |
| | | | [302.8] | 2491600 | 2821900 | 6 | 8 | 340 | 0.62 | 3.7 | 0.57 | C | *ls* |
| | | | [302.5] | 2491000 | 2821600 | 4 | 6 | 320 | 0.65 | 2.6 | 0.42 | C | *ls* |
| | | | [303.0] | 2491600 | 2821600 | 6 | 6 | 22 | 0.030 | 0.18 | −0.74 | D | *ls* |
| 69. | $5d$–$7p$ | $^2$D - $^2$P° | *207.6* | *2491400* | 2973100 | 10 | 6 | 67 | 0.0259 | 0.177 | −0.59 | C | 5 |
| | | | [207.7] | 2491600 | 2973100 | 6 | 4 | 60 | 0.0258 | 0.106 | −0.81 | C | *ls* |
| | | | [207.4] | 2491000 | 2973100 | 4 | 2 | 67 | 0.022 | 0.059 | −1.06 | C | *ls* |
| | | | [207.4] | 2491000 | 2973100 | 4 | 4 | 6.8 | 0.0044 | 0.012 | −1.76 | D | *ls* |
| 70. | $5d$–$7f$ | $^2$D - $^2$F° | *195.0* | *2491400* | *3004100* | 10 | 14 | 219 | 0.175 | 1.12 | 0.243 | C | 5 |
| | | | [195.1] | 2491600 | 3004200 | 6 | 8 | 220 | 0.17 | 0.64 | −0.00 | C | *ls* |
| | | | [195.0] | 2491000 | 3003900 | 4 | 6 | 204 | 0.174 | 0.448 | −0.156 | C | *ls* |
| | | | [195.2] | 2491600 | 3003900 | 6 | 6 | 15 | 0.0083 | 0.032 | −1.30 | D | *ls* |
| 71. | $5d$–$8p$ | $^2$D - $^2$P° | *163.6* | *2491400* | 3102700 | 10 | 6 | 40 | 0.0097 | 0.052 | −1.01 | D | 5 |
| | | | [163.6] | 2491600 | 3102700 | 6 | 4 | 36 | 0.0096 | 0.031 | −1.24 | D | *ls* |
| | | | [163.5] | 2491000 | 3102700 | 4 | 2 | 39 | 0.0079 | 0.017 | −1.50 | D | *ls* |
| | | | [163.5] | 2491000 | 3102700 | 4 | 4 | 4.1 | 0.0016 | 0.0035 | −2.19 | E | *ls* |
| 72. | $5d$–$8f$ | $^2$D - $^2$F° | | | | 10 | 14 | | 0.077 | | −0.11 | C | 5 |
| 73. | $5f$–$6d$ | $^2$F° - $^2$D | *349.4* | *2519300* | *2805500* | 14 | 10 | 36.5 | 0.0477 | 0.77 | −0.175 | C | 5 |
| | | | [349.4] | 2519400 | 2805600 | 8 | 6 | 35 | 0.048 | 0.44 | −0.42 | C | *ls* |
| | | | [349.4] | 2519100 | 2805300 | 6 | 4 | 37 | 0.045 | 0.31 | −0.57 | C | *ls* |
| | | | [349.0] | 2519100 | 2805600 | 6 | 6 | 1.7 | 0.0032 | 0.022 | −1.72 | D | *ls* |
| 74. | $5f$–$7d$ | $^2$F° - $^2$D | *210.6* | *2519300* | *2994100* | 14 | 10 | 18 | 0.0085 | 0.083 | −0.92 | D | 5 |
| | | | [210.6] | 2519400 | 2994200 | 8 | 6 | 17 | 0.0085 | 0.047 | −1.17 | D | *ls* |
| | | | [210.6] | 2519100 | 2993900 | 6 | 4 | 18 | 0.0079 | 0.033 | −1.32 | D | *ls* |
| | | | [210.5] | 2519100 | 2994200 | 6 | 6 | 0.87 | 5.8(−4) | 0.0024 | −2.46 | E | *ls* |
| 75. | $5f$–$8d$ | $^2$F° - $^2$D | [168] | *2519300* | *3115000* | 14 | 10 | 10 | 0.0031 | 0.024 | −1.36 | D | 5 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XV

## Forbidden Transitions

The electric quadrupole $gf$-value for the $3s$–$3d$ multiplet in this sodiumlike ion was reported by Godefroid *et al.*;[1] it was calculated earlier by Biemont and Godefroid[2] using a fully variational Hartree-Fock approach. This $f$-value was converted to a multiplet strength, which was then distributed between the two lines of the multiplet according to $LS$-coupling rules.

### References


[1] M. Godefroid, C. E. Magnusson, P. O. Zetterberg, and I. Joelsson, Phys. Scr. **32**, 125 (1985).

[2] E. Biemont and M. Godefroid, Phys. Scr. **18**, 323 (1978).


Mn XV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $3s$–$3d$ | $^2S$ - $^2D$ | | | | | | | | | | |
| | | | [157.80] | 0 | 633730 | 2 | 6 | E2 | 6.2(+5)[a] | 0.217 | C | 1,*ls* |
| | | | [158.35] | 0 | 631520 | 2 | 4 | E2 | 6.1(+5) | 0.144 | C | 1,*ls* |

[a] The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XVI

Ne Isoelectronic Sequence

Ground State: $1s^22s^22p^6\ ^1S_0$

Ionization Energy: 1134.7 eV = 9152000 cm$^{-1}$

## Allowed Transitions

For resonance transitions to $J = 1$ levels of the $2p^53s$ and $2p^53d$ configurations, we quote $A$-values which were calculated by Vainshtein and Safronova[1] using a charge-expansion perturbation theory approach with allowance for mixing of the $2p^53s$, $2p^53d$, and $2s2p^63p$ configurations. Their results for the $2p^6$–$2p^53d$ transitions in the isoelectronic ions Ar IX and Fe XVII are in rather good agreement with those of Shorer,[2] who used the relativistic random phase approximation (RRPA) with allowance for mixing between configurations of type $2p^5ns$ and $2p^5nd$, as well as correlation effects due to configurations having a vacancy in the $1s$ or $2s$ subshell. But the data of Ref. 1 for the two $2p^6$–$2p^53s$ transitions are approximately a factor of two smaller than those of Shorer for the abovementioned neonlike species, so we have increased the transition probabilities of Ref. 1 for these two lines by a factor of two.

$A$-values quoted here for a number of transitions involving an electron jump of the type $2s$–$2p$, $3s$–$3p$, or $3p$–$3d$ were taken from the work of Pokleba and Safronova,[3] who used wavefunctions calculated by a charge-expansion perturbation theory approach with allowance for mixing of configurations in which a single $2s$ or $2p$ electron is excited to an $n = 3$ orbital but with no inclusion of configurations in which an electron occupies the $n = 4$ shell. Transitions involving levels of the $2p^53p$ and $2p^53d$ configurations which are indicated by Fawcett[4] (in Ti XII) or by Jupen and Litzen[5] (in Ti XII or Fe XVII) to be of low to moderate purity in $LS$ coupling are excluded here, as are very weak lines. The pattern of levels within the $2s2p^63d$ configuration in the isoelectronic ions Fe XVII and Ni XIX resulting from the scaled Thomas-Fermi calculations of Loulergue and Nussbaumer[6] with extensive allowance for correlation is entirely different from that determined by Vainshtein and Safronova, whose energy levels were apparently used by Pokleba and Safronova in their transition probability calculations. We have thus excluded transitions out of these levels from our tabulation.

## References


[1] L. A. Vainshtein and U. I. Safronova, *Spektroskopicheskie Konstanty Atomov*, 5-122 (Ed. V. B. Belyanin, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Nauch. Sov. Spektrosk., Moscow, 1977).

[2] P. Shorer, Phys. Rev. A **20**, 642 (1979).

[3] A. K. Pokleba and U. I. Safronova, Preprint No. 11, Akad. Nauk SSSR, Ot. Ob. Fiz. Astron., Inst. Spektrosk. (Moscow, 1981).

[4] B. C. Fawcett, private communication, as quoted in E. Träbert, Z. Phys. A **319**, 25 (1984).

[5] C. Jupen and U. Litzen, Phys. Scr. **30**, 112 (1984).

[6] M. Loulergue and H. Nussbaumer, Astron. Astrophys. **45**, 125 (1975).


Mn XVI: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5(^2P^\circ_{3/2})3s-2s2p^63s$ | $(^3/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | [102] | | | 5 | 3 | 670 | 0.063 | 0.11 | −0.50 | E | 3 |
| 2. | $2s^22p^5(^2P^\circ_{1/2})3s-2s2p^63s$ | $(^1/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | [113] | | | 3 | 3 | 150 | 0.029 | 0.032 | −1.06 | E | 3 |
| 3. | $2s^22p^53p-2s2p^63p$ | $^3S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [96] | | | 3 | 3 | 170 | 0.023 | 0.022 | −1.15 | E | 3 |
| | | | [96] | | | 3 | 1 | 460 | 0.021 | 0.020 | −1.20 | D | 3 |
| 4. | | $^3D - {}^3P^\circ$ | | | | | | | | | | | |
| | | | [98] | | | 7 | 5 | 590 | 0.061 | 0.14 | −0.37 | D | 3 |
| 5. | $2p^6-2p^5(^2P^\circ_{3/2})3s$ | $^1S - (^3/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 18.935 | 0 | 5281200 | 1 | 3 | 7300 | 0.12 | 0.0073 | −0.93 | C− | 1*n* |
| 6. | $2p^6-2p^5(^2P^\circ_{1/2})3s$ | $^1S - (^1/_2,^1/_2)^\circ$ | | | | | | | | | | | |
| | | | 18.654 | 0 | 5360800 | 1 | 3 | 7200 | 0.11 | 0.0069 | −0.95 | C− | 1*n* |
| 7. | $2p^6-2p^53d$ | $^1S - {}^3P^\circ$ | | | | | | | | | | | |
| | | | 17.095 | 0 | 5849700 | 1 | 3 | 830 | 0.011 | 6.1(−4)[a] | −1.96 | E | 1 |
| 8. | | $^1S - {}^3D^\circ$ | | | | | | | | | | | |
| | | | 16.882 | 0 | 5923500 | 1 | 3 | 4.1(+4) | 0.53 | 0.029 | −0.28 | D | 1 |
| 9. | | $^1S - {}^1P^\circ$ | 16.616 | 0 | 6018300 | 1 | 3 | 2.00(+5) | 2.48 | 0.136 | 0.395 | C− | 1 |
| 10. | $2p^5(^2P^\circ_{3/2})3s-2p^53p$ | $(^3/_2,^1/_2)^\circ - {}^3S$ | | | | | | | | | | | |
| | | | [436] | | | 5 | 3 | 29 | 0.050 | 0.36 | −0.61 | D | 3 |
| 11. | | $(^3/_2,^1/_2)^\circ - {}^3D$ | | | | | | | | | | | |
| | | | [375] | | | 5 | 7 | 51 | 0.15 | 0.93 | −0.12 | D | 3 |

Mn XVI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | $2p^5(^2P^\circ_{1/2})3s-2p^53p$ | $(^1/_2,^1/_2)^\circ$ - $^3$S | | | | | | | | | | | |
| | | | [696] | | | 1 | 3 | 0.15 | 0.0033 | 0.0075 | −2.49 | E | 3 |
| 13. | $2p^53p-2p^53d$ | $^3$S - $^3$P° | *279* | | | 3 | 9 | 61 | 0.21 | 0.59 | −0.19 | E | 3 |
| | | | [274] | | | 3 | 5 | 45 | 0.084 | 0.23 | −0.60 | E | 3 |
| | | | [284] | | | 3 | 3 | 74 | 0.089 | 0.25 | −0.57 | D | 3 |
| | | | [290] | | | 3 | 1 | 89 | 0.037 | 0.11 | −0.95 | D | 3 |
| 14. | | $^3$D - $^3$P° | | | | | | | | | | | |
| | | | [306] | | | 7 | 5 | 3.9 | 0.0039 | 0.028 | −1.56 | E | 3 |
| 15. | | $^3$D - $^3$F° | | | | | | | | | | | |
| | | | [306] | | | 7 | 9 | 85 | 0.15 | 1.1 | 0.03 | D | 3 |
| 16. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | [397] | | | 1 | 3 | 1.6 | 0.011 | 0.015 | −1.95 | D− | 3 |
| 17. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | [305] | | | 1 | 3 | 43 | 0.18 | 0.18 | −0.74 | D | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XVII

F Isoelectronic Sequence

Ground State: $1s^22s^22p^5\ ^2P^\circ_{3/2}$

Ionization Energy: 1224 eV = 9872000 cm$^{-1}$

## Allowed Transitions

Oscillator strengths for lines of the multiplet $2s^22p^5\ ^2P^\circ - 2s2p^6\ ^2S$ are the results of the Dirac-Fock calculations of Cheng *et al.*,[1] which included a perturbative treatment of the Breit interaction and the Lamb shift.

For lines of the arrays $2p^5$–$2p^43s$ and $2p^5$–$2p^43d$, we quote the $f$-values calculated by Fawcett[2] using Cowan's Hartree-Fock-Relativistic (HFR) method and incorporating scaling of energy parameters on the basis of a least-squares fit to observed energies. Fawcett's calculations included fairly extensive allowance for configuration mixing in both odd- and even-parity states. Transitions involving levels which are indicated by Fawcett to be of low to moderate purity in *LS* coupling in neighboring fluorinelike ions are excluded from this compilation, as are lines characterized by very small $f$-values.

### References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables 24, 111 (1979).
[2]B. C. Fawcett, At. Data Nucl. Data Tables 31, 495 (1984).

Mn XVII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8\ s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^5$–$2s2p^6$ | $^2P^\circ$ - $^2S$ | *102.9* | *28500* | 1000000 | 6 | 2 | 1140 | 0.0605 | 0.123 | −0.440 | C+ | 1 |
| | | | 100.00 | 0 | 1000000 | 4 | 2 | 831 | 0.0623 | 0.0820 | −0.603 | C+ | 1 |
| | | | 109.35 | 85500 | 1000000 | 2 | 2 | 314 | 0.0562 | 0.0405 | −0.949 | C+ | 1 |
| 2. | $2p^5$–$2p^4(^3P)3s$ | $^2P^\circ$ - $^4P$ | | | | | | | | | | | |
| | | | 17.794 | 0 | 5619900 | 4 | 6 | 630 | 0.0045 | 0.0011 | −1.74 | E | 2 |
| 3. | | $^2P^\circ$ - $^2P$ | | | | | | | | | | | |
| | | | 17.729 | 85500 | 5725700 | 2 | 2 | 1.3(+4)[a] | 0.061 | 0.0071 | −0.91 | D | 2 |
| | | | 17.465 | 0 | 5725700 | 4 | 2 | 1.2(+4) | 0.027 | 0.0062 | −0.97 | D | 2 |
| 4. | $2p^5$–$2p^4(^1D)3s$ | $^2P^\circ$ - $^2D$ | | | | | | | | | | | |
| | | | 17.301 | 0 | 5780000 | 4 | 6 | 9400 | 0.063 | 0.014 | −0.60 | D | 2 |
| | | | 17.550 | 85500 | 5783500 | 2 | 4 | 1.1(+4) | 0.10 | 0.012 | −0.70 | D | 2 |
| 5. | $2p^5$–$2p^4(^1S)3s$ | $^2P^\circ$ - $^2S$ | *16.965* | *28500* | 5922900 | 6 | 2 | 1.1(+4) | 0.016 | 0.0055 | −1.01 | E | 2 |
| | | | 16.880 | 0 | 5922900 | 4 | 2 | 2700 | 0.058 | 0.0013 | −1.63 | E | 2 |
| | | | 17.131 | 85500 | 5922900 | 2 | 2 | 8400 | 0.037 | 0.0042 | −1.13 | D | 2 |
| 6. | $2p^5$–$2p^4(^3P)3d$ | $^2P^\circ$ - $^4F$ | | | | | | | | | | | |
| | | | [15.99] | | | 4 | 4 | 4200 | 0.016 | 0.0034 | −1.19 | E | 2 |
| 7. | $2p^5$–$2p^4(^1D)3d$ | $^2P^\circ$ - $^2S$ | *15.802* | *28500* | 6356700 | 6 | 2 | 1.5(+5) | 0.19 | 0.059 | 0.05 | D | 2 |
| | | | 15.732 | 0 | 6356700 | 4 | 2 | 1.3(+5) | 0.24 | 0.050 | −0.02 | D | 2 |
| | | | 15.946 | 85500 | 6356700 | 2 | 2 | 2.3(+4) | 0.089 | 0.0093 | −0.75 | D | 2 |
| 8. | | $^2P^\circ$ - $^2P$ | | | | | | | | | | | |
| | | | [15.676] | 0 | 6379200 | 4 | 4 | 1.6(+5) | 0.60 | 0.12 | 0.38 | E | 2 |
| | | | 15.889 | 85500 | 6379200 | 2 | 4 | 2.5(+4) | 0.19 | 0.020 | −0.42 | E | 2 |
| 9. | | $^2P^\circ$ - $^2D$ | | | | | | | | | | | |
| | | | 15.826 | 85500 | 6404100 | 2 | 4 | 1.3(+5) | 0.94 | 0.098 | 0.27 | E | 2 |
| | | | 15.615 | 0 | 6404100 | 4 | 4 | 3.3(+4) | 0.12 | 0.025 | −0.32 | E | 2 |
| 10. | $2p^5$–$2p^4(^1S)3d$ | $^2P^\circ$ - $^2D$ | *15.456* | *28500* | *6498300* | 6 | 10 | 5.4(+4) | 0.32 | 0.099 | 0.29 | E | 2 |
| | | | 15.404 | 0 | 6491800 | 4 | 6 | 1.2(+4) | 0.063 | 0.013 | −0.60 | D | 2 |
| | | | 15.570 | 85500 | 6508100 | 2 | 4 | 1.1(+5) | 0.83 | 0.085 | 0.22 | D | 2 |
| | | | [15.365] | 0 | 6508100 | 4 | 4 | 990 | 0.0035 | 7.1(−4) | −1.85 | E | 2 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XVII

## Forbidden Transitions

Line strengths for the magnetic dipole and electric quadrupole contributions to the transition between the two levels of the $2p^5$ configuration are the results of the Dirac-Fock calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor 2/3 which is needed to bring this value into conformance with the definition of quadrupole strengths used in the NBS tables.

### Reference

[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

Mn XVII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^5$–$2p^5$ | $^2P^\circ$ – $^2P^\circ$ | | | | | | | | | | |
| | | | [1170] | 0 | 85500 | 4 | 2 | M1 | 1.12(+4)[a] | 1.33 | C+ | 1 |
| | | | " | " | " | 4 | 2 | E2 | 0.96 | 0.0025 | E | 1 |

[a] The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XVIII

O Isoelectronic Sequence

Ground State: $1s^22s^22p^4\ ^3P_2$

Ionization Energy: 1317 eV = 10620000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 14.59 | 29 | 15.22 | 25 | 16.332 | 11 | 91.90 | 7 |
| 14.72 | 27 | 15.34 | 18 | 16.36 | 15 | 96.23 | 4 |
| 14.76 | 31 | 15.35 | 19 | 16.425 | 10 | 108.76 | 1 |
| 14.77 | 24 | 15.36 | 19 | 16.444 | 10 | 111.39 | 6 |
| 14.81 | 28 | 15.54 | 20 | 16.451 | 10 | 113.30 | 1 |
| 14.88 | 22 | 15.85 | 14 | 16.521 | 9 | 115.38 | 1 |
| 14.90 | 27 | 16.03 | 14 | 16.540 | 13 | 117.25 | 1 |
| 15.03 | 23 | 16.13 | 14 | 16.577 | 17 | 118.22 | 1 |
| 15.04 | 21 | 16.138 | 11 | 16.589 | 12 | 122.29 | 8 |
| 15.06 | 30 | 16.17 | 14 | 16.663 | 12 | 126.09 | 1 |
| 15.07 | 30,32 | 16.185 | 10 | 16.724 | 9 | 139.65 | 3 |
| 15.10 | 26 | 16.197 | 16 | 84.05 | 2 | 159.39 | 5 |
| 15.19 | 19 | 16.23 | 15 | 89.03 | 2 | | |
| 15.20 | 21 | 16.255 | 10 | 89.59 | 2 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^4$–$2s2p^5$ and $2s2p^5$–$2p^6$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. The results should be quite accurate, except in the case of weak lines. (The $2s^22p^4\ {}^1D_2$ – $2s2p^5\ {}^3P_1^\circ$ transition has been omitted from this tabulation, because its $f$-value as reported in Ref. 1 is extremely small, and thus very uncertain.)

Transition probabilities for lines of the $2s^22p^4$–$2s2p^5$ array were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis set included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these two sources are in reasonably good agreement, particularly for the stronger transitions.

For lines of the arrays $2p^4$–$2p^33s$ and $2p^4$–$2p^33d$, we quote the $f$-values calculated by Fawcett[3] using Cowan's Hartree-Fock-Relativistic (HFR) method and incorporating scaling of energy parameters on the basis of a least-squares fit to observed energies. Fawcett's calculations included fairly extensive allowance for configuration mixing in both odd- and even-parity states. The weakest lines were not reported, and thus are not tabulated here. Transitions involving levels which are indicated by Fawcett to be of low to moderate purity in *LS* coupling in neighboring oxygenlike ions are excluded from this compilation.

## References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, J. Phys. B **17**, 943 (1984).

[3]B. C. Fawcett, At. Data Nucl. Data Tables **34**, 215 (1986).


Mn XVIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^4$–$2s2p^5$ | $^3P$ - $^3P^\circ$ | *115.97* | *31930* | *894230* | 9 | 9 | 480 | 0.096 | 0.33 | −0.06 | C | 1 |
| | | | 115.38 | 0 | 866700 | 5 | 5 | 360 | 0.071 | 0.13 | −0.45 | C | 1 |
| | | | 118.22 | 73590 | 919460 | 3 | 3 | 117 | 0.0246 | 0.0287 | −1.132 | C | 1 |
| | | | 108.76 | 0 | 919460 | 5 | 3 | 277 | 0.0295 | 0.053 | −0.83 | C | 1 |
| | | | 113.30 | 73590 | 956220 | 3 | 1 | 550 | 0.0352 | 0.0394 | −0.98 | C | 1 |
| | | | 126.09 | 73590 | 866700 | 3 | 5 | 98 | 0.0391 | 0.0487 | −0.93 | C | 1 |
| | | | 117.25 | 66580 | 919460 | 1 | 3 | 150 | 0.091 | 0.035 | −1.04 | C | 1 |
| 2. | | $^3P$ - $^1P^\circ$ | | | | | | | | | | | |
| | | | 84.05 | 0 | 1189820 | 5 | 3 | 110 | 0.0067 | 0.0093 | −1.47 | E | 1 |
| | | | 89.59 | 73590 | 1189820 | 3 | 3 | 6.9 | 8.3(−4)[a] | 7.3(−4) | −2.60 | E | 1 |
| | | | 89.03 | 66580 | 1189820 | 1 | 3 | 12 | 0.0044 | 0.0013 | −2.36 | E | 1 |
| 3. | | $^1D$ - $^3P^\circ$ | | | | | | | | | | | |
| | | | 139.65 | 150640 | 866700 | 5 | 5 | 18 | 0.0053 | 0.012 | −1.58 | E | 1 |
| 4. | | $^1D$ - $^1P^\circ$ | 96.23 | 150640 | 1189820 | 5 | 3 | 1400 | 0.117 | 0.185 | −0.233 | C | 1 |
| 5. | | $^1S$ - $^3P^\circ$ | | | | | | | | | | | |
| | | | [159.39] | 292070 | 919460 | 1 | 3 | 6.5 | 0.0074 | 0.0039 | −2.13 | E | 1 |
| 6. | | $^1S$ - $^1P^\circ$ | 111.39 | 292070 | 1189820 | 1 | 3 | 100 | 0.056 | 0.021 | −1.25 | C | 1 |
| 7. | $2s2p^5$–$2p^6$ | $^3P^\circ$ - $^1S$ | | | | | | | | | | | |
| | | | 91.90 | 919460 | 2007550 | 3 | 1 | 83 | 0.0035 | 0.0032 | −1.98 | E | 1 |
| 8. | | $^1P^\circ$ - $^1S$ | 122.29 | 1189820 | 2007550 | 3 | 1 | 1500 | 0.112 | 0.135 | −0.474 | C | 1 |
| 9. | $2p^4$–$2p^3(^4S^\circ)3s$ | $^3P$ - $^3S^\circ$ | *16.609* | *31930* | 6052900 | 9 | 3 | 3.1(+4) | 0.043 | 0.021 | −0.42 | C− | 3 |
| | | | 16.521 | 0 | 6052900 | 5 | 3 | 1.7(+4) | 0.052 | 0.016 | −0.59 | C− | 3 |
| | | | 16.724 | 73590 | 6052900 | 3 | 3 | 6200 | 0.026 | 0.0043 | −1.11 | C− | 3 |
| | | | 16.724 | 66580 | 6052900 | 1 | 3 | 4100 | 0.052 | 0.0029 | −1.28 | C− | 3 |

Mn XVIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | $2p^4$–$2p^3(^2D°)3s$ | $^3P$ – $^3D°$ | | | | | | | | | | | |
| | | | 16.185 | 0 | 6178600 | 5 | 7 | 9500 | 0.052 | 0.014 | −0.59 | C | 3 |
| | | | 16.451 | 73590 | 6152000 | 3 | 5 | 2200 | 0.015 | 0.0024 | −1.35 | D | 3 |
| | | | 16.425 | 66580 | 6154900 | 1 | 3 | 1800 | 0.022 | 0.0012 | −1.6 | D | 3 |
| | | | 16.255 | 0 | 6152000 | 5 | 5 | 8100 | 0.032 | 0.0086 | −0.80 | D | 3 |
| | | | [16.444] | 73590 | 6154900 | 3 | 3 | 9400 | 0.038 | 0.0062 | −0.94 | D | 3 |
| 11. | | $^3P$ – $^1D°$ | | | | | | | | | | | |
| | | | [16.138] | 0 | 6196500 | 5 | 5 | 1200 | 0.0046 | 0.0012 | −1.64 | E | 3 |
| | | | [16.332] | 73590 | 6196500 | 3 | 5 | 2300 | 0.015 | 0.0024 | −1.35 | E | 3 |
| 12. | $2p^4$ – $2p^3(^2D°)3s$ | $^1D$ – $^3D°$ | | | | | | | | | | | |
| | | | [16.589] | 150640 | 6178600 | 5 | 7 | 760 | 0.0044 | 0.0012 | −1.66 | E | 3 |
| | | | [16.663] | 150640 | 6152000 | 5 | 5 | 1100 | 0.0044 | 0.0012 | −1.66 | E | 3 |
| 13. | | $^1D$ – $^1D°$ | 16.540 | 150640 | 619500 | 5 | 5 | 1.9(+4) | 0.078 | 0.021 | −0.41 | D | 3 |
| 14. | $2p^4$ – $2p^3(^2P°)3s$ | $^3P$ – $^3P°$ | | | | | | | | | | | |
| | | | [15.85] | | | 5 | 5 | 1300 | 0.0048 | 0.0013 | −1.62 | D− | 3 |
| | | | [16.17] | | | 3 | 1 | 9200 | 0.012 | 0.0019 | −1.44 | C | 3 |
| | | | [16.03] | | | 3 | 5 | 5600 | 0.036 | 0.0057 | −0.97 | D | 3 |
| | | | [16.13] | | | 1 | 3 | 6200 | 0.072 | 0.0038 | −1.14 | D | 3 |
| 15. | | $^1D$ – $^3P°$ | | | | | | | | | | | |
| | | | [16.23] | | | 5 | 5 | 5600 | 0.022 | 0.0059 | −0.96 | E | 3 |
| | | | [16.36] | | | 5 | 3 | 4200 | 0.010 | 0.0027 | −1.30 | E | 3 |
| 16. | | $^1D$ – $^1P°$ | [16.197] | 150640 | 6324600 | 5 | 3 | 9700 | 0.023 | 0.0061 | −0.94 | D | 3 |
| 17. | $2p^4$ – $2p^3(^2P°)3s$ | $^1S$ – $^1P°$ | 16.577 | 292070 | 6324600 | 1 | 3 | 1.1(+4) | 0.14 | 0.0076 | −0.85 | D | 3 |
| 18. | $2p^4$ – $2p^3(^4S°)3d$ | $^3P$ – $^5D°$ | | | | | | | | | | | |
| | | | [15.34] | | | 5 | 5 | 1700 | 0.0060 | 0.0015 | −1.52 | E | 3 |
| 19. | | $^3P$ – $^3D°$ | | | | | | | | | | | |
| | | | [15.19] | | | 5 | 7 | 5.6(+4) | 0.27 | 0.068 | 0.13 | D | 3 |
| | | | [15.35] | | | 1 | 3 | 3.43(+4) | 0.364 | 0.0184 | −0.439 | C− | 3 |
| | | | [15.36] | | | 3 | 3 | 1.8(+4) | 0.063 | 0.0096 | −0.72 | C− | 3 |
| | | | [15.19] | | | 5 | 3 | 2200 | 0.0046 | 0.0012 | −1.64 | D | 3 |
| 20. | | $^1D$ –$^3D°$ | | | | | | | | | | | |
| | | | [15.54] | | | 5 | 7 | 830 | 0.0042 | 0.0011 | −1.68 | E | 3 |
| 21. | $2p^4$ – $2p^3(^2D°)3d$ | $^3P$ – $^3F°$ | | | | | | | | | | | |
| | | | [15.20] | | | 3 | 5 | 4500 | 0.026 | 0.0039 | −1.11 | E | 3 |
| | | | [15.04] | | | 5 | 5 | 8800 | 0.030 | 0.0074 | −0.82 | E | 3 |
| 22. | | $^3P$ – $^3D°$ | | | | | | | | | | | |
| | | | [14.88] | | | 5 | 7 | 1.6(+5) | 0.75 | 0.18 | 0.57 | D | 3 |
| 23. | | $^3P$ – $^3P°$ | | | | | | | | | | | |
| | | | [15.03] | | | 3 | 1 | 6.7(+4) | 0.076 | 0.011 | −0.64 | D | 3 |

Mn XVIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24. | | $^3$P - $^1$F° | | | | | | | | | | | |
| | | | [14.77] | | | 5 | 7 | 3.9(+4) | 0.18 | 0.044 | −0.05 | E | 3 |
| 25. | $2p^4$ - $2p^3(^2D°)3d$ | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [15.22] | | | 5 | 7 | 2900 | 0.014 | 0.0035 | −1.15 | E | 3 |
| 26. | | $^1$D - $^1$F° | [15.10] | | | 5 | 7 | 8.4(+4) | 0.40 | 0.099 | 0.30 | D | 3 |
| 27. | $2p^4$ - $2p^3(^2P°)3d$ | $^3$P - $^3$F° | | | | | | | | | | | |
| | | | [14.72] | | | 5 | 7 | 4200 | 0.019 | 0.0046 | −1.02 | E | 3 |
| | | | [14.90] | | | 3 | 5 | 7800 | 0.043 | 0.0063 | −0.89 | E | 3 |
| 28. | | $^3$P - $^3$P° | | | | | | | | | | | |
| | | | [14.81] | | | 3 | 1 | 1.2(+5) | 0.13 | 0.019 | −0.41 | D | 3 |
| 29. | | $^3$P - $^1$P° | | | | | | | | | | | |
| | | | [14.59] | | | 3 | 3 | 6000 | 0.019 | 0.0027 | −1.24 | E | 3 |
| 30. | $2p^4$ - $2p^3(^2P°)3d$ | $^1$D - $^3$F° | | | | | | | | | | | |
| | | | [15.06] | | | 5 | 7 | 1.2(+4) | 0.058 | 0.014 | −0.54 | E | 3 |
| | | | [15.07] | | | 5 | 5 | 1.6(+4) | 0.054 | 0.013 | −0.57 | E | 3 |
| 31. | | $^1$D - $^1$P° | [14.76] | | | 5 | 3 | 1.1(+4) | 0.022 | 0.0053 | −0.96 | D | 3 |
| 32. | | $^1$S - $^1$P° | [15.07] | | | 1 | 3 | 2.3(+5) | 2.3 | 0.11 | 0.36 | D | 3 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

## Mn XVIII

### Forbidden Transitions

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^4$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables.

Transition probabilities for these same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these data are in quite good agreement with the data of Cheng *et al.* For this ion of the oxygen isoelectronic sequence, correlation effects due to mixing with configurations outside the complex were found by Froese Fischer and Saha to be rather small, as shown by a comparison of the results of their calculations employing an extensive basis to those derived by the same technique but limited to configurations within the $n=2$ complex.

*A*-values for forbidden transitions within the $2s2p^5$ configuration, and for transitions of the $2s^22p^4$–$2p^6$ array, were calculated by Bhatia[3] using scaled Thomas-Fermi wavefunctions with allowance for configuration interaction and relativistic effects. We utilized his M1 and E2 line strength data, which were communicated to us by Bhatia,[4] and we converted these to $A$-values with wavelengths derived from experimental data. This approach normally yields transition probabilities that are more accurate than those based on calculated wavelengths (which Bhatia published).

The weakest lines are excluded from this compilation, as their transition probabilities are considered to be very uncertain. (This applies to all lines of the $2s^22p^4$–$2p^6$ array.)

## References


[1]K. T. Cheng, Y.-K Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).

[3]A. K. Bhatia, J. Appl. Phys. **53**, 59 (1982).

[4]A. K. Bhatia, private communication (1986).


Mn XVIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^4$–$2p^4$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | [1359] | 0 | 73590 | 5 | 3 | M1 | 8170 | 2.28 | C+ | 1 |
| | | | " | " | " | 5 | 3 | E2 | 0.28 | 0.0023 | E | 1 |
| | | | [14300] | 66580 | 73590 | 1 | 3 | M1 | 4.9 | 1.6 | C | 1 |
| | | | [1502] | 0 | 66580 | 5 | 1 | E2 | 0.31 | 0.0014 | E | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [663.83] | 0 | 150640 | 5 | 5 | M1 | 1.1(+4)[a] | 0.58 | D | 1 |
| | | | " | " | " | 5 | 5 | E2 | 3.6 | 0.0014 | E | 1 |
| | | | [1298] | 73590 | 150640 | 3 | 5 | M1 | 540 | 0.22 | D | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [457.71] | 73590 | 292070 | 3 | 1 | M1 | 9.8(+4) | 0.35 | E | 1 |
| 4. | | $^1$D - $^1$S | [707.06] | 150640 | 292070 | 5 | 1 | E2 | 37 | 0.0039 | D | 1 |
| 5. | $2s2p^5$–$2s2p^5$ | $^3$P° - $^3$P° | | | | | | | | | | |
| | | | [1895] | 866700 | 919460 | 5 | 3 | M1 | 3220 | 2.44 | C | 3,4 |
| | | | [2720] | 919460 | 956220 | 3 | 1 | M1 | 2610 | 1.95 | C | 3,4 |
| | | | [1117] | 866700 | 956220 | 5 | 1 | E2 | 1.2 | 0.0012 | E | 3,4 |
| 6. | | $^3$P° - $^1$P° | | | | | | | | | | |
| | | | [309.48] | 866700 | 1189820 | 5 | 3 | M1 | 1.7(+4) | 0.056 | D− | 3,4 |
| | | | [369.88] | 919460 | 1189820 | 3 | 3 | M1 | 5900 | 0.033 | D− | 3,4 |
| | | | [428.08] | 956220 | 1189820 | 1 | 3 | M1 | 5200 | 0.045 | D− | 3,4 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XIX

N Isoelectronic Sequence

Ground State: $1s^22s^22p^3\ ^4S^\circ_{3/2}$

Ionization Energy: 1437 eV = 11590000 $cm^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 85.41 | 4 | 100.50 | 7 | 119.76 | 11 | 145.07 | 10 |
| 85.568 | 13 | 101.92 | 2 | 120.46 | 6 | 146.57 | 16 |
| 87.051 | 13 | 104.13 | 12 | 122.16 | 6 | 148.48 | 16 |
| 88.08 | 13 | 104.90 | 14 | 123.82 | 15 | 152.94 | 5 |
| 88.75 | 3 | 107.68 | 12 | 127.28 | 1 | 157.74 | 5 |
| 89.26 | 8 | 113.04 | 11 | 130.59 | 1 | 168.85 | 16 |
| 92.71 | 13 | 113.75 | 12 | 130.97 | 16 | 173.24 | 5 |
| 94.454 | 13 | 115.84 | 14 | 135.33 | 10 | 182.97 | 5 |
| 96.24 | 8 | 116.16 | 6 | 139.36 | 15 | 184.00 | 9 |
| 99.01 | 12 | 117.41 | 14 | 141.03 | 1 | 210.99 | 9 |
| 99.17 | 8 | 117.74 | 6 | 142.68 | 10 | 239.65 | 9 |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^3$–$2s2p^4$ and $2s2p^4$–$2p^5$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

### Reference

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

Mn XIX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8\ s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^3$–$2s2p^4$ | $^4S^\circ$ - $^4P$ | *135.00* | 0 | *740730* | 4 | 12 | 140 | 0.12 | 0.21 | −0.33 | C | 1 |
| | | | 141.03 | 0 | 709070 | 4 | 6 | 130 | 0.056 | 0.10 | −0.65 | C | 1 |
| | | | 130.59 | 0 | 765760 | 4 | 4 | 166 | 0.0425 | 0.073 | −0.77 | C | 1 |
| | | | 127.28 | 0 | 785670 | 4 | 2 | 186 | 0.0226 | 0.0379 | −1.044 | C | 1 |
| 2. | | $^4S^\circ$ - $^2D$ | | | | | | | | | | | |
| | | | 101.92 | 0 | 981120 | 4 | 4 | 11 | 0.0017 | 0.0023 | −2.17 | E | 1 |
| 3. | | $^4S^\circ$ - $^2S$ | | | | | | | | | | | |
| | | | 88.75 | 0 | 1126820 | 4 | 2 | 14 | 8.1(−4)[a] | 9.5(−4) | −2.49 | E | 1 |
| 4. | | $^4S^\circ$ - $^2P$ | | | | | | | | | | | |
| | | | 85.41 | 0 | 1170890 | 4 | 4 | 34 | 0.0037 | 0.0042 | −1.83 | E | 1 |

Mn XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5. | | $^2D^\circ - {}^4P$ | | | | | | | | | | | |
| | | | [182.97] | 162520 | 709070 | 6 | 6 | 1.9 | 9.6(−4) | 0.0035 | −2.24 | E | 1 |
| | | | [157.74] | 131820 | 765760 | 4 | 4 | 0.78 | 2.9(−4) | 6.0(−4) | −2.94 | E | 1 |
| | | | [152.94] | 131820 | 785670 | 4 | 2 | 2.1 | 3.7(−4) | 7.5(−4) | −2.83 | E | 1 |
| | | | [173.24] | 131820 | 709070 | 4 | 6 | 4.1 | 0.0028 | 0.0064 | −1.95 | E | 1 |
| 6. | | $^2D^\circ - {}^2D$ | *119.36* | *150240* | *988050* | 10 | 10 | 320 | 0.069 | 0.27 | −0.16 | C− | 1 |
| | | | 120.46 | 162520 | 992670 | 6 | 6 | 300 | 0.065 | 0.15 | −0.41 | C | 1 |
| | | | 117.74 | 131820 | 981120 | 4 | 4 | 380 | 0.079 | 0.12 | −0.50 | C | 1 |
| | | | [122.16] | 162520 | 981120 | 6 | 4 | 1.5 | 2.2(−4) | 5.3(−4) | −2.88 | E | 1 |
| | | | [116.16] | 131820 | 992670 | 4 | 6 | 0.063 | 1.9(−5) | 2.9(−5) | −4.12 | E | 1 |
| 7. | | $^2D^\circ - {}^2S$ | | | | | | | | | | | |
| | | | 100.50 | 131820 | 1126820 | 4 | 2 | 400 | 0.030 | 0.040 | −0.92 | E | 1 |
| 8. | | $^2D^\circ - {}^2P$ | *95.444* | *150240* | *1197970* | 10 | 6 | 890 | 0.073 | 0.23 | −0.14 | C | 1 |
| | | | 99.17 | 162520 | 1170890 | 6 | 4 | 950 | 0.093 | 0.18 | −0.25 | C | 1 |
| | | | 89.26 | 131820 | 1252140 | 4 | 2 | 298 | 0.0178 | 0.0209 | −1.148 | C | 1 |
| | | | 96.24 | 131820 | 1170890 | 4 | 4 | 153 | 0.0212 | 0.0269 | −1.072 | C | 1 |
| 9. | | $^2P^\circ - {}^4P$ | | | | | | | | | | | |
| | | | [239.65] | 291800 | 709070 | 4 | 6 | 0.26 | 3.3(−4) | 0.0010 | −2.88 | E | 1 |
| | | | [210.99] | 291800 | 765760 | 4 | 4 | 1.5 | 9.8(−4) | 0.0027 | −2.41 | E | 1 |
| | | | [184.00] | 242190 | 785670 | 2 | 2 | 1.6 | 8.0(−4) | 9.7(−4) | −2.80 | E | 1 |
| 10. | | $^2P^\circ - {}^2D$ | *140.29* | *275260* | *988050* | 6 | 10 | 49 | 0.024 | 0.067 | −0.84 | C− | 1 |
| | | | 142.68 | 291800 | 992670 | 4 | 6 | 57 | 0.0259 | 0.0487 | −0.98 | C | 1 |
| | | | 135.33 | 242190 | 981120 | 2 | 4 | 29.3 | 0.0161 | 0.0143 | −1.492 | C | 1 |
| | | | [145.07] | 291800 | 981120 | 4 | 4 | 6.7 | 0.0021 | 0.0040 | −2.08 | D | 1 |
| 11. | | $^2P^\circ - {}^2S$ | *117.43* | *275260* | 1126820 | 6 | 2 | 350 | 0.024 | 0.056 | −0.84 | C− | 1 |
| | | | 119.76 | 291800 | 1126820 | 4 | 2 | 41 | 0.0044 | 0.0069 | −1.75 | D | 1 |
| | | | 113.04 | 242190 | 1126820 | 2 | 2 | 340 | 0.066 | 0.049 | −0.88 | C | 1 |
| 12. | | $^2P^\circ - {}^2P$ | *108.38* | *275260* | *1197970* | 6 | 6 | 393 | 0.069 | 0.148 | −0.382 | C− | 1 |
| | | | 113.75 | 291800 | 1170890 | 4 | 4 | 92 | 0.0178 | 0.0267 | −1.148 | C | 1 |
| | | | 99.01 | 242190 | 1252140 | 2 | 2 | 47 | 0.0069 | 0.0045 | −1.86 | D | 1 |
| | | | 104.13 | 291800 | 1252140 | 4 | 2 | 870 | 0.071 | 0.097 | −0.55 | C | 1 |
| | | | 107.68 | 242190 | 1170890 | 2 | 4 | 80 | 0.0278 | 0.0197 | −1.255 | C | 1 |
| 13. | $2s2p^4–2p^5$ | $^4P - {}^2P^\circ$ | | | | | | | | | | | |
| | | | 88.08 | 709070 | 1844390 | 6 | 4 | 23 | 0.0018 | 0.0031 | −1.97 | E | 1 |
| | | | [85.568] | 765760 | 1934420 | 4 | 2 | 1.8 | 1.0(−4) | 1.1(−4) | −3.40 | E | 1 |
| | | | 92.71 | 765760 | 1844390 | 4 | 4 | 11 | 0.0014 | 0.0017 | −2.25 | E | 1 |
| | | | [87.051] | 785670 | 1934420 | 2 | 2 | 7.4 | 8.4(−4) | 4.8(−4) | −2.77 | E | 1 |
| | | | [94.454] | 785670 | 1844390 | 2 | 4 | 3.7 | 9.8(−4) | 6.1(−4) | −2.71 | E | 1 |
| 14. | | $^2D - {}^2P^\circ$ | *112.82* | *988050* | *1874400* | 10 | 6 | 540 | 0.062 | 0.23 | −0.21 | C | 1 |
| | | | 117.41 | 992670 | 1844390 | 6 | 4 | 410 | 0.057 | 0.13 | −0.47 | C | 1 |
| | | | 104.90 | 981120 | 1934420 | 4 | 2 | 444 | 0.0366 | 0.051 | −0.83 | C | 1 |
| | | | 115.84 | 981120 | 1844390 | 4 | 4 | 148 | 0.0298 | 0.0455 | −0.92 | C | 1 |

Mn XIX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | | $^2$S - $^2$P° | *133.76* | 1126820 | *1874400* | 2 | 6 | 65 | 0.052 | 0.0459 | −0.98 | C− | 1 |
| | | | 139.36 | 1126820 | 1844390 | 2 | 4 | 81 | 0.0470 | 0.0431 | −1.027 | C | 1 |
| | | | [123.82] | 1126820 | 1934420 | 2 | 2 | 15 | 0.0034 | 0.0028 | −2.17 | D | 1 |
| 16. | | $^2$P - $^2$P° | *147.83* | *1197970* | *1874400* | 6 | 6 | 390 | 0.13 | 0.37 | −0.12 | C | 1 |
| | | | 148.48 | 1170890 | 1844390 | 4 | 4 | 300 | 0.098 | 0.19 | −0.41 | C | 1 |
| | | | 146.57 | 1252140 | 1934420 | 2 | 2 | 300 | 0.098 | 0.095 | −0.71 | C | 1 |
| | | | 130.97 | 1170890 | 1934420 | 4 | 2 | 314 | 0.0404 | 0.070 | −0.79 | C | 1 |
| | | | [168.85] | 1252140 | 1844390 | 2 | 4 | 19.3 | 0.0165 | 0.0183 | −1.481 | C | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XIX

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 205.60 | 9 | 440.70 | 7 | 758.61 | 1 | 1764 | 6 |
| 216.53 | 9 | 464.34 | 7 | 773.51 | 4 | 2015 | 5 |
| 276.96 | 8 | 511.64 | 7 | 797.96 | 13 | 2268 | 13 |
| 342.70 | 2 | 526.95 | 12 | 906.04 | 4 | 3256 | 3 |
| 352.61 | 7 | 561.10 | 12 | 1111 | 15 | 5021 | 6 |
| 368.98 | 12 | 615.31 | 1 | 1231 | 14 | 8656 | 10 |
| 385.40 | 12 | 625.08 | 4 | 1255 | 4 | | |
| 412.90 | 2 | 745.43 | 11 | 1305 | 6 | | |

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^3$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. The weakest lines are excluded from this compilation, as their strengths are considered to be very uncertain.

$A$-values for forbidden transitions within the $2s2p^4$ configuration, for transitions of the $2s^22p^3$–$2p^5$ array, and for the M1 component of the single transition within the $2p^5$ configuration were calculated by Bhatia[2] using scaled Thomas-Fermi wavefunctions with allowance for configuration interaction and relativistic effects. We utilized his M1 and E2 line-strength data, which were communicated to us by Bhatia,[3] and we converted these to $A$-values with wavelengths derived from experimental data. This approach normally yields transition probabilities that are more accurate than those based on calculated wavelengths (as published in Ref. 2). The weakest lines are excluded from the compilation. (This applies to all lines of the $2s^22p^3$–$2p^5$ array.)

The $A$-value quoted here for the E2 component of the transition within the $2p^5$ configuration was obtained by applying a $Z$-expansion formula published by Oboladze and Safronova.[4] Their value for the magnetic dipole contribution to this line is in very good agreement with the result of Ref. 2. It is not clear whether Oboladze and Safronova incorporated configuration interaction into their calculations. Thus, the $A$-value of the E2 contribution should be considered rather uncertain.

## References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]A. K. Bhatia, J. Appl. Phys. **53**, 59 (1982).

[3]A. K. Bhatia, private communication (1986).

[4]N. S. Oboladze and U. I. Safronova, Opt. Spectrosc. (USSR) **48**, 469 (1980).


Mn XIX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^3$–$2p^3$ | $^4S°$ – $^2D°$ | | | | | | | | | | |
| | | | [615.31] | 0 | 162520 | 4 | 6 | M1 | 660 | 0.034 | D | 1 |
| | | | [758.61] | 0 | 131820 | 4 | 4 | M1 | 1.0(+4)[a] | 0.66 | D | 1 |
| 2. | | $^4S°$ – $^2P°$ | | | | | | | | | | |
| | | | [342.70] | 0 | 291800 | 4 | 4 | M1 | 2.2(+4) | 0.13 | D | 1 |
| | | | [412.90] | 0 | 242190 | 4 | 2 | M1 | 2.1(+4) | 0.11 | D | 1 |
| 3. | | $^2D°$ – $^2D°$ | | | | | | | | | | |
| | | | [3256] | 131820 | 162520 | 4 | 6 | M1 | 236 | 1.81 | C | 1 |
| | | | " | " | " | 4 | 6 | E2 | 0.0012 | 0.0016 | D− | 1 |
| 4. | | $^2D°$ – $^2P°$ | | | | | | | | | | |
| | | | [1255] | 162520 | 242190 | 6 | 2 | E2 | 0.67 | 0.0025 | E | 1 |
| | | | [773.51] | 162520 | 291800 | 6 | 4 | M1 | 8200 | 0.56 | D | 1 |
| | | | " | " | " | 6 | 4 | E2 | 9.6 | 0.0063 | E | 1 |
| | | | [906.04] | 131820 | 242190 | 4 | 2 | M1 | 4500 | 0.25 | D | 1 |
| | | | " | " | " | 4 | 2 | E2 | 4.0 | 0.0029 | E | 1 |
| | | | [625.08] | 131820 | 291800 | 4 | 4 | M1 | 2.7(+4) | 0.96 | D | 1 |
| | | | " | " | " | 4 | 4 | E2 | 4.4 | 0.0010 | E | 1 |
| 5. | | $^2P°$ – $^2P°$ | | | | | | | | | | |
| | | | [2015] | 242190 | 291800 | 2 | 4 | M1 | 800 | 0.97 | C | 1 |
| 6. | $2s2p^4$–$2s2p^4$ | $^4P$ – $^4P$ | | | | | | | | | | |
| | | | [1764] | 709070 | 765760 | 6 | 4 | M1 | 4360 | 3.55 | C | 2,3 |
| | | | [5021] | 765760 | 785670 | 4 | 2 | M1 | 339 | 3.18 | C | 2,3 |
| | | | [1305] | 709070 | 785670 | 6 | 2 | E2 | 0.47 | 0.0021 | E | 2,3 |
| 7. | | $^4P$ – $^2D$ | | | | | | | | | | |
| | | | [352.61] | 709070 | 992670 | 6 | 6 | M1 | 1.8(+4) | 0.18 | D | 2,3 |
| | | | [464.34] | 765760 | 981120 | 4 | 4 | M1 | 7400 | 0.11 | D | 2,3 |
| | | | [440.70] | 765760 | 992670 | 4 | 6 | M1 | 1200 | 0.022 | D− | 2,3 |
| | | | [511.64] | 785670 | 981120 | 2 | 4 | M1 | 1500 | 0.030 | D− | 2,3 |
| 8. | | $^4P$ – $^2S$ | | | | | | | | | | |
| | | | [276.96] | 765760 | 1126820 | 4 | 2 | M1 | 7.0(+4) | 0.11 | D | 2,3 |
| 9. | | $^4P$ – $^2P$ | | | | | | | | | | |
| | | | [216.53] | 709070 | 1170890 | 6 | 4 | M1 | 1.1(+4) | 0.017 | D− | 2,3 |
| | | | [205.60] | 765760 | 1252140 | 4 | 2 | M1 | 1.7(+4) | 0.011 | D− | 2,3 |
| 10. | | $^2D$ – $^2D$ | | | | | | | | | | |
| | | | [8656] | 981120 | 992670 | 4 | 6 | M1 | 16 | 2.3 | D | 2,3 |

Mn XIX: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11. | | $^2$D - $^2$S | | | | | | | | | | |
| | | | [745.43] | 992670 | 1126820 | 6 | 2 | E2 | 15 | 0.0041 | E | 2,3 |
| 12. | | $^2$D - $^2$P | | | | | | | | | | |
| | | | [385.40] | 992670 | 1252140 | 6 | 2 | E2 | 99 | 0.0010 | E | 2,3 |
| | | | [561.10] | 992670 | 1170890 | 6 | 4 | M1 | 3300 | 0.086 | D− | 2,3 |
| | | | [368.98] | 981120 | 1252140 | 4 | 2 | M1 | 1.3(+4) | 0.048 | D− | 2,3 |
| | | | [526.95] | 981120 | 1170890 | 4 | 4 | M1 | 7800 | 0.17 | D | 2,3 |
| 13. | | $^2$S - $^2$P | | | | | | | | | | |
| | | | [2268] | 1126820 | 1170890 | 2 | 4 | M1 | 140 | 0.24 | D | 2,3 |
| | | | [797.96] | 1126820 | 1252140 | 2 | 2 | M1 | 1.2(+4) | 0.44 | D | 2,3 |
| 14. | | $^2$P - $^2$P | | | | | | | | | | |
| | | | [1231] | 1170890 | 1252140 | 4 | 2 | M1 | 7200 | 1.0 | C | 2,3 |
| 15. | $2p^5$-$2p^5$ | $^2$P° - $^2$P° | | | | | | | | | | |
| | | | [1111] | 1844390 | 1934420 | 4 | 2 | M1 | 1.31(+4) | 1.33 | C | 2,3 |
| | | | " | " | " | 4 | 2 | E2 | 1.1 | 0.0022 | E | 4 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XX

C Isoelectronic Sequence

Ground State: $1s^2 2s^2 2p^2\ {}^3P_0$

Ionization Energy: 1539 eV = 12410000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 13.42 | 30 | 111.00 | 17 | 129.55 | 3 | 167.12 | 22 |
| 13.48 | 29 | 111.01 | 17 | 130.38 | 19 | 167.19 | 22 |
| 13.49 | 30 | 111.04 | 17 | 130.42 | 19 | 173.97 | 24 |
| 13.51 | 29 | 112.68 | 23 | 131.88 | 3 | 188.44 | 7 |
| 84.770 | 16 | 116.70 | 3 | 132.79 | 19 | 190.23 | 27 |
| 89.85 | 6 | 118.85 | 20 | 135.06 | 28 | 190.91 | 13 |
| 90.76 | 16 | 119.12 | 15 | 138.30 | 2 | 192.20 | 22 |
| 93.114 | 6 | 119.54 | 10 | 144.42 | 14 | 195.77 | 7 |
| 94.689 | 21 | 120.82 | 20 | 145.16 | 19 | 195.91 | 7 |
| 97.51 | 4 | 121.49 | 17 | 148.10 | 19 | 201.22 | 24 |
| 101.09 | 5 | 121.55 | 17 | 150.71 | 2 | 221.70 | 26 |
| 102.50 | 18 | 122.96 | 9 | 150.80 | 2 | 256.42 | 12 |
| 103.53 | 4 | 123.30 | 3 | 151.91 | 8 | 260.14 | 1 |
| 104.13 | 11 | 124.56 | 17 | 153.98 | 25 | 267.95 | 26 |
| 104.67 | 18 | 125.42 | 3 | 155.13 | 8 | 289.57 | 1 |
| 105.24 | 5 | 126.46 | 3 | 155.21 | 2 | | |
| 107.89 | 4 | 129.31 | 19 | 160.14 | 2 | | |

The tabulated oscillator strengths for transitions of the arrays $2s^22p^2$–$2s2p^3$ and $2s2p^3$–$2p^4$ are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. The results should be quite accurate, except in the case of weak lines. (A few very weak lines have been omitted from this tabulation.)

Transition probabilities for lines of the $2s^22p^2$–$2s2p^3$ array were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these two sources are in reasonably good agreement, particularly for the stronger transitions.

Data for a few lines of the $2p^2$–$2p3d$ array were interpolated from the HX (Hartree-Fock with statistical allowance for exchange) *f*-values of Bromage and Fawcett[3] for the isoelectronic ions Ca XV and Fe XXI.

## References


[1] K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2] C. Froese Fischer and H. P. Saha, Phys. Scr. **32**, 181 (1985).

[3] G. E. Bromage and B. C. Fawcett, Mon. Not. R. Astron. Soc. **178**, 605 (1977).


Mn XX: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^22p^2$–$2s2p^3$ | $^3$P - $^5$S° | | | | | | | | | | | |
| | | | [289.57] | 98630 | 443970 | 5 | 5 | 0.25 | 3.1(−4)[a] | 0.0015 | −2.81 | E | 1 |
| | | | [260.14] | 59560 | 443970 | 3 | 5 | 0.24 | 4.0(−4) | 0.0010 | −2.92 | E | 1 |
| 2. | | $^3$P - $^3$D° | | | | | | | | | | | |
| | | | 155.21 | 98630 | 742930 | 5 | 7 | 62 | 0.0316 | 0.081 | −0.80 | C | 1 |
| | | | 150.80 | 59560 | 722690 | 3 | 5 | 92 | 0.052 | 0.077 | −0.81 | C | 1 |
| | | | 138.30 | 0 | 723070 | 1 | 3 | 110 | 0.091 | 0.041 | −1.04 | C | 1 |
| | | | 150.71 | 59560 | 723070 | 3 | 3 | 9.4 | 0.0032 | 0.0048 | −2.02 | D | 1 |
| | | | [160.14] | 98630 | 723070 | 5 | 3 | 0.42 | 9.6(−5) | 2.5(−4) | −3.32 | E | 1 |
| 3. | | $^3$P - $^3$P° | *126.73* | *74650* | *863760* | 9 | 9 | 211 | 0.051 | 0.191 | −0.339 | C− | 1 |
| | | | 129.55 | 98630 | 870560 | 5 | 5 | 192 | 0.0483 | 0.103 | −0.62 | C | 1 |
| | | | 125.42 | 59560 | 856900 | 3 | 3 | 144 | 0.0339 | 0.0420 | −0.99 | C | 1 |
| | | | [131.88] | 98630 | 856900 | 5 | 3 | 34 | 0.0053 | 0.012 | −1.58 | D | 1 |
| | | | 126.46 | 59560 | 850320 | 3 | 1 | 219 | 0.0175 | 0.0219 | −1.280 | C | 1 |
| | | | 123.30 | 59560 | 870560 | 3 | 5 | 5.3 | 0.0020 | 0.0024 | −2.22 | D | 1 |
| | | | 116.70 | 0 | 856900 | 1 | 3 | 41.6 | 0.0255 | 0.0098 | −1.59 | C | 1 |
| 4. | | $^3$P - $^3$S° | *105.17* | *74650* | 1025500 | 9 | 3 | 930 | 0.051 | 0.16 | −0.34 | C | 1 |
| | | | 107.89 | 98630 | 1025500 | 5 | 3 | 590 | 0.062 | 0.11 | −0.51 | C | 1 |
| | | | 103.53 | 59560 | 1025500 | 3 | 3 | 255 | 0.0410 | 0.0419 | −0.91 | C | 1 |
| | | | 97.51 | 0 | 1025500 | 1 | 3 | 94 | 0.0403 | 0.0129 | −1.395 | C | 1 |
| 5. | | $^3$P - $^1$D° | | | | | | | | | | | |
| | | | 105.24 | 98630 | 1048820 | 5 | 5 | 72 | 0.012 | 0.021 | −1.22 | E | 1 |
| | | | [101.09] | 59560 | 1048820 | 3 | 5 | 3.3 | 8.3(−4) | 8.3(−4) | −2.60 | E | 1 |
| 6. | | $^3$P - $^1$P° | | | | | | | | | | | |
| | | | [93.114] | 98630 | 1172580 | 5 | 3 | 1.4 | 1.1(−4) | 1.7(−4) | −3.26 | E | 1 |
| | | | 89.85 | 59560 | 1172580 | 3 | 3 | 44 | 0.0053 | 0.0047 | −1.80 | E | 1 |
| 7. | | $^1$D - $^3$D° | | | | | | | | | | | |
| | | | [188.44] | 212260 | 742930 | 5 | 7 | 8.2 | 0.0061 | 0.019 | −1.52 | E | 1 |
| | | | [195.91] | 212260 | 722690 | 5 | 5 | 0.36 | 2.1(−4) | 6.8(−4) | −2.98 | E | 1 |
| | | | [195.77] | 212260 | 723070 | 5 | 3 | 1.6 | 5.6(−4) | 0.0018 | −2.55 | E | 1 |

Mn XX: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^1D - ^3P°$ | | | | | | | | | | | |
| | | | [151.91] | 212260 | 870560 | 5 | 5 | 2.3 | 7.9(−4) | 0.0020 | −2.40 | E | 1 |
| | | | [155.13] | 212260 | 856900 | 5 | 3 | 3.0 | 6.4(−4) | 0.0016 | −2.49 | E | 1 |
| 9. | | $^1D - ^3S°$ | [122.96] | 212260 | 1025500 | 5 | 3 | 1.6 | 2.2(−4) | 4.5(−4) | −2.96 | E | 1 |
| 10. | | $^1D - ^1D°$ | 119.54 | 212260 | 1048820 | 5 | 5 | 460 | 0.098 | 0.19 | −0.31 | C | 1 |
| 11. | | $^1D - ^1P°$ | 104.13 | 212260 | 1172580 | 5 | 3 | 660 | 0.064 | 0.11 | −0.49 | C | 1 |
| 12. | | $^1S - ^3D°$ | | | | | | | | | | | |
| | | | [256.42] | 333090 | 723070 | 1 | 3 | 0.44 | 0.0013 | 0.0011 | −2.89 | E | 1 |
| 13. | | $^1S - ^3P°$ | | | | | | | | | | | |
| | | | [190.91] | 333090 | 856900 | 1 | 3 | 1.3 | 0.0022 | 0.0014 | −2.66 | E | 1 |
| 14. | | $^1S - ^3S°$ | [144.42] | 333090 | 1025500 | 1 | 3 | 5.4 | 0.0051 | 0.0024 | −2.29 | E | 1 |
| 15. | | $^1S - ^1P°$ | 119.12 | 333090 | 1172580 | 1 | 3 | 169 | 0.108 | 0.0424 | −0.97 | C | 1 |
| 16. | $2s2p^3–2p^4$ | $^5S° - ^3P$ | | | | | | | | | | | |
| | | | 90.76 | 443970 | 1545780 | 5 | 5 | 11 | 0.0013 | 0.0019 | −2.19 | E | 1 |
| | | | [84.770] | 443970 | 1623630 | 5 | 3 | 2.3 | 1.5(−4) | 2.1(−4) | −3.12 | E | 1 |
| 17. | | $^3D° - ^3P$ | *117.90* | *732210* | *1580410* | 15 | 9 | 427 | 0.053 | 0.311 | −0.096 | C | 1 |
| | | | 124.56 | 742930 | 1545780 | 7 | 5 | 298 | 0.0495 | 0.142 | −0.460 | C | 1 |
| | | | 111.00 | 722690 | 1623630 | 5 | 3 | 217 | 0.0241 | 0.0440 | −0.92 | C | 1 |
| | | | 111.01 | 723070 | 1623890 | 3 | 1 | 349 | 0.0215 | 0.0236 | −1.190 | C | 1 |
| | | | 121.49 | 722690 | 1545780 | 5 | 5 | 133 | 0.0294 | 0.059 | −0.83 | C | 1 |
| | | | 111.04 | 723070 | 1623630 | 3 | 3 | 146 | 0.0269 | 0.0295 | −1.093 | C | 1 |
| | | | 121.55 | 723070 | 1545780 | 3 | 5 | 29.8 | 0.0110 | 0.0132 | −1.481 | C | 1 |
| 18. | | $^3D° - ^1D$ | | | | | | | | | | | |
| | | | 104.67 | 742930 | 1698270 | 7 | 5 | 48 | 0.0056 | 0.014 | −1.41 | E | 1 |
| | | | [102.50] | 722690 | 1698270 | 5 | 5 | 6.3 | 0.0010 | 0.0017 | −2.30 | E | 1 |
| 19. | | $^3P° - ^3P$ | *139.54* | *863760* | *1580410* | 9 | 9 | 121 | 0.0353 | 0.146 | −0.498 | C− | 1 |
| | | | 148.10 | 870560 | 1545780 | 5 | 5 | 35.9 | 0.0118 | 0.0288 | −1.229 | C | 1 |
| | | | [130.42] | 856900 | 1623630 | 3 | 3 | 0.26 | 6.6(−5) | 8.5(−5) | −3.70 | E | 1 |
| | | | 132.79 | 870560 | 1623630 | 5 | 3 | 158 | 0.0250 | 0.055 | −0.90 | C | 1 |
| | | | 130.38 | 856900 | 1623890 | 3 | 1 | 191 | 0.0162 | 0.0209 | −1.313 | C | 1 |
| | | | 145.16 | 856900 | 1545780 | 3 | 5 | 35.5 | 0.0187 | 0.0268 | −1.251 | C | 1 |
| | | | 129.31 | 850320 | 1623630 | 1 | 3 | 46.3 | 0.0348 | 0.0148 | −1.458 | C | 1 |
| 20. | | $^3P° - ^1D$ | | | | | | | | | | | |
| | | | 120.82 | 870560 | 1698270 | 5 | 5 | 16 | 0.0035 | 0.0070 | −1.76 | E | 1 |
| | | | [118.85] | 856900 | 1698270 | 3 | 5 | 9.6 | 0.0034 | 0.0040 | −1.99 | E | 1 |
| 21. | | $^3P° - ^1S$ | | | | | | | | | | | |
| | | | [94.689] | 856900 | 1912990 | 3 | 1 | 33 | 0.0015 | 0.0014 | −2.35 | E | 1 |

Mn xx: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8 s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22. | | $^3S° - ^3P$ | *180.21* | 1025500 | *1580410* | 3 | 9 | 92 | 0.13 | 0.24 | −0.39 | C | 1 |
| | | | 192.20 | 1025500 | 1545780 | 3 | 5 | 65 | 0.060 | 0.11 | −0.74 | C | 1 |
| | | | 167.19 | 1025500 | 1623630 | 3 | 3 | 130 | 0.053 | 0.088 | −0.80 | C | 1 |
| | | | 167.12 | 1025500 | 1623890 | 3 | 1 | 167 | 0.0233 | 0.0385 | −1.156 | C | 1 |
| 23. | | $^3S° - ^1S$ | [112.68] | 1025500 | 1912990 | 3 | 1 | 52 | 0.0033 | 0.0037 | −2.00 | E | 1 |
| 24. | | $^1D° - ^3P$ | | | | | | | | | | | |
| | | | [201.22] | 1048820 | 1545780 | 5 | 5 | 7.4 | 0.0045 | 0.015 | −1.65 | E | 1 |
| | | | [173.97] | 1048820 | 1623630 | 5 | 3 | 2.3 | 6.2(−4) | 0.0018 | −2.51 | E | 1 |
| 25. | | $^1D° - ^1D$ | 153.98 | 1048820 | 1698270 | 5 | 5 | 335 | 0.119 | 0.302 | −0.225 | C | 1 |
| 26. | | $^1P° - ^3P$ | | | | | | | | | | | |
| | | | [267.95] | 1172580 | 1545780 | 3 | 5 | 1.0 | 0.0018 | 0.0048 | −2.27 | E | 1 |
| | | | [221.70] | 1172580 | 1623630 | 3 | 3 | 6.0 | 0.0044 | 0.0096 | −1.88 | E | 1 |
| 27. | | $^1P° - ^1D$ | 190.23 | 1172580 | 1698270 | 3 | 5 | 45.6 | 0.0412 | 0.077 | −0.91 | C | 1 |
| 28. | | $^1P° - ^1S$ | 135.06 | 1172580 | 1912990 | 3 | 1 | 780 | 0.071 | 0.095 | −0.67 | C | 1 |
| 29. | $2p^2$–$2p3d$ | $^3P - ^3D°$ | | | | | | | | | | | |
| | | | [13.51] | | | 5 | 7 | 1.6(+5) | 0.60 | 0.13 | 0.48 | E | *interp.* |
| | | | [13.48] | | | 1 | 3 | 1.6(+5) | 1.3 | 0.058 | 0.11 | D | *interp.* |
| 30. | | $^3P - ^3P°$ | | | | | | | | | | | |
| | | | [13.42] | | | 3 | 3 | 8.9(+4) | 0.24 | 0.032 | −0.14 | E | *interp.* |
| | | | [13.49] | | | 5 | 3 | 4.0(+4) | 0.066 | 0.015 | −0.48 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn xx

## Forbidden Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 222.28 | 11 | 358.29 | 5 | 655.78 | 18 | 1014 | 1 |
| 222.46 | 11 | 358.78 | 5 | 676.27 | 8 | 1280 | 17 |
| 234.42 | 6 | 365.59 | 3 | 678.01 | 8 | 1285 | 17 |
| 242.17 | 6 | 465.72 | 20 | 679.90 | 16 | 1340 | 18 |
| 306.63 | 10 | 521.05 | 14 | 747.22 | 8 | 1679 | 1 |
| 316.78 | 15 | 560.98 | 14 | 783.51 | 8 | 2559 | 1 |
| 330.24 | 9 | 570.84 | 13 | 785.85 | 8 | 4939 | 7 |
| 330.66 | 9 | 593.12 | 13 | 827.61 | 4 | 7319 | 12 |
| 331.10 | 15 | 645.41 | 13 | 877.42 | 8 | 15200 | 12 |
| 345.59 | 19 | 654.88 | 2 | 880.05 | 2 | | |

Line strengths tabulated for magnetic dipole and electric quadrupole transitions within the $2p^2$ configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations included a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing was limited to the $n=2$ complex. Strengths of electric quadrupole transitions as defined in Ref. 1 were multiplied by the factor 2/3 which is needed to bring these values into conformance with the definition of quadrupole strengths used in the NBS tables. The weakest lines are excluded from this compilation, as their strengths are considered to be very uncertain.

Transition probabilities for these same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their basis included many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. Line strengths derived from these data are in good agreement with the data of Cheng *et al.*

*A*-values for forbidden transitions within the $2s2p^3$ and $2p^4$ configurations, and for transitions of the $2s^22p^2$–$2p^4$ array, were calculated by Bhatia[3] using scaled Thomas-Fermi wavefunctions with allowance for configuration interaction and relativistic effects. We utilized his M1 and E2 line-strength data, which were communicated to us by Bhatia,[4] and we converted these to *A*-values with wavelengths derived from experimental data. This approach normally yields transition probabilities that are more accurate than those based calculated wavelengths. The weakest lines are excluded from the compilation. (This applies to all lines of the $2s^22p^2$–$2p^4$ array.)

## References


[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Scr. **32**, 181 (1985).

[3]A. K. Bhatia J. Appl. Phys. **53**, 59 (1982)

[4]A. K. Bhatia, private communication (1986).


Mn XX: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p^2$–$2p^2$ | $^3$P - $^3$P | | | | | | | | | | |
| | | | [2559] | 59560 | 98630 | 3 | 5 | M1 | 640 | 2.0 | C+ | 1 |
| | | | " | " | " | 3 | 5 | E2 | 0.0052 | 0.0017 | E | 1 |
| | | | [1679] | 0 | 59560 | 1 | 3 | M1 | 3460 | 1.82 | C+ | 1 |
| | | | [1014] | 0 | 98630 | 1 | 5 | E2 | 0.38 | 0.0012 | E | 1 |
| 2. | | $^3$P - $^1$D | | | | | | | | | | |
| | | | [880.05] | 98630 | 212260 | 5 | 5 | M1 | 9500 | 1.2 | D | 1 |
| | | | " | " | " | 5 | 5 | E2 | 1.5 | 0.0024 | E | 1 |
| | | | [654.88] | 59560 | 212260 | 3 | 5 | M1 | 9600 | 0.50 | D | 1 |
| 3. | | $^3$P - $^1$S | | | | | | | | | | |
| | | | [365.59] | 59560 | 333090 | 3 | 1 | M1 | 9.4(+4)[a] | 0.17 | D | 1 |
| 4. | | $^1$D - $^1$S | [827.61] | 212260 | 333090 | 5 | 1 | E2 | 14 | 0.0033 | E | 1 |
| 5. | $2s2p^3$–$2s2p^3$ | $^5$S° - $^3$D° | | | | | | | | | | |
| | | | [358.78] | 443970 | 722690 | 5 | 5 | M1 | 9500 | 0.081 | E | 3,4 |
| | | | [358.29] | 443970 | 723070 | 5 | 3 | M1 | 3700 | 0.019 | E | 3,4 |
| 6. | | $^5$S° - $^3$P° | | | | | | | | | | |
| | | | [234.42] | 443970 | 870560 | 5 | 5 | M1 | 5.0(+4) | 0.12 | D | 3,4 |
| | | | 242.17 | 443970 | 856900 | 5 | 3 | M1 | 2.8(+4) | 0.044 | D− | 3,4 |
| 7. | | $^3$D° - $^3$D° | | | | | | | | | | |
| | | | [4939] | 722690 | 742930 | 5 | 7 | M1 | 120 | 3.9 | D | 3,4 |

Mn xx: Forbidden transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8. | | $^3D° - ^3P°$ | | | | | | | | | | |
| | | | [877.42] | 742930 | 856900 | 7 | 3 | E2 | 4.0 | 0.0037 | E | 3,4 |
| | | | [783.51] | 722690 | 850320 | 5 | 1 | E2 | 15 | 0.0026 | E | 3,4 |
| | | | [783.51] | 742930 | 870560 | 7 | 5 | M1 | 8100 | 0.72 | D | 3,4 |
| | | | [785.85] | 723070 | 850320 | 3 | 1 | M1 | 1.2(+4) | 0.21 | D | 3,4 |
| | | | [676.27] | 722690 | 870560 | 5 | 5 | M1 | 7500 | 0.43 | D | 3,4 |
| | | | [747.22] | 723070 | 856900 | 3 | 3 | M1 | 1.3(+4) | 0.60 | D | 3,4 |
| | | | [678.01] | 723070 | 870560 | 3 | 5 | M1 | 1700 | 0.10 | D− | 3,4 |
| 9. | | $^3D° - ^3S°$ | | | | | | | | | | |
| | | | [330.24] | 722690 | 1025500 | 5 | 3 | M1 | 1.0(+4) | 0.042 | E | 3,4 |
| | | | [330.66] | 723070 | 1025500 | 3 | 3 | M1 | 3700 | 0.015 | E | 3,4 |
| 10. | | $^3D° - ^1D°$ | | | | | | | | | | |
| | | | [306.63] | 722690 | 1048820 | 5 | 5 | M1 | 8600 | 0.046 | D− | 3,4 |
| 11. | | $^3D° - ^1P°$ | | | | | | | | | | |
| | | | [222.28] | 722690 | 1172580 | 5 | 3 | M1 | 3.8(+4) | 0.046 | D− | 3,4 |
| | | | [222.46] | 723070 | 1172580 | 3 | 3 | M1 | 1.1(+4) | 0.013 | D− | 3,4 |
| 12. | | $^3P° - ^3P°$ | | | | | | | | | | |
| | | | [7319] | 856900 | 870560 | 3 | 5 | M1 | 34 | 2.5 | D | 3,4 |
| | | | [15200] | 850320 | 856900 | 1 | 3 | M1 | 4.4 | 1.7 | D | 3,4 |
| 13. | | $^3P° - ^3S°$ | | | | | | | | | | |
| | | | [645.41] | 870560 | 1025500 | 5 | 3 | M1 | 1200 | 0.036 | D− | 3,4 |
| | | | [593.12] | 856900 | 1025500 | 3 | 3 | M1 | 1100 | 0.026 | D− | 3,4 |
| | | | [570.84] | 850320 | 1025500 | 1 | 3 | M1 | 2700 | 0.056 | D− | 3,4 |
| 14. | | $^3P° - ^1D°$ | | | | | | | | | | |
| | | | [560.98] | 870560 | 1048820 | 5 | 5 | M1 | 1.0(+4) | 0.33 | D | 3,4 |
| | | | [521.05] | 856900 | 1048820 | 3 | 5 | M1 | 5000 | 0.13 | D | 3,4 |
| 15. | | $^3P° - ^1P°$ | | | | | | | | | | |
| | | | [331.10] | 870560 | 1172580 | 5 | 3 | M1 | 8700 | 0.035 | D− | 3,4 |
| | | | [316.78] | 856900 | 1172580 | 3 | 3 | M1 | 5700 | 0.020 | D− | 3,4 |
| 16. | | $^3S° - ^1P°$ | [679.90] | 1025500 | 1172580 | 3 | 3 | M1 | 2.1(+4) | 0.75 | D | 3,4 |
| 17. | $2p^4$–$2p^4$ | $^3P - ^3P$ | | | | | | | | | | |
| | | | [1285] | 1545780 | 1623630 | 5 | 3 | M1 | 9700 | 2.3 | C | 3,4 |
| | | | [1280] | 1545780 | 1623890 | 5 | 1 | E2 | 0.59 | 0.0012 | E | 3,4 |
| 18. | | $^3P - ^1D$ | | | | | | | | | | |
| | | | [655.78] | 1545780 | 1698270 | 5 | 5 | M1 | 1.1(+4) | 0.58 | D | 3,4 |
| | | | [1340] | 1623630 | 1698270 | 3 | 5 | M1 | 470 | 0.21 | D | 3,4 |
| 19. | | $^3P - ^1S$ | | | | | | | | | | |
| | | | [345.59] | 1623630 | 1912990 | 3 | 1 | M1 | 1.4(+5) | 0.21 | D | 3,4 |

Mn XXI: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. | | $^2P - ^2P^o$ | | | | | | | | | | | |
| | | | 168.72 | 924710 | 1517410 | 4 | 4 | 180 | 0.075 | 0.17 | −0.52 | C | 1 |
| | | | 182.48 | 924710 | 1472710 | 4 | 2 | 23 | 0.0057 | 0.014 | −1.64 | D | 1 |
| 13. | $2p-3s$ | $^2P^o - ^2S$ | | | | | | | | | | | |
| | | | | | | 4 | 2 | | 0.019 | | −1.12 | E | *interp.* |
| | | | | | | 2 | 2 | | 0.019 | | −1.42 | E | *interp.* |
| 14. | $2p-3d$ | $^2P^o - ^2D$ | | | | | | | | | | | |
| | | | [13.02] | | | 4 | 6 | 1.5(+5) | 0.58 | 0.099 | 0.37 | D | *interp.* |
| | | | [12.89] | | | 2 | 4 | 1.3(+5) | 0.66 | 0.056 | 0.12 | D | *interp.* |
| | | | | | | 4 | 4 | | 0.064 | | −0.59 | D | *interp.* |
| 15. | $2p-4d$ | $^2P^o - ^2D$ | | | | | | | | | | | |
| | | | | | | 4 | 6 | | 0.11 | | −0.36 | D | *interp.* |
| | | | | | | 2 | 4 | | 0.12 | | −0.62 | E | *interp.* |
| | | | | | | 4 | 4 | | 0.012 | | −1.32 | D | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XXI

## Forbidden Transitions

The line strengths tabulated for the single magnetic dipole and single electric quadrupole transition within the $2s^22p$ ground state configuration are the results of the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include a perturbative treatment of the Breit interaction and the Lamb shift. Allowance for configuration mixing is limited to the $n=2$ complex. The strength of the electric quadrupole transition as defined in Ref. 1 was multiplied by the factor $^2/_3$ in order to bring this value into conformance with the definition of the quadrupole strength used in the NBS tables.

Transition probabilities for the same lines were calculated by Froese Fischer and Saha[2] using the multiconfiguration Hartree-Fock (MCHF) method with Breit-Pauli corrections. Their orbital basis includes many configurations outside the $n=2$ complex, but relativistic effects were not treated to the same degree as in Ref. 1. The line strengths for both the M1 and E2 transitions, derived from these data by interpolation between appropriately spaced ions of the B sequence, are in very good agreement with the data of Cheng *et al.*[1]

*A*-values for forbidden transitions within the $2s2p^2$ and $2p^3$ configurations, and for transitions of the $2s^22p-2p^3$ array, were calculated by Bhatia *et al.*[3] using scaled Thomas-Fermi wavefunctions with allowance for configuration interaction and relativistic effects. We utilized their M1 and E2 line strength data, which were communicated to us by Bhatia,[4] and converted these to *A*-values with wavelengths derived from experimental data. This approach should normally yield transition probabilities that are more accurate than those based on their theoretically determined wavelengths. The weakest lines determined by Bhatia *et al.*—for example, all lines of the $2s^22p-2p^3$ array—were excluded from this compilation.

### References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[2]C. Froese Fischer and H. P. Saha, Phys. Rev. A **28**, 3169 (1983).

[3]A. K. Bhatia, U. Feldman, and G. H. Doschek, J. Appl. Phys. **51**, 1464 (1980).

[4]A. K. Bhatia, private communication (1986).

Mn XXI: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p$–$2p$ | $^2P^\circ$ – $^2P^\circ$ | | | | | | | | | | |
| | | | [1006.4] | 0 | 99360 | 2 | 4 | M1 | 8800 | 1.33 | B | 1 |
| | | | " | " | " | 2 | 4 | E2 | 0.69 | 0.00170 | C | 1 |
| 2. | $2s2p^2$–$2s2p^2$ | $^4P$ – $^4P$ | | | | | | | | | | |
| | | | [2188.7] | 424980 | 470670 | 4 | 6 | M1 | 1500 | 3.51 | C | 3,4 |
| | | | " | " | " | 4 | 6 | E2 | 0.012 | 0.0022 | D– | 4 |
| | | | [2206.5] | 379660 | 424980 | 2 | 4 | M1 | 2030 | 3.23 | C | 3,4 |
| 3. | | $^2D$ – $^2D$ | | | | | | | | | | |
| | | | [6006.0] | 687540 | 704190 | 4 | 6 | M1 | 47.3 | 2.28 | C | 3,4 |
| 4. | | $^2P$ – $^2S$ | | | | | | | | | | |
| | | | [952.8] | 805930 | 910880 | 2 | 2 | M1 | 1.1(+4)[a] | 0.68 | C– | 3,4 |
| 5. | | $^2P$ – $^2P$ | | | | | | | | | | |
| | | | [841.9] | 805930 | 924710 | 2 | 4 | M1 | 8000 | 0.71 | C | 3,4 |
| 6. | | $^2S$ – $^2P$ | | | | | | | | | | |
| | | | [7230.7] | 910880 | 924710 | 2 | 4 | M1 | 10.3 | 0.58 | C– | 3,4 |
| 7. | $2p^3$–$2p^3$ | $^2D^\circ$ – $^2D^\circ$ | | | | | | | | | | |
| | | | [4135.6] | 1310890 | 1335070 | 4 | 6 | M1 | 130 | 2.05 | C | 3,4 |
| 8. | | $^2D^\circ$ – $^2P^\circ$ | | | | | | | | | | |
| | | | [548.4] | 1335070 | 1517410 | 6 | 4 | M1 | 1.3(+4) | 0.33 | D | 3,4 |
| | | | " | " | " | 6 | 4 | E2 | 55 | 0.0065 | D– | 4 |
| | | | [618.0] | 1310890 | 1472710 | 4 | 2 | M1 | 8600 | 0.15 | D | 3,4 |
| | | | [484.2] | 1310890 | 1517410 | 4 | 4 | M1 | 3.7(+4) | 0.62 | D | 3,4 |
| 9. | | $^2P^\circ$ – $^2P^\circ$ | | | | | | | | | | |
| | | | [2237.1] | 1472710 | 1517410 | 2 | 4 | M1 | 670 | 1.11 | C | 3,4 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XXII

Be Isoelectronic Sequence

Ground State: $1s^22s^2\ ^1S_0$

Ionization Energy: 1788 eV = 14420000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 11.77 | 11 | 12.43 | 12 | 12.81 | 19 | 145.27 | 4 |
| 11.87 | 10 | 12.47 | 29 | 12.82 | 25,31 | 154.28 | 3 |
| 11.88 | 11 | 12.49 | 24,29 | 12.91 | 30 | 157.58 | 3 |
| 11.91 | 10 | 12.51 | 24 | 12.93 | 21 | 159.33 | 7 |
| 11.97 | 9 | 12.55 | 27,29 | 12.94 | 19 | 164.48 | 3 |
| 12.00 | 8 | 12.56 | 28 | 12.98 | 21,35 | 175.18 | 3 |
| 12.02 | 10 | 12.58 | 27 | 12.99 | 21 | 181.69 | 3 |
| 12.08 | 16 | 12.63 | 28,33 | 13.07 | 21 | 188.45 | 3 |
| 12.17 | 15 | 12.64 | 27 | 13.10 | 21 | 239.87 | 6 |
| 12.27 | 14 | 12.66 | 34 | 13.14 | 21 | 277.80 | 1 |
| 12.35 | 24 | 12.67 | 27 | 13.20 | 22 | 334.03 | 5 |
| 12.37 | 24 | 12.71 | 27 | 13.30 | 20 | 385.83 | 5 |
| 12.39 | 24 | 12.73 | 26 | 13.58 | 23 | 496.06 | 5 |
| 12.40 | 29 | 12.74 | 27,32 | 130.60 | 4 | | |
| 12.42 | 13 | 12.76 | 19 | 141.09 | 2 | | |

Oscillator strengths for transitions of the arrays $2s^2$–$2s2p$ and $2s2p$–$2p^2$ are taken from the multiconfiguration Dirac-Fock (MCDF) calculations of Cheng *et al.*[1] These relativistic calculations include the configuration interaction most relevant for the states of these configurations, as well as a perturbative treatment of the Breit interaction and the Lamb shift. The results should be quite accurate, except for the weakest intercombination lines. (The $^3P^\circ_1$ - $^1S_0$ transition of the $2s2p$–$2p^2$ array has been omitted here, since the $f$-value is considerably smaller than those of the other lines of this array.)

A number of sources of reliable data, from other relativistic calculations, are available for the $2s$–$2p$ transitions. However, with the exception of some of the weaker lines, they all agree well with the results of Cheng *et al.*[1] The latter are quoted exclusively here since they provide data from a single set of comprehensive calculations, all done at a uniform and reasonably accurate level of approximation, for the valence shell $2s$–$2p$ transitions for all ions of the isoelectronic sequence.

The $f$-values for the $2s^2$–$2s3p$, $2s2p$–$2p3p$, $2s2p$–$2s3s$, $2p^2$–$2p3s$, $2s2p$–$2s3d$, and $2p^2$–$2p3d$ arrays of transitions are taken from the work of Fawcett,[2] who used Cowan's version of the relativistic Hartree-Fock method with intermediate coupling and configuration interaction. This work provides a comprehensive set of data for the entire isoelectronic sequence, calculated at a uniform level of approximation. Some of these transitions, for some ions of this sequence, have also been calculated by Bhatia *et al.*[3] using the program SUPERSTRUCTURE, which includes configuration interaction and intermediate coupling. Where they overlap, these two sets of calculations agree to within the uncertainties assigned here. Transitions involving the $J=1$ levels of $2p3p\ ^3S$ and $^3P$ have been omitted because of erratic behavior of the $f$-values along the sequence.

Oscillator strengths for the transition array $2s^2$–$2s4p$ have been interpolated from the relativistic random phase approximation (RRPA) calculations along the isoelectronic sequence by Lin and Johnson.[4]

A few multiplet $f$-values for transitions involving the outer electron alone, $2s3s$–$2s3p$ and $2s3p$–$2s3d$, have been interpolated along the isoelectronic sequence and assigned a low accuracy.

## References

[1]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).
[2]B. C. Fawcett, At. Data Nucl. Data Tables **30**, 1 (1984); **33**, 479 (1985).
[3]A. K. Bhatia, U. Feldman, and J. F. Seely, At. Data Nucl. Data Tables **35**, 449 (1986).
[4]C. D. Lin and W. R. Johnson, Phys. Rev. A **15**, 1046 (1977).

Mn XXII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^2$–$2s2p$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [277.80] | 0 | 359970 | 1 | 3 | 0.37 | 0.0013 | 0.0012 | −2.89 | D | 1 |
| 2. | | $^1$S - $^1$P° | [141.09] | 0 | 708770 | 1 | 3 | 178 | 0.159 | 0.0739 | −0.799 | B | 1 |
| 3. | $2s2p$–$2p^2$ | $^3$P° - $^3$P | *171.26* | *399970* | *983880* | 9 | 9 | 125 | 0.0548 | 0.278 | −0.307 | B | 1 |
| | | | [175.18] | 437300 | 1008140 | 5 | 5 | 75.0 | 0.0345 | 0.0995 | −0.763 | B | 1 |
| | | | [164.48] | 359970 | 967950 | 3 | 3 | 37.7 | 0.0153 | 0.0249 | −1.338 | B | 1 |
| | | | [188.45] | 437300 | 967950 | 5 | 3 | 42.3 | 0.0135 | 0.0419 | −1.171 | B | 1 |
| | | | [181.69] | 359970 | 910360 | 3 | 1 | 116 | 0.0192 | 0.0345 | −1.240 | B | 1 |
| | | | [154.28] | 359970 | 1008140 | 3 | 5 | 48.1 | 0.0286 | 0.0436 | −1.067 | B | 1 |
| | | | [157.58] | 333350 | 967950 | 1 | 3 | 58.7 | 0.0656 | 0.0340 | −1.183 | B | 1 |
| 4. | | $^3$P° - $^1$D | | | | | | | | | | | |
| | | | [145.27] | 437300 | 1125660 | 5 | 5 | 37.3 | 0.0118 | 0.0282 | −1.229 | C | 1 |
| | | | [130.60] | 359970 | 1125660 | 3 | 5 | 3.3 | 0.0014 | 0.0018 | −2.38 | D | 1 |
| 5. | | $^1$P° - $^3$P | | | | | | | | | | | |
| | | | [334.03] | 708770 | 1008140 | 3 | 5 | 2.8 | 0.0078 | 0.026 | −1.63 | D | 1 |
| | | | [385.83] | 708770 | 967950 | 3 | 3 | 0.058 | 1.3(−4)[a] | 5.0(−4) | −3.41 | E | 1 |
| | | | [496.06] | 708770 | 910360 | 3 | 1 | 0.22 | 2.7(−4) | 0.0013 | −3.09 | E | 1 |
| 6. | | $^1$P° - $^1$D | [239.87] | 708770 | 1125660 | 3 | 5 | 41.0 | 0.0589 | 0.140 | −0.753 | B | 1 |
| 7. | | $^1$P° - $^1$S | [159.33] | 708770 | 1336400 | 3 | 1 | 298 | 0.0378 | 0.0595 | −0.945 | B | 1 |
| 8. | $2s^2$–$2s3p$ | $^1$S - $^3$P° | | | | | | | | | | | |
| | | | [12.00] | 0 | 8335000 | 1 | 3 | 4.3(+4) | 0.28 | 0.011 | −0.55 | C− | 2 |
| 9. | | $^1$S - $^1$P° | [11.97] | 0 | 8354000 | 1 | 3 | 6.5(+4) | 0.42 | 0.017 | −0.38 | C− | 2 |
| 10. | $2s2p$–$2p3p$ | $^3$P° - $^3$D | | | | | | | | | | | |
| | | | [11.91] | 437300 | [8837000] | 5 | 7 | 4.7(+4) | 0.14 | 0.027 | −0.15 | C− | 1 |
| | | | [11.91] | 359970 | [8757000] | 3 | 5 | 4.5(+4) | 0.16 | 0.019 | −0.32 | C− | 2 |
| | | | [11.87] | 333350 | [8759000] | 1 | 3 | 1.3(+4) | 0.083 | 0.0032 | −1.08 | D | 2 |
| | | | [12.02] | 437300 | [8757000] | 5 | 5 | 1900 | 0.0042 | 8.3(−4) | −1.68 | D | 2 |
| | | | [11.91] | 359970 | [8759000] | 3 | 3 | 2.2(+4) | 0.047 | 0.0055 | −0.85 | D | 2 |
| 11. | | $^3$P° - $^3$P | | | | | | | | | | | |
| | | | [11.88] | 437300 | 8858000 | 5 | 5 | 4.5(+4) | 0.096 | 0.019 | −0.32 | C− | 2 |
| | | | [11.88] | 359970 | [8781000] | 3 | 1 | 5.7(+4) | 0.040 | 0.0047 | −0.92 | D | 2 |
| | | | [11.77] | 359970 | 8858000 | 3 | 5 | 2400 | 0.0083 | 9.6(−4) | −1.60 | D | 2 |
| 12. | | $^1$P° - $^1$P | [12.43] | 708770 | 8756000 | 3 | 3 | 1.7(+4) | 0.040 | 0.0049 | −0.92 | D | 2 |
| 13. | | $^1$P° - $^3$D | | | | | | | | | | | |
| | | | [12.42] | 708770 | [8759000] | 3 | 3 | 1.4(+4) | 0.032 | 0.0039 | −1.02 | D | 2 |
| 14. | | $^1$P° - $^3$P | | | | | | | | | | | |
| | | | [12.27] | 708770 | 8858000 | 3 | 5 | 1.6(+4) | 0.060 | 0.0073 | −0.74 | D | 2 |
| | | | [12.27] | 708770 | [8856000] | 3 | 3 | 3.1(+4) | 0.070 | 0.0085 | −0.68 | C− | 2 |

Mn XXII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | | $^1P^o - {}^1D$ | [12.17] | 708770 | 8924000 | 3 | 5 | 5.9(+4) | 0.22 | 0.026 | −0.18 | C− | 2 |
| 16. | | $^1P^o - {}^1S$ | [12.08] | 708770 | [8984000] | 3 | 1 | 5.5(+4) | 0.040 | 0.0048 | −0.92 | D | 2 |
| 17. | $2s^2$–$2s4p$ | $^1S - {}^3P^o$ | | | | | | | | | | | |
| | | | | | | 1 | 3 | | 0.023 | | −1.64 | D | *interp.* |
| 18. | | $^1S - {}^1P^o$ | | | | 1 | 3 | | 0.16 | | −0.80 | D | *interp.* |
| 19. | $2s2p$–$2s3s$ | $^3P^o - {}^3S$ | *12.87* | *399970* | 8168000 | 9 | 3 | 3.2(+4) | 0.026 | 0.010 | −0.63 | D | 2 |
| | | | [12.94] | 437300 | 8168000 | 5 | 3 | 1.7(+4) | 0.026 | 0.0055 | −0.89 | D | 2 |
| | | | [12.81] | 359970 | 8168000 | 3 | 3 | 1.1(+4) | 0.027 | 0.0034 | −1.09 | D | 2 |
| | | | [12.76] | 333350 | 8168000 | 1 | 3 | 3700 | 0.027 | 0.0011 | −1.57 | D | 2 |
| 20. | | $^1P^o - {}^1S$ | [13.30] | 708770 | [8230000] | 3 | 1 | 1.1(+4) | 0.010 | 0.0013 | −1.52 | D | 2 |
| 21. | $2p^2$–$2p3s$ | $^3P - {}^3P^o$ | *13.02* | *983880* | [*8664000*] | 9 | 9 | 2.1(+4) | 0.054 | 0.021 | −0.31 | D | 2 |
| | | | [12.99] | 1008140 | [8704000] | 5 | 5 | 1.4(+4) | 0.036 | 0.0077 | −0.74 | D | 2 |
| | | | [13.07] | 967950 | [8617000] | 3 | 3 | 3900 | 0.010 | 0.0013 | −1.52 | D | 2 |
| | | | [13.14] | 1008140 | [8617000] | 5 | 3 | 9700 | 0.015 | 0.0032 | −1.12 | D | 2 |
| | | | [13.10] | 967950 | [8602000] | 3 | 1 | 2.0(+4) | 0.017 | 0.0022 | −1.29 | D | 2 |
| | | | [12.93] | 967950 | [8704000] | 3 | 5 | 7400 | 0.031 | 0.0040 | −1.03 | D | 2 |
| | | | [12.98] | 910360 | [8617000] | 1 | 3 | 7400 | 0.056 | 0.0024 | −1.25 | D | 2 |
| 22. | | $^1D - {}^1P^o$ | [13.20] | 1125660 | 8702000 | 5 | 3 | 1.8(+4) | 0.028 | 0.0061 | −0.85 | D | 2 |
| 23. | | $^1S - {}^1P^o$ | [13.58] | 1336400 | 8702000 | 1 | 3 | 6800 | 0.056 | 0.0025 | −1.25 | D | 2 |
| 24. | $2s2p$–$2s3d$ | $^3P^o - {}^3D$ | *12.43* | *399970* | *8443000* | 9 | 15 | 1.8(+5) | 0.71 | 0.26 | 0.80 | C− | 2 |
| | | | [12.49] | 437300 | 8445000 | 5 | 7 | 1.8(+5) | 0.60 | 0.12 | 0.48 | C− | 2 |
| | | | [12.37] | 359970 | 8445000 | 3 | 5 | 1.4(+5) | 0.55 | 0.067 | 0.22 | C− | 2 |
| | | | [12.35] | 333350 | 8433000 | 1 | 3 | 1.1(+5) | 0.74 | 0.030 | −0.13 | C− | 2 |
| | | | [12.49] | 437300 | 8445000 | 5 | 5 | 4.7(+4) | 0.11 | 0.023 | −0.26 | C− | 2 |
| | | | [12.39] | 359970 | 8433000 | 3 | 3 | 7.8(+4) | 0.18 | 0.022 | −0.27 | C− | 2 |
| | | | [12.51] | 437300 | 8433000 | 5 | 3 | 5100 | 0.0072 | 0.0015 | −1.44 | C− | 2 |
| 25. | | $^1P^o - {}^1D$ | [12.82] | 708770 | 8512000 | 3 | 5 | 1.5(+5) | 0.61 | 0.077 | 0.26 | C− | 2 |
| 26. | $2p^2$–$2p3d$ | $^3P - {}^3F^o$ | | | | | | | | | | | |
| | | | [12.73] | 1008140 | [8864000] | 5 | 7 | 5.6(+4) | 0.19 | 0.040 | −0.02 | C− | 2 |
| 27. | | $^3P - {}^3D^o$ | *12.62* | *983880* | *8909000* | 9 | 15 | 1.8(+5) | 0.72 | 0.27 | 0.81 | C− | 2 |
| | | | [12.58] | 1008140 | 8957000 | 5 | 7 | 2.0(+5) | 0.66 | 0.14 | 0.52 | C− | 2 |
| | | | [12.67] | 967950 | 8860000 | 3 | 5 | 1.09(+5) | 0.437 | 0.055 | 0.118 | C− | 2 |
| | | | [12.55] | 910360 | 8878000 | 1 | 3 | 1.82(+5) | 1.29 | 0.053 | 0.111 | C− | 2 |
| | | | [12.74] | 1008140 | 8860000 | 5 | 5 | 1.2(+4) | 0.028 | 0.0059 | −0.85 | D | 2 |
| | | | [12.64] | 967950 | 8878000 | 3 | 3 | 3.9(+4) | 0.093 | 0.012 | −0.55 | C− | 2 |
| | | | [12.71] | 1008140 | 8878000 | 5 | 3 | 1500 | 0.0022 | 4.6(−4) | −1.96 | D | 2 |
| 28. | | $^3P - {}^1D^o$ | | | | | | | | | | | |
| | | | [12.63] | 1008140 | 8928000 | 5 | 5 | 1.7(+4) | 0.040 | 0.0083 | −0.70 | C− | 2 |
| | | | [12.56] | 967950 | 8928000 | 3 | 5 | 9.4(+4) | 0.37 | 0.046 | 0.05 | D | 2 |

Mn XXII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ ($cm^{-1}$) | $E_k$ ($cm^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ $s^{-1}$) | $f_{ik}$ | S (at. u.) | log *gf* | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29. | | $^3P - ^3P^\circ$ | *12.51* | *983880* | [*8977000*] | 9 | 9 | 1.33(+5) | 0.313 | 0.116 | 0.450 | C− | 2 |
| | | | [12.55] | 1008140 | 8976000 | 5 | 5 | 1.06(+5) | 0.250 | 0.052 | 0.097 | C− | 2 |
| | | | [12.49] | 967950 | 8975000 | 3 | 3 | 9.8(+4) | 0.23 | 0.028 | −0.16 | C− | 2 |
| | | | [12.55] | 1008140 | 8975000 | 5 | 3 | 5.2(+4) | 0.074 | 0.015 | −0.43 | C− | 2 |
| | | | [12.47] | 967950 | [8986000] | 3 | 1 | 1.4(+5) | 0.11 | 0.014 | −0.48 | C− | 2 |
| | | | [12.49] | 967950 | 8976000 | 3 | 5 | 1.5(+4) | 0.060 | 0.0074 | −0.74 | D | 2 |
| | | | [12.40] | 910360 | 8975000 | 1 | 3 | 480 | 0.0033 | 1.3(−4) | −2.48 | D | 2 |
| 30. | | $^1D - ^3F^\circ$ | | | | | | | | | | | |
| | | | [12.91] | 1125660 | [8872000] | 5 | 5 | 7600 | 0.019 | 0.0040 | −1.02 | D | 2 |
| 31. | | $^1D - ^1D^\circ$ | [12.82] | 1125660 | 8928000 | 5 | 5 | 2.0(+4) | 0.050 | 0.011 | −0.60 | C− | 2 |
| 32. | | $^1D - ^3P^\circ$ | | | | | | | | | | | |
| | | | [12.74] | 1125660 | 8976000 | 5 | 5 | 5.3(+4) | 0.13 | 0.027 | −0.19 | C− | 2 |
| 33. | | $^1D - ^1P^\circ$ | [12.63] | 1125660 | [9042000] | 5 | 3 | 1.0(+4) | 0.015 | 0.0031 | −1.12 | D | 2 |
| 34. | | $^1D - ^1F^\circ$ | [12.66] | 1125660 | 9027000 | 5 | 7 | 3.03(+5) | 1.02 | 0.213 | 0.71 | C− | 2 |
| 35. | | $^1S - ^1P^\circ$ | [12.98] | 1336400 | [9042000] | 1 | 3 | 1.70(+5) | 1.29 | 0.055 | 0.111 | C− | 2 |
| 36. | $2s3s-2s3p$ | $^3S - ^3P^\circ$ | | | | 3 | 9 | | 0.13 | | −0.41 | D | *interp.* |
| 37. | | $^1S - ^1P^\circ$ | | | | 1 | 3 | | 0.053 | | −1.28 | E | *interp.* |
| 38. | $2s3p-2s3d$ | $^3P^\circ - ^3D$ | | | | 9 | 15 | | 0.028 | | −0.60 | E | *interp.* |
| 39. | | $^1P^\circ - ^1D$ | | | | 3 | 5 | | 0.049 | | −0.83 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XXII

## Forbidden Transitions

The tabulated data were all calculated by Bhatia,[1] who used scaled Thomas-Fermi wavefunctions with allowance for configuration interaction and relativistic effects. We utilized the M1 and E2 line-strength data which were communicated to us by Bhatia,[2] and converted these to *A*-values with wavelengths derived from experimental data. This approach should normally yield transition probabilities that are more accurate than those based on the theoretically determined wavelengths which he published.

### References

[1]A. K. Bhatia, J. Appl. Phys. **53**, 59 (1982).
[2]A. K. Bhatia, *private communication* (1986).

Mn XXII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2s^2$–$2p^2$ | $^1$S – $^3$P | | | | | | | | | | |
| | | | [99.193] | 0 | 1008140 | 1 | 5 | E2 | 1300 | 3.8(−5)[a] | E | 1,2 |
| | | | [103.31] | 0 | 967950 | 1 | 3 | M1 | 7800 | 9.6(−4) | E | 1,2 |
| 2. | $2s2p$–$2s2p$ | $^3$P° – $^3$P° | | | | | | | | | | |
| | | | [1293.2] | 359970 | 437300 | 3 | 5 | M1 | 6110 | 2.45 | C+ | 1,2 |
| | | | [3755.5] | 333350 | 359970 | 1 | 3 | M1 | 333 | 1.96 | C+ | 1,2 |
| 3. | | $^3$P° – $^1$P° | | | | | | | | | | |
| | | | [368.36] | 437300 | 708770 | 5 | 3 | M1 | 8600 | 0.048 | D | 1,2 |
| | | | [286.70] | 359970 | 708770 | 3 | 3 | M1 | 1.1(+4) | 0.028 | D− | 1,2 |
| | | | " | " | " | 3 | 3 | E2 | 32 | 1.1(−4) | D | 2 |
| | | | [266.37] | 333350 | 708770 | 1 | 3 | M1 | 1.8(+4) | 0.038 | D | 1,2 |
| 4. | $2p^2$–$2p^2$ | $^3$P – $^3$P | | | | | | | | | | |
| | | | [2487.4] | 967950 | 1008140 | 3 | 5 | M1 | 700 | 1.99 | C | 1,2 |
| | | | [1736.4] | 910360 | 967950 | 1 | 3 | M1 | 3260 | 1.90 | C | 1,2 |
| 5. | | $^3$P – $^1$D | | | | | | | | | | |
| | | | [850.92] | 1008140 | 1125660 | 5 | 5 | M1 | 1.08(+4) | 1.23 | C | 1,2 |
| | | | [634.08] | 967950 | 1125660 | 3 | 5 | M1 | 1.1(+4) | 0.52 | D+ | 1,2 |
| 6. | | $^3$P – $^1$S | | | | | | | | | | |
| | | | [271.41] | 967950 | 1336400 | 3 | 1 | M1 | 1.3(+5) | 0.10 | D | 1,2 |

[a]The number in the parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XXIII

Li Isoelectronic Sequence

Ground State: $1s^22s\ ^2S_{1/2}$

Ionization Energy: 1879.9 eV = 15162000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 2.014 | 2,5 | 7.60 | 16 | 11.604 | 7 | 34.2 | 22 |
| 2.019 | 1 | 7.66 | 16 | 12.028 | 13 | 34.5 | 22 |
| 2.020 | 4 | 7.797 | 9 | 12.172 | 13 | 34.8 | 22 |
| 2.021 | 1,3,4 | 8.029 | 15 | 12.188 | 13 | 75.8 | 30 |
| 2.024 | 3 | 8.090 | 15 | 23.2 | 19 | 76.9 | 30 |
| 2.025 | 4 | 8.684 | 8 | 23.8 | 23 | 206.89 | 6 |
| 7.16 | 11 | 8.694 | 8 | 23.9 | 23 | 266.89 | 6 |
| 7.36 | 17 | 8.970 | 14 | 24.0 | 23 | | |
| 7.39 | 10 | 9.018 | 14 | 33.3 | 18 | | |
| 7.41 | 17 | 11.563 | 7 | 33.6 | 18 | | |

Transition probabilities for the strongest inner-shell transitions to doubly excited $n = 2$ states are taken from the multiconfiguration Dirac-Fock (MCDF) calculations of Hata and Grant.[1] Their results are in good agreement with the $Z$-expansion perturbation calculations of Vainshtein and Safronova,[2] who included relativistic corrections at the level of the Pauli approximation.

Oscillator strengths for lines of the principal ($2s$–$2p$) resonance multiplet are the results of the MCDF calculations of Cheng *et al.*,[3] which include a perturbative treatment of the Breit interaction and the Lamb shift. The results of the MCDF calculations of Armstrong *et al.*[4] were interpolated to provide $f$-values for the $2p$–$3d$ transitions.

The $f$-value for the $3d$–$4f$ transition was taken from a study of systematic trends along isoelectronic sequences by Smith and Wiese.[5] The tabulated data for many additional transitions were taken from the theoretical analysis of Martin and Wiese,[6] which was based on a generalized study of systematic trends for several spectral series of the lithium isoelectronic sequence.

Results of the relativistic Hartree-Fock calculations of Kim and Desclaux[7] for several ions of the Li sequence were incorporated into the data of Ref. 6 for the $2s$–$3p$ transitions. For all other transitions for which the results of Ref. 6 are quoted here, no relativistic calculations were available. However, the relativistic calculations of Younger and Weiss[8] for the hydrogen isoelectronic sequence provide a means of assessing the magnitude of relativistic corrections since the Li sequence is very similar in structure to the H sequence. For those transitions for which relativistic effects were estimated to be significant (specifically, whenever the ratio of the weighted relativistic hydrogenic $f$-values $g_i f_{ik}$ of any two lines within a multiplet was found to deviate from the corresponding $LS$-coupling linestrength ratio by more than 5% for the appropriate value of the nuclear charge $Z$), the $f$-values were excluded from the compilation. A more detailed discussion of this comparison is given in Ref. 6.

Although the $2p$–$3s$ multiplet did not satisfy the criterion described in the paragraph above, we have nevertheless quoted the multiplet $f$-value obtained by Onello[9] using a $Z$-expansion technique based on a variational calculation for O VI that allowed for large-scale configuration interaction. The resulting multiplet oscillator strengths for Fe XXIV and Ni XXVI are in very good agreement with data derived from the results of calculations that included relativistic effects.[10,11] We thus felt that the results of Ref. 9 should be sufficiently accurate for inclusion in this compilation.

Transition probability data are available for numerous transitions involving doubly excited states with the spectator electron occupying the $n = 3$ shell, or higher.[12] These have not been tabulated, however, since they belong to, or are very close to belonging to, the unresolved satellites of the helium-like ion.

## References


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[8] S. M. Younger and A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **79**, 629 (1975).

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[11] B. C. Fawcett, A. Ridgeley, and T. P. Hughes, Mon. Not. R. Astron. Soc. **188**, 365 (1979).

[12] L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **25**, 311 (1980).

Mn XXIII: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^22s$–$1s(^2S)2s2p(^3P°)$ | $^2S$ – $^2P°$ | *2.020* | | | 2 | 6 | 4.5(+5)[a] | 0.083 | 0.0011 | −0.78 | D | 1 |
| | | | [2.019] | | | 2 | 4 | 2.4(+4) | 0.0029 | 3.9(−5) | −2.23 | D | 1 |
| | | | [2.021] | | | 2 | 2 | 1.4(+6) | 0.086 | 0.0011 | −0.77 | C | 1 |
| 2. | $1s^22s$–$1s(^2S)2s2p(^1P°)$ | $^2S$ – $^2P°$ | | | | | | | | | | | |
| | | | [2.013] | | | 2 | 2 | 2.9(+6) | 0.18 | 0.0023 | −0.45 | C | 1 |
| 3. | $1s^22p$–$1s2p^2$ | $^2P°$ – $^2D$ | | | | | | | | | | | |
| | | | [2.024] | | | 4 | 6 | 1.9(+6) | 0.18 | 0.0047 | −0.15 | C | 1 |
| | | | [2.021] | | | 2 | 4 | 2.7(+6) | 0.33 | 0.0044 | −0.18 | C | 1 |
| 4. | | $^2P°$ – $^2P$ | | | | | | | | | | | |
| | | | [2.020] | | | 4 | 4 | 5.3(+6) | 0.32 | 0.0086 | 0.11 | C | 1 |
| | | | [2.021] | | | 2 | 2 | 4.6(+6) | 0.28 | 0.0037 | −0.25 | C | 1 |
| | | | [2.025] | | | 4 | 2 | 1.5(+6) | 0.046 | 0.0012 | −0.73 | C | 1 |
| 5. | | $^2P°$ – $^2S$ | | | | | | | | | | | |
| | | | [2.014] | | | 4 | 2 | 2.0(+6) | 0.061 | 0.0016 | −0.61 | C | 1 |
| 6. | $2s$–$2p$ | $^2S$ – $^2P°$ | *223.65* | 0 | *447130* | 2 | 6 | 29.7 | 0.0668 | 0.0983 | −0.874 | B+ | 3 |
| | | | 206.89 | 0 | 483350 | 2 | 4 | 37.6 | 0.0483 | 0.0658 | −1.015 | B+ | 3 |
| | | | 266.89 | 0 | 374690 | 2 | 2 | 17.3 | 0.0185 | 0.0325 | −1.432 | B+ | 3 |
| 7. | $2s$–$3p$ | $^2S$ – $^2P°$ | *11.577* | 0 | *8638100* | 2 | 6 | 6.20(+4) | 0.374 | 0.0285 | −0.126 | B | 6 |
| | | | 11.563 | 0 | 8648300 | 2 | 4 | 6.14(+4) | 0.246 | 0.0187 | −0.308 | B | 6 |
| | | | 11.604 | 0 | 8617700 | 2 | 2 | 6.34(+4) | 0.128 | 0.00978 | −0.592 | B | 6 |
| 8. | $2s$–$4p$ | $^2S$ – $^2P°$ | *8.688* | 0 | *11510000* | 2 | 6 | 2.9(+4) | 0.10 | 0.0057 | −0.70 | C+ | 6 |
| | | | 8.684 | 0 | 11520000 | 2 | 4 | 2.9(+4) | 0.066 | 0.0038 | −0.88 | C+ | *ls* |
| | | | 8.694 | 0 | 11500000 | 2 | 2 | 2.9(+4) | 0.033 | 0.0019 | −1.18 | C+ | *ls* |
| 9. | $2s$–$5p$ | $^2S$ – $^2P°$ | 7.797 | 0 | 12830000 | 2 | 6 | 1.5(+4) | 0.040 | 0.0021 | −1.10 | C+ | 6 |
| 10. | $2s$–$6p$ | $^2S$ – $^2P°$ | [7.39] | | | 2 | 6 | 8630 | 0.0212 | 0.00103 | −1.373 | C+ | 6 |
| 11. | $2s$–$7p$ | $^2S$ – $^2P°$ | [7.16] | | | 2 | 6 | 5420 | 0.0125 | 5.89(−4) | −1.602 | C+ | 6 |
| 12. | $2p$–$3s$ | $^2P°$ – $^2S$ | *12.394* | *447130* | 8515400 | 6 | 2 | 2.2(+4) | 0.017 | 0.0042 | −0.99 | D | 9 |
| 13. | $2p$–$3d$ | $^2P°$ – $^2D$ | *12.125* | *447130* | *8694800* | 6 | 10 | 1.84(+5) | 0.676 | 0.162 | 0.608 | B | *interp.* |
| | | | 12.172 | 483350 | 8699000 | 4 | 6 | 1.83(+5) | 0.611 | 0.0979 | 0.388 | B | *interp.* |
| | | | 12.028 | 374690 | 8688600 | 2 | 4 | 1.54(+5) | 0.670 | 0.0531 | 0.127 | B | *interp.* |
| | | | 12.188 | 483350 | 8688600 | 4 | 4 | 3.1(+4) | 0.068 | 0.011 | −0.57 | B | *interp.* |
| 14. | $2p$–$4d$ | $^2P°$ – $^2D$ | *9.009* | *447130* | *11550000* | 6 | 10 | 5.9(+4) | 0.12 | 0.021 | −0.14 | B | 6 |
| | | | 9.018 | 483350 | 11570000 | 4 | 6 | 6.0(+4) | 0.11 | 0.013 | −0.36 | B | *ls* |
| | | | 8.970 | 374690 | 11520000 | 2 | 4 | 4.9(+4) | 0.12 | 0.0070 | −0.63 | B | *ls* |
| | | | 9.018 | 483350 | 11520000 | 4 | 4 | 9700 | 0.012 | 0.0014 | −1.33 | C+ | *ls* |

Mn XXIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15. | $2p$–$5d$ | $^2$P° – $^2$D | *8.078* | *447130* | *12830000* | 6 | 10 | 2.76(+4) | 0.0450 | 0.00718 | −0.569 | C+ | 6 |
| | | | 8.090 | 483350 | 12840000 | 4 | 6 | 2.75(+4) | 0.0405 | 0.00431 | −0.791 | C+ | *ls* |
| | | | 8.029 | 374690 | 12820000 | 2 | 4 | 2.34(+4) | 0.0452 | 0.00239 | −1.044 | C+ | *ls* |
| | | | 8.090 | 483350 | 12820000 | 4 | 4 | 4600 | 0.0045 | 4.8(−4) | −1.74 | D | *ls* |
| 16. | $2p$–$6d$ | $^2$P° – $^2$D | *7.64* | | | 6 | 10 | 1.51(+4) | 0.0220 | 0.00332 | −0.879 | C+ | 6 |
| | | | [7.66] | | | 4 | 6 | 1.50(+4) | 0.0197 | 0.00199 | −1.103 | C+ | *ls* |
| | | | [7.60] | | | 2 | 4 | 1.28(+4) | 0.0222 | 0.00111 | −1.353 | C+ | *ls* |
| | | | [7.66] | | | 4 | 4 | 2500 | 0.0022 | 2.2(−4) | −2.06 | D | *ls* |
| 17. | $2p$–$7d$ | $^2$P° – $^2$D | *7.39* | | | 6 | 10 | 9230 | 0.0126 | 0.00184 | −1.121 | C+ | 6 |
| | | | [7.41] | | | 4 | 6 | 9130 | 0.0113 | 0.00110 | −1.346 | C+ | *ls* |
| | | | [7.36] | | | 2 | 4 | 7790 | 0.0126 | 6.13(−4) | −1.597 | C+ | *ls* |
| | | | [7.41] | | | 4 | 4 | 1500 | 0.0012 | 1.2(−4) | −2.31 | D | *ls* |
| 18. | $3s$–$4p$ | $^2$S – $^2$P° | *33.4* | 8515400 | *11510000* | 2 | 6 | 8800 | 0.44 | 0.097 | −0.06 | C | 6 |
| | | | [33.3] | 8515400 | 11520000 | 2 | 4 | 8900 | 0.30 | 0.065 | −0.23 | C | *ls* |
| | | | [33.6] | 8515400 | 11500000 | 2 | 2 | 8500 | 0.14 | 0.032 | −0.54 | C | *ls* |
| 19. | $3s$–$5p$ | $^2$S – $^2$P° | [23.2] | 8515400 | 12830000 | 2 | 6 | 4460 | 0.108 | 0.0165 | −0.67 | C | 6 |
| 20. | $3s$–$6p$ | $^2$S – $^2$P° | | | | 2 | 6 | | 0.047 | | −1.03 | C | 6 |
| 21. | $3s$–$7p$ | $^2$S – $^2$P° | | | | 2 | 6 | | 0.0249 | | −1.303 | C | 6 |
| 22. | $3p$–$4d$ | $^2$P° – $^2$D | *34.4* | *8638100* | *11550000* | 6 | 10 | 2.0(+4) | 0.59 | 0.40 | 0.55 | B | 6 |
| | | | [34.2] | 8648300 | 11570000 | 4 | 6 | 2.0(+4) | 0.53 | 0.24 | 0.33 | B | *ls* |
| | | | [34.5] | 8617700 | 11520000 | 2 | 4 | 1.6(+4) | 0.57 | 0.13 | 0.06 | B | *ls* |
| | | | [34.8] | 8648300 | 11520000 | 4 | 4 | 3200 | 0.059 | 0.027 | −0.63 | C+ | *ls* |
| 23. | $3p$–$5d$ | $^2$P° – $^2$D | *23.9* | *8638100* | *12830000* | 6 | 10 | 9670 | 0.138 | 0.0651 | −0.082 | C+ | 6 |
| | | | [23.9] | 8648300 | 12840000 | 4 | 6 | 9670 | 0.124 | 0.0391 | −0.304 | C+ | *ls* |
| | | | [23.8] | 8617700 | 12820000 | 2 | 4 | 8150 | 0.138 | 0.0217 | −0.558 | C+ | *ls* |
| | | | [24.0] | 8648300 | 12820000 | 4 | 4 | 1600 | 0.014 | 0.0043 | −1.26 | D | *ls* |
| 24. | $3p$–$6d$ | $^2$P° – $^2$D | | | | 6 | 10 | | 0.0558 | | −0.475 | C+ | 6 |
| 25. | $3p$–$7d$ | $^2$P° – $^2$D | | | | 6 | 10 | | 0.0289 | | −0.761 | C+ | 6 |
| 26. | $3d$–$4f$ | $^2$D – $^2$F° | | | | 10 | 14 | | 1.00 | | 1.000 | B | 5 |
| 27. | $4s$–$5p$ | $^2$S – $^2$P° | | | | 2 | 6 | | 0.475 | | −0.022 | C | 6 |
| 28. | $4s$–$6p$ | $^2$S – $^2$P° | | | | 2 | 6 | | 0.128 | | −0.59 | C | 6 |
| 29. | $4s$–$7p$ | $^2$S – $^2$P° | | | | 2 | 6 | | 0.056 | | −0.95 | C | 6 |
| 30. | $4p$–$5d$ | $^2$P° – $^2$D | *75.8* | *11510000* | *12830000* | 6 | 10 | 4070 | 0.584 | 0.874 | 0.545 | C+ | 6 |
| | | | [75.8] | 11520000 | 12840000 | 4 | 6 | 4060 | 0.525 | 0.524 | 0.322 | C+ | *ls* |
| | | | [75.8] | 11500000 | 12820000 | 2 | 4 | 3380 | 0.583 | 0.291 | 0.067 | C+ | *ls* |
| | | | [76.9] | 11520000 | 12820000 | 4 | 4 | 650 | 0.057 | 0.058 | −0.64 | D | *ls* |
| 31. | $4p$–$6d$ | $^2$P° – $^2$D | | | | 6 | 10 | | 0.142 | | −0.070 | C+ | 6 |

Mn XXIII: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32. | $4p$–$7d$ | $^2$P° – $^2$D | | | | 6 | 10 | | 0.0616 | | −0.432 | C+ | 6 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XXIII

## Forbidden Transitions

The single magnetic dipole transition within the $1s^22p$ configuration has the line strength of 1.33 in the absence of relativistic effects in the wavefunctions.[1] It is estimated that these effects are negligible, since comprehensive relativistic calculations by Cheng *et al.*[2] for the analogous transition in the $1s^22s^22p$ configuration of the boron sequence show that such relativistic corrections are negligible until much more highly charged ions.

The listed transition probability data are also expected to be quite accurate since the energy levels are derived from experimental data.

An electric quadrupole transition at the same wavelength is estimated to be of negligible strength, as calculated by Bhatia[3] for this transition.. (He obtains a ratio of about $10^{-3}$ for the ratio of E2 to M1 line strengths).

### References

[1]W. L. Wiese, M. W. Smith, and B. M. Miles, "Atomic Transition Probabilities", Vol. II, NSRDS–NBS 22, U.S. Govt. Print. Office, Washington, DC 1969.

[2]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables **24**, 111 (1979).

[3]A. K. Bhatia, private communication (1986).

Mn XXIII: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | $S$ (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $2p$–$2p$ | $^2$P° – $^2$P° | | | | | | | | | | |
| | | | [920.6] | 374700 | 483320 | 2 | 4 | M1 | 1.15(+4)[a] | 1.33 | B | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XXIV

He Isoelectronic Sequence

Ground State: $1s^2\ ^1S_0$

Ionization Energy: 8140.7 eV = 65660000 cm$^{-1}$

## Allowed Transitions

List of tabulated lines

| Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. | Wavelength (Å) | No. |
|---|---|---|---|---|---|---|---|
| 1.5840 | 17 | 1.940 | 7,10 | 8.2726 | 24 | 32.355 | 44 |
| 1.5844 | 16 | 1.941 | 3 | 8.3085 | 31 | 32.801 | 45 |
| 1.6206 | 15 | 1.942 | 7 | 8.4583 | 32 | 68.190 | 55 |
| 1.6213 | 14 | 1.945 | 9 | 10.889 | 21 | 68.729 | 56 |
| 1.7057 | 13 | 1.951 | 5 | 11.099 | 22 | 70.156 | 58 |
| 1.7077 | 12 | 1.960 | 6 | 11.262 | 27 | 70.912 | 59 |
| 1.929 | 11 | 2.0059 | 2 | 11.489 | 28 | 209.6 | 19 |
| 1.934 | 4,8 | 2.0156 | 1 | 21.631 | 41 | 298.2 | 18 |
| 1.935 | 3 | 7.2778 | 25 | 21.865 | 42 | 420.0 | 18 |
| 1.936 | 7 | 7.4000 | 26 | 22.010 | 48 | 424.1 | 20 |
| 1.937 | 7 | 7.4137 | 35 | 22.279 | 49 | 448.0 | 18 |
| 1.938 | 7 | 7.5401 | 36 | 31.410 | 39 | | |
| 1.939 | 3 | 8.1292 | 23 | 31.765 | 40 | | |

Oscillator strengths for transitions of the $1s^2$–$1s2p$ array are taken from the results of Drake,[1] who incorporated accurate nonrelativistic matrix elements and Dirac hydrogenic matrix elements into a $Z$-expansion technique in order to provide $f$-values which would accurately reflect correlation effects for low-$Z$ ions and relativistic effects for high-$Z$ ions of the helium isoelectronic sequence. The $f$-values for the $1s^2\ ^1S$ - $1snp\ ^3P^\circ$ ($n=3$–5) transitions were interpolated from results of the relativistic random phase approximation (RRPA) calculations of Johnson and Lin.[2] Data for other $s$–$p$ and $p$–$s$ transitions were interpolated from the RRPA results of Lin *et al.*,[3] with the exception of the $2s$–$2p$ transitions, where we tabulate the actual published RRPA $A$-values of these same authors.[4]

The charge expansion results of Laughlin[5] are given for various $p$–$d$ and $d$–$p$ transitions, as well as transitions between $4d$ and $4f$ levels. For those multiplets involving no change in principal quantum number ($3p$–$3d$, $4p$–$4d$, $4d$–$4f$) the $f$-values should be considered rather uncertain, since they are sensitive to energy differences. Oscillator strengths for the $2p$–$3d$ transitions, and for $1s3p\ ^3P^\circ$ - $1s3d\ ^3D$, were interpolated from the variational calculations of Weiss.[6] Both of these calculations indicate that, unlike the triplets, the $nd\ ^1D$ energy levels ($n=3,4$) lie below the $np\ ^1P^\circ$ levels, and the $4f\ ^1F^\circ$ lies below the $4d\ ^1D$.

Brown and Cortez[7] have provided $f$-values for numerous $d$–$f$ and $f$–$d$ transitions for the isoelectronic sequence by fitting $Z$-expansion formulas to the results of variational calculations for the low-$Z$ ions. Their results for transitions between the lower-lying D and F° terms are tabulated here.

Transition probabilities for the stronger transitions involving the doubly excited $n=2$ states are taken from the comprehensive, charge expansion perturbation theory calculations of Vainshtein and Safronova.[8] Numerous data are also available for transitions involving doubly excited states where the spectator electron has principal quantum number $n=3$.[9] However, these data are not tabulated here since most of the transitions are very close to belonging to the unresolved satellites of the H-like ions, if they do not in fact do so.

## References


[1] G. W. F. Drake, Phys. Rev. A **19**, 1387 (1979).
[2] W. R. Johnson and C. D. Lin, Phys. Rev. A **14**, 565 (1976).
[3] C. D. Lin, W. R. Johnson, and A. Dalgarno, Astrophys. J. **217**, 1011 (1977).
[4] C. D. Lin, W. R. Johnson, and A. Dalgarno, Phys. Rev. A **15**, 154 (1977).
[5] C. J. Laughlin, J. Phys. B **6**, 1942 (1973).
[6] A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **71**, 163 (1967).
[7] R. T. Brown and J.-L. M. Cortez, Astrophys. J. **176**, 267 (1972).
[8] L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **21**, 49 (1978).
[9] L. A. Vainshtein and U. I. Safronova, At. Data Nucl. Data Tables **25**, 311 (1980).

Mn XXIV: Allowed transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm⁻¹) | $E_k$ (cm⁻¹) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s⁻¹) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2$–$1s2p$ | $^1S$ – $^3P°$ | | | | | | | | | | | |
| | | | [2.0156] | 0 | [49614100] | 1 | 3 | 3.25(+5)[a] | 0.0594 | 3.94(−4) | −1.226 | B | 1 |
| 2. | | $^1S$ – $^1P°$ | [2.0059] | 0 | [49853100] | 1 | 3 | 3.93(+6) | 0.712 | 0.00470 | −0.148 | B | 1 |
| 3. | $1s2s$–$2s2p$ | $^3S$ – $^3P°$ | *1.937* | [49376000] | [*101000000*] | 3 | 9 | 2.4(+6) | 0.40 | 0.0077 | 0.08 | C | 8 |
| | | | [1.935] | [49376000] | [101050000] | 3 | 5 | 2.4(+6) | 0.22 | 0.0043 | −0.17 | C | 8 |
| | | | [1.939] | [49376000] | [100950000] | 3 | 3 | 2.3(+6) | 0.13 | 0.0025 | −0.41 | C | 8 |
| | | | [1.941] | [49376000] | [100890000] | 3 | 1 | 2.4(+6) | 0.045 | 8.7(−4) | −0.87 | C | 8 |
| 4. | | $^1S$ – $^1P°$ | [1.934] | [49617300] | [101320000] | 1 | 3 | 2.4(+6) | 0.40 | 0.0026 | −0.39 | C | 8 |
| 5. | $1s2p$–$2s^2$ | $^3P°$ – $^1S$ | | | | | | | | | | | |
| | | | [1.951] | [49614100] | [100870000] | 3 | 1 | 3.7(+5) | 0.0070 | 1.4(−4) | −1.68 | D | 8 |
| 6. | | $^1P°$ – $^1S$ | [1.960] | [49853100] | [100870000] | 3 | 1 | 5.5(+5) | 0.011 | 2.0(−4) | −1.50 | D | 8 |
| 7. | $1s2p$–$2p^2$ | $^3P°$ – $^3P$ | *1.939* | [*49666400*] | [*101230000*] | 9 | 9 | 4.35(+6) | 0.245 | 0.0141 | 0.344 | C | 8 |
| | | | [1.940] | [49711300] | [101250000] | 5 | 5 | 2.6(+6) | 0.15 | 0.0047 | −0.13 | C | 8 |
| | | | [1.938] | [49614100] | [101220000] | 3 | 3 | 1.1(+6) | 0.062 | 0.0012 | −0.73 | C | 8 |
| | | | [1.942] | [49711300] | [101220000] | 5 | 3 | 2.0(+6) | 0.068 | 0.0022 | −0.47 | C | 8 |
| | | | [1.940] | [49614100] | [101150000] | 3 | 1 | 4.5(+6) | 0.085 | 0.0016 | −0.60 | C | 8 |
| | | | [1.936] | [49614100] | [101250000] | 3 | 5 | 1.5(+6) | 0.14 | 0.0027 | −0.38 | C | 8 |
| | | | [1.937] | [49599200] | [101220000] | 1 | 3 | 1.6(+6) | 0.27 | 0.0017 | −0.57 | C | 8 |
| 8. | | $^3P°$ – $^1D$ | | | | | | | | | | | |
| | | | [1.934] | [49711300] | [101410000] | 5 | 5 | 1.1(+6) | 0.062 | 0.0020 | −0.51 | C | 8 |
| 9. | | $^1P°$ – $^3P$ | | | | | | | | | | | |
| | | | [1.945] | [49853100] | [101250000] | 3 | 5 | 7.9(+5) | 0.075 | 0.0014 | −0.65 | D | 8 |
| 10. | | $^1P°$ – $^1D$ | [1.940] | [49853100] | [101410000] | 3 | 5 | 3.8(+6) | 0.36 | 0.0068 | 0.03 | C | 8 |
| 11. | | $^1P°$ – $^1S$ | [1.929] | [49853100] | [101690000] | 3 | 1 | 4.2(+6) | 0.078 | 0.0015 | −0.63 | C | 8 |
| 12. | $1s^2$–$1s3p$ | $^1S$ – $^3P°$ | | | | | | | | | | | |
| | | | [1.7077] | 0 | [58559300] | 1 | 3 | 1.1(+5) | 0.015 | 8.4(−5) | −1.82 | E | *interp.* |
| 13. | | $^1S$ – $^1P°$ | [1.7057] | 0 | [58627100] | 1 | 3 | 1.06(+6) | 0.139 | 7.81(−4) | −0.857 | C+ | *interp.* |
| 14. | $1s^2$–$1s4p$ | $^1S$ – $^3P°$ | | | | | | | | | | | |
| | | | [1.6213] | 0 | [61677300] | 1 | 3 | 4.3(+4) | 0.0051 | 2.7(−5) | −2.29 | E | *interp.* |
| 15. | | $^1S$ – $^1P°$ | [1.6206] | 0 | [61705400] | 1 | 3 | 4.32(+5) | 0.0510 | 2.72(−4) | −1.292 | C+ | *interp.* |
| 16. | $1s^2$–$1s5p$ | $^1S$ – $^3P°$ | | | | | | | | | | | |
| | | | [1.5844] | 0 | [63116500] | 1 | 3 | 2.2(+4) | 0.0025 | 1.3(−5) | −2.60 | E | *interp.* |
| 17. | | $^1S$ – $^1P°$ | [1.5840] | 0 | [63130800] | 1 | 3 | 2.18(+5) | 0.0246 | 1.28(−4) | −1.609 | C+ | *interp.* |

Mn XXIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18. | 1s2s–1s2p | $^3$S – $^3$P° | 344.4 | [49376000] | [49666400] | 3 | 9 | 7.72 | 0.0412 | 0.140 | −0.908 | B | 4 |
| | | | [298.2] | [49376000] | [49711300] | 3 | 5 | 12.2 | 0.0271 | 0.0798 | −1.090 | B | 4 |
| | | | [420.0] | [49376000] | [49614100] | 3 | 3 | 4.06 | 0.0107 | 0.0445 | −1.492 | B | 4 |
| | | | [448.0] | [49376000] | [49599200] | 3 | 1 | 3.59 | 0.00360 | 0.0159 | −1.966 | B | 4 |
| 19. | | $^3$S – $^1$P° | | | | | | | | | | | |
| | | | [209.6] | [49376000] | [49853100] | 3 | 3 | 2.60 | 0.00171 | 0.00354 | −2.289 | B | 4 |
| 20. | | $^1$S – $^1$P° | [424.1] | [49617300] | [49853100] | 1 | 3 | 4.05 | 0.0328 | 0.0457 | −1.485 | B | 4 |
| 21. | 1s2s–1s3p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [10.889] | [49376000] | [58559300] | 3 | 3 | 6.92(+4) | 0.123 | 0.0132 | −0.433 | C | *interp.* |
| 22. | | $^1$S – $^1$P° | [11.099] | [49617300] | [58627100] | 1 | 3 | 6.61(+4) | 0.366 | 0.0134 | −0.437 | C | *interp.* |
| 23. | 1s2s–1s4p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [8.1292] | [49376000] | [61677300] | 3 | 3 | 3.0(+4) | 0.030 | 0.0024 | −1.05 | C+ | *interp.* |
| 24. | | $^1$S – $^1$P° | [8.2726] | [49617300] | [61705400] | 1 | 3 | 2.9(+4) | 0.089 | 0.0024 | −1.05 | C+ | *interp.* |
| 25. | 1s2s–1s5p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | [7.2778] | [49376000] | [63116500] | 3 | 3 | 1.5(+4) | 0.012 | 8.6(−4) | −1.44 | C+ | *interp.* |
| 26. | | $^1$S – $^1$P° | [7.4000] | [49617300] | [63130800] | 1 | 3 | 1.5(+4) | 0.036 | 8.8(−4) | −1.44 | C+ | *interp.* |
| 27. | 1s2p–1s3s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [11.262] | [49614100] | [58493600] | 3 | 3 | 7400 | 0.014 | 0.0016 | −1.38 | C− | *interp.* |
| 28. | | $^1$P° – $^1$S | [11.489] | [49853100] | [58557300] | 3 | 1 | 2.1(+4) | 0.014 | 0.0016 | −1.38 | C+ | *interp.* |
| 29. | 1s2p–1s3d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.69 | | 0.79 | C+ | *interp.* |
| 30. | | $^1$P° – $^1$D | | | | 3 | 5 | | 0.70 | | 0.32 | C+ | *interp.* |
| 31. | 1s2p–1s4s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [8.3085] | [49614100] | [61650000] | 3 | 3 | 3000 | 0.0031 | 2.5(−4) | −2.03 | D | *interp.* |
| 32. | | $^1$P° – $^1$S | [8.4583] | [49853100] | [61675800] | 3 | 1 | 8700 | 0.0031 | 2.6(−4) | −2.03 | C | *interp.* |
| 33. | 1s2p–1s4d | $^3$P° – $^3$D | | | | 9 | 15 | | 0.12 | | 0.03 | C | 5 |
| 34. | | $^1$P° – $^1$D | | | | 3 | 5 | | 0.12 | | −0.44 | C | 5 |
| 35. | 1s2p–1s5s | $^3$P° – $^3$S | | | | | | | | | | | |
| | | | [7.4137] | [49614100] | [63102700] | 3 | 3 | 1500 | 0.0012 | 8.8(−5) | −2.44 | D | *interp.* |
| 36. | | $^1$P° – $^1$S | [7.5401] | [49853100] | [63115600] | 3 | 1 | 4200 | 0.0012 | 8.9(−5) | −2.44 | C | *interp.* |
| 37. | 1s3s–1s3p | $^3$S – $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.017 | | −1.29 | E | *interp.* |

Mn XXIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | $S$ (at. u.) | log $gf$ | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38. | | $^1$S - $^1$P° | | | | 1 | 3 | | 0.057 | | −1.24 | D | *interp.* |
| 39. | 1s3s–1s4p | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | [31.410] | [58493600] | [61677300] | 3 | 3 | 9100 | 0.135 | 0.0419 | −0.393 | C | *interp.* |
| 40. | | $^1$S - $^1$P° | [31.765] | [58557300] | [61705400] | 1 | 3 | 8900 | 0.402 | 0.0420 | −0.396 | C | *interp.* |
| 41. | 1s3s–1s5p | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | [21.631] | [58493600] | [63116500] | 3 | 3 | 4800 | 0.034 | 0.0073 | −0.99 | C | *interp.* |
| 42. | | $^1$S - $^1$P° | [21.865] | [58557300] | [63130800] | 1 | 3 | 4840 | 0.104 | 0.00749 | −0.983 | C+ | *interp.* |
| 43. | 1s3p–1s3d | $^3$P° - $^3$D | | | | 9 | 15 | | 0.012 | | −0.97 | D | *interp.* |
| 44. | 1s3p–1s4s | $^3$P° - $^3$S | | | | | | | | | | | |
| | | | [32.355] | [58559300] | [61650000] | 3 | 3 | 2100 | 0.033 | 0.011 | −1.00 | C− | *interp.* |
| 45. | | $^1$P° - $^1$S | [32.801] | [58627100] | [61675800] | 3 | 1 | 6300 | 0.034 | 0.011 | −0.99 | C | *interp.* |
| 46. | 1s3p–1s4d | $^3$P° - $^3$D | | | | 9 | 15 | | 0.60 | | 0.73 | C | 5 |
| 47. | | $^1$P° - $^1$D | | | | 3 | 5 | | 0.62 | | 0.27 | C | 5 |
| 48. | 1s3p–1s5s | $^3$P° - $^3$S | | | | | | | | | | | |
| | | | [22.010] | [58559300] | [63102700] | 3 | 3 | 1000 | 0.0073 | 0.0016 | −1.66 | D | *interp.* |
| 49. | | $^1$P° - $^1$S | [22.279] | [58627100] | [63115600] | 3 | 1 | 3100 | 0.0077 | 0.0017 | −1.64 | C | *interp.* |
| 50. | 1s3d–1s3p | $^1$D - $^1$P° | | | | 5 | 3 | | 0.0021 | | −1.98 | E | 5 |
| 51. | 1s3d–1s4p | $^3$D - $^3$P° | | | | 15 | 9 | | 0.012 | | −0.74 | C | 5 |
| 52. | | $^1$D - $^1$P° | | | | 5 | 3 | | 0.011 | | −1.26 | C | 5 |
| 53. | 1s4s–1s4p | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.024 | | −1.14 | E | *interp.* |
| 54. | | $^1$S - $^1$P° | | | | 1 | 3 | | 0.079 | | −1.10 | E | *interp.* |
| 55. | 1s4s–1s5p | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | [68.190] | [61650000] | [63116500] | 3 | 3 | 2150 | 0.150 | 0.101 | −0.347 | C | *interp.* |
| 56. | | $^1$S - $^1$P° | [68.729] | [61675800] | [63130800] | 1 | 3 | 2100 | 0.45 | 0.10 | −0.35 | D | *interp.* |
| 57. | 1s4p–1s4d | $^3$P° - $^3$D | | | | 9 | 15 | | 0.020 | | −0.74 | D | 5 |
| 58. | 1s4p–1s5s | $^3$P° - $^3$S | | | | | | | | | | | |
| | | | [70.156] | [61677300] | [63102700] | 3 | 3 | 730 | 0.054 | 0.037 | −0.79 | D | *interp.* |
| 59. | | $^1$P° - $^1$S | [70.912] | [61705400] | [63115600] | 3 | 1 | 2200 | 0.055 | 0.039 | −0.78 | C | *interp.* |
| 60. | 1s4d–1s4p | $^1$D - $^1$P° | | | | 5 | 3 | | 0.0033 | | −1.78 | E | 5 |

Mn XXIV: Allowed transitions — Continued

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | $A_{ki}$ ($10^8$ s$^{-1}$) | $f_{ik}$ | S (at. u.) | log gf | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 61. | 1s4d–1s4f | $^3$D - $^3$F° | | | | 15 | 21 | | 8.2(−4) | | −1.91 | E | 5 |
| 62. | 1s4d–1s5f | $^3$D - $^3$F° | | | | 15 | 21 | | 0.89 | | 1.13 | B | 7 |
| 63. | | $^1$D - $^1$F° | | | | 5 | 7 | | 0.89 | | 0.65 | B | 7 |
| 64. | 1s4f–1s4d | $^1$F° - $^1$D | | | | 7 | 5 | | 4.3(−4) | | −2.52 | E | 5 |
| 65. | 1s4f–1s5d | $^3$F° - $^3$D | | | | 21 | 15 | | 0.0089 | | −0.73 | C | 7 |
| 66. | | $^1$F° - $^1$D | | | | 7 | 5 | | 0.0089 | | −1.21 | C | 7 |
| 67. | 1s5s–1s5p | $^3$S - $^3$P° | | | | | | | | | | | |
| | | | | | | 3 | 3 | | 0.030 | | −1.05 | E | *interp.* |
| 68. | | $^1$S - $^1$P° | | | | 1 | 3 | | 0.10 | | −1.00 | E | *interp.* |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XXIV

## Forbidden Transitions

The results of multi-configuration Dirac-Fock calculations by Hata and Grant[1] have been selected for this tabulation. Their work includes both a very detailed consideration of configuration interaction—with configurational wavefunction sets containing as many as 51 interacting states—as well as a fully relativistic treatment based on the Dirac Hamiltonian. Their calculated wavelengths are in very close agreement with experimental values. For the ions Ti XXI, V XXII and Fe XXV, where accurate experimental lifetime data are available, the agreement between these and the theoretical results of Hata and Grant[1] is excellent, with differences not exceeding a few percent (see the comparison table in the introduction to the forbidden lines of Ti XXI).

### Reference

[1]J. Hata and I. P. Grant, Mon. Not. R. Astr. Soc. **211**, 549 (1984).

Mn XXIV: Forbidden transitions

| No. | Transition Array | Multiplet | λ (Å) | $E_i$ (cm$^{-1}$) | $E_k$ (cm$^{-1}$) | $g_i$ | $g_k$ | Type of transition | $A_{ki}$ (s$^{-1}$) | S (at. u.) | Accuracy | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | $1s^2$–1s2s | $^1$S - $^3$S | [2.0255] | 0 | [49369590] | 1 | 3 | M1 | 1.42(+8)[a] | 1.31(−4) | B | 1 |
| 2. | $1s^2$–1s2p | $^1$S - $^3$P° | | | | | | | | | | |
| | | | [2.0118] | 0 | [49706640] | 1 | 5 | M2 | 4.82(+9) | 0.120 | B | 1 |

[a]The number in parentheses following the tabulated value indicates the power of ten by which this value has to be multiplied.

# Mn XXV

H Isoelectronic Sequence

Ground State: $1s\ ^2S_{1/2}$

Ionization Energy: 8572.01 eV = 69137400 $cm^{-1}$

## Allowed Transitions

Electric dipole transition probability data for this hydrogen-like ion can be obtained directly, in a non-relativistic approximation, from the data for neutral hydrogen.[1] The oscillator strength is independent of $Z$ along the entire isoelectronic sequence and is therefore identical to the value for the hydrogen atom. Line strengths scale as $Z^{-2}$ and transition probabilities scale as $Z^4$, i.e.,

$$S_Z = Z^{-2} S_H, \qquad A_Z = Z^4 A_H.$$

For higher nuclear charges in this sequence, relativistic corrections will cause these values to deviate increasingly from the non-relativistic ones. The first effect of relativity will be to alter the transition energies, or wavelengths, from the non-relativistic, even though the line strength itself is still well approximated by the non-relativistic value. In this case, experimental energies should be used in the standard conversion formulas, given in the general introduction to this volume, to calculate the most accurate values of $f$ and $A$. It should be noted that the relativistic removal of the $j$-degeneracy introduces dipole transitions which do not occur in the non-relativistic theory, e.g., $2s_{1/2} - 2p_{3/2}$.

For very high $Z$, it is necessary to use the four-component Dirac spinors rather than two-component Schroedinger functions in theoretical calculations, and this introduces relativistic corrections to the line strengths themselves. Several recent systematic studies of the problem[2,3] indicate that these corrections are not large for stages of ionization in the range 20–30. Corrections for $Z = 30$ are usually no larger than 5–10% and generally substantially less than 5%. If an accuracy greater than this is required, the reader is referred to these papers[2,3] for a more detailed error analysis.

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[2] S. M. Younger and A. W. Weiss, J. Res. Nat. Bur. Stand., Sect. A **79**, 629 (1975).

[3] S. J. Rose, Rutherford Appleton Laboratory Report RL–82–114 (December 1982).

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