

Energy Levels of Scandium, Sc I through Sc XXI

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The energy levels of the scandium atom in all of its stages of ionization, as derived from the analyses of atomic spectra, have been critically compiled. In cases where only line classifications are reported in the literature, level values have been derived. Electron configurations, term designations, J -values, experimental g -values, and ionization energies are included. Calculated percentages of the two leading components of the eigenvectors of the levels are given, where available.

Key words: Atomic energy levels; atomic spectra; scandium energy levels.

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Introduction

At the time of the first compilation of atomic energy levels by Bacher and Goudsmit in 1932, only the first 3 of the 21 spectra of scandium had been studied. By 1949, Moore was able to compile energy levels for the first 12 spectra of scandium. At that time, oxygen was the heaviest atom for which some levels of all stages of ionization were known.

A great amount of new experimental work has been carried out since then, particularly in the higher stages of ionization. Today, experimental results are available for every stage of ionization of scandium. This is the result of the development of more energetic light sources, which was stimulated by the need to interpret new spectroscopic observations of the sun at short wavelengths from rocket- and satellite-borne spectrographs. A new impetus for the interpretation of spectra of highly ionized atoms has arisen from the investigation of hot laboratory plasmas generated to achieve controlled nuclear fusion.

These activities have produced a substantial increase in spectroscopic information, particularly for elements of the iron period, making the earlier compilations of energy levels inadequate. The NBS Atomic Energy Levels Data Center has

undertaken to provide new compilations of energy levels, including the elements of the iron period. The material on each atom and its ions is being published as a separate paper. A collection of these compilations, with revisions, is planned as one volume for the iron period. Already completed are the compilation for iron by Reader and Sugar (1975), chromium, vanadium, and calcium by Sugar and Corliss (1977, 1978, 1979), and manganese, titanium, and potassium by Corliss and Sugar (1977, 1979a, 1979b). The present work on scandium will be followed by a compilation of the energy levels of nickel.

The present compilation comprises the energy levels of the scandium atom and all of its ions, as derived from analyses of atomic spectra. For many of the ions the original papers do not give energy level values, but only classifications of observed lines. In these cases we have derived the level values. Although generally we used only published papers as sources of data, unpublished data have been included when they constituted a substantial improvement over material in the literature.

Ionization energies found in the literature are usually given in eV or in cm^{-1} . The latest conversion factor $8065.479 \pm 0.021 \text{ cm}^{-1}/\text{eV}$ is given by Cohen and Taylor (1973).

In a few cases where Rydberg series were available but the ionization energy was not derived, we carried out the calculation. For a large number of ions, no suitable series are

known. In these cases we have quoted values obtained by extrapolation along isoelectronic sequences. Although uncertainties are not usually provided with these extrapolated values, they are probably accurate to a few units of the last significant figure given.

Nearly all of the data are the result of observations of various types of laboratory light sources. However, they are sometimes supplemented by data obtained from solar observations. This is particularly true where spin-forbidden lines are needed to establish the absolute energy of a system of excited levels and also where parity-forbidden transitions between levels of a ground configuration are used to obtain accurate relative energies for the low levels. Whenever both solar data and equivalent laboratory data are available preference is generally given to the laboratory measurements in order to avoid the problem of blended lines of various elements in the solar spectrum.

For a convenient source of wavelengths of scandium lines below 2000 Å we refer the reader to the compilation by Kelly and Palumbo (1973). The strong scandium lines above 2000 Å are in the tables of spectral lines by Meggers, Corliss, and Scribner (1975).

When no observations are available to connect independent systems of levels, an estimate of the connecting energy is frequently made. Those levels affected by the estimate are denoted by "+x" following the level values. The value of x is the systematic error of the estimate. For Sc XX and XXI, which are isoelectronic with He I and H I, respectively, we give only calculated level values since they are much more accurate than experimental x-ray wavelengths from which level values may be obtained.

We have included the results of calculations, under the heading "Leading percentages," that express the percentage composition of levels in terms of the basis states of a single configuration, or more than one configuration where configuration interaction has been included. Where these results contradict an author's designation, we have accepted the theoretical term and configuration labeling of a level to conform with its calculated leading percentages. In some cases these are low and the labeling has less physical meaning.

In the columns of the present tables headed "Leading percentages" we give first the percentage of the basis state corresponding to the level's name; next the second largest percentage together with the related basis state.

Of course, the percentage compositions cannot be considered to be as reliable as experimental quantities inasmuch as a new calculation using a different approximation, such as the introduction of configuration interaction where none had been used before, might yield a different set of percentages. For some levels the percentages may change drastically in a new calculation. In the present tables, the percentages are taken mostly from published least squares level-fitting calculations. When only *ab initio* calculations are found in the literature, we have used them if there appears to be a reasonable correspondence with the experimental data. For higher ionization stages there have been fewer publications relating quantitatively the theoretical results to the observations by means of least-squares calculations.

For configurations of equivalent d electrons, repeating terms of the same LS type sometimes occur. These are theoretically distinguished by their seniority number. In the present compilations they are designated in the notation of Nielson and Koster (1963). For example, in the $3d^5$ configuration there are three 2D terms with seniorities of 1, 3, and 5. These terms are denoted as 2D_1 , 2D_2 , and 2D_3 , respectively, by Nielson and Koster. Martin, Zalubas, and Hagan (1978) give a complete summary of the coupling notations used here.

In assembling the data for each spectrum, we referred to the following bibliographies:

- i. papers cited by Moore (1949)
- ii. C. E. Moore (1968)
- iii. L. Hagan and W. C. Martin (1972)
- iv. L. Hagan (1977)
- v. card file of publications since June 1975 maintained by the NBS Atomic Energy Levels Data Center.

A selection of data was made that, in our judgment, represents the most accurate and reliable available. The text for each ion is not always a complete review of the literature but is intended to credit the major contributions. This compilation is intended to include all material available as of March 1, 1979.

Acknowledgments

Throughout this work we have made extensive use of the bibliographical files and reprint collection maintained in the Atomic Energy Levels Data Center by Dr. Romuald Zalubas. Our thanks are extended to him for generous cooperation. The compilation has also benefited greatly from the preprints that were provided by many of our colleagues.

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Sc I

Z=21

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d 4s^2 \ ^2D_{3/2}$ Ionization energy = $52\ 922.0 \pm 0.5\ \text{cm}^{-1}$ ($6.56154 \pm 0.00006\ \text{eV}$)

The first extensive analysis of Sc I was carried out by Russell and Meggers (1927), who classified about 350 lines between 2690 and 8250 Å as combinations among 128 energy levels of nine configurations. The analysis was extended by Neufeld (1970) and Neufeld and Schrenk (1975), who added 150 newly classified lines and 22 new levels and measured g -values for 98 levels.

Observations of the absorption spectrum of Sc in the range 1200–3200 Å were made by Garton, Reeves, Tomkins, and Ercoli (1973) with a measurement accuracy of $\pm 0.01\ \text{Å}$. They identified eight series arising from the $\ ^2D$ ground term in combination with $4s^2 nf^2 F^\circ$, $3d 4s(^1D)np\ ^2P^\circ$, $3d 4s(^1D)np\ ^2D^\circ$, and $3d^2(^3F)np\ ^2L^\circ$ (where L may be D, F, or G). By far the strongest series arises from the $3d 4s^2\ ^2D-4s^2 nf^2 F^\circ$ transitions. The three series $3d 4s^2\ ^2D-3d 4s(^1D)np\ ^2P^\circ$ were observed to much higher n and were used to derive the ionization energy. Two more series found to converge to the $3d 4s(^1D)$ limit were identified tentatively as $3d 4s^2\ ^2D-3d 4s(^1D)np\ ^2D^\circ$ with unresolved $\ ^2D^\circ$ splitting. A final series labeled $3d 4s^2-3d^2(^3F)np\ ^2L^\circ$ observed from $n=7$ to 15 and much stronger than the $\ ^2D^\circ$ series was reported. Since L may represent D° , F° , or G° terms, the most likely candidate for a strong series is $\ ^2F^\circ$ and we have used this designation for the series. Many additional absorption features not compiled here were reported with no identification of the upper levels.

A new analysis of Sc I based on new observations between 2000 and 34 000 Å has been published by Ben Ahmed and Verges (1977) together with a theoretical interpretation by Ben Ahmed (1977). They established 108 additional levels and derived the complete system of known levels up to $49\ 000\ \text{cm}^{-1}$ from their new measurements, classifying 1230 lines.

Our compilation is from the papers of Ben Ahmed and Verges, Ben Ahmed, and Garton et al. The ionization energy is from the latter authors, who derived their value from the $3d 4s(^1D)np\ ^2P_{3/2}^\circ$ series.

The g -values are from Ben Ahmed and Verges, except for those of the ground term, which are taken from the report of the magnetic resonance experiments by Childs (1971).

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Sc I

Configuration	Term	J	Level (cm^{-1})	g	Leading percentages
$3d 4s^2$	$\ ^2D$	$3/2$	0.00	0.79933	98
		$5/2$	168.34	1.20029	98
$3d^2(^3F)4s$	$\ ^4F$	$3/2$	11 519.99	0.400	100
		$5/2$	11 557.69	1.026	100
		$7/2$	11 610.28	1.244	100
		$9/2$	11 677.38	1.325	100
$3d^2(^3F)4s$	$\ ^2F$	$5/2$	14 926.07	0.861	100
		$7/2$	15 041.92	1.134	100
$3d 4s(^3D)4p$	$\ ^4F^\circ$	$3/2$	15 672.58	0.426	96
		$5/2$	15 756.57	1.036	96
		$7/2$	15 881.75	1.232	98
		$9/2$	16 026.62	1.33	99
$3d 4s(^3D)4p$	$\ ^4D^\circ$	$1/2$	16 009.77	0.002	97
		$3/2$	16 021.82	1.039	92
		$5/2$	16 141.06	1.336	79
		$7/2$	16 210.85	1.43	96

9 $(^1D)\ ^2D^\circ$

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Configuration	Term	J	Level (cm^{-1})	g	Leading percentages		
$3d\ 4s(^1D)4p$	$^2D^\circ$	$5/2$	16 022.73	1.19	43	34	$(^3D)\ ^2D^\circ$
		$3/2$	16 096.90	0.956	50	39	
$3d^2(^1D)4s$	2D	$5/2$	17 012.76	1.226	94	4	$(^3P)\ ^4P$
		$3/2$	17 025.14	0.815	98		
$3d^2(^3P)4s$	4P	$1/2$	17 226.04	2.662	100		$(^1D)\ ^2D$
		$3/2$	17 255.07	1.719	99		
		$5/2$	17 307.08	1.575	96	4	
$3d\ 4s(^3D)4p$	$^4P^\circ$	$1/2$	18 504.06	2.529	83	7	$4s^24p\ ^2P^\circ$
		$3/2$	18 515.69	1.698	88	4	
		$5/2$	18 571.41	1.600	98		
$4s^2\ 4p$	$^2P^\circ$	$1/2$	18 711.02	0.777	37	31	$3d4s(^3D)4p\ ^2P^\circ$
		$3/2$	18 855.74	1.356	37	33	
$3d^2(^1G)4s$	2G	$9/2$	20 236.86	1.10	100		
		$7/2$	20 239.66	0.89	100		
$3d^2(^3P)4s$	2P	$1/2$	20 681.43	0.668	99		
		$3/2$	20 719.86	1.331	99		
$3d\ 4s(^1D)4p$	$^2F^\circ$	$5/2$	21 032.75	0.855	79	14	$(^3D)\ ^2F^\circ$
		$7/2$	21 085.85	1.14	77	16	
$3d\ 4s(^1D)4p$	$^2P^\circ$	$1/2$	24 656.72		74	17	$4s^24p\ ^2P^\circ$
		$3/2$	24 656.88		68	17	
$3d\ 4s(^3D)4p$	$^2D^\circ$	$3/2$	24 866.17	0.804	38	30	$3d^2(^3F)4p\ ^2D^\circ$
		$5/2$	25 014.21	1.201	40	32	
$3d\ 4s(^3D)4p$	$^2F^\circ$	$5/2$	25 584.64	0.857	64	21	$3d^2(^3F)4p\ ^2F^\circ$
		$7/2$	25 724.68	1.138	62	22	
$3d^2(^1S)4s$	2S	$1/2$	26 936.98		100		
$3d^2(^3F)4p$	$^4G^\circ$	$5/2$	29 022.32	0.584	100		
		$7/2$	29 096.18	0.981	100		
		$9/2$	29 189.84	1.16	100		
		$11/2$	29 303.51		100		
$3d\ 4s(^3D)4p$	$^2P^\circ$	$1/2$	30 573.17	0.680	44	31	$4s^24p\ ^2P^\circ$
		$3/2$	30 706.66	1.332	43	32	
$3d^2(^3F)4p$	$^4F^\circ$	$3/2$	31 172.70	0.400	99		
		$5/2$	31 215.81	1.027	99		
		$7/2$	31 275.39	1.240	98		
		$9/2$	31 350.84	1.33	98		
$3d^2(^3F)4p$	$^4D^\circ$	$1/2$	32 637.40	0.03	96		
		$3/2$	32 659.30		96		
		$5/2$	32 696.84	1.373	95		
		$7/2$	32 751.50	1.414	95		
$3d^2(^3F)4p$	$^2G^\circ$	$7/2$	33 055.98	0.91	60	20	$(^3F)\ ^2F^\circ$ $(^1G)\ ^2G^\circ$
		$9/2$	33 151.20	1.06	90	10	

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	<i>g</i>	Leading percentages		
$3d^2(^3F)4p$	$^2F^\circ$	$5/2$	33 153.79	0.853	62	13	$3d4s(^1D)4p^2F^\circ$
		$7/2$	33 278.40	1.146	42	30	$3d^2(^3F)4p^2G^\circ$
$3d^2(^3F)4p$	$^2D^\circ$	$3/2$	33 614.88	0.824	40	30	$3d^2(^3P)4p^2D^\circ$
		$5/2$	33 707.06	1.186	39	30	
$3d^3$	4F	$3/2$	33 763.53	0.395	100		
		$5/2$	33 798.64	1.026	100		
		$7/2$	33 846.59	1.23	100		
		$9/2$	33 906.38	1.33	100		
$3d4s(^3D)5s$	4D	$1/2$	34 390.25	0.00	100		
		$3/2$	34 422.83	1.192	100		
		$5/2$	34 480.00	1.370	100		
		$7/2$	34 567.19	1.43	100		
$3d^2(^3P)4p$	$^2S^\circ$	$1/2$	35 346.35	2.00	100		
$3d4s(^3D)5s$	2D	$3/2$	35 671.04		83	8	$3d^3^2D1$
		$5/2$	35 745.62	1.212	82	12	$3d4s(^1D)5s^2D$
$3d^3$	2D2	$3/2$	36 276.63		40	34	2D1
		$5/2$	36 330.59	1.196	42	35	
$3d^3$	4P	$1/2$	36 492.64	2.634	98		
		$3/2$	36 515.76	1.712	95		
		$5/2$	36 572.77	1.59	96		
$3d^2(^1D)4p$	$^2F^\circ$	$5/2$	36 666.42		84	11	$(^3F)^2F^\circ$
		$7/2$	36 730.12		82	10	
$3d^2(^3P)4p$	$^4D^\circ$	$1/2$	36 764.20	0.016	98		
		$3/2$	36 793.65	1.184	94		
		$5/2$	36 860.20	1.348	94		
		$7/2$	36 959.03		94	4	$(^1D)^2F^\circ$
$3d^2(^1D)4p$	$^2D^\circ$	$3/2$	36 933.91	0.879	58	14	$3d4s(^3D)5p^2D^\circ$
		$5/2$	37 039.57	1.207	59	14	
$3d^3$	2G	$7/2$	36 977.51	0.89	100		
		$9/2$	37 054.51	1.110	99		
$3d^3$	2P	$1/2$	37 085.84	0.682	96		
		$3/2$	37 148.22	1.328	93		
$3d^2(^1D)4p$	$^2P^\circ$	$3/2$	37 086.02	1.278	68	17	$(^3P)^2P^\circ$
		$1/2$	37 125.40		70	17	
$3d^2(^3P)4p$	$^4S^\circ$	$3/2$	37 486.86	1.986	91	9	$^4P^\circ$
$3d4s(^1D)5s$	2D	$3/2$	37 780.87	0.80	66	14	$(^3D)^2D$
		$5/2$	37 855.61	1.18	63	17	
$3d^2(^3P)4p$	$^4P^\circ$	$1/2$	37 877.78	2.662	93	5	$3d4s(^3D)5p^4P^\circ$
		$3/2$	37 908.50	1.731	85	9	$3d^2(^3P)4p^4S^\circ$
		$5/2$	37 964.89	1.58	93	5	$3d4s(^3D)5p^4P^\circ$

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Configuration	Term	J	Level (cm^{-1})	g	Leading percentages		
$3d\ 4s(^3D)4d$	2F	$5/2$	38 871.65	0.855	49	36	4G
		$7/2$	38 959.16	1.14	46	37	4D
$3d^2(^1G)4p$	$^2H^\circ$	$9/2$	39 153.14		98		
		$11/2$	39 248.82		100		
$3d^3$	2H	$9/2$	39 164.11		100		
		$11/2$	39 225.33		100		
$3d^2(^1G)4p$	$^2G^\circ$	$7/2$	39 392.79	0.89	90	10	$(^3F) ^2G^\circ$
		$9/2$	39 423.39		88	10	
$3d\ 4s(^3D)4d$	4D	$1/2$	39 701.44	0.008	96		
		$3/2$	39 721.79	1.203	97		
		$5/2$	39 755.02	1.364	71	26	4G
		$7/2$	39 799.99	1.439	41	47	2F
$3d\ 4s(^3D)4d$	4G	$5/2$	39 861.37	0.555	36	45	2F
		$7/2$	39 902.75	0.968	78	20	4D
		$9/2$	39 957.79	1.17	98		
		$11/2$	40 028.38	1.26	99		
$3d\ 4s(^3D)5p$	$^4F^\circ$	$3/2$	39 949.75		96		
		$5/2$	39 989.58		93	6	$^4D^\circ$
		$7/2$	40 048.72		91	7	
		$9/2$	40 145.90		100		
$3d\ 4s(^3D)5p$	$^4D^\circ$	$1/2$	40 044.63		97		
		$3/2$	40 073.49		95		
		$5/2$	40 128.13		89	6	$^4F^\circ$
		$7/2$	40 210.88		88	8	$^4F^\circ$
$3d\ 4s(^3D)4d$	2P	$3/2$	40 063.38	1.295	76	10	2D
		$1/2$	40 070.30	0.660	94		
$3d\ 4s(^3D)5p$	$^2F^\circ$	$5/2$	40 104.19		76	15	$3d^2(^1G)4p ^2F^\circ$
		$7/2$	40 151.08		75	16	
$3d\ 4s(^3D)4d$	2D	$3/2$	40 257.52	1.305	47	22	$(^3D) ^4S$
		$5/2$	40 334.31	1.196	66	17	$(^1D) ^2D$
$3d\ 4s(^3D)4d$	4S	$3/2$	40 282.16	1.535	72	13	2P
$3d\ 4s(^3D)5p$	$^2D^\circ$	$3/2$	40 347.34		68	16	$3d^2(^1D)4p ^2D^\circ$
		$5/2$	40 351.30		67	15	
$3d\ 4s(^3D)4d$	2G	$7/2$	40 418.55		69	27	$(^1D) ^2G$
		$9/2$	40 562.06		69	27	
$3d\ 4s(^3D)5p$	$^2P^\circ$	$1/2$	40 499.71		77	11	$3d^2(^3P)4p ^2P^\circ$
		$3/2$	40 594.07		72	10	
$3d\ 4s(^3D)4d$	4F	$3/2$	40 521.27	0.401	99		
		$5/2$	40 554.99	1.035	99		
		$7/2$	40 603.95	1.235	99		
		$9/2$	40 670.87	1.336	100		

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	<i>g</i>	Leading percentages		
<i>3d 4s</i> (³ D) <i>5p</i>	⁴ P°	1/2	40 595.28	2.570	94	5	<i>3d</i> ² (³ P) <i>4p</i> ⁴ P°
		3/2	40 644.64	1.687	88	5	<i>3d4s</i> (³ D) <i>5p</i> ² P°
		5/2	40 715.42	1.58	94	5	<i>3d</i> ² (³ P) <i>4p</i> ⁴ P°
<i>3d</i> ³	² F	5/2	40 802.76	0.843	77	22	<i>3d</i> ² (³ F) <i>5s</i> ² F
		7/2	40 825.78	1.140	80	20	
<i>3d</i> ² (³ P) <i>4p</i>	² D°	3/2	41 153.42		46	30	<i>3d4s</i> (¹ D) <i>5p</i> ² D°
		5/2	41 162.52		45	30	
<i>3d 4s</i> (³ D) <i>4d</i>	⁴ P	1/2	41 446.85	2.659	88	5	² S
		3/2	41 474.87	1.725	97		
		5/2	41 505.60	1.60	97		
<i>3d</i> ² (³ F) <i>5s</i>	⁴ F	3/2	41 921.89	0.395	100		
		5/2	41 960.97	1.021	100		
		7/2	42 015.58	1.237	100		
		9/2	42 085.18	1.32	100		
<i>3d 4s</i> (¹ D) <i>4d</i>	² F	5/2	42 149.66		87	8	<i>3d</i> ² (¹ D) <i>4d</i> ² F
		7/2	42 198.84		86	8	
<i>3d 4s</i> (¹ D) <i>4d</i>	² D	5/2	42 445.55		68	22	(³ D) ² D
		3/2	42 466.39	0.802	69	23	
<i>3d 4s</i> (¹ D) <i>5p</i>	² P°	3/2	42 780.41		69	10	(³ D) ² P°
		1/2	42 819.49		67	11	
<i>3d 4s</i> (³ D) <i>4d</i>	² S	1/2	42 877.65	1.991	45	41	(¹ D) ² S
<i>3d</i> ³	² D1	5/2	42 917.83	1.19	44	35	² D2
		3/2	42 937.50	0.78	54	45	
<i>3d 4s</i> (¹ D) <i>5p</i>	² F°	5/2	42 938.79		82	12	<i>3d</i> ² (¹ D) <i>5p</i> ² F°
		7/2	42 978.81		83	12	
<i>3d 4s</i> (¹ D) <i>4d</i>	² G	9/2	42 942.51	1.01	63	30	(³ D) ² G
		7/2	42 969.78	0.93	63	30	
<i>3d 4s</i> (¹ D) <i>5p</i>	² D°	3/2	43 170.45		52	18	<i>3d</i> ² (³ P) <i>4p</i> ² P°
		5/2	43 252.56		51	18	<i>3d</i> ² (³ P) <i>4p</i> ² D°
<i>3d 4s</i> (¹ D) <i>4d</i>	² P	1/2	43 429.68	0.680	87	7	<i>3d</i> ² (¹ D) <i>4d</i> ² P
		3/2	43 435.40	1.336	86	7	
<i>4s</i> ² <i>4d</i>	² D	3/2	43 597.16		85	11	<i>3d4s</i> (³ D) <i>4d</i> ² D
		5/2	43 658.53		86	11	
<i>3d 4s</i> (³ D) <i>6s</i>	⁴ D	1/2	43 809.76	0.009			
		3/2	43 814.47				
		5/2	43 898.31				
		7/2	43 988.20	1.42			
<i>3d</i> ² (¹ G) <i>4p</i>	² F°	5/2	43 830.12	0.845	72	16	<i>3d4s</i> (³ D) <i>5p</i> ² F°
		7/2	43 860.12	1.14	71	17	

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Configuration	Term	<i>J</i>	Level (cm ⁻¹)	<i>g</i>	Leading percentages		
<i>3d</i> (² D) <i>4p</i> ² (³ P)	⁴ P	1/2	44 030.34	2.665			
		3/2	44 107.25	1.726			
		5/2	44 238.23	1.60			
<i>3d</i> ² (³ P) <i>4p</i>	² P°	1/2	44 105.45	0.668	52	16	<i>3d4s</i> (¹ D) <i>5p</i> ² P°
		3/2	44 189.29	1.331	52	15	
<i>3d</i> (² D) <i>4p</i> ² (³ P)	² P	3/2	44 594.97	1.35			
		1/2	44 690.65	0.670			
<i>3d</i> (² D) <i>4p</i> ² (³ P)	⁴ F	3/2	44 823.21	0.399			
		5/2	44 909.55	0.992			
		7/2	45 016.43	1.22			
		9/2	45 125.73	1.33			
<i>3d</i> (² D) <i>4p</i> ² (³ P)	² F	5/2	44 838.56	0.90			
		7/2	44 941.81	1.16			
<i>3d 4s</i> (¹ D) <i>4d</i>	² S	1/2	45 514.98	2.00	49	49	(³ D) ² S
<i>3d</i> (² D) <i>4p</i> ² (³ P)	⁴ D	1/2	45 574.64	0.00			
		3/2	45 605.80	1.188			
		5/2	45 659.09	1.38			
		7/2	45 737.17	1.41			
<i>3d</i> ² (³ F) <i>5p</i>	⁴ G°	5/2	45 610.52		100		
		7/2	45 645.10		100		
		9/2	45 691.26		100		
		11/2	45 761.23		100		
<i>3d</i> ² (³ F) <i>4d</i>	⁴ G	5/2	45 715.79		88	10	² F
		7/2	45 752.28		80	18	⁴ H
		9/2	45 804.10	1.16	79	20	⁴ H
		11/2	45 870.92		82	17	⁴ H
<i>3d 4s</i> (³ D) <i>5d</i>	⁴ D	1/2	45 875.18	0.00			
		3/2	45 900.04	1.183			
		5/2	45 945.09				
		7/2	46 016.63	1.4			
<i>3d</i> ² (³ F) <i>4d</i>	⁴ H	7/2	45 878.06	0.65	82	17	⁴ G
		9/2	45 925.09	1.00	80	20	
		11/2	45 985.91	1.14	83	16	
		13/2	46 054.28	1.21	100		
<i>3d 4s</i> (³ D) <i>5d</i>	⁴ G	5/2	45 886.66	0.62			
		7/2	45 931.16	0.97			
		9/2	45 988.93	1.08			
		11/2	46 053.54	1.24			
		3/2	45 898.61				
<i>3d</i> ² (³ F) <i>4d</i>	⁴ D	1/2	45 927.81	0.00	97		
		3/2	45 947.35		97		
		5/2	45 983.23	1.33	96		
		7/2	46 042.69	1.43	91	7	² F

Configuration	Term	J	Level (cm^{-1})	g	Leading percentages	
$3d^2(^3F)5p$	$^4F^\circ$	$3/2$	46 206.80		100	
		$5/2$	46 255.40		99	
		$7/2$	46 266.21		99	
		$9/2$	46 369.23		100	
$3d\ 4s(^3D)5d$	4F	$3/2$	46 329.23	0.44		
		$5/2$	46 354.41	1.02		
		$7/2$	46 403.30	1.23		
		$9/2$	46 458.64	1.31		
	2F	$5/2$	46 378.86	0.86		
		$7/2$	46 459.66	1.14		
	$3d^2(^3F)5p$	$^4D^\circ$	$1/2$	46 485.47		100
			$3/2$	46 517.55		99
$5/2$			46 570.25		98	
$7/2$			46 641.64		97	
4P		$5/2$	46 623.54	1.60		
		$3/2$	46 914.54	0.88		
2D		$5/2$	46 989.52	1.13		
		$3/2$	47 229.54		84	
$3d^2(^3F)5p$		$^2D^\circ$	$5/2$	47 314.53		84
			$3/2$	47 375.66		
$3d\ 4s(^3D)7s$	2D	$5/2$	47 425.46			
		$3/2$	47 475.90			
$3d\ 4s(^3D)7s$	4D	$1/2$	47 475.90			
		$3/2$	47 507.39			
		$5/2$	47 563.31			
		$7/2$	47 652.61			
	4P	$1/2$	47 488.72			
		$3/2$	47 535.78			
		$5/2$	47 604.59			
	2G	$7/2$	47 514.22			
		$9/2$	47 589.73			
	4P	$3/2$	48 324.66	1.73		
		$5/2$	48 373.17	1.6		
	$3d\ 4s(^1D)7p$	4P	$1/2$	48 830.11	2.64	
			$3/2$	48 869.56	1.73	
			$5/2$	48 920.60	1.59	
$3d\ 4s(^1D)7p$	$^2P^\circ$	$3/2$	51 110.61			
Sc II $3d4s(^3D_1)$	<i>Limit</i>		52 922.0			
$3d\ 4s(^1D)9p$	$^2D^\circ$	$3/2, 5/2$	53 162.8			
$3d\ 4s(^1D)9p$	$^2P^\circ$	$3/2$	53 222.9			
$3d^2(^3F_3)7p$	$^2F^\circ$	$5/2, 7/2$	53 692.6			

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Configuration	Term	J	Level (cm^{-1})	g	Leading percentages
$3d\ 4s(^1D)10p$	$^2D^\circ$	$3/2, 5/2$	53 706.4		
$3d\ 4s(^1D)10p$	$^2P^\circ$	$3/2$	53 784.		
$3d\ 4s(^1D)11p$	$^2D^\circ$	$3/2, 5/2$	54 080.0		
$3d\ 4s(^1D)11p$	$^2P^\circ$	$3/2$	54 111.8		
$3d\ 4s(^1D)12p$	$^2D^\circ$	$3/2, 5/2$	54 343.6		
$3d\ 4s(^1D)12p$	$^2P^\circ$	$3/2$	54 366.6		
$3d\ 4s(^1D)13p$	$^2D^\circ$	$3/2, 5/2$	54 539.3		
$3d\ 4s(^1D)13p$	$^2P^\circ$	$1/2$ $3/2$	54 553.4 54 556.6		
$3d\ 4s(^1D)14p$	$^2D^\circ$	$3/2, 5/2$	54 687.6		
$3d\ 4s(^1D)14p$	$^2P^\circ$	$3/2$	54 712.1		
$3d\ 4s(^1D)15p$	$^2D^\circ$	$3/2, 5/2$	54 803.2		
$3d\ 4s(^1D)15p$	$^2P^\circ$	$3/2$	54 822.0		
$3d\ 4s(^1D)16p$	$^2D^\circ$	$3/2, 5/2$	54 895.0		
$3d^2(^3F_3)8p$	$^2F^\circ$	$5/2, 7/2$	54 903.5		
$3d\ 4s(^1D)16p$	$^2P^\circ$	$1/2$ $3/2$	54 906.2 54 908.4		
$3d\ 4s(^1D)17p$	$^2D^\circ$	$3/2, 5/2$	54 971.4		
$3d\ 4s(^1D)18p$	$^2D^\circ$	$3/2, 5/2$	55 030.7		
$3d\ 4s(^1D)18p$	$^2P^\circ$	$1/2$ $3/2$	55 036.4 55 038.2		
$3d\ 4s(^1D)19p$	$^2P^\circ$	$1/2$ $3/2$	55 084.2 55 086.0		
$3d\ 4s(^1D)20p$	$^2P^\circ$	$1/2$ $3/2$	55 125.0 55 126.6		
$3d\ 4s(^1D)21p$	$^2P^\circ$	$1/2$ $3/2$	55 159.2 55 160.8		
$3d\ 4s(^1D)22p$	$^2P^\circ$	$3/2$	55 190.2		
$3d\ 4s(^1D)23p$	$^2P^\circ$	$1/2$ $3/2$	55 214.3 55 215.4		
$3d\ 4s(^1D)24p$	$^2P^\circ$	$1/2$ $3/2$	55 236.3 55 237.4		
$3d\ 4s(^1D)25p$	$^2P^\circ$	$1/2$ $3/2$	55 255.6 55 256.2		

Configuration	Term	J	Level (cm^{-1})	g	Leading percentages
3d 4s(¹ D)26p	² P°	1/2	55 272.6		
		3/2	55 273.1		
3d 4s(¹ D)27p	² P°	1/2	55 287.4		
		3/2	55 288.0		
3d 4s(¹ D)28p	² P°	3/2	55 301.2		
3d 4s(¹ D)29p	² P°	3/2	55 312.6		
3d 4s(¹ D)30p	² P°	3/2	55 323.2		
3d 4s(¹ D)31p	² P°	3/2	55 332.8		
3d 4s(¹ D)32p	² P°	3/2	55 341.4		
3d 4s(¹ D)33p	² P°	3/2	55 349.0		
3d 4s(¹ D)34p	² P°	3/2	55 356.8		
3d 4s(¹ D)35p	² P°	3/2	55 362.8		
3d 4s(¹ D)36p	² P°	3/2	55 368.7		
3d 4s(¹ D)37p	² P°	3/2	55 373.6		
3d 4s(¹ D)38p	² P°	3/2	55 378.1		
Sc II 3d4s(¹ D)	Limit		55 463		
3d ² (³ F)9p	² F°?	5/2, 7/2	55 657.3		
3d ² (³ F)10p	² F°?	5/2, 7/2	56 147.0		
3d ² (³ F)11p	² F°?	5/2, 7/2	56 486.9		
3d ² (³ F)12p	² F°?	5/2, 7/2	56 733.2		
3d ² (³ F)13p	² F°?	5/2, 7/2	56 916.3		
3d ² (³ F)14p	² F°?	5/2, 7/2	57 057.2		
3d ² (³ F)15p	² F°?	5/2, 7/2	57 167.5		
4s ² 4f	² F°	7/2	57 485.7		
		5/2	57 503.9		
Sc II 3d ² (³ F ₃)	Limit		57 805		
4s ² 5f	² F°	5/2, 7/2	60 090.4		
4s ² 6f	² F°	5/2, 7/2	61 498.0		
4s ² 7f	² F°	5/2, 7/2	62 343.8		
4s ² 8f	² F°	5/2, 7/2	62 886.2		
4s ² 9f	² F°	5/2, 7/2	63 267.0		
4s ² 10f	² F°	5/2, 7/2	63 533.2		
4s ² 11f	² F°	5/2, 7/2	63 729.6		
4s ² 12f	² F°	5/2, 7/2	63 878.6		
4s ² 13f	² F°	5/2, 7/2	63 993.8		
4s ² 14f	² F°	5/2, 7/2	64 086.2		
4s ² 15f	² F°	5/2, 7/2	64 160.4		
4s ² 17f	² F°	5/2, 7/2	64 271.2		
4s ² 18f	² F°	5/2, 7/2	64 312.4		
4s ² 19f	² F°	5/2, 7/2	64 348.0		
4s ² 20f	² F°	5/2, 7/2	64 378.3		
4s ² 21f	² F°	5/2, 7/2	64 404.8		
4s ² 22f	² F°	5/2, 7/2	64 426.6		
4s ² 23f	² F°	5/2, 7/2	64 445.8		
Sc II 4s ² (¹ S)	Limit		64 658		

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Z=21

Ca I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d 4s \ ^3D_1$ Ionization energy = $103\,237.1 \pm 2 \text{ cm}^{-1}$ ($12.79987 \pm 0.0002 \text{ eV}$)

The first extensive analysis of Sc II was reported by Russell and Meggers (1927). They classified 142 lines in the range 2540 to 6600 Å as combinations among 53 energy levels of eight configurations. Many of these levels were determined to better accuracy by Neufeld (1970). Neufeld also provided *g*-values for 18 levels.

Johansson and Litzén (1979) have reobserved the spectrum from 1100 to 10 000 Å with a pulsed hollow cathode. They extended the analysis and redetermined the level values. Their results are quoted below.

Roth (1969) calculated the composition of the $3d4p$ configuration. Wyart has calculated $3d4p$, $3d5p$, $3d4f$, $3d5f$,

and $4s4p$ with configuration interaction. His results, as reported by Johansson and Litzén, are given here.

The ionization energy was derived by Johansson and Litzén from a polarization formula.

References

- Johansson, S. and Litzén, V. (1980), Phys. Scr. (to be published).
 Neufeld, L. W. (1970), Dissertation, Kansas State Univ.
 Roth, C. (1969), J. Res. Nat. Bur. Stand. (U.S.) **73A**, 159.
 Russell, H. N., and Meggers, W. F. (1927), Sci. Papers Bur. Stand. **22**, 329.

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Configuration	Term	<i>J</i>	Level (cm^{-1})	<i>g</i>	Leading percentages	
$3d\ 4s$	3D	1	0.00	0.501		
		2	67.72	1.163		
		3	177.76	1.330		
$3d\ 4s$	1D	2	2 540.95	0.998		
$3d^2$	3F	2	4 802.87	0.665		
		3	4 883.57	1.083		
		4	4 987.79			
$3d^2$	1D	2	10 944.56			
$4s^2$	1S	0	11 736.36			
$3d^2$	3P	0	12 074.10			
		1	12 101.50	1.487		
		2	12 154.42	1.481		
$3d^2$	1G	4	14 261.32			
$3d^2$	1S	0	25 955.2			
$3d\ 4p$	$^1D^\circ$	2	26 081.34	0.999	99	
$3d\ 4p$	$^3F^\circ$	2	27 443.71	0.671	99	
		3	27 602.45	1.086	99	
		4	27 841.35	1.233	100	
$3d\ 4p$	$^3D^\circ$	1	27 917.78	0.506	100	
		2	28 021.29	1.162	99	
		3	28 161.17	1.323	99	
$3d\ 4p$	$^3P^\circ$	0	29 736.27		94	
		1	29 742.16	1.484	92	
		2	29 823.93	1.495	94	
					6	$4s4p\ ^3P^\circ$
					6	
					6	

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	<i>g</i>	Leading percentages		
3 <i>d</i> 4 <i>p</i>	¹ P°	1	30 815.70	1.006	93	5	4 <i>s</i> 4 <i>p</i> ¹ P°
3 <i>d</i> 4 <i>p</i>	¹ F°	3	32 349.98		100		
4 <i>s</i> 4 <i>p</i>	³ P°	0	39 002.20		94	6	3 <i>d</i> 4 <i>p</i> ³ P°
		1	39 115.04		94	6	
		2	39 345.52		94	6	
4 <i>s</i> 4 <i>p</i>	¹ P°	1	55 715.36		91	5	3 <i>d</i> 4 <i>p</i> ¹ P°
3 <i>d</i> 5 <i>s</i>	³ D	1	57 551.88				
		2	57 614.40				
		3	57 743.92				
3 <i>d</i> 5 <i>s</i>	¹ D	2	58 252.09				
3 <i>d</i> 4 <i>d</i>	¹ F	3	59 528.42				
3 <i>d</i> 4 <i>d</i>	³ D	1	59 875.08				
		2	59 929.46				
		3	60 001.91				
3 <i>d</i> 4 <i>d</i>	³ G	3	60 267.16				
		4	60 348.46				
		5	60 457.12				
3 <i>d</i> 4 <i>d</i>	¹ P	1	60 400.41				
3 <i>d</i> 4 <i>d</i>	³ S	1	61 071.43				
3 <i>d</i> 4 <i>d</i>	³ F	2	63 374.63				
		3	63 445.16				
		4	63 528.54				
3 <i>d</i> 4 <i>d</i>	¹ D	2	64 366.68				
3 <i>d</i> 4 <i>d</i>	³ P	0	64 615.77				
		1	64 646.70				
		2	64 705.89				
3 <i>d</i> 4 <i>d</i>	¹ G	4	65 236.04				
3 <i>d</i> 5 <i>p</i>	¹ D°	2	66 048.39		94	3	³ F°
3 <i>d</i> 5 <i>p</i>	³ D°	1	66 389.74		100		
		2	66 492.66		60	35	³ F°
		3	66 583.86		78	22	³ F°
3 <i>d</i> 5 <i>p</i>	³ F°	2	66 459.64		62	37	³ D°
		3	66 563.73		78	22	³ D°
		4	66 718.99		100		
3 <i>d</i> 4 <i>d</i>	¹ S	0	67 216.56				
3 <i>d</i> 5 <i>p</i>	³ P°	0	67 236.7		100		
		1	67 297.68		99		
		2	67 396.19		100		

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Sc II

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	<i>g</i>	Leading percentages		
3d 5p	¹ F°	3	67 743.72		100		
3d 5p	¹ P°	1	68 498.06		95	4	4s4p ¹ P°
4p ²	¹ D	2	74 433.3				
3d4f	¹ G°	4	75 221.47		71	15	³ G°
3d4f	³ F°	2	75 308.13		89	8	¹ D°
		3	75 373.10		43	28	³ G°
		4	75 470.24		65	22	³ G°
3d4f	³ G°	3	75 308.70		58	40	³ F°
		4	75 390.49		43	20	³ F°
		5	75 471.25		79	18	³ H°
3d4f	¹ F°	3	75 552.46		65	15	³ F°
3d4f	³ H°	4	75 561.00		71	22	³ G°
		5	75 610.83		76	21	³ G°
		6	75 699.88		100		
3d4f	¹ D°	2	75 590.84		76	14	³ D°
3d4f	³ D°	1	75 650.90		92	4	¹ P°
		2	75 680.69		76	14	¹ D°
		3	75 715.75		83	14	¹ D°
3d4f	³ P°	2	75 912.58		90	7	³ D°
		1	75 951.88		77	16	¹ P°
		0	75 994.43		100		
3d4f	¹ H°	5	75 919.75		94	6	³ H°
3d4f	¹ P°	1	76 073.28		79	19	³ P°
4p ²	³ P	0	76 243.2				
		1	76 360.8				
		2	76 589.3				
3d 6s	³ D	1	77 195.19				
		2	77 256.99				
		3	77 387.17				
3d 6s	¹ D	2	77 833.88				
4s5s	³ S	1	78 265.7				
3d 5d	¹ F	3	78 394.05				
3d 5d	³ D	1	78 479.25				
		2	78 539.96				
		3	78 612.48				
3d 5d	³ G	3	78 648.06				
		4	78 713.21				
		5	78 820.24				

Configuration	Term	<i>J</i>	Level (cm^{-1})	<i>g</i>	Leading percentages		
3d 5d	¹ P	1	78 757.46				
3d 5d	³ S	1	79 174.74				
3d 5d	³ F	2	79 852.02				
		3	79 925.59				
		4	80 001.24				
3d 5d	¹ D	2	80 395.38				
3d 5d	¹ G	4	80 711.71				
3d 5d	³ P	0	80 974.94				
		1	81 040.25				
		2	81 103.75				
4s5s	¹ S	0	81 121.77				
4s4d	³ D	1	82 791.8				
		2	82 806.3				
		3	82 828.3				
3d5f	¹ G°	4	85 353.96		58	20	³ F°
3d5f	³ G°	3	85 405.39		50	46	³ F°
		4	85 605.99		59	20	³ F°
		5	85 636.05		70	29	³ H°
3d5f	³ H°	4	85 445.35		69	21	³ G°
		5	85 504.42		61	28	¹ H°
		6	85 666.26		100		
3d5f		3	85 452.99		31	¹ F°	25 ³ F°
3d5f	¹ D°	2	85 558.24		40	31	³ D°
3d5f	³ F°	4	85 580.3		56	30	¹ G°
3d(² D _{3/2})5g	² [⁹ / ₂]	5	85 587.87				
		4	85 588.17				
3d5f	³ D°	1	85 591.59		75	14	¹ P°
		2	85 661.0		41	39	¹ D°
		3	85 700.7		71	24	¹ F°
3d(² D _{3/2})5g	² [⁷ / ₂]	3	85 611.4				
		4	85 611.55				
3d5f	¹ F°	3	85 622.6		44	25	³ F°
3d(² D _{3/2})5g	² [¹¹ / ₂]	5	85 659.66				
		6	85 660.42				
3d(² D _{3/2})5g	² [⁵ / ₂]	2,3	85 688.9				
3d5f	³ P°	2	85 778.78		70	23	³ D°
		1	85 800.62		65	22	³ D°
		0	85 832.20		100		

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Sc II

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	<i>g</i>	Leading percentages
3d(² D _{5/2})5g	² [⁹ / ₂]	5	85 788.01		
		4	85 788.22		
3d(² D _{5/2})5g	² [¹¹ / ₂]	5	85 803.40		
		6	85 804.11		
3d5f	¹ H°	5	85 817.40		89 10 ³ H°
3d(² D _{5/2})5g	² [⁷ / ₂]	3	85 819.8		
		4	85 820.00		
3d(² D _{5/2})5g	² [⁵ / ₂]	2,3	85 867.9		
3d(² D _{5/2})5g	² [¹³ / ₂]	7	85 877.52		
		6	85 878.48		
3d(² D _{5/2})5g	² [³ / ₂]	1,2	85 915.9		
3d7s	³ D	1	86 557.7		
		2	86 607.5		
		3	86 751.0		
3d6d	³ G	3	87 233.09		
		4	87 295.23		
		5	87 405.48		
3s4d	¹ D	2	89 940.27		
3d6f	³ G°	3	90 821.1		
		4	91 074.4		
		5	91 094.7		
3d6f	³ H°	5	90 937.9		
3d6f	³ F°	4	91 062.5		
3d6f	¹ F°	3	91 083.4		
3d6f	³ D°	3	91 128.0		
3d6f	³ P°	2	91 165.0		
3d6f	¹ H°	5	91 197.0		
Sc III (² D _{3/2})	<i>Limit</i>		103 237.1		

Sc III

Z=21

K I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 D_{3/2}$ Ionization energy = $199\,677.37 \pm 0.1 \text{ cm}^{-1}$ ($24.75704 \pm 0.00005 \text{ eV}$)

The early work on Sc III was reported by Gibbs and White (1926), Smith (1927), and Russell and Lang (1927).

Two modern analyses of Sc III were published by Holmstrom (1972) and Van Deurzen, Conway, and Davis (1973). Holmstrom lists 64 observed lines between 557 and 8882 Å. He states the accuracy of his level values to be $\pm 0.4 \text{ cm}^{-1}$. Van Deurzen, Conway, and Davis observed 93 lines between 557 and 9371 Å. Their level values are stated to be accurate to less than 0.1 cm^{-1} . This compilation is taken from Van Deurzen et al. except for the 2H terms given only by Holmstrom. They are derived here from Holmstrom's lines and the levels of Van Deurzen et al.

Van Deurzen et al. calculated the ionization energy from

four members ($n=5-8$) of the ng series. Their value agrees with the value calculated by Holmstrom with a polarization formula. The uncertainty in eV is determined by the uncertainty in the conversion factor.

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Sc III

Configuration	Term	<i>J</i>	Level (cm^{-1})	Configuration	Term	<i>J</i>	Level (cm^{-1})
$3p^6(^1S)3d$	2D	$3/2$	0.00	$3p^6(^1S)6d$	2D	$3/2$	165 592.55
		$5/2$	197.64			$5/2$	165 603.29
$3p^6(^1S)4s$	2S	$1/2$	25 539.32	$3p^6(^1S)7s$	2S	$1/2$	166 157.17
$3p^6(^1S)4p$	$^2P^\circ$	$1/2$	62 104.30	$3p^6(^1S)7p$	$^2P^\circ$	$1/2$	169 637.96
		$3/2$	62 578.18			$3/2$	169 685.9
$3p^6(^1S)4d$	2D	$3/2$	112 257.62	$3p^6(^1S)6f$	$^2F^\circ$	$5/2, 7/2$	171 787.64
		$5/2$	112 302.95			$7/2, 9/2$	172 177.41
$3p^6(^1S)5s$	2S	$1/2$	114 862.48	$3p^6(^1S)6g$	2G	$7/2, 9/2$	172 224.57
$3p^6(^1S)5p$	$^2P^\circ$	$1/2$	128 107.12	$3p^6(^1S)6h$	$^2H^\circ$	$9/2, 11/2$	175 457.03
		$3/2$	128 283.15			$5/2$	175 463.56
$3p^6(^1S)4f$	$^2F^\circ$	$5/2$	136 873.87	$3p^6(^1S)7d$	2D	$3/2$	175 795.73
		$7/2$	136 874.12			$5/2$	179 214.70
$3p^6(^1S)5d$	2D	$3/2$	148 130.03	$3p^6(^1S)8s$	2S	$1/2$	179 477.24
		$5/2$	148 150.14			$7/2, 9/2$	179 508.37
$3p^6(^1S)6s$	2S	$1/2$	149 194.03	$3p^6(^1S)7g$	2G	$7/2, 9/2$	184 214.61
$3p^6(^1S)6p$	$^2P^\circ$	$1/2$	155 489.78			$3p^6(^1S)7h$	$^2H^\circ$
		$3/2$	155 575.20	$7/2, 9/2$			
$3p^6(^1S)5f$	$^2F^\circ$	$5/2, 7/2$	159 472.24	$3p^6(^1S)8g$	2G	$7/2, 9/2$	
$3p^6(^1S)5g$	2G	$7/2, 9/2$	160 072.18			Sc IV (1S_0)	Limit

Sc IV

Z=21

Ar I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 \ ^1S_0$ Ionization energy = $592\,732 \pm 3 \text{ cm}^{-1}$ ($73.4900 \pm 0.0004 \text{ eV}$)

Four resonance lines were classified by Kruger, Weissberg, and Phillips (1937). Smitt (1973) has carried out the extensive analysis quoted here, which confirmed only two of the four resonance lines. The uncertainty of his level values is estimated to be $\pm 2 \text{ cm}^{-1}$. He calculated the ionization energy with a polarization formula.

The $3s3p^5p \ ^1P^\circ$ term was observed by Kastner, Crooker, Behring, and Cohen (1977) in absorption in a high voltage spark.

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Sc IV

Configuration	Term	J	Level (cm ⁻¹)	Configuration	Term	J	Level (cm ⁻¹)
$3s^2 3p^6$	1S	0	0.0	$3s^2 3p^5 4p$	1D	2	384 661.3
$3s^2 3p^5 3d$	$^3P^\circ$	0	239 723.2	$3s^2 3p^5 4p$	1S	0	397 510.7
		1	240 403.0	$3s3p^6 3d$	3D	1	429 695.7
		2	241 814.0			2	429 842.4
		3	430 078.5				
$3s^2 3p^5 3d$	$^3F^\circ$	4	250 708.2	$3s^2 3p^5 4d$	$^3P^\circ$	0	440 517.9
		3	252 108.3			1	440 983.0
		2	253 405.7			2	441 927.3
$3s^2 3p^5 3d$	$^1D^\circ$	2	267 424.4				
$3s^2 3p^5 3d$	$^3D^\circ$	3	268 034.2	$3s3p^6 3d$	1D	2	442 046.0
		1	269 426.5	$3s^2 3p^5 4d$	$^3F^\circ$	4	442 558.6
		2	269 459.9			3	443 191.3
		2	444 427.4				
$3s^2 3p^5 3d$	$^1F^\circ$	3	271 055.4				
$3s^2 3p^5 4s$	$^3P^\circ$	2	333 090.8	$3s^2 3p^5 4d$	$^3D^\circ$	3	445 207.5
		1	334 405.1			1	447 622.4
		0	337 340.1			2	448 725.1
$3s^2 3p^5 4s$	$^1P^\circ$	1	337 483.5	$3s^2 3p^5 4d$	$^1D^\circ$	2	448 062.0
$3s^2 3p^5 3d$	$^1P^\circ$	1	345 005.4	$3s^2 3p^5 4d$	$^1F^\circ$	3	448 607.8
$3s^2 3p^5 4p$	3S	1	371 735.2	$3s^2 3p^5 4d$	$^1P^\circ$	1	453 972.7
$3s^2 3p^5 4p$	3D	3	378 077.0	$3s^2 3p^5 (^2P_{3/2}^\circ) 5s$	$^2[3/2]^\circ$	2	459 496.9
		2	378 418.6			1	460 426.9
		1	380 148.3	$3s^2 3p^5 (^2P_{1/2}^\circ) 5s$	$^2[1/2]^\circ$	0	463 768.9
		1	464 457.2				
$3s^2 3p^5 4p$	3P	2	381 712.0	$3s^2 3p^5 (^2P_{3/2}^\circ) 5p$	$^2[1/2]$	1	474 764.4
		0	384 817.8			0	480 286.6
		1	385 570.0				
$3s^2 3p^5 4p$	1P	1	383 527.1				

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	Configuration	Term	<i>J</i>	Level (cm ⁻¹)
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 5p$	$2[{}^5_2]$	3	476 818.5	$3s^2 3p^5 ({}^2P_{1/2}^\circ) 7s$	$2[{}^1_2]^\circ$	1	542 052
		2	477 018.0			$3s^2 3p^5 ({}^2P_{3/2}^\circ) 6g$	$2[{}^5_2]^\circ$
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 5p$	$2[{}^3_2]$	1	477 746.6	$3s^2 3p^5 ({}^2P_{3/2}^\circ) 6g$	$2[{}^{11}_2]^\circ$		
		2	478 213.2			$3s^2 3p^5 ({}^2P_{3/2}^\circ) 6g$	$2[{}^7_2]^\circ$
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 4f$	$2[{}^3_2]$	1	478 495.9	$3s^2 3p^5 ({}^2P_{3/2}^\circ) 6h$	$2[{}^7_2]$		
		2	478 767.7			4	543 843.6
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 4f$	$2[{}^9_2]$	5	478 609.5	$3s^2 3p^5 ({}^2P_{3/2}^\circ) 6h$	$2[{}^{13}_2]$	6,7	543 869.8
		4	478 768.4			$3s^2 3p^5 ({}^2P_{3/2}^\circ) 6g$	$2[{}^9_2]^\circ$
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 4f$	$2[{}^5_2]$	3	479 452.9	5	543 893.3		
		2	480 097.9	$3s^2 3p^5 ({}^2P_{3/2}^\circ) 6h$	$2[{}^9_2]$	4,5	543 942.1
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 4f$	$2[{}^7_2]$	3	479 908.9			$3s^2 3p^5 ({}^2P_{3/2}^\circ) 6h$	$2[{}^{11}_2]$
		4	479 933.2	$3s^2 3p^5 ({}^2P_{1/2}^\circ) 6g$	$2[{}^9_2]^\circ$		
$3s^2 3p^5 ({}^2P_{1/2}^\circ) 5p$	$2[{}^3_2]$	1	481 377.4			$3s^2 3p^5 ({}^2P_{1/2}^\circ) 6g$	$2[{}^7_2]^\circ$
		2	481 975.2	$3s^2 3p^5 ({}^2P_{1/2}^\circ) 6h$	$2[{}^{11}_2]$		
$3s^2 3p^5 ({}^2P_{1/2}^\circ) 5p$	$2[{}^1_2]$	1	481 939.9			$3s^2 3p^5 ({}^2P_{1/2}^\circ) 6g$	$2[{}^9_2]$
		0	484 972.9	$3s^2 3p^5 ({}^2P_{1/2}^\circ) 6h$	$2[{}^{13}_2]$		
$3s^2 3p^5 ({}^2P_{1/2}^\circ) 4f$	$2[{}^7_2]$	3	483 609.4			$3s^2 3p^5 ({}^2P_{3/2}^\circ) 7i$	$2[{}^9_2]^\circ$
		4	483 708.0	$3s^2 3p^5 ({}^2P_{3/2}^\circ) 7i$	$2[{}^{15}_2]^\circ$		
$3s^2 3p^5 ({}^2P_{1/2}^\circ) 4f$	$2[{}^5_2]$	3	483 962.8			$3s^2 3p^5 ({}^2P_{3/2}^\circ) 7h$	$2[{}^9_2]$
		2	484 257.6	$3s^2 3p^5 ({}^2P_{3/2}^\circ) 7i$	$2[{}^{11}_2]^\circ$		
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 6s$	$2[{}^3_2]^\circ$	2	511 228.2			$3s^2 3p^5 ({}^2P_{3/2}^\circ) 7h$	$2[{}^{11}_2]$
		1	511 630.3	$3s^2 3p^5 ({}^2P_{3/2}^\circ) 7i$	$2[{}^{13}_2]^\circ$		
$3s^2 3p^5 ({}^2P_{1/2}^\circ) 6s$	$2[{}^1_2]^\circ$	1	515 738			$3s^2 3p^5 ({}^2P_{1/2}^\circ) 7h$	$2[{}^{11}_2]$
		$3s^2 3p^5 ({}^2P_{3/2}^\circ) 5g$	$2[{}^5_2]^\circ$	2	521 999.2		
3	522 004.8			$3s^2 3p^5 ({}^2P_{1/2}^\circ) 7i$	$2[{}^{11}_2]^\circ$	5,6	561 213.9
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 5g$	$2[{}^{11}_2]^\circ$	6	522 110.2			$3s^2 3p^5 ({}^2P_{1/2}^\circ) 7i$	$2[{}^{13}_2]^\circ$
		5	522 110.7	Sc V (${}^2P_{3/2}^\circ$)	Limit		
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 5g$	$2[{}^7_2]^\circ$	4	522 304.5			$3s 3p^6 5p$	${}^1P^\circ$
		3	522 307.3				
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 5g$	$2[{}^9_2]^\circ$	4	522 424.8				
		5	522 425.7				
$3s^2 3p^5 ({}^2P_{1/2}^\circ) 5g$	$2[{}^9_2]^\circ$	4	526 561.6				
		5	526 563.1				
$3s^2 3p^5 ({}^2P_{1/2}^\circ) 5g$	$2[{}^7_2]^\circ$	4	526 571.2				
		3	526 574.0				
$3s^2 3p^5 ({}^2P_{3/2}^\circ) 7s$	$2[{}^3_2]^\circ$	1	537 845				

Sc V

Z=21

Cl I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^5 \ ^2P_{3/2}^\circ$ Ionization energy = 741 000 cm^{-1} (91.9 eV)

Measurements by Beckman (1937) ($\pm 10 \text{ cm}^{-1}$) and by Kruger and Phillips (1937) ($\pm 5 \text{ cm}^{-1}$) between 220 and 590 Å in Sc V established the $3s^2 3p^5$, $3s 3p^6$, and $3s^2 3p^4 4s$ configurations. The level values given here for the $3s^2 3p^4 4s$ configuration are averages of their determinations. For the $^4P_{5/2}$ and $^4P_{1/2}$ levels, the values of Kruger and Phillips are not in accord with the isoelectronic sequence and are not used.

The values for $3s^2 3p^5 \ ^2P^\circ$ and $3s 3p^6 \ ^2S$ are from Smitt (1973) ($\pm 0.8 \text{ cm}^{-1}$). The $3p^4(^3P)3d$ terms are taken from Svensson and Ekberg (1968) ($\pm 10 \text{ cm}^{-1}$) and the $3p^4(^1D)3d$ terms from Fawcett and Gabriel (1966) ($\pm 20 \text{ cm}^{-1}$). The $3p^4 5s$ terms were identified by Fawcett, Peacock, and Cowan

(1968), whose measurements at 180 Å are stated to be accurate to 0.03 Å ($\pm 90 \text{ cm}^{-1}$).

The ionization energy was determined by extrapolation by Lotz (1967).

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Sc v

Configuration	Term	<i>J</i>	Level (cm^{-1})	Configuration	Term	<i>J</i>	Level (cm^{-1})
$3s^2 3p^5$	$^2P^\circ$	$\frac{3}{2}$	0.0	$3s^2 3p^4(^3P)4s$	4P	$\frac{5}{2}$	386 387
		$\frac{1}{2}$	4 325.6			$\frac{3}{2}$	388 862
$3s 3p^6$	2S	$\frac{1}{2}$	174 412.0	$3s^2 3p^4(^3P)4s$	2P	$\frac{3}{2}$	395 498
$3s^2 3p^4(^3P)3d$	2P	$\frac{1}{2}$	254 638			$\frac{1}{2}$	398 440
		$\frac{3}{2}$	257 284	$3s^2 3p^4(^1D)4s$	2D	$\frac{5}{2}$	410 046
$3s^2 3p^4(^3P)3d$	2D	$\frac{3}{2}$	264 077			$\frac{3}{2}$	410 122
		$\frac{5}{2}$	266 633	$3s^2 3p^4(^1S)4s$	2S	$\frac{1}{2}$	437 508
$3s^2 3p^4(^1D)3d$	2S	$\frac{1}{2}$	337 650			$3s^2 3p^4(^3P)5s$	2P
$3s^2 3p^4(^1D)3d$	2P	$\frac{3}{2}$	345 320	$\frac{3}{2}$	552 600		
		$\frac{1}{2}$	346 890	$3s^2 3p^4(^1D)5s$	2D	$\frac{5}{2}$	556 020
$3s^2 3p^4(^1D)3d$	2D	$\frac{3}{2}$	355 880			$\frac{3}{2}$	557 400
		Sc VI (3P_2)	<i>Limit</i>	741 000			

Sc VI

Z=21

S I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^4 \ ^3P_2$ Ionization energy = $892\,700 \pm 400 \text{ cm}^{-1}$ ($110.68 \pm 0.05 \text{ eV}$)

The analysis of Sc VI was initiated by Beckman (1937) and by Kruger and Pattin (1937), who reported terms of the $3s^2 3p^4$, $3s 3p^5$, and $3s^2 3p^3 4s$ configurations. The $3s 3p^5 \ ^1P^\circ$ term was found by Edlén (1942).

The $3s^2 3p^3 3d$ configuration was observed by Svensson and Ekberg (1968) and the level values given here (with an uncertainty of about $\pm 5 \text{ cm}^{-1}$) are derived from their observations.

The values for the two lower configurations ($3s^2 3p^4$ and $3s 3p^5$) are from the more accurate observations of Smitt, Svensson and Outred (1976).

The $3p^3 4s$ levels are derived from Beckman ($\pm 5 \text{ cm}^{-1}$) and the $3p^3 4d$ and $5s$ levels are from Fawcett, Peacock, and Cowan (1968) ($\pm 100 \text{ cm}^{-1}$). Fawcett, Cowan, and Hayes (1972) have observed transitions in the $3p^3 3d-3p^3 4f$ array,

but they are not connected with the present system.

We derived the ionization energy from the $3p^3(^4S^\circ)4s$ and $5s \ ^3S^\circ$ terms, adopting a value for the change in the effective quantum number between them of 1.0247 obtained from the $3p^6 ns$ terms of Cr VI from the analysis of Ekberg (1973).

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Sc VI

Configuration	Term	J	Level (cm ⁻¹)	Configuration	Term	J	Level (cm ⁻¹)		
$3s^2 3p^4$	3P	2	0.0	$3s^2 3p^3(^2P^\circ)3d$	$^1P^\circ$	1	403 098		
		1	3 346.1			$3s^2 3p^3(^4S^\circ)4s$	$^3S^\circ$	1	452 070
		0	4 457.1						
$3s^2 3p^4$	1D	2	21 393.0	$3s^2 3p^3(^2D^\circ)4s$	$^3D^\circ$			1	472 402
						2	472 566		
$3s^2 3p^4$	1S	0	49 224.6			3	473 001		
$3s 3p^5$	$^3P^\circ$	2	175 346.6	$3s^2 3p^3(^2D^\circ)4s$	$^1D^\circ$	2	478 354		
		1	178 202.1			$3s^2 3p^3(^2P^\circ)4s$	$^3P^\circ$	0	491 820
		0	179 784.5					1	492 086
$3s 3p^5$	$^1P^\circ$	1	224 470.4	2	492 800				
$3s^2 3p^3(^2D^\circ)3d$	$^1D^\circ$	2	288 026	$3s^2 3p^3(^2P^\circ)4s$	$^1P^\circ$	1	497 990		
$3s^2 3p^3(^2D^\circ)3d$	$^1F^\circ$	3	323 226	$3s^2 3p^3(^4S^\circ)4d$	$^3D^\circ$	1-3	590 800		
$3s^2 3p^3(^2D^\circ)3d$	$^3S^\circ$	1	335 099	$3s^2 3p^3(^2D^\circ)4d$	$^1D^\circ$	2	619 600		
$3s^2 3p^3(^2P^\circ)3d$	$^3P^\circ$	2	338 435	$3s^2 3p^3(^2D^\circ)4d$	$^1F^\circ$	3	622 500		
		1	339 807						
$3s^2 3p^3(^2D^\circ)3d$	$^1P^\circ$	1	341 955	$3s^2 3p^3(^4S^\circ)5s$	$^3S^\circ$	1	648 100		
$3s^2 3p^3(^2P^\circ)3d$	$^3D^\circ$	3	351 787	$3s^2 3p^3(^2D^\circ)5s$	$^3D^\circ$	3	674 900		
		2	353 983			$3s^2 3p^3(^2D^\circ)5s$	$^1D^\circ$	2	676 700
		1	355 461						
$3s^2 3p^3(^2P^\circ)3d$	$^1D^\circ$	2	363 456	$3s^2 3p^3(^2P^\circ)5s$	$^1P^\circ$	1	696 400		
$3s^2 3p^3(^2P^\circ)3d$	$^1F^\circ$	3	375 740	Sc VII ($^4S_{3/2}$)	Limit		892 700		

Sc VII

Z=21

P I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^3 \ ^4S_{3/2}^{\circ}$ Ionization energy = $1\ 113\ 000\ \text{cm}^{-1}$ (138.0 eV)

The levels are from the work of Ekberg and Svensson (1970) and Smitt, Svensson, and Outred (1976). The levels for the $3s^2 3p^3$ and $3s 3p^4$ configurations are taken from the latter paper and have an uncertainty of about $\pm 2\ \text{cm}^{-1}$. We have combined these values with the measurements and classifications given by Ekberg and Svensson in the wavelength range of 182–598 Å to derive new level values for the $3p^2 3d$ and $4s$ configurations. Most of the wavelengths used by Ekberg and Svensson are taken from Beckman (1937), Kruger and Pattin (1937), and Fawcett (1970). The uncertainty of these upper levels is about $\pm 10\ \text{cm}^{-1}$. Since no intersystem transitions have been observed, all of the doublets have an added systematic error "x," relative to the

ground term $^4S^{\circ}$. The value of x depends on the accuracy of calculations by Smitt, Svensson and Outred and is expected to be less than $\pm 20\ \text{cm}^{-1}$.

The ionization energy is from an extrapolation by Lotz (1967).

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Sc VII

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	Configuration	Term	<i>J</i>	Level (cm ⁻¹)
$3s^2 3p^3$	$^4S^{\circ}$	$\frac{3}{2}$	0.0	$3s^2 3p^2(^1D)3d$	2D	$\frac{3}{2}$	360 886+x
$3s^2 3p^3$	$^2D^{\circ}$	$\frac{3}{2}$ $\frac{5}{2}$	29 562.5+x 30 239.9+x	$3s^2 3p^2(^1D)3d$	2P	$\frac{1}{2}$ $\frac{3}{2}$	372 840+x 374 787+x
$3s^2 3p^3$	$^2P^{\circ}$	$\frac{1}{2}$ $\frac{3}{2}$	49 387.1+x 50 300.9+x	$3s^2 3p^2(^1D)3d$	2F	$\frac{5}{2}$ $\frac{7}{2}$	378 080+x 378 760+x
$3s 3p^4$	4P	$\frac{5}{2}$ $\frac{3}{2}$ $\frac{1}{2}$	175 055.0 177 776.5 179 197.3	$3s^2 3p^2(^1D)3d$	2S	$\frac{1}{2}$	382 195+x
$3s 3p^4$	2D	$\frac{3}{2}$ $\frac{5}{2}$	217 023.9+x 217 326.5+x	$3s^2 3p^2(^1S)3d$	2D	$\frac{5}{2}$ $\frac{3}{2}$	392 364+x 393 384+x
$3s 3p^4$	2P	$\frac{3}{2}$ $\frac{1}{2}$	250 443.6+x 252 995.3+x	$3s^2 3p^2(^3P)4s$	4P	$\frac{1}{2}$ $\frac{3}{2}$ $\frac{5}{2}$	541 691 543 600 546 469
$3s 3p^4$	2S	$\frac{1}{2}$	261 800.6+x	$3s^2 3p^2(^3P)4s$	2P	$\frac{1}{2}$ $\frac{3}{2}$	551 487+x 554 782+x
$3s^2 3p^2(^3P)3d$	2P	$\frac{3}{2}$ $\frac{1}{2}$	329 516+x 332 923+x	$3s^2 3p^2(^1D)4s$	2D	$\frac{5}{2}$ $\frac{3}{2}$	568 431+x 568 574+x
$3s^2 3p^2(^3P)3d$	4P	$\frac{5}{2}$ $\frac{3}{2}$ $\frac{1}{2}$	334 944 336 396 337 224	$3s^2 3p^2(^1S)4s$	2S	$\frac{1}{2}$	597 518+x
				Sc VIII (3P_0)	<i>Limit</i>		1 113 000

Sc VIII

Z=21

Si I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^2 \ ^3P_0$ Ionization energy = $1\ 275\ 000\ \text{cm}^{-1}$ (158.1 eV)

The study of this spectrum was initiated by Kruger and Phillips (1937), who classified fifteen lines as transitions between the ground term and three odd terms $3s3p^3 \ ^3S^\circ$, $3s^2 3p3d \ ^3P^\circ$ and $3s^2 3p4s \ ^3P^\circ$. Phillips (1939) found $3s^2 3p^2 \ ^1D_2$ and $3s3p^3 \ ^1P_1^\circ$. Fawcett, Gabriel, and Saunders (1967) extended the $3p^2$ - $3p3d$ array; Fawcett (1970) added to the $3s^2 3p^2$ - $3s3p^3$ array. Fawcett, Cowan, and Hayes (1972) identified lines in $3p3d$ - $3p4f$ which are not connected with the other levels.

Ekberg and Svensson (1970) reanalyzed the spectrum using a compilation of wavelengths between 164 and 572 Å. Smitt, Svensson, and Outred (1976) made new observations between 362 and 640 Å. The level values for the $3s^2 3p^2$ and $3s3p^3$ configurations are taken from the more accurate data of Smitt et al. and the values for $3s^2 3p3d$ and $3s^2 3p4s$ are

derived by combining those values with the wavelengths in Ekberg and Svensson. The uncertainty of the level values from Smitt et al. is about $\pm 5\ \text{cm}^{-1}$. Four intersystem transitions have been observed.

The ionization energy was obtained by Ekberg and Svensson from an extrapolation formula.

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Sc VIII

Configuration	Term	J	Level (cm^{-1})	Configuration	Term	J	Level (cm^{-1})		
$3s^2 3p^2$	3P	0	0.0	$3s3p^3$	$^1P^\circ$	1	281 522.1		
		1	2 271.9			$3s^2 3p3d$	$^3P^\circ$	2	319 569
		2	5 507.7	1	322 541				
$3s^2 3p^2$	1D	2	25 026.9	0	323 673				
$3s^2 3p^2$	1S	0	54 864.4	$3s^2 3p3d$	$^3D^\circ$	1	329 862		
$3s3p^3$	$^3D^\circ$	1	179 962.3			2	330 716		
		2	180 032.7			3	331 153		
		3	180 503.6	$3s^2 3p3d$	$^1F^\circ$	3	363 462		
$3s3p^3$	$^3P^\circ$	0	207 690.9			$3s^2 3p3d$	$^1P^\circ$	1	372 790
		1	207 761.0					$3s^2 3p4s$	$^3P^\circ$
		2	207 814.4	1	604 609				
$3s3p^3$	$^1D^\circ$	2	228 618.3	2	609 174				
		$3s3p^3$	$^3S^\circ$	1	272 417.4	$3s^2 3p4s$	$^1P^\circ$	1	614 090
				Sc IX ($^2P_{1/2}^\circ$)	Limit			1 275 000	

Sc IX

Z=21

Al I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^2 P_{1/2}$ Ionization energy = $1\,452\,000 \pm 1000 \text{ cm}^{-1}$ ($180.03 \pm 0.1 \text{ eV}$)

The initial work on the analysis of this spectrum was by Kruger and Phillips (1937) and by Beckman (1937). About a third of Beckman's identifications were corrected by Fawcett (1970).

Using the earlier measurements, Ekberg and Svensson (1970) reanalyzed the spectrum between 90 and 540 Å and identified all the remaining terms given here. They extrapolated the position of $3s3p^2\ ^4P$ along the isoelectronic sequence. Since no intersystem transitions have been observed, we use their extrapolation to establish the energy of $^4P_{1/2}$ relative to the ground level. The error is indicated by *x*.

Smitt, Svensson, and Outred (1976) remeasured the $3s^2 3p-3s3p^2$ array between 380 and 540 Å and determined

the doublet terms of those configurations with an uncertainty of $\pm 4 \text{ cm}^{-1}$. We used their term values in combination with the earlier measurements of Ekberg and Svensson to establish the higher doublet term values.

The ionization energy was obtained by Ekberg and Svensson from the *nf* series.

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Sc IX

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	Configuration	Term	<i>J</i>	Level (cm ⁻¹)
$3s^2 3p$	$^2P^\circ$	$\frac{1}{2}$ $\frac{3}{2}$	0.0 5 761.1	$3s^2 4s$	2S	$\frac{1}{2}$	666 259
$3s3p^2$	4P	$\frac{1}{2}$ $\frac{3}{2}$ $\frac{5}{2}$	143 500+x 145 622+x 148 779+x	$3s3p(^3P^\circ)4s$	$^4P^\circ$	$\frac{1}{2}$ $\frac{3}{2}$ $\frac{5}{2}$	822 056+x 823 985+x 827 620+x
$3s3p^2$	2D	$\frac{3}{2}$ $\frac{5}{2}$	191 609.3 191 987.1	$3s^2 4d$	2D	$\frac{3}{2}$ $\frac{5}{2}$	837 212 837 459
$3s3p^2$	2S	$\frac{1}{2}$	240 361.4	$3s^2 4f$	$^2F^\circ$	$\frac{5}{2}$ $\frac{7}{2}$	889 330 889 384
$3s3p^2$	2P	$\frac{1}{2}$ $\frac{3}{2}$	255 829.4 259 153.7	$3s^2 5s$	2S	$\frac{1}{2}$	979 930
$3s^2 3d$	2D	$\frac{3}{2}$ $\frac{5}{2}$	313 860 314 214	$3s^2 5d$	2D	$\frac{3}{2}$ $\frac{5}{2}$	1 070 740 1 070 850
$3p^3$	$^4S^\circ$	$\frac{3}{2}$	333 047+x	$3s^2 5f$	$^2F^\circ$	$\frac{5}{2}$ $\frac{7}{2}$	1 095 200 1 095 250
				Sc X (1S_0)	Limit		1 452 000

Sc X

 $Z=21$

Mg I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 \ ^1S_0$ Ionization energy = $1\ 815\ 600 \pm 1000\ \text{cm}^{-1}$ ($225.1 \pm 0.1\ \text{eV}$)

The initial work on the analysis was done by Beckman (1937) and Parker and Phillips (1940).

Ekberg (1971), using wavelengths between 76 and 470 Å, taken from the papers above, has redone the analysis and determined all the levels given in this compilation except the $3p^2 \ ^1S$, the $3p3d$, and the $3p4f$ levels. These are taken from Fawcett (1970, 1976). The singlets and triplets have not been connected by observations. Ekberg has estimated the value for $3s3p \ ^3P_1$ used here by interpolation along the isoelectronic sequence. The uncertainty "x" is less than $1000\ \text{cm}^{-1}$.

Ekberg derived the quoted value for the ionization energy by extrapolation.

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Sc x

Configuration	Term	<i>J</i>	Level (cm^{-1})	Configuration	Term	<i>J</i>	Level (cm^{-1})
$3s^2$	1S	0	0	$3s4p$	$^1P^\circ$	1	980 604
$3s3p$	$^3P^\circ$	0	156 386+x	$3s4d$	3D	1	1 073 220+x
		1	158 392+x			2	1 073 400+x
		2	162 699+x			3	1 073 740+x
$3s3p$	$^1P^\circ$	1	236 490	$3s4d$	1D	2	1 081 820
$3p^2$	1D	2	372 398	$3p4s$	$^3P^\circ$	0	1 097 220+x
$3p^2$	3P	0	373 441+x			1	1 098 760+x
		1	376 042+x			2	1 103 750+x
		2	380 977+x	$3s4f$	$^3F^\circ$	2	1 116 850+x
$3p^2$	1S	0	440 480			3	1 116 870+x
$3s3d$	3D	1	454 161+x			4	1 116 940+x
		2	454 348+x	$3s4f$	$^1F^\circ$	3	1 128 150
		3	454 662+x	$3p4p$	3D	2	1 169 400+x
$3s3d$	1D	2	516 218			3	1 173 930+x
$3p3d$	$^3F^\circ$	2	621 950+x	$3p4p$	3P	0	1 175 030+x
		3	624 720+x			1	1 176 650+x
		4	628 040+x			2	1 179 760+x
$3p3d$	$^1D^\circ$	2	633 100	$3p4p$	3S	1	1 181 110+x
$3p3d$	$^3D^\circ$	2	663 280+x	$3p4f$	3G	4	1 305 170+x
		3	664 620+x			5	1 309 160+x
$3p3d$	$^1P^\circ$	1	683 850	$3p4f$	3F	3	1 307 580+x
$3s4s$	3S	1	898 419+x			4	1 310 210+x
$3s4s$	1S	0	915 165	$3s5p$	$^1P^\circ$	1	1 309 880
				$3p4f$	3D	2	1 318 150+x

Sc x

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	Configuration	Term	<i>J</i>	Level (cm ⁻¹)	
3s5d	³ D	1	1 350 270+x	3s6f	³ F°	4	1 506 300+x	
		2,3	1 350 280+x			3	1 506 400+x	
3s5d	¹ D	2	1 350 870	Sc XI (² S _{1/2})	<i>Limit</i>	2	1 506 550+x	
3s5f	³ F°	4	1 369 700+x			<i>Limit</i>		1 815 600
		3	1 369 870+x					
		2	1 369 900+x					

Sc XI

 $Z=21$

Na I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 3s^2 S_{1/2}$ Ionization energy = $2\ 015\ 050 \pm 10\ \text{cm}^{-1}$ ($249.837 \pm 0.001\ \text{eV}$)

We have used the measurements and classifications of Kruger and Phillips (1939) between 97 and 523 Å to determine the $3p$, $3d$, $4d$, and $5f$ levels and those of Edlén (1936) between 94 and 129 Å for the $4s$, $4p$, and $4f$ levels. The $5s$, $5p$, $5d$, $6s$, $6p$, $6d$, $6f$, and $7d$ levels are from Beckman's (1937) measurements. The p , d , and f terms for $n=8,9$ are from Fawcett (1976) and the $7p$, $7f$ and $10p$ are from Cohen and Behring (1976).

The limit is from Edlén (1978). It agrees with the determination of Crooker, which was reported by Cohen and Behring.

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Sc XI

Configuration	Term	J	Level (cm^{-1})	Configuration	Term	J	Level (cm^{-1})
$2p^6(^1S)3s$	2S	$1/2$	0	$2p^6(^1S)6s$	2S	$1/2$	1 589 040
$2p^6(^1S)3p$	$^2P^\circ$	$1/2$ $3/2$	191 274 197 974	$2p^6(^1S)6p$	$^2P^\circ$	$3/2$	1 609 500
$2p^6(^1S)3d$	2D	$3/2$ $5/2$	459 725 460 337	$2p^6(^1S)6d$	2D	$3/2, 5/2$	1 635 270
$2p^6(^1S)4s$	2S	$1/2$	997 720	$2p^6(^1S)6f$	$^2F^\circ$	$5/2$ $7/2$	1 645 250 1 645 270
$2p^6(^1S)4p$	$^2P^\circ$	$1/2$ $3/2$	1 051 640 1 054 170	$2p^6(^1S)7p$	$^2P^\circ$	$1/2, 3/2$	1 721 700
$2p^6(^1S)4d$	2D	$3/2$ $5/2$	1 148 750 1 149 040	$2p^6(^1S)7d$	2D	$3/2, 5/2$	1 736 900
$2p^6(^1S)4f$	$^2F^\circ$	$5/2$ $7/2$	1 182 880 1 182 980	$2p^6(^1S)7f$	$^2F^\circ$	$5/2, 7/2$	1 743 800
$2p^6(^1S)5s$	2S	$1/2$	1 382 340	$2p^6(^1S)8p$	$^2P^\circ$	$3/2$	1 792 500
$2p^6(^1S)5p$	$^2P^\circ$	$1/2$ $3/2$	1 418 260 1 419 550	$2p^6(^1S)8d$	2D	$5/2$	1 802 700
$2p^6(^1S)5d$	2D	$3/2$ $5/2$	1 465 010 1 465 120	$2p^6(^1S)8f$	$^2F^\circ$	$7/2$	1 807 700
$2p^6(^1S)5f$	$^2F^\circ$	$5/2$ $7/2$	1 482 340 1 482 410	$2p^6(^1S)9p$	$^2P^\circ$	$3/2$	1 840 100
				$2p^6(^1S)9d$	2D	$5/2$	1 847 100
				$2p^6(^1S)9f$	$^2F^\circ$	$7/2$	1 858 500
				$2p^6(^1S)10p$	$^2P^\circ$	$1/2, 3/2$	1 875 000
				Sc XII (1S_0)	Limit		2 015 050

Sc XII

Z=21

Ne I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^6 \ ^1S_0$ Ionization energy = $5\,543\,900 \pm 500 \text{ cm}^{-1}$ ($687.36 \pm 0.06 \text{ eV}$)

Only resonance lines between 20 and 31 Å are classified by this system of energy levels. Edlén and Tyrén (1936) identified transitions from the $2p^5 3s$ and $3d$ configurations. We derived the ionization energy by application of a Ritz formula to the $2s^2 2p^5 (^2P_{3/2}^\circ) nd \ ^2[3/2]^\circ$ series for $n=3, 4$, and 5. The result is in agreement with the value given by Edlén and Tyrén. Fawcett (1965) observed three transitions arising from $2p^5 4d$ and from $2s 2p^6 3p \ ^1P_1^\circ$. Feldman and Cohen (1967) observed eight transitions, including those reported by Fawcett. We have adopted the more accurate values of Feldman and Cohen.

In order to determine the coupling for the $2p^5 3s$ and $2p^5 3d$ levels, we calculated these configurations by using for the radial integrals, Hartree-Fock values scaled according to fitted values in Al IV by Artru and Kaufman (1975). The result confirmed our use of Jj -coupling for $2p^5 3s$ and $J_1 l$ -coupling

for $2p^5 3d$ in this sequence. However, it also put in question the identification of the resonance lines assigned to the $2p^5 3d$ configuration. The total spread of the calculated levels of $J=1$ is $53\,120 \text{ cm}^{-1}$ compared with the observed value of $98\,900 \text{ cm}^{-1}$. The percentages given for these levels are from this calculation.

Kastner, Behring, and Cohen (1975) identified transitions between $2p^5 3p$ and $2p^5 4d$, but there is no connection with the levels given here.

References

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Sc XII

Configuration	Term	<i>J</i>	Level (cm^{-1})	Leading percentages		
$2s^2 2p^6$	1S	0	0			
$2s^2 2p^5 (^2P_{3/2}^\circ) 3s$	$(\frac{3}{2}, \frac{1}{2})^\circ$	1	3 245 100	96	4	$(\frac{1}{2}, \frac{1}{2})^\circ$
$2s^2 2p^5 (^2P_{1/2}^\circ) 3s$	$(\frac{1}{2}, \frac{1}{2})^\circ$	1	3 280 800	96	4	$(\frac{3}{2}, \frac{1}{2})^\circ$
$2s^2 2p^5 3d$	$^3P^\circ$	1	3 668 400	90	9	$^3D^\circ$
$2s^2 2p^5 3d$	$^3D^\circ$	1	3 714 700	60	37	$^1P^\circ$
$2s^2 2p^5 3d$	$^1P^\circ$	1	3 767 300	63	31	$^3D^\circ$
$2s 2p^6 3p$	$^3P^\circ$	1	4 198 000			
$2s 2p^6 3p$	$^1P^\circ$	1	4 215 000			
$2s^2 2p^5 (^2P_{3/2}^\circ) 4s$	$(\frac{3}{2}, \frac{1}{2})^\circ$	1	4 339 300			
$2s^2 2p^5 (^2P_{1/2}^\circ) 4s$	$(\frac{1}{2}, \frac{1}{2})^\circ$	1	4 378 800			
$2s^2 2p^5 (^2P_{3/2}^\circ) 4d$	$^2[3/2]^\circ$	1	4 521 000			
$2s^2 2p^5 (^2P_{1/2}^\circ) 4d$	$^2[3/2]^\circ$	1	4 557 900			
$2s^2 2p^5 (^2P_{3/2}^\circ) 5d$	$^2[3/2]^\circ$	1	4 892 800			
$2s^2 2p^5 (^2P_{1/2}^\circ) 5d$	$^2[3/2]^\circ$	1	4 926 600			
Sc XIII ($^2P_{3/2}^\circ$)	<i>Limit</i>		5 543 900			

Sc XIII

Z=21

F I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^5 \ ^2P_{3/2}^{\circ}$ Ionization energy = 6 103 000 cm^{-1} (756.7 eV)

The first work on this spectrum was by Fawcett (1965), who classified lines of the $2s^2 2p^5 - 2s^2 2p^4 3s$ and $3d$ transition arrays between 24 and 28 Å. This work was revised and extended by Feldman, Doschek, Cowan, and Cohen (1973), from whose improved wavelengths the $3s$ and $3d$ levels are determined. Their estimated uncertainty of ± 0.01 Å gives a level uncertainty of $\pm 2000 \text{ cm}^{-1}$. The ground term interval is from Fawcett, Burgess, and Peacock (1967), who identified the $2s^2 2p^5 - 2s^2 2p^6$ doublet at ~ 134 Å. The uncertainty of these 3 levels is $\sim 500 \text{ cm}^{-1}$.

The composition of the $2p^4 3s$ and $2p^4 3d$ levels is from Chapman and Shadmi (1973).

The $2s^2 2p^5 3s \ ^2P^{\circ}$ term is from Feldman et al. (1973).

The ionization energy was obtained by extrapolation by Lotz (1967).

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Sc XIII

Configuration	Term	J	Level (cm^{-1})	Leading percentages		
$2s^2 2p^5$	$^2P^{\circ}$	$3/2$	0			
		$1/2$	37 900			
$2s^2 2p^6$	2S	$1/2$	763 600			
$2s^2 2p^4(^3P)3s$	4P	$5/2$	3 513 300	96		
		$3/2$	3 530 600	72	24	$(^3P) \ ^2P$
		$1/2$	3 547 200	95		
$2s^2 2p^4(^3P)3s$	2P	$3/2$	3 554 800	70	26	$(^3P) \ ^4P$
		$1/2$	3 574 100	96		
$2s^2 2p^4(^1D)3s$	2D	$5/2$	3 619 500	96		
		$3/2$	3 620 800	94		
$2s^2 2p^4(^1S)3s$	2S	$1/2$	3 718 400	90		
$2s^2 2p^4(^3P)3d$	4P	$1/2$	3 961 700	91		
		$3/2$	3 968 300	84		
		$5/2$	3 978 800	77		
$2s^2 2p^4(^3P)3d$	4F	$5/2$	3 968 300	85		
$2s^2 2p^4(^3P)3d$	2P	$1/2$	3 974 100	58	32	$(^1D) \ ^2P$
		$3/2$	4 000 300	48	28	
$2s^2 2p^4(^3P)3d$	2D	$3/2$	3 984 200	42	25	$(^1D) \ ^2D$
		$5/2$	4 004 800	45	24	
$2s^2 2p^4(^3P)3d$	2F	$5/2$	3 987 400	65	12	$(^3P) \ ^4P$
$2s^2 2p^4(^1D)3d$	2S	$1/2$	4 054 200	92		
$2s^2 2p^4(^1D)3d$	2F	$5/2$	4 057 100	92		

Sc XIII

Configuration	Term	<i>J</i>	Level (cm ⁻¹)	Leading percentages		
$2s^2 2p^4 ({}^1D) 3d$	2D	$\frac{5}{2}$	4 071 700	57	23	$({}^3P) {}^2D$
		$\frac{3}{2}$	4 084 300	63	22	
$2s^2 2p^4 ({}^1S) 3d$	2D	$\frac{5}{2}$	4 149 900	79		$({}^3P) {}^2D$
		$\frac{3}{2}$	4 156 100	62	7	
$2s 2p^5 ({}^3P^{\circ}) 3s$	${}^2P^{\circ}$	$\frac{3}{2}$	4 242 100			
		$\frac{1}{2}$	4 264 200			
Sc XIV (3P_2)	Limit		6 103 000			

Sc XIV

Z=21

O I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^4 \ ^3P_2$ Ionization energy = $6\ 701\ 000\ \text{cm}^{-1}$ (830.8 eV)

The observed spectrum of Sc XIV consists of the strong transition array $2s^2 2p^4 - 2s 2p^5$, which lies between 122 and 158 Å, and the arrays $2p^4 - 2p^3 3s$ at 25 Å and $2p^4 - 2p^3 3d$ at 23 Å. The 1S_0 due to $2p^6$ combines with $2s 2p^5 \ ^1P_1^\circ$ at 157 Å. The arrays at 25 Å and 23 Å were first observed by Goldsmith, Feldman, and Cohen (1971). The $J=0$ and 1 levels of the ground term could not be resolved at these wavelengths. Fawcett (1971) then observed the $2s^2 2p^4 - 2s 2p^5$ array at 150 Å and resolved the ground term. We have determined the levels of the $2s 2p^5$ configurations from his measurements with an uncertainty of $\pm 200\ \text{cm}^{-1}$. The levels of $2s^2 2p^4$ are adopted from Edlén's (1972) re-evaluation of the data for this isoelectronic sequence. These are probably accurate to $\pm 50\ \text{cm}^{-1}$. Since no intersystem transitions have been observed, we based the singlet system on Edlén's extrapolated value for $2p^4 \ ^1D$. Its uncertainty is probably $\pm 100\ \text{cm}^{-1}$.

The $2s 2p^5 \ ^1P_1^\circ - 2p^6 \ ^1S_0$ transition was reported by Fawcett, Galanti, and Peacock (1974).

Improved measurements of the $2p^4 - 2p^3 3s$ array were obtained from Doschek, Feldman, and Cohen (1973).

A revised analysis of $2p^4 - 2p^3 3d$ by Fawcett and Hayes (1975) is adopted here. A level uncertainty of $\pm 3000\ \text{cm}^{-1}$ is indicated. The subsequent revisions of this array proposed by Bromage and Fawcett (1977), following a new calculation, are regarded as tentative and the levels put in question are omitted pending further study.

The ionization energy was evaluated by Lotz (1967) by extrapolation.

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Sc xiv

Configuration	Term	J	Level (cm ⁻¹)	Configuration	Term	J	Level (cm ⁻¹)		
$2s^2 2p^4$	3P	2	0	$2s^2 2p^3(^2P^\circ)3s$	$^3P^\circ$	2	4 004 600		
		1	31 170			$2s^2 2p^3(^2P^\circ)3s$	$^1P^\circ$	1	4 034 500+x
		0	35 220						
$2s^2 2p^4$	1D	2	98 140+x	$2s^2 2p^3(^4S^\circ)3d$	$^3D^\circ$	2	4 245 000		
$2s^2 2p^4$	1S	0	196 090+x			3	4 248 800		
$2s 2p^5$	$^3P^\circ$	2	664 630	$2s^2 2p^3(^2D^\circ)3d$	$^3D^\circ$	1	4 332 500		
		1	689 500			2	4 349 700		
		0	704 710			3	4 353 900		
$2s 2p^5$	$^1P^\circ$	1	913 140+x	$2s^2 2p^3(^2D^\circ)3d$	$^1D^\circ$	2	4 367 600+x		
$2p^6$	1S	0	1 549 840+x	$2s^2 2p^3(^2D^\circ)3d$	$^3S^\circ$	1	4 378 100		
$2s^2 2p^3(^4S^\circ)3s$	$^3S^\circ$	1	3 848 500	$2s^2 2p^3(^2D^\circ)3d$	$^1F^\circ$	3	4 395 300+x		
$2s^2 2p^3(^2D^\circ)3s$	$^3D^\circ$	1	3 929 400	$2s^2 2p^3(^2P^\circ)3d$	$^3P^\circ$	2	4 405 900		
		2	3 930 800			$2s^2 2p^3(^2P^\circ)3d$	$^3D^\circ$	3	4 433 000
		3	3 938 200					2	4 444 800
$2s^2 2p^3(^2D^\circ)3s$	$^1D^\circ$	2	3 956 000+x	Sc xv ($^4S_{3/2}$)	Limit		6 701 000		

Sc xv

 $Z=21$

N I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^3 \ ^4S_{3/2}^{\circ}$ Ionization energy = $7\,481\,000\text{ cm}^{-1}$ (927.5 eV)

The strong transition arrays $2s^2 2p^3-2s 2p^4$ and $2s 2p^4-2p^5$ were identified by Fawcett (1971) between 118 and 190 Å. The levels have an uncertainty of $\pm 200\text{ cm}^{-1}$. The position of the doublets relative to the ground state is based on the estimated position of $2s^2 2p^3 \ ^2D_{5/2}^{\circ}$ by Edlén (1972).

The $2p^2 3d$ terms are from observations by Fawcett and Hayes (1975) at 22 Å. They have an uncertainty of $\pm 3000\text{ cm}^{-1}$.

The ionization energy is from Lotz's (1967) extrapolation.

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Sc xv

Configuration	Term	J	Level (cm^{-1})	Configuration	Term	J	Level (cm^{-1})
$2s^2 2p^3$	$^4S^{\circ}$	$3/2$	0	$2p^5$	$^2P^{\circ}$	$3/2$	$1\,440\,100+x$
$2s^2 2p^3$	$^2D^{\circ}$	$3/2$	$109\,560+x$			$1/2$	$1\,480\,800+x$
		$5/2$	$120\,380+x$	$2s^2 2p^2(^3P)3d$	2P	$3/2$	$4\,634\,500+x$
$2s^2 2p^3$	$^2P^{\circ}$	$1/2$	$183\,210+x$	$2s^2 2p^2(^3P)3d$	4P	$5/2$	$4\,671\,800$
		$3/2$	$198\,770+x$			$3/2$	$4\,679\,000$
$2s 2p^4$	4P	$5/2$	$551\,850$	$2s^2 2p^2(^3P)3d$	2F	$7/2$	$4\,681\,600+x$
		$3/2$	$577\,130$	$2s^2 2p^2(^3P)3d$	2D	$5/2$	$4\,730\,000+x$
		$1/2$	$588\,240$	$2s^2 2p^2(^1D)3d$	2F	$7/2$	$4\,767\,000+x$
$2s 2p^4$	2D	$3/2$	$759\,680+x$			$5/2$	$4\,776\,800+x$
		$5/2$	$762\,380+x$	$2s^2 2p^2(^1D)3d$	2D	$5/2$	$4\,774\,000+x$
$2s 2p^4$	2S	$1/2$	$880\,380+x$	$2s^2 2p^2(^1D)3d$	2P	$3/2$	$4\,787\,600+x$
$2s 2p^4$	2P	$3/2$	$915\,100+x$				
		$1/2$	$949\,970+x$	Sc XVI (3P_0)	<i>Limit</i>		$7\,481\,000$

Sc XVI

Z=21

C I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^2 \ ^3P_0$ Ionization energy = 8 140 000 cm^{-1} (1009 eV)

The $2s^2 2p^2 - 2s 2p^3$ array was observed by Fawcett (1971) between 130 and 202 Å. New measurements and some revised classifications were given by Fawcett and Hayes (1975), who also identified $2s 2p^3 - 2p^4$ lines in the same region. The levels of $2s^2 2p^2$, $2s 2p^3$, and $2p^4$ are derived from the data of Fawcett and of Fawcett and Hayes and have an uncertainty of $\pm 100 \text{ cm}^{-1}$. All levels of the higher configurations are from the measurements of Goldsmith, Feldman, Crooker and Cohen (1972) at 20–22 Å with an estimated uncertainty of $\pm 0.005 \text{ Å}$, giving a level uncertainty of $\pm 1000 \text{ cm}^{-1}$.

No intersystem combinations have been observed. Goldsmith et al. extrapolated the position of $2p^2 \ ^1D_2$ to 123 900 cm^{-1} . Fawcett and Cowan (1975) obtained an extrapolated value of 123 400 cm^{-1} . We have used the mean

of these values as the reference value for the singlet system. Goldsmith et al. identified two quintet transitions but they are not connected to the triplet system.

The ionization energy is from the extrapolation by Lotz (1967).

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Sc xvi

Configuration	Term	J	Level (cm^{-1})	Configuration	Term	J	Level (cm^{-1})		
$2s^2 2p^2$	3P	0	0	$2p^4$	1D	2	1 285 900+x		
		1	22 930			$2s^2 2p3s$	$^3P^\circ$	1	4 606 000
		2	44 940					2	4 646 000
$2s^2 2p^2$	1D	2	123 600+x	$2s^2 2p3s$	$^1P^\circ$	1	4 663 000+x		
$2s^2 2p^2$	1S	0	219 200+x	$2s^2 2p3d$	$^3D^\circ$	2	4 942 000		
$2s 2p^3$	$^3D^\circ$	1	530 500	3		4 964 000			
		2	536 500	$2s^2 2p3d$	$^3P^\circ$	1	4 973 300		
		3	541 800						
$2s 2p^3$	$^3P^\circ$	0	628 600	$2s^2 2p3d$	$^1P^\circ$	1	5 020 000+x		
		1	630 200	$2s^2 2p3d$	$^1F^\circ$	3	5 027 000+x		
		2	634 600						
$2s 2p^3$	$^3S^\circ$	1	782 300	$2s 2p^2 (^2D) 3s$	3D	2	5 120 000		
$2s 2p^3$	$^1D^\circ$	2	786 100+x	$2s 2p^2 (^4P) 3d$	3F	3	5 273 000		
$2s 2p^3$	$^1P^\circ$	1	877 400+x	$2s 2p^2 (^2D) 3d$	3F	4	5 430 000		
$2p^4$	3P	2	1 187 600	Sc XVII ($^2P_{1/2}^\circ$)	Limit		8 140 000		
		0	1 214 100						
		1	1 221 100						

Sc XVII

 $Z=21$

B I isoelectronic sequence

Ground state: $1s^2 2s^2 2p^2 P_{1/2}^\circ$ Ionization energy = $8\,820\,000\text{ cm}^{-1}$ (1094 eV)

Fawcett and Hayes (1975) analyzed the transition arrays $2s^2 2p-2s 2p^2$ and $2s 2p^2-2p^3$ found between 143 and 211 Å. Their wavelength uncertainty is $\pm 0.02\text{ Å}$ giving an uncertainty in the levels of $\pm 100\text{ cm}^{-1}$. The quartet system is based on an interpolation between the predictions of the position of the $^4P_{3/2}$ level of $2s 2p^2$ in Ti XVIII by Kasyanov et al. (1974) and in Ca XVI by Kononov, Koshelev, Podobedova, and Churilov (1975).

The levels of $2p 3p$ and $2p 3d$ are also from the classifications made by Fawcett and Hayes of wavelengths at $\sim 19\text{ Å}$. The level uncertainty in this case is $\pm 3000\text{ cm}^{-1}$.

The ionization energy is from an extrapolation by Lotz (1967).

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Sc xvii

Configuration	Term	J	Level (cm^{-1})	Configuration	Term	J	Level (cm^{-1})
$2s^2 2p$	$^2P^\circ$	$1/2$	0	$2s 2p(^3P^\circ) 3p$	2P	$1/2$	5 325 000
		$3/2$	45 630			$3/2$	5 356 000
$2s 2p^2$	4P	$1/2$	290 600 + x	$2s 2p(^3P^\circ) 3p$	2D	$3/2$	5 431 000
		$3/2$	309 060 + x			$5/2$	5 457 000
		$5/2$	331 700 + x				
$2s 2p^2$	2D	$3/2$	516 660	$2s 2p(^3P^\circ) 3d$	$^2D^\circ$	$5/2$	5 529 000
		$5/2$	520 670	$2s 2p(^3P^\circ) 3d$	$^4D^\circ$	$7/2$	5 535 000 + x
$2s 2p^2$	2S	$1/2$	632 390	$2s 2p(^3P^\circ) 3d$	$^4P^\circ$	$5/2$	5 535 000 + x
$2s 2p^2$	2P	$1/2$	682 260	$2s 2p(^3P^\circ) 3d$	$^2F^\circ$	$5/2$	5 585 000
		$3/2$	694 930			$7/2$	5 609 000
$2p^3$	$^4S^\circ$	$3/2$	899 170 + x	$2s 2p(^1P^\circ) 3d$	$^2F^\circ$	$7/2$	5 765 000
$2s^2 3d$	2D	$3/2$	5 219 000	$2s 2p(^1P^\circ) 3d$	$^2D^\circ$	$5/2$	5 797 000
		$5/2$	5 224 000	Sc XVIII (1S_0)	Limit		8 820 000

Sc XVIII

 $Z=21$

Be I isoelectronic sequence

Ground state: $1s^2 2s^2 \ ^1S_0$ Ionization energy = $9\ 780\ 000\ \text{cm}^{-1}$ (1213 eV)

Fawcett and Hayes (1975) have identified the resonance transition $2s^2 \ ^1S_0 - 2s2p \ ^1P^{\circ}$. The resonance transition from $2s2p \ ^3P^{\circ}$ has not been observed. Edlén (1979) has made an extensive study of the Be I isoelectronic sequence and has proposed values for the $^3P^{\circ}$ term of $2s2p$ obtained by interpolation. We have adopted his values and combined them with the classifications of Fawcett and Hayes to obtain the higher-lying configurations. From their wavelength uncertainty of $\pm 0.01\ \text{\AA}$ and an equal uncertainty assumed for Edlén's interpolations, we estimate the level uncertainty to be $\pm 3000\ \text{cm}^{-1}$.

The ionization energy was obtained by Lotz (1967) by extrapolation.

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Sc XVIII

Configuration	Term	J	Level (cm^{-1})	Configuration	Term	J	Level (cm^{-1})
$2s^2$	1S	0	0	$2s3p$	$^1P^{\circ}$	1	5 692 000
$2s2p$	$^3P^{\circ}$	0	273 100	$2s3d$	3D	3	5 774 800
		1	286 900			2	5 777 500
		2	321 300				
$2s2p$	$^1P^{\circ}$	1	553 400	$2p3p$	3D	3	6 054 300
				Sc XIX ($^2S_{1/2}$)	Limit		9 780 000

Sc XIX

 $Z=21$

Li I isoelectronic sequence

Ground state: $1s^2 2s^2 S_{1/2}$ Ionization energy = $10\,388\,200 \pm 1600\text{ cm}^{-1}$ ($1287.98 \pm 0.2\text{ eV}$)

The first observations were reported by Goldsmith, Feldman, Oren, and Cohen (1972), who identified the transitions to $2s$ from $3p$, $4p$, and $5p$ and to $2p$ from $3s$, $3d$, $4d$, and $5d$ in the range of 11–19 Å. These results were extended by Boiko, Faenov, and Pikuz (1978) to include transitions through $7p$ and $8d$.

In a comprehensive review of all the available data for the Li I isoelectronic sequence Edlén (1979) derived smoothed-out values for all the wavelengths and new values for the energy levels through $4d$. These are given below and combined with the classifications of Boiko et al. to obtain the

higher-lying levels. The uncertainty for both sets of data is estimated to be about $\pm 0.003\text{ Å}$ or $\sim 1500\text{ cm}^{-1}$.

Edlén derived the value for the ionization energy by means of a polarization formula applied to the $2p$ - nd series.

References

- Boiko, V. A., Faenov, A. Y., and Pikuz, S. A. (1978), *J. Quant. Spectrosc. Radiat. Transfer* **19**, 11.
 Edlén, B. (1979), *Phys. Scr.* **19**, 255.
 Goldsmith, S., Feldman, U., Oren, L., and Cohen, L. (1972), *Astrophys. J.* **174**, 209.

Sc XIX

Configuration	Term	J	Level (cm^{-1})	Configuration	Term	J	Level (cm^{-1})
$1s^2 2s$	2S	$1/2$	0	$1s^2 5p$	$^2P^\circ$	$1/2, 3/2$	8 789 700
$1s^2 2p$	$^2P^\circ$	$1/2$ $3/2$	306 700 357 400	$1s^2 5d$	2D	$3/2$ $5/2$	8 797 800 8 799 800
$1s^2 3s$	2S	$1/2$	5 846 700	$1s^2 6p$	$^2P^\circ$	$1/2, 3/2$	9 272 100
$1s^2 3p$	$^2P^\circ$	$1/2$ $3/2$	5 930 100 5 945 300	$1s^2 6d$	2D	$3/2$ $5/2$	9 282 600 9 282 800
$1s^2 3d$	2D	$3/2$ $5/2$	5 977 900 5 982 700	$1s^2 7p$	$^2P^\circ$	$1/2, 3/2$	9 575 800
$1s^2 4s$	2S	$1/2$	7 853 800	$1s^2 7d$	2D	$5/2$ $3/2$	9 577 400 9 578 800
$1s^2 4p$	$^2P^\circ$	$1/2$ $3/2$	7 887 700 7 894 500	$1s^2 8d$	2D	$3/2$ $5/2$	9 762 100 9 766 500
$1s^2 4d$	2D	$3/2$ $5/2$	7 907 800 7 909 700	Sc XX (1S_0)	Limit		10 388 200
				$1s2p3p$	2S	$1/2$	40 715 000

Sc XX

Z=21

He I isoelectronic sequence

Ground state: $1s^2 \ ^1S_0$ Ionization energy = $45\,773\,660 \pm 200 \text{ cm}^{-1}$ ($5675.26 \pm 0.03 \text{ eV}$)

The theoretical values calculated by Ermolaev and Jones (1974) for the singlet and triplet S and P terms of this two-electron ion are expected to be more accurate than the observed values, and we have quoted them up to $n=5$. The uncertainty of the ionization energy and level values was estimated to be of the order of $\pm 40 \text{ cm}^{-1}$, but this should probably be increased to several hundred cm^{-1} . For comparison, the $1s^2-1s2p$ transition of this ion has been

observed by Boiko et al. (1978) in a laser-produced plasma. They place $1s2p \ ^3P_1^\circ$ at $34\,660\,000 \text{ cm}^{-1}$ and $1s2p \ ^1P_1^\circ$ at $34\,820\,000 \text{ cm}^{-1}$.

References

- Ermolaev, A. M., and Jones, M. (1974), J. Phys. B 7, 199.
Boiko, V. A., Faenov, A. Y., and Pikuz, S. A. (1978), J. Quant. Spectrosc. Radiat. Transfer 19, 11.

Sc xx

Configuration	Term	<i>J</i>	Level (cm^{-1})	Configuration	Term	<i>J</i>	Level (cm^{-1})
$1s^2$	1S	0	0	$1s4s$	3S	1	42 986 490
$1s2s$	3S	1	34 451 690	$1s4p$	$^3P^\circ$	0	43 007 220
$1s2p$	$^3P^\circ$	0	34 632 630	$1s4s$	1S	1	43 008 300
		1	34 641 640			2	43 013 880
		2	34 685 690			$1s4p$	$^1P^\circ$
$1s2s$	1S	0	34 648 190	$1s4p$	$^1P^\circ$	1	43 027 490
$1s2p$	$^1P^\circ$	1	34 808 800	$1s5s$	3S	1	43 995 360
$1s3s$	3S	1	40 793 730	$1s5p$	$^3P^\circ$	0	44 005 840
$1s3p$	$^3P^\circ$	0	40 843 650			1	44 006 390
		1	40 846 210			2	44 009 250
		2	40 859 440	$1s5s$	1S	0	44 005 860
$1s3s$	1S	0	40 845 600	$1s5p$	$^1P^\circ$	1	44 016 130
$1s3p$	$^1P^\circ$	1	40 892 810	Sc XXI ($^2S_{1/2}$)	Limit		45 773 660

Sc XXI

 $Z=21$

H 1 isoelectronic sequence

Ground state: $1s^2S_{1/2}$ Ionization energy = $48\,665\,240 \pm 90 \text{ cm}^{-1}$ ($6033.769 \pm 0.016 \text{ eV}$)

No observations of this spectrum are available.

The theoretical values calculated by Erikson for terms of this hydrogen-like ion are given below through $n=5$. The binding energy of the $1s$ electron is reported with an uncertainty of $\pm 90 \text{ cm}^{-1}$; the levels measured from the ground state taken as zero will also have this uncertainty. The

uncertainty in the conversion factor determines the uncertainty in eV.

References

Erikson, G. W. (1977), J. Phys. Chem. Ref. Data 6, 831.

Sc XXI

Configuration	Term	J	Level (cm^{-1})	Configuration	Term	J	Level (cm^{-1})
$1s$	2S	$1/2$	0	$4d$	2D	$3/2$	45 635 070
						$5/2$	45 638 050
$2p$	$^2P^\circ$	$1/2$	36 476 890	$4f$	$^2F^\circ$	$5/2$	45 638 050
		$3/2$	36 549 130			$7/2$	45 639 530
$2s$	2S	$1/2$	36 479 130	$5p$	$^2P^\circ$	$1/2$	46 721 690
$3p$	$^2P^\circ$	$1/2$	43 256 240			$3/2$	46 726 310
		$3/2$	43 277 650	$5s$	2S	$1/2$	46 721 840
$3s$	2S	$1/2$	43 256 910	$5d$	2D	$3/2$	46 726 300
$3d$	2D	$3/2$	43 277 610			$5/2$	46 727 830
		$5/2$	43 284 670	$5f$	$^2F^\circ$	$5/2$	46 727 830
$4p$	$^2P^\circ$	$1/2$	45 626 060			$7/2$	46 728 590
		$3/2$	45 635 090	$5g$	2G	$7/2$	46 728 590
$4s$	2S	$1/2$	45 626 340			$9/2$	46 729 040
					Limit		48 665 240