Energy Levels of Neutral Helium (^{4}He I)

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This compilation of all identified levels is based on the most accurate available observations. It includes 48 levels above the He II 1^2S limit (two-electron excitation).

Key words: Atomic energy levels; atomic spectra; autoionization; electron scattering; fine structure; helium; photoionization resonances; photon absorption.

1. Introduction

Experimental and theoretical knowledge of the energy levels of He I has been significantly improved and extended during the past decade or so. The most comprehensive earlier table of levels, published in 1960 [1][1], has thus become obsolete for several purposes of current interest. This paper gives a new compilation of the levels based on the most accurate measurements now available. With few exceptions the references are limited to results that entered into the determination of the new or revised levels or designations.

2. Energy Levels; One-Electron Excitation

The levels below the He II $1s\,^2S$ limit are given in table 1. The error limits listed with the ground level [2] and the ^2S limit [2–4] are the respective estimated uncertainties in these positions with respect to the best determined excited levels (the 2–5*s*, 2*p*, 3*p*, 3–6*d* levels, etc.). The positions of the baricenters of most of the excited terms with respect to the ground level are as given in the 1960 compilation [1], which should be consulted for other pertinent references. The values in units of eV were obtained by dividing the wavenumber values in cm^{-1} by 8065.465 cm^{-1}/eV [5]. Since the uncertainty of ±0.027 cm^{-1}/eV in this divisor [5] gives an uncertainty of ±0.00007 or ±0.00008 eV in the absolute energies of the single-excitation levels, most of the values are rounded off to four places in the eV column.

Most of the observed fine-structure intervals are from level-crossing experiments [6–8] or from measurements made with microwave-optical resonance techniques [9–12]. A number of the triplet levels are given to 0.0001 cm^{-1} to show the accurately known intervals. In some cases, several more decimal places would be required to give the intervals to the accuracy of the measurements. The $7d\,^3D_2-{}^3D_1$ interval, which was recently obtained by analysis of intensity modulations observed with the beam-foil technique [13], is accurate to about ±0.0005 cm^{-1}. The $4d\,^3D_2-{}^3D_1$ interval is based partly on measurements by this technique [13] and partly on an earlier interferometric measurement [14]; the average is probably accurate to ±0.0007 cm^{-1}.

The $^3P_0^\circ$ levels of the 7*p*, 8*p*, and 9*p* configurations are given in brackets because the $^3P_1^\circ-{}^3P_0^\circ$ intervals were calculated from the experimental values of the corresponding $^3P_2^\circ-{}^3P_1^\circ$ intervals and the assumption of a value of 12.2 for the ratio of the two $np\,^3P^\circ$ intervals. The experimental intervals for the 3–6$p\,^3P^\circ$ terms indicate that this ratio is constant and accurate to about 1 percent. The experimental accuracy of the $^3P_2^\circ-{}^3P_1^\circ$ intervals for the 7*p*, 8*p*, and 9*p* configurations is higher than can be shown in four-place wavenumber tables, but the full accuracy of these intervals was used in obtaining the corresponding $^3P_1^\circ-{}^3P_0^\circ$ intervals.

Some accurate separations between 1*snl* terms of the same principal quantum number ("electrostatic fine structure") have recently been determined for $n=7$, 10, and 11 by a microwave-optical resonance method [15]. These terms are given to three or four decimal places (cm^{-1}), with the accurate connections being indicated by lines to the right of the values. The 4–6*f* and 5,6*g* terms, and the baricenter of the $5p\,^3P^\circ$ term, are from Litzén's measurements [16]. The microwave-optical data and Litzén's data indicate that polarization-theory values [4, 17] for the relative energies of different 1*snl* configurations (singlet-triplet means) with $n \geqq 5$, $l \geqq f$ are accurate to ~0.02 cm^{-1}. Litzén's measurements also indicate a similar accuracy for the absolute values of the polarization-theory energies of such configurations (with respect to Seaton's value for the limit). The 6*h*, 7*g*, and 7*i* positions have thus been taken to be consistent with the polarization-theory values [4], in preference to the previous less accurate positions, as indicated by brackets for the levels.

The observed positions for the 8*f* and $9f\,^1F^\circ$ levels are consistent with expected separations of less than 0.01 cm^{-1} from the corresponding $^3F^\circ$ positions. The two $^1F^\circ$ levels have therefore been taken at the somewhat more accurately known $^3F^\circ$ values. The position listed for the (unobserved) $14f\,^3F^\circ$ term was calculated from polarization theory. The $11s\,^1S$ level and some higher *np* and *nd* levels also given in brackets were evaluated from series formulae [1].

The expected accuracies of the various inter-term separations (in cm^{-1}) can be roughly indicated by noting those levels in table 1 that should be rounded off for this purpose. The levels of the $2p,3p\,^3P^\circ$ and $3d$–$6d\,^3D$ terms should be rounded off to three decimal places (cm^{-1}). The levels of the 4–$9p\,^3P^\circ$ and $7d\,^3D$ terms, and the accurately connected terms for $n=7$, 10, 11, should be rounded off to only two places. It should also be noted that although the error in the adopted intersystem

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[1] Figures in brackets indicate literature references at the end of this paper.

(singlet-triplet) connection [1] is probably less than 0.01 cm^{-1} [16], all intersystem differences except those from the microwave measurements [15] have this additional uncertainty. Accurate measurement of the $3d$–$7f$ lines (1.003 μm), for example, might further reduce the uncertainty in the intersystem connection since the $7f\,^3F^\circ$–$^1F^\circ$ separation is now accurately known [15].

Very accurate measurements of the Zeeman effect have been made for the $1s2s\,^3S_1$ level by Drake, Hughes, Lurio, and White [18], and for the $1s2p\,^3P^\circ$ levels by Lewis, Pichanick, and Hughes [19].

3. Energy Levels; Two-Electron Excitation

Table 2 gives 48 levels or resonances observed above the He II $1s\,^2S$ limit that have been assigned to expected terms. The energies are relative to the He I $1s^2\,^1S$ ground level. The experimental and theoretical activity on double-excitation terms of He I during the past decade or so can be indicated by noting that the earlier compilations [1, 20] included only one of these terms, $2p^2\,^3P$. The L and S values for these terms are well defined, but in many cases the configuration assignment represents merely a leading component of a highly configuration-mixed eigenvector. The notation for the terms having sp character indicates explicitly a mixture of two configurations, as explained below.

Most of the levels in table 2 decay mainly by autoionization, the principal exceptions being the terms below the He II ($n=2$) limit whose parity is opposite to the numerical parity of their L values (odd-parity D terms, even parity P terms). Such a term does not interact with the only available continuum of the proper L value ($1s\epsilon l$, where $l=L$ for the term) because it has the wrong parity. Thus the levels in table 2 vary from those whose present accuracy is limited only by the available wavelength standards in the region near 300 Å ($2p^2\,^3P$, uncertainty ± 1.2 cm^{-1}) to those with accuracies limited by large inherent autoionization widths ($2s^2\,^1S$, width $\Gamma = \sim 1000$ cm^{-1}). It is important to note that the autoionizing levels have been taken directly from measurements of the energy at the peak value for a resonance process, such as photon absorption, emission of autoionization electrons, etc. The profiles of some types of these resonances are very asymmetric (Beutler-Fano profiles), and the enery "level" position defined in the theory of the asymmetric resonances is in general not the energy at the resonance peak.

The estimated errors given with the levels are based on values reported with the observations, where available; most of these should probably be taken as standard-deviation errors. A number of the level values are based partly on theoretical calculations, as explained below; the corresponding errors (my estimates) are given in parentheses. The errors in eV are not listed with the two terms known to about 1 cm^{-1} or with the various limits, since most of the uncertainty would derive from the conversion factor used (8065.465 ± 0.027 cm^{-1}/eV[5]).[2]

The He II limits above the He II $1s\,^2S$ ground level were obtained by adding 198310.76 cm^{-1} to theoretical values of the ^{4}He II levels [21], the theoretical values first having been adjusted to a value [22] of 109737.318 cm^{-1} for R_∞. The errors for the limits are relative to the best known single-excitation levels in table 1.

The last column in table 2 has a letter for each term, each letter indicating a group of terms discussed below under that letter heading.

A.

These $^1P^\circ$ terms are taken from Madden and Codling's measurements of the autoionization resonances observed by optical absorption spectroscopy [23]. The terms are mainly sp in character, and the simplest approximations for the wavefunctions are of the type $(|\,nsmp\rangle \pm |\,msnp\rangle)$ [24]. There are thus two $^1P^\circ$ terms for each combination of principal quantum numbers n and $m(m>n)$, one for each of the alternate signs in this expression. The notations $n,m;sp(\pm)$ in table 2 indicate such combinations of single-configuration wavefunctions; thus the second member of the strongest series observed by Madden and Codling [23] is classified $1s^2\,^1S$–$2,3;sp(+)\,^1P^\circ$. The strengths of the $nsnp\ ^1P^\circ$ resonances indicate that they should be designated as the respective first members of the corresponding $n,m;sp(+)\,^1P^\circ$ series $(m>n)$, a correlation borne out by the calculated radial wavefunctions. The $n,m;sp(\pm)$ combinations also give rise to corresponding $^3P^\circ$ terms, of course, but these are not observed in photon absorption from the ^1S ground state.

The profiles of the $sp\,^1P^\circ$ absorption resonances are very asymmetric (Beutler-Fano profiles); the positions reported by Madden and Codling and reproduced in table 2 are the energies at *maximum absorption.* The energy position defined in the theory of these resonances (which may be referred to as the "resonance center" energy [23]) is in general not the energy at the absorption peak. The "center" of the $2s2p\,^1P^\circ$ resonance, for example, is displaced from the absorption maximum by about 55 cm^{-1} (0.007 eV) [23], which is about half the experimental uncertainty of the measured peak position. The displacement of the center of the $3s3p\,^1P^\circ$ resonance from the absorption maximum is about -380 cm^{-1} (-0.047 eV) [23a], whereas the uncertainty in the determination of the center position is only about ± 200 cm^{-1}. These examples show that, at least in some cases, the more accurate calculations of autoionizing levels should be compared with the positions in table 2 only after a correction for the peak-to-center displacement is made.

B.

Some of the apparently more accurate experimental positions attributed to autoionizing ^1S terms [25, 26, 27] are collected in table 3, together with some theoretical results [28–31]. The value adopted for the lowest double-

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[2] Corrections of results based on earlier values of this conversion factor have been made for a few of the calculated levels quoted here.

excitation level in He I, $2s^2\ ^1S$, is inconsistent with the position and accuracy given by Siegbahn et al. [26], but their value is inconsistent with the other two listed measurements and probably also with the theoretical values of Burke [28] and of Holøien and Midtdal [31]. It is possible that the inconsistency arises from variations in the resonance shape according to the excitation method and/or the angle at which the ejected electron is detected. The measurements of the other levels in table 3 are in good agreement, but the resonance at 64.15 eV has been listed only by Bordenave-Montesquieu and Benoit-Cattin [27].

The identification of the three highest resonances in table 3 is complicated. The $2,4;sp(+)\ ^3P^\circ$, $2p3p\ ^1S$, $2p3d\ ^1P^\circ$, and $2s4s\ ^1S$ terms all are predicted within about ±0.1 eV of the resonance observed at 64.22 eV. It is unlikely that either of the first two of these terms contributes to the 64.22 eV resonance observed by Siegbahn et al. [26] (neither the $2,3;sp(+)\ ^3P^\circ$ nor the $2p^2\ ^1S$ term was observed by them), and the calculated small autoionization probability of the $2p3d\ ^1P^\circ$ term [29] eliminates it as a contributor. Since the best single-configuration designation for the 64.22 eV resonance thus appears to be $2s4s\ ^1S$, the assignment given by Rudd [25] and by Siegbahn et al. [26], this energy has been correlated with a theoretical resonance (64.182 eV) calculated by Burke and McVicar [29] to have 89 percent $2sns\ ^1S$ character. Their predicted $2pnp$ term (80 percent) at 64.216 eV has been tentatively correlated with the experimental resonance [27] at 64.15 eV. Bhatia et al. [30] also predict two ^1S resonances in this region, but the correlation is uncertain since their method gave no configuration compositions. Holøien and Midtdal [31] find such strong configuration mixing for the ^1S terms that the assignment of their fourth and fifth terms to specific configurations is doubtful.

The assignment of the resonance at 64.70 eV to $2s5s\ ^1S$ is also taken from the results of Rudd [25] and of Siegbahn et al. [26]. In a separate experiment, Rudd [25] also found contributions from the $2,4;sp(+)\ ^3P^\circ$ and $2,5;sp(+)\ ^3P^\circ$ terms to resonances at 64.22 and 64.71 eV, respectively. These $^3P^\circ$ terms apparently have not been resolved from the respective ^1S terms and are not listed in table 2.

A resonance has been observed near 63.8 eV by Quéméner et al. [32] (63.81 eV) and by Marchand [33] (63.8 eV). They designate this resonance as $2p3p\ ^3S$, which appears to be the only autoionizing level expected sufficiently near the observed energy; two calculated values for its position are 63.776 eV [30] and 63.822 eV [29].

C.

The positions adopted for these ^1D terms are based on the data collected in table 4. The adopted energy for $2p^2\ ^1D$, for example, is 0.02 eV above the most accurate measurement (59.86 ± 0.02 eV [26]) mainly in order to put it within 0.02 eV of the average (59.900 eV) of the three calculated values shown [28, 34, 35].

D.

Rudd's experimental value for the energy of the $2,3;sp(+)\ ^3P^\circ$ resonance [25] (table 5) is consistent with the value calculated by Bhatia and Temkin [36]. The latter value is probably more accurate and is adopted in table 2. The error is somewhat arbitrarily taken equal to the difference between the corresponding calculated $2s2p\ ^3P^\circ$ position [36] and the adopted value (table 5) discussed under "G" below.

E.

The positions of the $2p^2\ ^3P$, $2p3p\ ^1P$, and $2p4p\ ^3D$ terms are based entirely on measurements of their optical transitions (286–320 Å) to single-excitation terms. Tech and Ward determined the $2p^2\ ^3P^\circ$ position accurately from their wave-length measurement of the $1s2p\ ^3P^\circ$–$2p^2\ ^3P$ line [37]. The $2p3p\ ^1P$ and $2p4p\ ^3D$ terms are based on the measurements of Knystautas and Drouin [38]. They have observed 14 lines between 286 Å and 345 Å, including several lines observed earlier by Berry et al. [39]. The classifications for the stronger of these lines evolved through the efforts of a number of authors (see [38] and references therein; also see under F, G, and H, below), and Knystautas and Drouin [38] list classifications for 13 lines. The probable classification for the remaining line is given in the next section.

F.

This group comprises mainly $2pnd\ ^3D^\circ$ and $^3P^\circ$ terms with energies based on the wavelengths of transitions to the accurately known $2p^2\ ^3P$ term [40, 41]. The lines (2279–3014 Å) were excited with a beam-foil technique. Bhatia's [42] recent calculations of the $2pnd\ ^1D^\circ$ and $^3D^\circ$ energies ($3 \leqq n \leqq 6$) gave a value for $2p3d\ ^3D^\circ$ within a few cm^{-1} of the value in table 2, which is based on an improved measurement of the 3013.7 Å line by Berry [41]. The other three calculated members of this $^3D^\circ$ series [42] all agree with observation [40] to within 40 cm^{-1}.

The classifications of the transitions from $2p3d\ ^3D^\circ$ and $^3P^\circ$ to $2p^2\ ^3P$ by Berry et al. [40] are also supported by observed transitions from the same two upper terms to $1s3d\ ^3D$. The group of He lines near 300 Å listed by Knystautas and Drouin [38] (who also used beam-foil excitation) includes a relatively strong line at 304.5 ±0.1 Å and a weaker line at 302.3±0.2 Å. Their classification of the stronger line as $1s3d\ ^3D$–$2p3d\ ^3D^\circ$ is in good agreement with Berry's more accurate determination of the $2p3d\ ^3D^\circ$ term [41]. The weaker line is almost certainly due mainly to the transition $1s3d\ ^3D$–$2p3d\ ^3P^\circ$, which has a predicted wavelength (levels from table 2) of 302.414±0.005 Å.

A comparison of the observed intensities of the optical transitions from $2p3d\,^3P^\circ$ with the intensities of the corresponding lines from $2p3d\,^3D^\circ$ is of interest, since autoionization is allowed for the $^3P^\circ$ term and forbidden for the $^3D^\circ$ term. The measured lifetimes of these two terms are not very different, the values being 0.15 ± 0.05 ns for $^3P^\circ$ and 0.11 ± 0.02 ns for $^3D^\circ$ [40]. However, the autoionization rate of the $^3P^\circ$ term is probably at least comparable to its radiative decay rate, since the measured lifetime of this term is in agreement with a calculation of the lifetime for decay by autoionization alone [40]. Because any recombination processes inverse to autoionization are probably negligible in the beam sources, this autoionization should significantly decrease the intensity of the observed optical transitions from the $^3P^\circ$ term relative to the $^3D^\circ$ transitions. Such an effect could explain at least in part why the observed ratio of the $1s3d\,^3D$–$2p3d\,^3P^\circ$ line intensity to the $1s3d\,^3D$–$2p3d\,^3D^\circ$ intensity [38] was only 3/25, whereas the ratio of the theoretical strengths of these respective multiplets [43] is 3/5. The theoretical strengths of the $2p^2\,^3P$–$2p3d\,^3P^\circ$ and $2p^2\,^3P$–$2p3d\,^3D^\circ$ multiplets [43] have the ratio 1/3. In this case, a significant difference in the wavenumbers of the corresponding two observed lines [40] should be allowed for; multiplication of the strength ratio by $(\sigma_1/\sigma_2)^3$ gives a (statistical) theoretical transition probability ratio of $(1.22)(1/3) = 0.41$. This is to be compared with an observed photon-counting rate ratio of 0.20 between the two lines (not corrected for detection efficiency) [40]. It should be noted that the theoretical strengths used in these comparisons are based on level populations assumed proportional to the statistical weights, and deviations from such statistical relative intensities might occur even without autoionization. The effects of configuration interaction on these strengths have also been ignored.[3]

The tentative position listed for the $2,3;sp(-)\,^3P^\circ$ term in table 2 is from a weak line at 3470 ± 3 Å with the possible classification $2p^2\,^3P$–$2,3;sp(-)\,^3P^\circ$ [40]. The $2,3;sp(-)\,^3P^\circ$ energy calculated by Bhatia and Temkin [36] is about 240 cm^{-1} higher.

G.

Berry et al. [40] have measured the $2s2p\,^3P^\circ$–$2p3p\,^3D$ and $2s2p\,^3P^\circ$–$2p3p\,^3P$ lines with errors of less than 10 cm^{-1}, and the relative positions of the three terms involved are taken from their results. The difference in the energy of the $2p3p\,^3P$ term calculated by Doyle et al. [44] and the $2s2p\,^3P^\circ$ energy calculated by Drake and Dalgarno [45] agrees with the observed $2s2p\,^3P^\circ$–$2p3p\,^3P$ wavenumber [40] to within about 30 cm^{-1}, and the difference between the calculated $2p3p\,^3P$ energy [44] and Bhatia's calculated value for $2p3p\,^3D$ [34] agrees with the wavenumber difference of the two observed lines to within 20 cm^{-1}. The absolute positions of the three terms are thus based mainly on these three calculations [34, 44, 45], and are also consistent with other available data. The adopted $2p3p\,^3P$ and ^3D energies are in agreement with the most accurate wavelength measurements of transitions from these terms to $1snp\,^3P^\circ$ terms (near 300 Å) [38] to well within the $\sim \pm 100$ cm^{-1} accuracy of the measurements. Three additional values for the $2s2p\,^3P^\circ$ energy, all independent of the measurements and calculations on which the adopted value is based, are shown in table 5.

H.

Both the calculation by Doyle et al. [44] and that by Bhatia [42] give the $2p3d\,^1D^\circ$ term at 513500 cm^{-1} to within 5 cm^{-1}. It is quite possible that this value is accurate to within a few cm^{-1}, but the adopted position (50 cm^{-1} higher) agrees somewhat better with the value 513760 ± 220 cm^{-1} obtained from the measurement [38] of the $1s3d\,^1D$–$2p3d\,^1D^\circ$ line (305.2 ± 0.2 Å).

The results of four different calculations that included both the $2p3d$ and $2,4;sp\,(-)\,^1P^\circ$ terms are given in table 6. These results indicate that the two terms are quite close, with $2p3d\,^1P^\circ$ slightly higher. The $2p3d\,^1P^\circ$ position in table 2 is based on an adopted value of 170 ± 150 cm^{-1} for the separation of these $^1P^\circ$ terms, together with the observed position of $2,4;sp\,(-)\,^1P^\circ$ (517330 ± 130 cm^{-1} [23]).

The tentative classification $2p^2\,^1D$–$2p3d\,^1D^\circ$ previously listed for a weak line observed at 3372 ± 2 Å (29647 ± 20 cm^{-1}) [40] is inconsistent with the energies for these terms in table 2. The classification is also now inconsistent with energy values based wholly on other measurements; the difference between the $2p^2\,^1D$ energy observed by Siegbahn et al. [26] and the $2p3d\,^1D^\circ$ energy given by the recent measurement of the $1s3d\,^1D$–$2p3d\,^1D^\circ$ line [38] is 30960 cm^{-1}, with a probable error of less than 300 cm^{-1}. The tentative classification of another weak line at 2885 ± 1 Å (34652 ± 12 cm^{-1}) as $2p^2\,^1D$–$2p3d\,^1P^\circ$ [40] is consistent with the corresponding energy difference from table 2 (34540 ± 250 cm^{-1}), but the classification nevertheless appears doubtful. Since several calculations of the width of the $2p^2\,^1D$ level (see, e.g., [28, 34, 46]) give $\Gamma = 0.07$ eV, or about 560 cm^{-1}, it is unlikely that a weak line resulting from a transition to this level would be measured to ± 12 cm^{-1}. This consideration also applies to the classification of the 3372 Å line as $2p^2\,^1D$–$2p3d\,^1D^\circ$.

In assembling the data for this compilation I have had very helpful conversations with H. G. Berry, A. K. Bhatia, K. T. Chung, J. W. Cooper, G. W. F. Drake, R. D. Kaul, E. J. Knystautas, C. E. Kuyatt, A. W. Weiss, and W. H. Wing. I appreciate the assistance of each of these colleagues, several of whom also kindly supplied unpublished results. Lucy Hagan collected the more recent

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[3] The eigenvector of the nominal $2p3d\,^3P^\circ$ term probably has significant contributions from $2snp$ and $2pns$ ($n \geqq 3$) configurations [29] and the theoretical strength of the $1s3d\,^3D-2p3d\,^3P^\circ$ multiplet would be reduced by a percentage equal to the total percentage from such components. The effect of such components on the strength of the $2p^2\,^3P-2p3d\,^3P^\circ$ multiplet would depend on the various phases and integrals involved.

references on He I and prepared preliminary tables of the data on two-electron excitation. My special gratitude is due her for this help.

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5. Tables

TABLE 1. Energy levels of ^{4}He I; one-electron excitation

Desig.	J	Level (cm^{-1})	Level (eV)
$1s^2\,^1S$	0	0.00 ±0.15	0.0000
$2s\,^3S$	1	159856.069	19.8198
$2s\,^1S$	0	166277.546	20.6160
$2p\,^3P^\circ$	2	169086.8636	20.96430
	1	169086.9400	20.96431
	0	169087.9280	20.96444
$2p\,^1P^\circ$	1	171135.000	21.2182
$3s\,^3S$	1	183236.892	22.7187
$3s\,^1S$	0	184864.936	22.9206
$3p\,^3P^\circ$	2	185564.6540	23.00731
	1	185564.6760	23.00731
	0	185564.9466	23.00735
$3d\,^3D$	3	186101.6436	23.0739
	2	186101.6460	
	1	186101.6903	
$3d\,^1D$	2	186105.065	23.0743
$3p\,^1P^\circ$	1	186209.471	23.0873
$4s\,^3S$	1	190298.210	23.5942
$4s\,^1S$	0	190940.331	23.6738
$4p\,^3P^\circ$	2	191217.1237	23.7081
	1	191217.1327	
	0	191217.2430	
$4d\,^3D$	3	191444.5834	23.7363
	2	191444.5846	
	1	191444.6029	
$4d\,^1D$	2	191446.559	23.7366
$4f\,^3F^\circ$		191451.98	23.7373
$4f\,^1F^\circ$	3	191451.99	23.7373
$4p\,^1P^\circ$	1	191492.817	23.7423
$5s\,^3S$	1	193347.089	23.9722
$5s\,^1S$	0	193663.627	24.0115
$5p\,^3P^\circ$	2	193800.8021	24.0285
	1	193800.8067	
	0	193800.8621	
$5d\,^3D$	3	193917.2427	24.0429
	2	193917.2434	
	1	193917.2528	
$5d\,^1D$	2	193918.391	24.0431
$5f\,^3F^\circ$		193921.18	24.0434
$5f\,^1F^\circ$	3	193921.19	24.0434
$5g\,^{3,1}G$		193921.73	24.0435
$5p\,^1P^\circ$	1	193942.57	24.0460
$6s\,^3S$	1	194936.23	24.1692
$6s\,^1S$	0	195115.00	24.1914
$6p\,^3P^\circ$	2	195192.9055	24.2011
	1	195192.9081	
	0	195192.9398	
$6d\,^3D$	3	195260.1657	24.2094
	2	195260.1661	
	1	195260.1716	
$6d\,^1D$	2	195260.86	24.2095
$6f\,^3F^\circ$		195262.49	24.2097
$6f\,^1F^\circ$	3	195262.50	24.2097
$6g\,^{3,1}G$		195262.84	24.2097
$6h\,^{3,1}H^\circ$		[195262.89]	[24.2097]
$6p\,^1P^\circ$	1	195275.04	24.2113
$7s\,^3S$	1	195868.35	24.2848
$7s\,^1S$	0	195979.04	24.2985
$7p\,^3P^\circ$	2	196027.3970	24.3045
	1	196027.3986	
	0	[196027.4183]	
$7d\,^3D$	3	196069.7298	24.3098
	2	196069.7300	
	1	196069.7331	
$7d\,^1D$	2	196070.2230	24.3098
$7f\,^3F^\circ$		196071.272	24.3100
$7f\,^1F^\circ$	3	196071.2757	24.3100
$7g\,^{3,1}G$		[196071.459]	24.3100
$7h\,^{3,1}H^\circ$		196071.494	24.3100
$7i\,^{3,1}I$		[196071.52]	[24.3100]
$7p\,^1P^\circ$	1	196079.24	24.3110
$8s\,^3S$	1	196461.42	24.3584
$8s\,^1S$	0	196534.88	24.3675
$8p\,^3P^\circ$	2	196566.8189	24.3714
	1	196566.8200	
	0	[196566.8332]	
$8d\,^3D$		196595.18	24.3749
$8d\,^1D$	2	196595.54	24.3750
$8f\,^3F^\circ$		196596.17	24.3751

TABLE 1. Energy levels of ^{4}He I; one-electron excitation—Continued

Desig.	J	Level (cm^{-1})	Level (eV)
$8f\ ^1F^\circ$	3	[196596.17]	[24.3751]
$8p\ ^1P^\circ$	1	196601.51	24.3757
$9s\ ^3S$	1	196862.04	24.4080
$9s\ ^1S$	0	196912.98	24.4143
$9p\ ^3P^\circ$	2	196935.4192	
	1	196935.4200	24.4171
	0	[196935.429]	
$9d\ ^3D$		196955.28	24.4196
$9d\ ^1D$	2	196955.52	24.4196
$9f\ ^3F^\circ$		196956.04	24.4197
$9f\ ^1F^\circ$	3	[196956.04]	[24.4197]
$9p\ ^1P^\circ$	1	196959.79	24.4201
$10s\ ^3S$	1	197145.28	24.4431
$10s\ ^1S$	0	197182.17	24.4477
$10p\ ^3P^\circ$		197198.34	24.4497
$10d\ ^3D$		197212.88	24.4515
$10d\ ^1D$	2	197213.0700	24.4515
$10f\ ^3F^\circ$		197213.433	24.4516
$10f\ ^1F^\circ$	3	197213.4341	24.4516
$10p\ ^1P^\circ$	1	197216.24	24.4519
$11s\ ^3S$	1	197352.89	24.4689
$11s\ ^1S$	0	[197380.44]	[24.4723]
$11p\ ^3P^\circ$		197392.72	24.4738
$11d\ ^3D$		197403.47	24.4752
$11d\ ^1D$	2	197403.6200	24.4752
$11f\ ^3F^\circ$		197403.893	24.4752
$11f\ ^1F^\circ$	3	197403.8940	24.4752
$11p\ ^1P^\circ$	1	[197405.99]	[24.4755]
$12s\ ^3S$	1	197509.52	24.4883
$12s\ ^1S$	0	197530.68	24.4909
$12p\ ^3P^\circ$		197540.19	24.4921
$12d\ ^3D$		197548.41	24.4931
$12d\ ^1D$	2	197548.54	24.4931
$12f\ ^3F^\circ$		197548.76	24.4932
$12p\ ^1P^\circ$	1	[197550.36]	[24.4934]
$13s\ ^3S$	1	197630.75	24.5033
$13s\ ^1S$	0	197647.38	24.5054
$13p\ ^3P^\circ$		197654.83	24.5063
$13d\ ^3D$		197661.21	24.5071
$13d\ ^1D$	2	197661.22	24.5071
$13f\ ^3F^\circ$		197661.50	24.5071
$13p\ ^1P^\circ$	1	[197662.75]	[24.5073]
$14s\ ^3S$	1	197726.37	24.5152
$14s\ ^1S$	0	197739.67	24.5168
$14p\ ^3P^\circ$		197745.65	24.5176
$14d\ ^3D$		197750.69	24.5182
$14d\ ^1D$	2	197750.75	24.5182
$14f\ ^3F^\circ$		[197750.92]	[24.5182]
$14p\ ^1P^\circ$	1	[197751.94]	[24.5184]
$15s\ ^3S$	1	197803.12	24.5247
$15s\ ^1S$	0	197813.95	24.5260
$15p\ ^3P^\circ$		197818.83	24.5266
$15d\ ^3D$		197822.91	24.5272
$15d\ ^1D$	2	197822.96	24.5272
$15f\ ^3F^\circ$		197823.15	24.5272
$15p\ ^1P^\circ$	1	[197823.91]	[24.5273]
$16s\ ^3S$	1	197865.87	24.5325
$16p\ ^3P^\circ$		197878.69	24.5341
$16d\ ^3D$		197882.00	24.5345
$16d\ ^1D$	2	197882.01	24.5345
$16p\ ^1P^\circ$	1	[197882.82]	[24.5346]
$17s\ ^3S$	1	197917.53	24.5389
$17p\ ^3P^\circ$		197928.26	24.5402
$17d\ ^3D$		197930.96	24.5406
$17d\ ^1D$	2	197931.00	24.5406
$17p\ ^1P^\circ$	1	[197931.65]	[24.5406]
$18p\ ^3P^\circ$		197969.75	24.5454
$18d\ ^3D$		197972.00	24.5456
$18d\ ^1D$	2	197972.07	24.5456
$18p\ ^1P^\circ$	1	[197972.58]	[24.5457]
$19p\ ^3P^\circ$		198004.85	24.5497
$19d\ ^3D$		198006.75	24.5499
$19p\ ^1P^\circ$	1	[198007.21]	[24.5500]
$20p\ ^3P^\circ$		198034.80	24.5534
$20d\ ^3D$		[198036.4]	[24.5536]
$20p\ ^1P^\circ$	1	[198036.79]	[24.5537]
$21p\ ^3P^\circ$		198060.58	24.5566
$21d\ ^3D$		198062.3	24.5568
$22p\ ^3P^\circ$		198082.89	24.5594
He II ($^2S_{1/2}$)	***Limit***	***198310.76 ± 0.02***	***24.5876***

TABLE 2. Energy levels of ^{4}He I; two-electron excitation.[a]

Desig.			Level (cm^{-1})		Level (eV)		Text
He II	($1\ ^2S$)	***Limit***	***198310.76***		***24.5876***		
$2s^2$	^1S		466750	± 300	57.87	±0.04	B
$2s2p$	$^3P^\circ$		470310	(50)	58.312	(.006)	G
$2p^2$	^3P		481301.5	1.2	59.6744		E
$2p^2$	^1D		482960	(150)	59.88	(.02)	C
$2s2p$	$^1P^\circ$		484940[b]	120	60.125[b]	.015	A
$2p^2$	^1S		501200	300	62.14	.04	B
$2, 3; sp(-)$	$^1P^\circ$		506175	80	62.758	.010	A

TABLE 2. Energy levels of ^{4}He I; two-electron excitation.[a]—Continued

Desig.	Level (cm^{-1})	Level (eV)	Text
$2s3s$ ^1S	507720 ± 250	62.95 ± .03	B
$2,3;sp(+)$ $^3P^\circ$	508920 (100)	63.099 (.012)	D
$2p3p$ ^3D	509094 (50)	63.120 (.006)	G
$2p3p$ ^1P	509890 120	63.219 .015	E
$2,3;sp(-)$ $^3P^\circ$	510111? 25	63.246? .003	F
$2p3p$ ^1D	512160 150	63.50 .02	C
$2p3p$ ^3P	512600 (50)	63.555 (.006)	G
$2,3;sp(+)$ $^1P^\circ$	513400 50	63.654 .006	A
$2p3d$ $^1D^\circ$	513550 (100)	63.673 (.012)	H
$2p3d$ $^3D^\circ$	514473.5 1.2	63.7872	F
$2p3p$ ^3S	514700	63.81	B
$2p3d$ $^3P^\circ$	516775 5	64.0726 .001	F
$2,4;sp(-)$ $^1P^\circ$	517330 130	64.141 .016	A
$2p3p$ ^1S	517400? ?	64.15?	B
$2p3d$ $^1P^\circ$	[517500] (200)	[64.16] (.02)	H
$2s4s$ ^1S	517960 ± 250	64.22 ± .03	B
$2p4p$ ^3D	518240 100	64.254 .012	E
$2p4p$ ^1D	519340 150	64.39 .02	C
$2,4;sp(+)$ $^1P^\circ$	519940 50	64.465 .006	A
$2p4d$ $^3D^\circ$	520337 15	64.514 .002	F
$2p4d$ $^3P^\circ$	521433 30	64.650 .004	F
$2,5;sp(-)$ $^1P^\circ$	521570 140	64.67 .02	A
$2s5s$ ^1S	521840 150	64.70 .02	B
$2,5;sp(+)$ $^1P^\circ$	522766 55	64.815 .007	A
$2p5d$ $^3D^\circ$	522920 20	64.834 .002	F
$2,6;sp(+)$ $^1P^\circ$	524246 55	64.999 .007	A
$2p6d$ $^3D^\circ$	524410 20	65.019 .002	F
$2,7;sp(+)$ $^1P^\circ$	525127 55	65.108 .007	A
$2p7d$ $^3D^\circ$	525167 60	65.113 .007	F
$2,8;sp(+)$ $^1P^\circ$	525707 55	65.180 .007	A
$2,9;sp(+)$ $^1P^\circ$	526094 55	65.228 .007	A
$2,10;sp(+)$ $^1P^\circ$	526371 55	65.262 .007	A
He II ($2\,^2P^\circ_{1/2}$) *Limit*	*527490.06 ± 0.05*	*65.4011*	
$3s3p$ $^1P^\circ$	564270[c] 200	69.96[c] .02	A
$3,4;sp(+)$ $^1P^\circ$	578000 100	71.664 .012	A
$3,5;sp(+)$ $^1P^\circ$	582380 100	72.207 .012	A
$3,6;sp(+)$ $^1P^\circ$	584490 100	72.468 .012	A
$3,7;sp(+)$ $^1P^\circ$	585650 100	72.612 .012	A
$3,8;sp(+)$ $^1P^\circ$	586410 ± 100	72.706 ± .012	A
He II ($3\,^2P^\circ_{1/2}$) *Limit*	*588451.59 ± 0.05*	*72.9594*	
$4s4p$ $^1P^\circ$	594920 180	73.76 .02	A
$4,5;sp(+)$ $^1P^\circ$	602050 180	74.65 .02	A
$4,6;sp(+)$ $^1P^\circ$	604920 180	75.00 .02	A
He II ($4\,^2P^\circ_{1/2}$) *Limit*	*609787.89 ± 0.05*	*75.6048*	
He^{2+} ***Limit***	***637219.65 ± 0.05***	***79.0059***	

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[a] The levels of group "A" have not been corrected to compensate for the peak-to-center displacements defined in the theory of the corresponding absorption resonances (see text).

[b] The analysis of the $2s2p$ $^1P^\circ$ absorption profile by Madden and Codling [23] gives the "center" of the resonance at 485 000 cm^{-1} (60.133 eV). See text.

[c] This is a weighted average of the measurements of the $3s3p$ $^1P^\circ$ maximum-absorption position given in [23] and [23a]. By fitting a theoretical expression to their measurements of the profile, Dhez and Ederer [23a] obtained a value of 69.92±0.03 eV for the energy position E_0 defined in the theory.

TABLE 3. Some experimental [25–27] and theoretical [28–31] results for the energies of several even-parity ^1S levels. The units are eV.

Desig.	Rudd [25]	Sieghahn et al. [26]	B.-Montesquieu and B.-Cattin [27]	Burke [28]	Burke and McVicar [29]	Bhatia et al.[b] [30]	Holøien and Midtdal [31]	Adopted
$2s^2\ ^1S$	57.82±0.05	57.95±0.03	57.86±0.06	57.842	57.865	57.817	57.874	57.87±0.04
$2p^2\ ^1S$	62.15± .05		62.14± .06	62.134	[a] 62.808	62.063	62.131	62.14± .04
$2s3s\ ^1S$	62.95± .05	62.94± .02	62.96± .06	62.975	63.009	62.953	62.994	62.95± .03
$2p3p\ ^1S$			64.15 ?		64.216	64.091 ?	64.190 ?	64.15 ?
$2s4s\ ^1S$	64.22± .05	64.22± .03	64.25		64.182	64.181 ?	?	64.22± .03
$2s5s\ ^1S$	64.71± .05	64.70± .02			64.679	64.649 ?		64.70± .02

[a] The reason for the inaccuracy of this value is known; see Burke, P. G., and Taylor, A. J., Proc. Phys. Soc., London **88**, 549 (1966).

[b] Values do not include the energy shift Δ_Q; see [30].

TABLE 4. Energies of three ^1D levels (eV).

Desig.	Burrow[a]	Siegbahn et al. [26]	Bhatia [34]	Burke [28]	Drake [35]	Adopted
$2p^2\ ^1D$	59.95±0.08	59.86±0.02	59.902	59.911	59.887	59.88±0.02
$2p3p\ ^1D$		63.50± .02	63.515			63.50± .02
$2p4p\ ^1D$		64.38± .03	64.403			64.39± .02

[a] Burrow, P. D., Phys. Rev. A **2**, 1774 (1970). Burrow calibrated his energy scale by using the value 58.34 eV for the $2s2p\ ^3P^\circ$ resonance. A change of his scale to give an energy of 58.31 eV for this term (table 2) would decrease his value for the $2p^2\ ^1D$ resonance to 59.92±0.08 eV.

TABLE 5. Energies of two $^3P^\circ$ terms (eV).

Desig.	Rudd [25]	Quéméner et al. [32]	Bhatia and Temkin[a] [36]	Adopted
$2s2p\ ^3P^\circ$	58.34±0.05	58.40	58.300	[b] 58.312±0.006
$2,3;sp(+)\ ^3P^\circ$	63.08± .05		63.099	63.099± .012

[a] Values adjusted to a value of 13.60583 eV for R_∞.

[b] This value is not based on energies in this table; see text under "G".

TABLE 6. Calculated values of the $2,4;sp(-)\ ^1P^\circ$ and $2p3d\ ^1P^\circ$ levels (cm^{-1}).

$2p3d\ ^1P^\circ$	$2,4;sp(-)\ ^1P^\circ$	Difference
517300 [a]	517170 [a]	130
517580 [b]	517270 [b]	310
517600 [c]	517380 [c]	220
517170 [d]	517090 [d]	80
[517500±200] [e]	517330±130 [f]	[170±150] [e]

[a] Chung, K. T., and Chen, I., Phys. Rev. Lett. **28**, 783 (1972).

[b] Ref. [29].

[c] Altick, P. L., and Moore, E. N., Phys. Rev. **147**, 59 (1966).

[d] Lipsky, L., and Russek, A., Phys. Rev. **142**, 59 (1966).

[e] Adopted value.

[f] Observed position, Ref. [23].