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ATOMIC DATA FOR RESONANCE ABSORPTION LINES. III. WAVELENGTHS LONGWARD OF THE LYMAN LIMIT FOR THE ELEMENTS HYDROGEN TO GALLIUM

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ABSTRACT

This compilation revises the 1991 listing of atomic data for the lighter elements from hydrogen to gallium. The tabulation emphasizes resonance lines, i.e., lines whose lower level is the ground state, or an excited fine-structure state of the ground term, and is restricted to wavelengths longward of the H I Lyman limit at 911.753 Å. All but the very weakest known and predicted electric-dipole transitions are included, but no forbidden lines. This paper has attempted to review all data published by the end of 2002.

The tables contain the best data available to the author on ionization potentials, level designations, vacuum and air wavelengths, lower and upper energy levels, statistical weights, transition probabilities, natural damping constants (reciprocal lifetimes), oscillator strengths, and the often used combinations of log *gf* and log λf. All ion stages with relevant classified lines are included. Individual components resulting from isotope shift and hyperfine structure are listed explicitly for certain species. The accompanying text provides references, explanations for the critical selection of data, and notes indicating where new measurements or calculations are needed.

This compilation should be particularly useful in the analysis of interstellar and quasar absorption lines and other astrophysical sites where the density of particles and radiation is low enough to excite only the lowest atomic levels. The data also are relevant to the study of stellar atmospheres, and gaseous nebulae.

An Appendix summarizes new data relevant to the similar compilation in Paper II for the elements germanium to uranium.

Subject headings: atomic data — ISM: atoms — quasars: absorption lines — stars: atmospheres — ultraviolet: general

On-line material: machine-readable tables

1. INTRODUCTION

During the past decade there have been many improvements in atomic data, and new spectroscopic instruments have begun operation on the ground and in space. Consequently, the time is appropriate to update the compilation of wavelengths and transition probabilities of resonance lines by Morton (1991, hereafter Paper I). This revision (Paper III) for the lighter elements hydrogen to gallium will complement the recently completed compilation for the heavier elements germanium to uranium by Morton (2000, hereafter Paper II). Both papers deal with only transitions longward of the Lyman limit at 911.7535 Å where the bound-free absorption of hydrogen is not a major source of opacity in the interstellar medium.

Verner, Barthel, & Tytler (1994) have published useful tables of resonance lines longward of the He II limit at 228 Å, with *f*-values adopted from earlier critical compilations. The most recent tabulations from the US National Institute of Standards and Technology (NIST) were by Wiese, Fuhr, & Deters (1996) for carbon, nitrogen, and oxygen and by Fuhr & Wiese (1996) for all elements. The present paper is a new critical review of resonance-line data current to the end of 2002 and includes all but the weakest lines of all ion stages, whether or not *f*-values are available, to assist in line identifications and to indicate where new experiments or calculations would be useful.

Although the primary use of the present compilation will be for interstellar and quasar absorption lines, it also will be relevant for most of the P Cygni lines that appear in stellar winds, and to some extent for the analysis of stellar and nebular spectra, where resonance lines usually are prominent.

2. ELEMENT ABUNDANCES

Since the strength of an interstellar absorption line will depend on the element's abundance, as well as the *f*-value and any depletion on to grains, Table 1 lists the cosmic abundances by number of atoms from the summaries of Grevesse & Sauval (1998, 2002). Most of these are for CI carbonaceous chondrite meteorites according to Anders & Grevesse (1989) and Palme & Beer (1993). They normalized the relative meteorite abundances to hydrogen by adopting a mean of several reliable solar measurements. As spectroscopic abundances from the solar photosphere become more reliable, they usually replicate the meteoritic values, as discussed by Grevesse & Sauval (1998, 2000, 2002). Consequently, the meteorite abundances represent a useful basis for comparisons. When the *f*-values for the solar lines and the atmospheric models become more accurate, convincing differences with the meteorite abundances may arise and provide important clues about the formation of both the Sun and meteorites.

Carbon, nitrogen, and oxygen are depleted in the meteorites, so that Table 1 lists solar photospheric values. Prieto, Lambert, & Asplund (2001) found log $(N_{\rm O}/N_{\rm H}) = 8.69 \pm 0.05$ from the [O I] line at 6300 Å compared with 8.73 ± 0.06 in Table 1, which Grevesse & Sauval (2002) obtained from three weak permitted lines. The noble gases helium, neon, and argon are not observed in the photosphere and also are partially lost from meteorites. Grevesse & Sauval (2000,

TABLE 1
Summary of Elements

Element	Symbol	Atomic Number	Ionization Potentials (eV) I	II	III	$\log N/N_{\rm H} + 12.00$	Lower Limit $\log \lambda f$ (Å)	T_C (10^{-4} bar)
Hydrogen.................	H	1	13.59843			12.00	−8.52	180
Deuterium	D	1	13.60213			7.00	−3.52	...
Helium.....................	He	2	24.58739	54.41776		10.99	−7.51	...
Lithium....................	Li	3	5.39172	75.6400	122.4542	3.31	+0.17	1225
Beryllium	Be	4	9.32270	18.21115	153.8954	1.42	+2.06	1490[a]
Boron	B	5	8.29802	25.1548	93.9306	2.79	+0.69	964[a]
Carbon	C	6	11.26030	24.3833	47.8878	8.52	−5.04	78
Nitrogen	N	7	14.53413	29.6013	47.4492	7.95	−4.44	120
Oxygen	O	8	13.61805	35.12113	54.9355	8.73	−5.35	...
Fluorine...................	F	9	17.42282	34.9708	62.7083	4.48	−1.00	736
Neon........................	Ne	10	21.56454	40.96296	63.4227	8.06	−4.58	~5
Sodium	Na	11	5.13908	47.2864	71.6200	6.32	−2.84	970
Magnesium	Mg	12	7.64623	15.03527	80.1437	7.58	−4.10	1340
Aluminum	Al	13	5.98577	18.82855	28.44764	6.49	−3.01	1670
Silicon......................	Si	14	8.15168	16.34584	33.49300	7.56	−4.08	1340
Phosphorus..............	P	15	10.48669	19.76946	30.20263	5.56	−2.08	1151
Sulfur.......................	S	16	10.36001	23.33788	34.79	7.20	−3.72	674
Chlorine...................	Cl	17	12.96763	23.8136	39.61	5.28	−1.80	863
Argon	Ar	18	15.75961	27.62966	40.735	6.40	−2.92	50
Potassium	K	19	4.34066	31.63	45.8060	5.13	−1.65	1000
Calcium	Ca	20	6.11316	11.87172	50.9131	6.35	−2.92	1634
Scandium.................	Sc	21	6.56149	12.79977	24.75685	3.10	+0.38	1652
Titanium..................	Ti	22	6.82812	13.576	27.4917	4.94	−1.46	1600
Vanadium................	V	23	6.74619	14.618	29.311	4.02	−0.54	1455
Chromium	Cr	24	6.76651	16.4857	30.959	5.69	−2.21	1301
Manganese...............	Mn	25	7.43402	15.6400	33.668	5.53	−2.05	1190
Iron..........................	Fe	26	7.9024	16.188	30.651	7.50	−4.02	1337
Cobalt......................	Co	27	7.88101	17.084	33.50	4.91	−1.43	1356
Nickel	Ni	28	7.6398	18.16884	35.187	6.25	−2.77	1354
Copper.....................	Cu	29	7.72637	20.29239	36.841	4.29	−0.81	1170
Zinc	Zn	30	9.39420	17.9644	39.7233	4.67	−1.19	684
Gallium....................	Ga	31	5.99930	20.5151	30.726	3.13	+0.35	918

[a] At 10^{-3} bar.

2002) adopted $N_{\rm He}/N_{\rm H} = 0.098$ for the birth abundance from models of the solar interior, and values for neon and argon mainly from the measurements of the solar corona. The abundances in Table 1 are within 0.02 dex of those from Anders & Grevesse (1989) adopted in Paper I, except for B, C, N, O, Ne, S, and Ar, where the corrections to the earlier data are −0.09, −0.04, −0.10, −0.20, −0.03, −0.07, and −0.16 dex, respectively.

Although individual isotopes are not resolvable in most astrophysical spectra, a change in the distribution for an element can shift the center of a line or affect its profile. Consequently, the first entry for each element in the Table 2 contains the percentages for every stable isotope from the IUPAC standards (Rosman & Taylor 1997). These represent the likely composition of a laboratory source, and hence are relevant to the wavelengths quoted here. These percentages provide a standard for comparison with isotope distributions in various stars.

Table 1 also lists the first three ionization potentials (IPs) for each element in eV using the conversion 1 $\rm cm^{-1}$ = 1.23984186 (5) $\times 10^{-4}$ eV according to the 1998 CODATA Recommended Values of the Fundamental Physical Constants (Mohr & Taylor 2000). The IP sources are the same as those for the energy levels unless they are referenced explicitly in § 6, or as M70a (Moore 1970a) in Table 2. The dominant ion stage in interstellar clouds of neutral hydrogen is likely to be the lowest stage whose IP exceeds the 13.59843 eV of H I, that is, the lowest stage that cannot be ionized by radiation that is not absorbed in the ionization of hydrogen. However, in many clouds in front of QSOs as well as in the winds from hot stars, higher levels of ionization may prevail.

As explained in Paper I, the column density of a particular interstellar absorber N $\rm cm^{-2}$ is related to the equivalent width W_λ in Å of an unsaturated line with vacuum wavelength λ in Å and oscillator strength f by

$$\log N = 20.053 + \log({\rm W}_\lambda/\lambda) - \log \lambda f \ . \qquad (1)$$

Thus, if a line is detectable at $W_\lambda \geq 2 \times 10^{-4}$ Å at 3000 Å, and the column density of all forms of hydrogen

TABLE 2

Resonance Lines by Element

Multiplet Number	Air Wavelength (Å)	Vacuum (Å)	$E_{\rm low}$ ($\rm cm^{-1}$)	$E_{\rm up}$ ($\rm cm^{-1}$)	g_l	g_u	A ($\rm s^{-1}$)	Gamma ($\rm s^{-1}$)	f	log gf	log λf (Å)	Error (dex)
HYDROGEN = H Z = 1 A = 1:99.9885, 2:0.0115% in fresh water												
H I	1s 2S J = 1/2 GROUND		IP = 109678.7717 $\rm cm^{-1}$ Ref E77, GM65 = M72									
1u	2p 2Po		All Ref P98, (GRC57 = WSG66)									
MltMean		1215.6700	0.	82259.16300	2	6	6.265E+08		4.164E−01	−0.079	2.704	
		1215.6736	0.	82258.91907	2	2	6.265E+08	6.265E+08	1.388E−01	−0.557	2.227	
		1215.6682	0.	82259.28496	2	4	6.265E+08	6.265E+08	2.776E−01	−0.256	2.528	
2u	3p 2Po		All Ref P98									
MltMean		1025.7222	0.	97492.28344	2	6	1.673E+08		7.914E−02	−0.801	1.909	
		1025.7230	0.	97492.21117	2	2	1.673E+08	1.897E+08	2.638E−02	−1.278	1.432	
		1025.7218	0.	97492.31958	2	4	1.673E+08	1.897E+08	5.276E−02	−0.977	1.733	
3u	4p 2Po		All Ref P98									
MltMean		972.5367	0.	102823.8790	2	6	6.819E+07		2.901E−02	−1.236	1.450	
		972.5370	0.	102823.8485	2	2	6.819E+07	8.127E+07	9.669E−03	−1.714	0.973	
		972.5366	0.	102823.8943	2	4	6.819E+07	8.127E+07	1.934E−02	−1.413	1.274	
4u	5p 2Po		All Ref P98									
MltMean		949.7430	0.	105291.6442	2	6	3.437E+07		1.395E−02	−1.555	1.122	
		949.7431	0.	105291.6286	2	2	3.438E+07	4.204E+07	4.648E−03	−2.032	0.645	
		949.7429	0.	105291.6520	2	4	3.438E+07	4.204E+07	9.297E−03	−1.731	0.946	
5u	6p 2Po		All Ref P98									
MltMean		937.8034	0.	106632.1575	2	6	1.973E+07		7.803E−03	−1.807	0.864	
		937.8035	0.	106632.1485	2	2	1.973E+07	2.450E+07	2.601E−03	−2.284	0.387	
		937.8034	0.	106632.1620	2	4	1.973E+07	2.450E+07	5.202E−03	−1.983	0.688	

Note.—Table 2 is available in its entirety in the electronic edition of the *Astrophysical Journal Supplement*. A portion is shown here for guidance regarding its form and content.

$N_{\rm H} = 2.5 \times 10^{21}$ atoms $\rm cm^{-1}$, then

$$\log(\lambda f N/N_{\rm H}) \geq -8.52 \; . \qquad (2)$$

The limit of 2×10^{-4} Å is about right for the Hubble GHRS (Sofia et al. 1997), but the Ultrahigh Resolution Facility (UHRF) on the Anglo-Australian Telescope can reach 1×10^{-4} Å at visible wavelengths, lowering the limit by 0.6 dex. The adopted hydrogen density is a typical upper limit for sight lines through diffuse clouds studied by Bohlin, Savage, & Drake (1978). (The one exception in their list is ρ Oph with $N_{\rm H} = 7.2 \times 10^{21}$ $\rm cm^{-2}$). The next-to-last column of Table 1 lists $-8.52 - \log(N/N_{\rm H})$ for comparison with log λf for individual lines. Many effects reduce the detectability of a line, including distribution of an element over more than one ion stage, the population of excited levels, condensation onto grains, and lower $N_{\rm H}$. However, abundance anomalies in stellar spectra can strengthen the lines of certain elements.

The last column of Table 1 gives condensation temperatures T_C from Lodders & Fegley (1998, p. 83). At this temperature the element begins to form a compound at 10^{-4} bar in a cooling mixture, or if the element is not sufficiently abundant in a solar-type mixture, the temperature at which half is condensed. Element depletion in the interstellar gas increases with T_C, but the correlation is not tight, indicating that other factors also must contribute.

3. USEFUL FORMULAE

For easy reference, the basic relations for an atomic transition between a lower level l and an upper level u are repeated here from Paper I. If E_l and E_u are the energies of the levels in the usual units of $\rm cm^{-1}$, the vacuum wavelength in Å is

$$\lambda_{lu} = 10^8/(E_u - E_l) \; . \qquad (3)$$

If J is the angular momentum of a state, its electronic statistical weight is

$$g = 2J + 1 \; . \qquad (4)$$

If f_{lu} is the absorption oscillator strength or f-value, $S_{lu} = S_{ul}$ is the line strength in atomic units of $a_o^2 e^2 = 6.46048 \times 10^{-36}$ $\rm cm^2$ $\rm esu^{-2}$, and A_{ul} is the transition probability in $\rm s^{-1}$, then for electric-dipole transitions

$$\lambda_{lu} g_l f_{lu} = \frac{8\pi^2 m_e c}{3he^2} S_{lu} = \frac{m_e c}{8\pi^2 e^2} \lambda_{lu}^3 g_u A_{ul} \; , \qquad (5)$$

where λ is the wavelength in Å, c is the speed of light in cm $\rm s^{-1}$, h is Planck's constant in erg-seconds, $m_{\rm e}$ is the mass of the electron in g, and e is the electron charge in esu. Numerically,

$$\lambda_{lu} g_l f_{lu} = 303.756 S_{lu} = 1.49919 \times 10^{-16} \lambda_{lu}^3 g_u A_{ul} \; . \quad (6)$$

Morton & Noreau (1994) have shown these equations in rationalized mks units with e in coulombs.

Additional quantities may be defined or calculated if the multiplet is of the Russell-Saunders or LS type, i.e., there is no change in the spin quantum number S and the angular momentum number L changes by 0 or ± 1. The relative strengths within a multiplet are s_{lu} such that

$$S_{lu} = s_{lu} S_M , \text{ where } S_M = \sum_{lu} S_{lu} , \; \sum_{lu} s_{lu} \equiv 1 \; , \quad (7)$$

and the sum is over all lines in the multiplet. Many multiplets of the lighter elements are close to pure *LS* coupling so that the relative strengths can be obtained from the formulae and tables of Condon & Shortley (1957) or Cowley et al. (2000).

The natural width of a spectral line γ_{ul} in frequency units s^{-1} is the sum of the reciprocal lifetimes τ of the upper and lower levels, i.e.,

$$\gamma_{ul} = 1/\tau_u + 1/\tau_l = \sum_l A_{ul} \qquad (8)$$

because τ_l for the ground state is infinite and is very nearly so for excited levels of the ground term.

In some transitions the measured lifetimes or A-values do not separate the multiplet structure and hence apply to a mean for the multiplet, which must be resolved by the assumption of *LS* coupling. The extensive Opacity Project calculations also quote results for only the whole multiplet. Consequently, the first entry for many *LS* multiplets in Table 2 is labeled "MltMean " and lists the mean values defined as follows:

$$E_{Mu} = \frac{l}{g_{Mu}} \sum_u g_u E_u, \quad E_{Ml} = \frac{1}{g_{Ml}} \sum_l g_l E_l \qquad (9)$$

and

$$1/\lambda_M = E_{Mu} - E_{Ml} \ , \qquad (10)$$

where the total statistical weights of the upper and lower terms are

$$g_{Ml} = \sum_l g_l \ , \qquad g_{Mu} = \sum_u g_u \ . \qquad (11)$$

Finally, according to Wiese, Smith, & Glennon (1966), the multiplet *f*- and *A*-values f_M and A_M are given by

$$\lambda_M g_{Ml} f_M = \sum_{lu} \lambda_{lu} g_l f_{lu} \qquad (12)$$

and

$$\lambda_M^3 g_{Mu} A_M = \sum_{lu} \lambda_{lu}^3 g_u A_{ul} = \sum_u g_u \sum_l \lambda_{lu}^3 A_{ul} \ . \qquad (13)$$

Combining these with equations (5) and (7) gives

$$\lambda_{ul}^3 g_u A_{ul} = \lambda_M^3 s_{lu} g_{Mu} A_M \qquad (14)$$

and

$$\lambda_{ul} g_l f_{lu} = \lambda_M s_{lu} g_{Ml} f_M \ . \qquad (15)$$

Following the current practice at the US National Institute of Standards and Technology, air wavelengths $\lambda_{\rm air}$ in this paper were obtained from vacuum values $\lambda_{\rm vac} > 2000$ Å according to the dispersion formula of Peck & Reeder (1972):

$$\lambda_{\rm vac}/\lambda_{\rm air} = n = 1 + 8.06051 \times 10^{-5} + \frac{2.480990 \times 10^{-2}}{132.274 - \sigma^2} + \frac{1.74557 \times 10^{-4}}{39.32957 - \sigma^2} \ , \qquad (16)$$

where $\sigma = 10^4/\lambda_{\rm vac}$ with λ in Å. The formula of Edlén (1953) adopted by the IAU in 1955 gives air wavelengths shorter by 0.028 mÅ at 2000 Å, 0.043 mÅ longer at 10000 Å, and 0.43 mÅ longer at 50000 Å, while the revision by Edlén (1966) gives air values all shorter by 0.026, 0.036, and 0.24 mÅ and the expression by Birch & Downs (1993, 1994) described in Paper II shorter by 0.058, 0.17, and 0.91 mÅ at these respective reference points.

4. DETERMINATION OF TRANSITION PROBABILITIES

4.1. *Experiments*

Thorne, Litzén, & Johansson (1999) have written a useful summary. Absorption or emission experiments require an accurate knowledge of the temperatures and particle densities in the source. Nonuniformity was a serious problem with the unsuccessful attempt by Corliss & Bozman (1962) to convert their emission intensities to an absolute scale of *f*-values. The hook method, which depends on anomalous dispersion, provides f directly. Electron energy loss spectrometry (Chan et al. 1992) has been useful for the noble gases. However, lifetime experiments usually are preferred as a basis for absolute *f*-values. The measurement techniques include, phase shift, delayed coincidence, beam-foil (BF) and beam-laser spectroscopy, time-resolved laser-induced fluorescence (TRLIF), and the Hanle effect, also called zero-field level crossing.

One must be careful of early beam-foil lifetimes from the 1970s when repopulation of the upper level by cascades was not always considered properly, sometimes resulting in a published lifetime longer than its true value. Even the use of multiexponential fits may not be sufficient. Curtis, Berry, & Bromander (1971a) allowed for the cascades with a method of arbitrarily normalized decay curves (ANDC), which works well if there are only a few contributors. Now the usual method to eliminate cascades is laser-induced fluorescence (LIF) through the excitation of a single level by a tunable laser and measurement of the decay of the light with distance along a beam of atoms or ions, or with time from a small region of excited gas. Ion traps and storage rings are useful for lifetimes of 10 μs and longer (Träbert 2000). However, unless a lifetime represents only a single decay path, accurate measurements of branching fractions also are necessary. Intensity-calibrated Fourier transform spectrometers (FTS) have been useful for this purpose, and the addition of CaF_2 optics has extended their range to far-UV wavelengths (Thorne et al. 1987).

4.2. *Calculations*

The theoretical *f*-values for hydrogen, tabulated by Wiese et al. (1966), are essentially exact, though the lack of the relativistic correction limits the accuracy to four figures. Other simple transitions, such as ^1S–$^1P^o$ and ^2S–$^2P^o$ now have excellent ab initio theoretical treatments, which accurately match the experimental energies and *f*-values. In any calculation an important reliability test is the agreement of the derived transition wavelength with the laboratory measurement. For complex systems there is a strong preference for the semiempirical technique, which applies small corrections to the diagonal terms in the Hamiltonian matrix to force the eigenvalue separations to conform to the laboratory energies. Where the calculated and laboratory wavelengths disagree, one must derive A and f from the energy-independent line strength S using the laboratory wavelength according to equation (6). Some theoretical approaches permit equivalent formulations in terms of either a length or velocity operator so that the closeness of the two results is another test of the accuracy of the wave functions. If the *f*-values differ, the length calculation is expected to be more reliable.

The international team contributing to the Opacity Project (OP; see The Opacity Project Team 1995) has provided many theoretical *f*-values and other parameters for the lighter elements. These calculations depend on the close-coupling approximation also used for collision processes. In the frozen-cores approximation bound-bound transitions are represented by a target ion with *n* electrons, plus an electron of negative energy bound in the field of the ion. The OP yields only multiplet *f*-values, but in most cases pure *LS* coupling is a reliable assumption for the individual lines of the lighter elements. The available experimental data generally confirm the OP results except for some neutrals such as C I and N I (see Musielok et al. 2000). With increasing nuclear mass, the relativity correction, which splits the multiplet, can cause significant deviations from the *LS* ratios.

4.3. *Astrophysical Observations*

When one has equivalent-width measures of multiple interstellar absorption lines with known *f*-values from the same atom or ion, it is possible to construct an empirical curve of growth. If there is another species with multiple transitions and *f*-values, it can fill out the curve by adjusting the abscissa log $Nf\lambda$ for the fixed ordinate log $W\lambda/\lambda$ provided there is a reason to assume the lines of the two species originate in the same interstellar region. Then interpolation of other equivalent widths can provide estimates of *f*, if they do not lie on the saturated part of the curve. For examples see the papers by de Boer & Morton (1974) or Shull, Snow, & York (1981).

Unfortunately, when laboratory measurements eventually become available, the astrophysical values are not always confirmed. One problem is narrow saturated components of a line profile that can hide considerable column density unless the spectral resolution is extremely high. Another difficulty can arise from the inadequate definition of the curve of growth. Welty et al. (1999) in their analysis of 23 Ori have shown that the shapes can deviate significantly from the simple form generated by a single-component Voigt profile. Table 2 lists a few astrophysical values for Mn II where no better information was available.

5. TABLE FORMAT

Table 2 contains the main atomic data. There is a title for each element giving its atomic number *Z*, and the nucleon numbers *A* of the stable isotopes, each with a colon followed by the percentage typical of laboratory samples from the IUPAC standards by Rosman & Taylor (1997). In some cases, particularly hydrogen and the noble gases, these may differ significantly from the meteoritic or astrophysical ratios quoted by Anders & Grevesse (1989). Next there is a title for each ion stage with the spectroscopic designation of the ground state or a low-lying excited state with the *J*-value listed explicitly, the ionization potential in cm^{-1}, and references for energy levels, wavelengths, and the IP. Then each multiplet or group of lines has a header beginning with Moore's multiplet number if she assigned one in her (Moore 1945) tables of visual (v) lines or her (Moore 1950, 1952) tables of ultraviolet (u) lines. This header continues with the designation of the upper term, which is complete except for closed shells and shows the parentage in parentheses. The last entry in the header provides the references to data relevant to the transition probability. (A reference in parenthesis indicates one, which substantiates the adopted values but was not used in forming the average.) Sometimes the word "All" or "Part" is used to indicate that all or only some lines of a multiplet are listed, while "*LS*" notes that pure *LS* coupling was assumed for the relative line strengths. The word "One" reminds the reader that the multiplet consists of a single line. Blanks occur where the upper level lacks a complete designation. To simplify the printing from the output of a FORTRAN program, the superscripts indicating the numbers of *s*, *p*, *d*, etc. electrons in a configuration are not elevated, nor are the multiplicities preceding the total orbital angular momentum *S*, *P*, *D*, etc. In most cases in which *LS* coupling is possible, i.e., $\Delta L = 0$, ± 1, and $\Delta S = 0$, there is a row of data beginning with the designation "MltMean," which represents mean values for the multiplet as defined in § 3. These are useful where the input datum is the multiplet transition probability or lifetime.

For all but a few transitions Ritz wavelengths derived directly from the published energy levels are listed because they are based on the most accurate measurements usually involving several lines. The wavelengths normally are quoted to about the same accuracy as the published levels, which often have absolute errors affecting the second to last digit.

The entries in Table 2 for the individual lines of a multiplet are the following.

Wavelength (Å).

Air: For $\lambda > 2000$ Å calculated by equation (16).

Vacuum: Calculated by equation (10).

E_{low}, E_{up} (cm^{-1}): Level energies, both lower and upper. A letter following the upper energy level indicates that it is from a particular source noted in § 6, while a colon labels an uncertain value.

g_l, g_u: Lower and upper statistical weights, where $g = 2J + 1$.

A (s^{-1}): The spontaneous transition probability A_{ul}.

Gamma (s^{-1}): The natural damping constant γ, which is the sum of all *A* to lower levels, and is the reciprocal of the lifetime of the upper state for resonance lines.

f: The absorption oscillator strength or *f*-value, f_{lu}.

$\log gf = \log_{10} g_l f_{lu}$.

$\log \lambda f = \log_{10} \lambda_{\mathrm{vac}} f_{lu}(\lambda \text{ in Å})$.

Error: $0.5 \log[(x + \sigma)/(x - \sigma)]$. Thus, a 1 σ error of 10% corresponds to 0.044 dex and 25% to 0.11 dex. Usually, the tabulated errors are simply the random ones quoted by the authors without any attempt to include systematic effects. In most cases, no errors are given for theoretical values.

Ref: References indicated by the first letter of each author's surname, and the last two digits of the year. The corresponding full names are listed in Table 3. This table includes the following descriptions of content:

A: Transition probability (experiment or theory);

b: Branching fraction (experiment or theory);

E: Energy levels;

f: Oscillator strength (experiment, theory, or astrophysics);

TABLE 3

REFERENCES ABBREVIATED IN TABLE 2

Abbreviation	Citation and Type of Data	Ion
A95	V. I. Azarov 1995, private communication to W. C. Martin; E	F I
ADJS70	Andersen, Désesquelles, Jessen, & Sørensen 1970; τ exp	Mg I
AEPR79	Andersen, Eriksen, Poulsen, & Ramanujam 1979; τ exp	Ga II
AIV77	Arimondo, Inguscio, & Violino 1977; hfs	Na I, K I
AKM01	Aggarwal, Keenan, & Msezane 2001; f theory	F IV
ALP89	Ansbacher, Li, & Pinnington 1989, τ exp	Mg II
APBK85	Ansbacher, Pinnington, Bahr, & Kernahan 1985; τ exp	Ga II, III
AS72	Andersen & Sørensen 1972; τ exp	Ga I
ASJ90	Allen, Snow, & Jenkins 1990; f astrophysics	Mn II
ASVW89	Adelman, Svatek, Van Winkler, & Warren 1989; multiplet numbers	Mn I
BBB70a	Berry, Bromander, & Buchta 1970a; τ exp	Al III
BBBLM69	Bergström, Bromander, Buchta, Lundin, & Martinson 1969; τ exp	Be II
BBKAP91	Biémont, Baudoux, Kurucz, Ansbacher, & Pinnington 1991; τ exp	Fe II
BBLB98	Baugh, Burkhardt, Leventhal, & Bergeman 1998; IP	Na I
BBPL89	Blackwell, Booth, Peford, & Laming 1989; f exp	Ni I
BBPS84	Booth, Blackwell, Petford, & Shallis 1984; f exp	Mn I
BCZSB97	Berzinsh, Caiyan, Zerne, Svanberg, & Biémont 1997; τ exp	S I
Betal98	Bergeson et al. 1998; IP	He I
BDHS86	Buurman, Dönszelmann, Hansen, & Snoek 1986; τ exp	Al I
BF93	Brage & Froese Fischer 1993; A theory	P II, S III, Ar V
BFVGH93	Brage, Froese Fischer, Vaeck, Godefroid, & Hibbert 1993; $f\tau$ exp	Ca I
BGFLS98	Biémont, Garnir, Federman, Li, & Svanberg 1998; b theory	S I
BGFMLW89	Biémont, Grevesse, Faires, Marsden, Lawler, & Whaling 1989; t b A f exp	V II
BGJT88	Brown, Ginter, Johansson, & Tilford 1988; IP	Fe I
BGZ94	Biémont, Gebarowski, & Zeippen 1994; f theory	Cl I
BH73	Banfield & Huber 1973; f exp	Fe I
BHL97	Brage, Hibbert, & Leckrone 1997; A theory	N II
BHNGBTL93	Bizzarri, Huber, Noels, Grevesse, Bergeson, Tsekeris, & Lawler 1993; τ exp	Ti II
BHSB95	Bell, Hibbert, Stafford, & Brage 1995; A f theory	N III
BIPS79	Blackwell, Ibbetson, Petford, & Shallis 1979; f exp	Fe I
BJB96	Brage, Judge, & Brekke 1996; A f theory	O IV
BK80	Bernheim & Kittrell 1980; λ E	C I
BL93a	Bergeson & Lawler 1993a; τ, b exp	Cr II, Zn II
BL93b	Bergeson & Lawler 1993b; f exp	Si II
BL93c	Bergeson & Lawler 1993c; τ exp	Ni I
BM71	Bashkin & Martinson 1971; τ exp	Cl II, III, IV
BMBEM85	Bashkin, McIntyre, Buttlar, Ekberg, & Martinson 1985; τ exp	B II
BML94	Bergeson, Mullman, & Lawler 1994; f exp	Fe II
BMP83	Blackwell, Menon, & Petford 1983; f exp	Ti I
BMPSVW90	Beverini, Maccioi, Pereira, Strumia, Vissani, & Wang 1990; E	Mg I
BMWLLJ96	Bergeson, Mullman, Wickliffe, Lawler, Litzén, & Johansson 1996; b f exp	Fe II
BMZ93	Butler, Mendoza, & Zeippen 1993; f theory	Mg I isoelectronic
BPSL82a	Blackwell, Petford, Shallis, & Legget 1982a; f exp	Ti I
BSFE94	Beideck, Schectman, Federman, & Ellis 1994; t b exp	S I
BSMBB70b	Berry, Schectman, Martinson, Bickel, & Bashkin 1970b; τ exp	S III
BSZ96	Biémont, Storey, & Zeippen 1996; f τ theory	S I
BWG98	Bridges, Wiese, & Griesmann 1998; b exp	N II
BWWI85	Bollinger, Wells, Wineland, & Itano 1985; E hfs	Be II
BZ91	Butler & Zeippen 1991; f theory	O I
BZ92	Biémont & Zeippen 1992; b theory	O I
C00	Curtis 2000; A theory	Ga II
C91	Curtis 1991; τ theory	Cl VI
C98	Chen 1998; f theory	Be I
CBK91	Czajkowki, Bobkowski, & Krause 1991; τ exp	Zn I
CBLB92	Ciocca, Burkhardt, Leventhal, & Bergeman 1992; IP	Na I
CCGBB92	Chan, Cooper, Guo, Burton, & Brion 1992; f exp	Ar I
CCH93	Cho, Chi, & Huang 1993; f theory	Mg I isoelectronic
CCJ01	Chen, Cheng, & Johnson 2001; τ theory	C III
CE96	Curtis & Ellis 1996; τ theory	Be I isoelectronic
CG98	Chang & Geller 1998; λ E, IP	C I
CGL97	Curry, Gibson, & Lawler 1997; b exp	N II
CH02	Corrégé & Hibbert 2002; A theory	C II, N III, O IV
CHP92	Calamai, Han, & Parkinson 1992; τ exp	P II
CJSF92	Carlsson, Jönsson, Sturesson, & Froese Fischer 1992; τ exp	Na I
CL67	Cunningham & Link 1967; τ exp	Ga I

TABLE 3—*Continued*

Abbreviation	Citation and Type of Data	Ion
CM00	Charro & Martín 2000; f theory	Si II
CMB71b	Curtis, Martinson, & Buchta 1971b; τ exp	P I, III, IV, V
CSB93	Calamai, Smith, & Bergeson 1993, t b exp	Si II
CSS89	Carlsson, Sturesson, & Svanberg 1989; τ exp	Fe I, Cu I
CSSTW82	Cardon, Smith, Scalo, Testerman, & Whaling 1982; f exp	Co I
CT89	Curtis & Theodosiou 1989; t f theory	Cu I isoelectronic
CT90	Chang & Tang 1990; f theory	Mg I
CZ93	Chung & Zhu 1993; τ theory	Be I
D90	Doering 1990; f exp	S I
D95	Doidge 1995; f compilation	Li I–U I
DBG74	Dumont, Biémont, & Grevesse 1974; τ exp	N II
DEK90	Delalic, Erman, & Källne 1990; τ exp	S I
Detal95	Doerfert et al. 1995; τ exp	N IV
DH99	Donnelly & Hibbert 1999; f theory	Fe II
DHB99	Donnelly, Hibbert, & Bell 1999; A f theory	Cu II
DK85	Doerr & Kock 1985; f exp	Ni I
DKHOS92	Dufton, Keenan, Hibbert, Ojha, & Stafford 1992; f theory	Si II
DKHSBA91	Dufton, Keenan, Hibbert, Stafford, Byrne, & Agnew 1991; A theory	Si II
DKKWZ85	Doerr, Kock, Kwiatkowski, Werner, & Zimmerman 1985; t f ex	V I
DMPY74	de Boer, Morton, Pottasch, & York 1974; f astrophysics	Mn II, Fe II
DT78	Dankwort & Trefftz 1978; A f theory	B I isoelectronic
DTWSU97	Doerfort, Träbert, Wolf, Schwalm, & Uwira 1997; τ exp	C III
DVD90	Davidson, Volten, & Dönszelmann 1990; t b f exp	Al I
DWB80	Drullinger, Wineland, & Bergquist 1980; hfs	Mg II
E72	Eidelsberg 1972; IP	Be III
E74	Eidelsberg 1974; IP	B IV
E77	Erickson 1977; E, IP	H I, D I, He II
E82	Engström 1982; τ exp	Ga II
E83	Eriksson 1983; λ E	N II
E84	Engström 1984; λ E, IP	F VII
E85	Engström 1985; λ E, IP	F VI
E93	Ekberg 1993; l E A exp	Fe III
E97	Ekberg 1997; λ E	Cr III
E99	R. Engleman 1999, private communication; E	K I
EBK93	Engelke, Bard, & Kock 1993; τ exp	Fe I
Eetal83	Ekberg et al. 1983; τ exp	S VI
EL01	R. Engleman & U. Litzén 2001 private communication to W. C. Martin; E	B I
EM84	Ellis & Martinson 1984; λ	Cl IV
ES76	Erdevdi & Shimon 1976; τ exp	Ga I
EUVH97	Eikema, Ubachs, Vassen, & Hogervorst 1997: IP	He I
F00	Froese Fischer 2000; f theory	C III, N IV, O V
F02	Froese Fischer 2002; A f theory	S IV, Cl V, Ar VI
F86	Fawcett 1986; f theory	P I
F91	Forsberg 1991; λ E	Ti I
F97	Fitzpatrick 1997; f astrophysics	Mg II
FB97	Fleming & Brage 1997; A theory	O III
FBBVHGF95	Fleming, Brage, Bell, Vaeck, Hibbert, Godefroid, & Froese Fischer 1995; A f theory	N IV
FBDMR76	Feldman, Brown, Doschek, Moore, & Rosenberg 1976; λ E	C I
FBHVG96a	Fleming, Bell, Hibbert, Vaeck, & Godefroid 1996a; A theory	B II, C III, O V
FBSY92	Federman, Beideck, Schectman, & York 1992; τ exp	Ar I
FG97	Froese Fischer & Gaigalas 1997; A theory	B II, C III
FH95	Fleming & Hibbert 1995; A f theory	Ga II
FHBV98	Fleming, Hibbert, Bell, & Vaeck 1998; f theory	Mg II
FHS94	Fleming, Hibbert, & Stafford 1994; f theory	C III
FL99	Fedchak & Lawler 1999; t b A f exp	Ni II
FLB01	Feuchtgruber, Lutz, & Bientema 2001; E	Cl IV, V, Ar VI
FMW88	Fuhr, Martin, & Wiese 1988; A f compilation	Fe, Co, Ni
FP29	Filippov & Prokofiev 1929; f exp	Na I
FSGG98	Froese Fischer, Saparov, Gaigalas, & Godefroid 1998; A theory	Li I isoelectronic
FVHBG96b	Fleming, Vaeck, Hibbert, Bell, & Godefroid 1996b; f theory	B II
FWB75	Furcinitti, Wright, & Balling 1975b; τ exp	Mg I
FWL00a	Fedchak, Wiese, & Lawler 2000a; f exp	Ni II
GAPJB92	Guo, Ansbacher, Pinnington, Ji, & Berends 1992; τ exp	Fe II
GF99	Godefroid & Froese Fischer 1999; f theory	Mg II
GINRV77	Griffith, Isaak, New, Ralls, van Zyl 1977; hfs	Na I
GK00	Griesmann & Kling 2000; λ E	C IV, Al II, III, Si II, IV

TABLE 3—*Continued*

Abbreviation	Citation and Type of Data	Ion
GL00	Gullberg & Litzén 2000; λ E	Zn I, II
GLMN92	Goldbach, Lüdtke, Martín, & Nollez 1992; f exp	N I
GM65	Garcia & Mack 1965; E	H I
GMN89	Goldbach, Martin, & Nollez 1989; f exp	C I
GMNPZB86	Goldbach, Martin, Nollez, Plomdeur, Zimmermann, & Babic 1986; f exp	N I
GN87	Goldbach & Nollez 1987; f exp	C I
GN92	Godone & Novero 1992; τ exp	Mg I
GN94	Goldbach & Nollez 1994; f exp	O I
GOJF95	Godefroid, Olsen, Jönsson, & Froese Fischer 1995; f theory	B II
GPA88	Gosselin, Pinnington, & Ansbacher 1988; τ exp	Ca II
GRC57	Green, Rush, & Chandler 1957; f theory	H I
H79	Hallstadius 1979; E	Mg I
H86	Hayes 1986; b theory	S III
H88	Hibbert 1988; A theory	P II
H93	Hibbert 1993; τ theory	P II
HBF02	Hibbert, Brage, & Fleming 2002; A f theory	S IV
HBGV91b	Hibbert, Biémont, Godefroid, & Vaeck 1991b; A f theory	O I
HBW77	Havey, Balling, & Wright 1977; τ exp	Ga I
HDK85	Hibbert, Dufton, & Keenan 1985; A f theory	N I
HH87	Ho & Henry 1987; f theory	S III
HH94	Haridass & Huber 1994; λ	C I
HK87	Hibbert & Keenan 1987; f theory	Al II
HL81	Hannaford & Lowe 1981; τ exp	Fe I
HLGN92	Hannaford, Lowe, Grevesse, & Noels 1992; τ exp	Fe II
HM78	Hannaford & McDonald 1978; f exp	Cu I
HMEB72	Hontzeas, Martinson, Erman, & Buchta 1972; τ exp	Be I
HOS92	Hibbert, Ojha, & Stafford 1992; f theory	Si II
HS80	Huber & Sandeman 1980; f exp	Ni I
HSC95	Heise, Smith, & Calamai 1995; τ exp	S III
ICD88	Iglesias, Cabeza, & de Luis 1988; E, IP	V II
IHCMB99	Irving, Henderson, Curtis, Martinson, & Bengtsson 1999; τ exp	Be I, B II
IL73	Irwin & Livingston 1973; τ exp	F I, Si III
IL85	Isberg & Litzén 1985; λ E, IP	Ga II
IL86	Isberg & Litzén 1986; λ E, IP	Ga III
IW81	Itano & Wineland 1981; hfs	Mg II
J59	Johansson 1959; IP	Li I
J61	Johansson 1961; λ E, IP	Be II
J72	Johnson 1972; τ exp	O I
J78	Johansson 1978; λ E, IP	Fe II
J84	Johansson 1984; λ	Fe II
J99	S. Johansson 1999, private communication; λ	Fe II
JBLNW95	Johansson, Brage, Leckrone, Nave, & Wahlgren 1995; f theory	Fe II
JC94	Jin & Church 1994; τ exp	Ca II
JC96	Jupén & Curtis 1996; λ	Cl V
JF97	Jönsson & Froese Fischer 1997; A f theory	Mg I isoelectronic
JF98	Jönsson & Froese Fischer 1998; A theory	C III
JFG96a	Jönsson, Froese Fischer, & Godefroid 1996; f theory	C II
JFG99	Jönsson, Froese Fischer, & Godefroid 1999; f theory	B II, Mg I
JJLPTW96	Jones, Julienne, Lett, Phillips, Tiesinga, & Williams 1996; τ exp	Na I
JKLCOS94	James, Kowalczyk, Langlois, Campbell, Ogawa, & Simard 1994; IP	V I
JL67	Johansson & Litzén 1967; E, IP	Ga I
JLKK93	Johansson, Litzén, Kasten, & Kock 1993; λ E	B I
JLS96	Johnson, Liu, & Sapirstein 1996; A theory	Li, Na I isoelectronic
JLZKL98	Jönsson, Litzén, Zethson, Kling, & Launay 1998; λ	B II
JMKUWS97	Jans, Möbus, Kühne, Ulm, Werner, & Schartner 1997; b exp	Ar II
JPHC81	Juncar, Pinard, Harmon, & Chartier 1981; λ	Na I
JSK84	Johnson, Smith, & Knight 1984; τ exp	O III
JSP86	Johnson, Smith, & Parkinson 1986; A exp	Al II
K47	King 1947; f exp	V I
K57	Kelly 1957; E	Mg I
K98	Kurucz 1998; f theory	V II, III, Cr III, Mn I, II, Co III
K99	Kurucz 1999; f theory	Fe II
KBBDG99a	Kramida, Bastin, Biémont, Dumont, & Garnir 1999a; λ E, IP	Ne IV
KBBDG99b	Kramida, Bastin, Biémont, Dumont, & Garnir 1999b; λ E, IP	Ne V
KBBDG99c	Kramida, Bastin, Biémont, Dumont, & Garnir 1999c; λ E, IP	Ne VI
KBND71	Knystautas, Barrette, Neveu, & Drouin 1971; τ exp	C IV, O VI

TABLE 3—*Continued*

Abbreviation	Citation and Type of Data	Ion
KFFS98	Kohstall, Fritzsche, Fricke, & Sepp 1998; A theory	Ar V
KG00	Kling & Griesmann 2000; b A f ex	Mn II
KJSP83	Kwong, Johnson, Smith, & Parkinson 1983; A exp	Si III
KL00	Karlsson & Litzén 2000; λ	Ga I, II
KL95	Kelly & Lacey 1995; E	Ar V
KM72	Kaufman & Minnhagen 1972; E, IP	Ne I
KM78	Kelly & Mathur 1978; τ ex	Mg I
KM89	Kaufman & Martin 1989; λ	O VI
KM91a	Kaufman & Martin 1991a; λ	Mg I–XII
KM91b	Kaufman & Martin 1991b; λ	Al I–XIII
KM93	Kaufman & Martin 1993; λ	S I–XVI
KM97	Kramida & Martin 1997; λ E, IP	Be I
KMWZ82	Kwiatkowski, Micali, Werner, & Zimmermann 1982; τ exp	Mn II
KMZKK86	Karamatskos, Michalak, Zimmermann, Kroll, & Kock 1986; t b f exp	V II
KP73	Kohl & Parkinson 1973; f exp	Al I
KPOBD79	Kernahan, Pinnington, O'Neil, Brooks, & Donnelly 1979; τ exp	Al II
KR68	Koch & Richter 1968; A f exp	Cu I
KSG01	Kling, Schnabel, & Griesmann 2001; t b A f exp	Mn II
KSP82	Kwong, Smith, & Parkinson 1982; f exp	Mg I
KW96	Kaufman & Whaling 1996; IP	Ar III
L49	Lidén 1949; λ E, IP	F I
L64	Lurio 1964; τ exp	Mg I
L69	Lawrence 1969; τ exp	S II, Cl II
L73	Löfstrand 1973; IP	Be III
L91	Lawler 1991; τ exp	Ti I
L92	Liaw 1992; f theory	K I
L95	Liaw 1995; f b theory	Ca II
L99	U. Litzén 1999, private communication; λ E	Ca II
LB82	Laguna & Beatty 1982; E hfs	F I
LBG80	Longmire, Brown, & Ginter 1980; IP	Cu I
LBS99	Loock, Beaty, & Simard 1999; IP	Cu I
LBT93	Litzén, Brault, & Thorne 1993; l E	Ni I
LBYO82	Lugger, Barker, York, & Oegerle 1982; f astrophysics	Mn II, Fe II
LCK81	Lombardi, Cardon, & Kurucz 1981; f exp	Al I
LD89	Lawler & Dakin 1989; b A exp	Sc I, II
LEHM73	Lundin, Engman, Hilke, & Martinson 1973; τ exp	Mg I
Lev91	Levashov 1991; E	Cl VI
LGBDBG76	Livingston, Garnier, Baudinet-Robinet, Dumont, Biémont, & Grevesse 1976; τ exp	Si III, S III
LH91	Lowe & Hannaford 1991; τ exp	Ti I
LK98	Litzén & Kling 1998; λ	B III
LKIP75	Livingston, Kernahan, Irwin, & Pinnington 1975; τ exp	P I, II, III, IV, V
LL93a	LaJohn & Luke 1993a; τ theory	P II
LL93b	LaJohn & Luke 1993b; t, A theory	Si I isoelectronic
LLBJS00	Li, Lundberg, Berzinsh, Johansson, & Svanberg 2000; τ exp	C I, Fe II
LLMVJ80	Liljeby, Lindgärd, Mannervick, Veje, & Jelenkovick 1980; τ exp	Mg I
LLVSLDPS99	Lauer, Liebel, Vollweiler, Schmoranzer, Lagutin, Demekhin, Petrov, & Sukhorukov 1999; τ exp	Ar II
LP89	Luo & Pradhan 1989; f theory	C I isoelectronic
LPSGB98	Li, Persson, Svanberg, Garnier, & Biémont 1998; τ exp	S I
LRLS98	Lang, Roth, Lang, & Schmoranzer 1998; f exp	Ar I
LS93	Larsson & Svanberg 1993; τ exp	Mg I
LSH95	Langhans, Schade, & Helbig 1995; τ exp	Fe I
LV79	Laughlin & Victor 1979; f theory	Mg I isoelectronic
LYBM78	Lugger, York, Blanchard, & Morton 1978; f astrophysics	N I
LZJKKL98	Litzén, Zethson, Jönsson, Kasten, Kling, & Launay 1998; λ E	B II
M02	W. C. Martín 2002, private communication; E	Si I
M68	Müller 1968; f exp	S I
M70a	Moore 1970a; IP	H–Am
M70b	Moore 1970b; λ E, IP	C I–VI
M71	Moore 1971; λ E, IP	N IV–VII
M72	Moore 1972; λ E	H I, D I
M75	Moore 1975; λ E, IP	N I–III
M76	Moore 1976; λ E, IP	O I
M79	Moore 1979; λ E, IP	O VI–V III
M80	Moore 1980; λ E, IP	O V
M83	Moore 1983; λ E, IP	O IV
M85	Moore 1985; λ E, IP	O III

TABLE 3—*Continued*

Abbreviation	Citation and Type of Data	Ion
M90	Mason 1990; τ exp	O I
MABCLMRR97	Martin, Aubert-Frécon, Bacis, Crozet, Linton, Magnier, Ross, & Russier 1997; τ exp	Li I
MAH96	McAlexander, Abraham, & Hulet 1996; τ exp	Li I
Mar75	Marek 1975; τ exp	Mn I
MB79	Migdalek & Bayliss 1979; *f* theory	Cu I isoelectronic
MBDW96	Musielok, Bridges, Djurovic, & Wiese 1996; *b* exp	N II
MCL98a	Mullman, Cooper, & Lawler 1998a; *f* exp	Co II
MDLDR88	Marsden, Den Hartog, Lawler, Dakin, & Roberts 1988; τ exp	Sc I, II
MFW88	Martin, Fuhr, & Wiese 1988; *A f* compilation	Sc–Mn
MGC74	Martinson, Gaupp, & Curtis 1974; τ exp	Be I
Min71	Minnhagen 1971; λ *E*	Ar II
Min73	Minnhagen 1973; λ *E*	Ar I
Mit75	Mitchell 1975; *f* exp	Mg I
MK98	Migdalek & Kim 1998; *f* theory	K I
MKM93	Martin, Kaufman, & Musgrove 1993; λ *E*, IP	O II
MLZF98b	Mullman, Lawler, Zsargó, & Federman 1998b; *f* exp	Co II
MMGDMM02	Majumder, Merlitz, Gopakumar, Das, Mahapatra, & Mukherjee 2002; *f* theory	Mg II
MR73	Marek & Richter 1973; τ exp	Mg I, Mn I
MR96	Mazzoni & Ricci 1996; b exp	P I
MS88	Moccia & Spizzo 1988; *f* theory	Mg I
MSL97	Mullman, Sakai, & Lawler 1997; *f* exp	Fe II
MTC93	Maniak, Träbert, & Curtis 1993; τ exp	Si IV
MZ79	Martin & Zalubas 1979; *E*, IP	Al I–XIII
MZ80	Martin & Zalubas 1980; *E*, IP	Mg I–XII
MZ81	Martin & Zalubas 1981; *E*, IP	Na I–XI
MZ83	Martin & Zalubas 1983; *E*, IP	Si I–XIV
MZ87	Mendoza & Zeippen 1987; *f* theory	Mg I
MZM85	Martin, Zalubas, & Musgrove 1985; *E*, IP	P I–XV
MZM90	Martin, Zalubas, & Musgrove 1990; *E*, IP	S I–XVI
MZS99	Mendoza, Zeippen, & Storey 1999; *A* theory	C I isoelectronic
N77	Nussbaumer 1977; *A f* theory	Si II
N93	Nahar 1993; *A* theory	Si I
N97	Nahar 1997; *A f* theory	S II
N98	Nahar 1998; *f* theory	Si II
NBF78	Nowak, Borst, & Fricke 1978; τ exp	O I
NBL95	Nitz, Bergeson, & Lawler 1995; τ exp	Co I
ND82	Neijzen & Dönszelmann 1982; *E*, IP	Ga I
NG71	Norton & Gallager 1971; τ exp	Ga I
NJLTB94	Nave, Johansson, Learner, Thorne, & Brault 1994; λ *E*	Fe I
NJT97	Nave, Johansson, & Thorne 1997; 1	Fe II
NKWL99	Nitz, Kunau, Wilson & Lentz 1999; *b A f* exp	Co I
NP93	Nahar & Pradhan 1993; *f* theory	S III
NS79	Nussbaumer & Storey 1979; *A* theory	N IV, O V, F V, F VI
O69	Ölme 1969; λ *E*	B III
O70	Ölme 1970; λ *E*	B II
OH89	Ojha & Hibbert 1989; *f* theory	S II
OL91	O'Brian & Lawler 1991; t, *A* exp	Si I
OL92	O'Brian & Lawler 1992; τ exp	B I
OP57	Ostrovskii & Penkin 1957; *f* exp	Mn I
OP58	Ostrovskii & Penkin 1958; *f* exp	V I
OS79	Odintzova & Striganov 1979; λ *E*	B I
OVH96	Oates, Vogel, & Hall 1996; τ exp	Na I
OWLWB91	O'Brian, Wickliffe, Lawler, Whaling, & Brault 1991; τ, *b A* exp	Fe I
P69	Palenius 1969; λ *E*, IP	F II
P70	Palenius 1970; λ *E*, IP	F III
P71	Palenius 1971; λ *E*, IP	F IV, V
P98	Pal'chikov 1998; *A* theory	H I
PDNHJ02a	Pickering, Donnelly, Nilsson, Hibvert, & Johansson 2002a; *b A f* exp	Fe II
Per71	Persson 1971; λ *E*, IP	Ne II
PG90	Page & Gudeman 1990; IP	Fe I, Co I, Ni I
PGJBAB92	Pinnington, Guo, Ji, Berends, Ansbacher, & Biémont 1992; τ exp	Mn II
PILK74	Pinnington, Irwin, Livingston, & Kernahan 1974; τ exp	O VI
PILK76	Pinnington, Irwin, Livingston, & Kernahan 1976; τ exp	F I
PJGBVB93	Pinnington, Ji, Guo, Berends, van Hunen, & Biémont 1993; τ exp	Cr II
PJLPW99	Proffitt, Jonsson, Litzén, Pickering, & Wahlgren 1999; *E* hfs	B III
PJS01	Pickering, Johansson, & Smith 2001; *b A f* exp	Fe II

TABLE 3—*Continued*

Abbreviation	Citation and Type of Data	Ion
PRKB97	Pinnington, Rieger, Kernahan, & Biémont 1997; t A exp theory	Cu II
PRT76a	Parkinson, Reeves, & Tomkins 1976a; f exp	Ca I
PRT76b	Parkinson, Reeves, & Tomkins 1976b; f exp	Sc I
PRUJ98a	Pickering, Raassen, Uylings, & Johansson 1998a; 1 E	Co II
PS65.........................	Penkin & Shabanova 1965; f exp	Al I, Ga I
PSS88........................	Peach, Saraph, & Seaton 1988; f theory	Li I isoelectronic
PT96	Pickering & Thorne 1996; λ E	Co I
PTMLJZW00	Pickering, Thorne, Murray, Litzén, Johansson, Zilio, & Webb 2000; λ	Cr II, Ni II, Zn II
PTP01	Pickering, Thorne, & Perez 2001, b A f exp	Ti II
PTP02b.....................	Pickering, Thorne, & Perez 2002b; correction	Ti II
PTW98b	Pickering, Thorne, & Webb 1998b; λ	Mg I, II
PWJD91	Persson, Wahlström, Jönsson, & Di Rocco 1991; λ E, IP	Ne III
QWL99	Qu, Wang, & Li 1999; f theory	Li I, Be II
RA65	Ramsey & Anderson 1965; hfs	Na I
REB95	Radziemski, Engleman, & Brault 1995; E hfs	Li I
RH82	Rudolph & Helbig 1982; τ exp	Ti I
RHNM86	Reistad, Hutton, Nilsson, & Martinson 1986; τ exp	C II, C III
RHS97	Rosner, Holt, & Scholl 1997; τ exp	Ca II
RK69	Radziemski & Kaufman 1969; λ E, IP	Cl I
RK74	Radziemski & Kaufman 1974; λ E, IP	Cl II
RM86	Reistad & Martinson 1986; τ theory	B II
RM94	Ricci & Mazzoni 1994; b exp	S I
RO84	Raassen & Ortin 1984; λ E	Co III
RPU98.....................	Raassen, Pickering, & Uylings 1998; f theory	Co II
RSVUMJ92	Raassen, Snoek, Volten, Uylings, Meijer, & Joshi 1992; λ E	Cl III, IV
RT76	Roig & Tondello 1976; λ E	B I
RU98	Raassen & Uylings 1998; f theory	Ti II, Cr II, Fe II, III, Co II
S87..........................	Schade 1987; τ exp	Mg I
SBK95	Schnabel, Bard, & Kock 1995; τ exp	Mn I, II
SC85	Sugar & Corliss 1985; E	K to Ni
SFBE93	Schectman, Federman, Beideck, & Ellis 1993; τ, f exp	Cl I
SFH00	Sofia, Fabian, & Howk 2000; f astrophysics	Mg II
SG66........................	Smith & Gallagher 1966; τ exp	Mg I
SGM96	Stanek, Glowacki, & Migdalek 1996; f theory	Mg I
SHTGCL87	Smith, Huber, Tozzi, Griesinger, Cardon, & Lombardi 1987; b exp	Si I
SK00........................	Schnabel & Kock 2000; τ exp	Fe II
SK78........................	Smith & Kühne 1978; f exp	Ti I
SK85........................	Shabanova & Khlyustalov 1985; f exp	K I
SL66	Savage & Lawrence 1966; τ exp	P I, II
SL71	Smith & Liszt 1971; τ exp	Mg I
SL90	Salih & Lawler 1990; τ exp	Ti I
SM03	J. E. Sansonetti & W. C. Martín 2003, in preparation; compilation E, IP	H–Es; I, II
SM90	Sugar & Musgove 1990; E, IP	Cu I–XXIX
SM95	Sugar & Musgrove 1995; E, IP	Zn I–XXX
SMH88	Schade, Mundt, & Helbig 1988; τ exp	Fe II
SMH90	Schade, Mundt, & Helbig 1990; τ exp	Cr II
SMK98	Siegel, Migdalek, & Kim 1998; f theory	Na I isoelectronic
SPC98......................	Schectman, Povolny, & Curtis 1998; τ exp	Si II
SRER95...................	Sansonetti, Richou, Engleman, & Radziemski 1995; λ E hfs	Li I
SSK99......................	Schultz-Johanning, Schnabel, & Kock 1999; τ exp	Fe II
SSKLNJLR99	Sikström, Schultz-Johanning, Kock, Li, Nilsson, Johansson, Lundberg, & Raassen 1999; τ exp	Fe II
SZK90	Sohl, Zhu, & Knight 1990; IP	Ti I
T95	Tayal 1995; f theory	S III
TC88........................	Theodosiou & Curtis 1988; τ theory	Na I isoelectronic
TCE91	Theodosious, Curtis, & El-Mekki 1991; t f theory	Be II, B III
TCGGTW00	Träbert, Calamai, Gillaspy, Gwinner, Tordoir, & Wolf 2000; τ exp	O III
TCN95.....................	Theodosiou, Curtis, & Nicoliades 1995; f theory	Ca II
TE84........................	Tursunov & Eshkobilov 1984; t ep	Ga I
TEJK97	Tunklev, Engström, Jupén, & Kink 1997; IP	C IV
TF00........................	Tachiev & Froese Fischer 2000; A f theory	B I isoelectronic
TF01	Tachiev & Froese Fischer 2001; A f theory	C I
TF02a	Tachiev & Froese Fischer 2002a; A f theory	N I, O I
TF02b......................	Tachiev & Froese Fischer 2002b; A f theory	F I
TF02c	Tachiev & Froese Fischer 2002c; A f theory	Al II
TF99	Tachiev & Froese Fischer 1999; A f theory	Be I isoelectronic
TGKTW99a	Träbert, Gwinner, Knystautas, Tordoir, & Wolf 1999; τ exp	C II, N III

TABLE 3—*Continued*

Abbreviation	Citation and Type of Data	Ion
ThFe99	Theodosiou & Federman 1999; *f* theory	Mg II
THHM88	Träbert, Heckmann, Hutton, & Martinson 1998; λ	Ar V, VI
TKR96	Tiemann, Knöckel, & Richling 1996; τ exp	Na I
TWG02	Träbert, Wolf, & Gwinner 2002; *A* exp	N IV, O V
TWLT99b	Träbert, Wolf, Linkemann, & Tordoir 1999; τ exp	B II, Al II
TWPLKCBB98	Träbert, Wolf, Pinnington, Linkemann, Knystautas, Curtis, Bhattacharya, & Berry1998; τ exp	N II
UH87	Uehara & Horiai 1987; *E*	Cl I
VAZW76	Vetter, Ackermann, zu Putlitz, & Weber 1976; *E* hfs	Be II
VHU99	Velchev, Hogervorst, & Ubachs 1999; *E*, IP	Ar I
VKP89	Verolainen, Komarovskii, & Penkin 1989; τ exp	Ga I
VMLSS96	Volz, Majerus, Liebel, Schmitt, & Schmoranzer 1996; τ exp	Na I
VS96	Volz & Schmoranzer 1996; τ exp	Li I, K I
VSL76	Victor, Stewart, & Laughlin 1976; *f* theory	Mg I isoelectronic
W67	Weiss 1967; *A f A* theory	Sc III
W95	Weiss 1995; *f* theory	B II
WBL02	Wiese, Bonvallet, & Lawler 2002; *f* exp	Fe II
WCDCMPC84	Worden, Comaskey, Deusberger, Christensen, McAfee, Paisner, & Conway 1984; IP	Fe I
WFD96	Wiese, Fuhr, & Deters 1996; *A f* compilation	C, N, O
WFL01	Wiese, Fedchak, & Lawler 2001; *f* exp	Ti II
WHLBG85	Whaling, Hannaford, Lowe, Biémont, & Grevesse 1985; *A* exp	V I
WHLMSY99	Welty, Hobbs, Lauroesch, Morton, Spitzer, & York 1999; *f* astrophysics	Mn II, Fe II
WLWWGS97	Wang, Li, Wang, Williams, Gould, & Stwalley 1997; τ exp	K I
WSG66	Wiese, Smith, & Glennon 1966; *A f* compilation	H–Ne
WST77	Whaling, Scalo, & Testerman 1977; *b A* exp	Ti I
WZ74	Wells & Zipf 1974; τ exp	O I
YSH93	Yei, Sieradzan, & Havey 1993; hfs	Na I
YTD98	Yan, Tambasco, & Drake 1998; *f* theory	Li I isoelectronic
YTS87	Yan, Taylor, & Seaton 1987; *f* theory	C II, N III
ZF00	Zou & Froese Fischer 2000; *A* theory	Al II, Si III, P IV, S V
ZF02	Zatsarinny & Froese Fischer 2002; *A f* theory	C I
ZF98	Zsargó & Federman 1998; *f* astrophysics	Ni II
ZJL01	I. Zapadlik, S. Johansson, & U. Litzén 2001, private communication; λ *E*	Ti II
ZSM77	Zeippen, Seaton, & Morton 1977; *f* theory	O I
ZT02	Zatsarinny & Tayal 2002; *f* theory	S I

hfs: Hyperfine structure;
IP: Ionization potential;
τ: Lifetime (experiment or theory);
λ: Wavelengths.

Table 2 lists all electric-dipole transitions longward of 911.753 Å involving the ground term that have *f*-values known to the author. Additional lines are included to complete multiplets or highlight the stronger transitions that have no *f*-values. Where term designations of upper levels are incomplete they may be grouped together in the same format as for multiplets.

6. SUMMARY OF INDIVIDUAL ELEMENTS

Certain abbreviations are useful in this section.

ANDC:	Arbitrarily normalized decay curves, described by Curtis et al. (1971a)
BF:	Beam foil
FTS:	Fourier transform spectrometer
BL:	Beam laser
hfs:	Hyperfine structure
IP:	Ionization potential
LIF:	Laser-induced fluorescence
OP:	Opacity Project
TRLIF:	Time-resolved laser-induced fluorescence
λ:	Wavelength in Å in air longward of 2000 Å and in vacuum shortward

6.1. *Hydrogen* (H)*; Deuterium* (D)*;* $Z = 1$

The energy levels for H I and D I to $n = 20$ are from the calculations of Erickson (1977) corrected to a Rydberg constant $R_\infty = 109{,}737.31568549(83)$ cm^{-1} (Mohr & Taylor 2000). The higher transitions of H I are from the earlier calculations of Garcia & Mack (1965) scaled to match. Compared with their original values adopted by Moore (1972) and Paper I, the new wavelengths for the Lyman lines are smaller by a little less than 0.0001 Å.

The relativistic calculations of V. G. Pal'chikov (1998, and 2000, private communication) listed here for the *A*-values of H I to $n = 22$ are only a factor of 1.00050 larger than the nonrelativistic results of Green, Rush, & Chandler (1957) as quoted by Wiese et al. (1966). I have applied this same factor to this last reference for $n = 23$–31. The *A*-values for D I are equal to $\lambda^3(\mathrm{H\,I}) \times A(\mathrm{H\,I})/\lambda^3(\mathrm{D\,I})$.

6.2. *Helium* (He)*;* $Z = 2$

All the resonance lines of He I and II lie well shortward of the Lyman limit for H I. Martin (1987) has tabulated the energy levels for ^{4}He I, while Eikema et al. (1997) and Bergeson et al. (1998) have determined the IP. This number for ^{3}He I follows from their average, the isotope shift 8.7864 cm^{-1} for $1s^2\ ^1S_0$–$2s2p\ ^1P^o_1$ quoted by Eikema et al., and the shift of 1.68 cm^{-1} in the ionization energy of the upper level determined by Bradley & Kuhn (1951). Erickson (1977) has calculated the levels for both ^{3}He II and ^{4}He II.

6.3. *Lithium* (Li); $Z = 3$

The energy levels for the two isotopes in Table 2 are from the extremely precise measurements of Sansonetti et al. (1995) for multiplet 1v and Radziemski, Engleman, & Brault (1995) for the next three, while the higher multiplets and the IPs are from Johansson (1959). The first two papers provided hfs measurements and relevant parameters for the listing in Table 4.

As summarized by Volz & Schmoranzer (1998), the Li I $2s$–$2p$ doublet at 6708 Å has attracted the efforts of many experimentalists and theoreticians to compare precise lifetimes and oscillator strengths. With the beam-laser technique, Volz & Schmoranzer (1996) measured $\tau = 27.11\pm 0.06$ ns, while the analysis of high vibration levels of Li_2 by McAlexander, Abraham, & Hulet (1996) and Martin et al. (1997) has given 27.102 ± 0.007 and 27.13 ± 0.01 ns, respectively. In the most thorough calculations to date, Yan, Tambasco, & Drake (1998) obtained $\tau(1/2) = 27.1058$, $\tau(3/2) = 27.1044$ for ^{6}Li and $\tau(1/2) = 27.1045$, $\tau(3/2) = 27.1031$ for ^{7}Li, in excellent agreement with the most accurate experiments. Their estimated uncertainties are 0.0014 ns for each $\tau(1/2)$ and 0.0018 for each $\tau(3/2)$. Table 2 and 4 list these ab initio theoretical values, which include corrections for relativity by comparison with the results of Johnson, Liu, & Sapirstein (1996) and estimates for the effect of finite nuclear mass. The higher series members are from the nonrelativistic calculations of Qu, Wang, & Li (1999), who obtained excellent agreement between their length and velocity results, and with the model-potential and close-coupling calculations of Peach, Saraph, & Seaton (1988). However, the Faraday rotation measurement by Nawaz, Farooq, & Connerade (1992) is 40% larger for $2s$–$9p$.

6.4. *Beryllium* (Be); $Z = 4$

The energy levels and IP for Be I are from Kramida & Martin (1997) and for Be II from Bollinger et al. (1985) and Johansson (1961) decreased by 0.02 cm^{-1} to match the previous reference. Vetter et al. (1976) and Bollinger et al. (1985) provided the hyperfine constants of Be II used in Table 4. The IP for Be III is a mean of the results of Eidelsberg (1972) and Löfstrand (1973).

The A-value adopted here for the first intersystem transition of Be I is from the intermediate-coupling calculation of Chung & Zhu (1993); it is twice as large as the earlier theoretical results of Laughlin, Constantinides, & Victor (1978) and Glass & Hibbert (1978) and nearly 3 times that of Mühlethaler & Nussbaumer (1976). For multiplet 1u, the recent theoretical results summarized by Tachiev & Froese Fischer (1999) are all very close to $A = 5.53 \times 10^8$ s^{-1} and consistent with the BF lifetimes of Hontzeas et al. (1972), Martinson, Gaupp, & Curtis (1974), and Irving et al. (1999), which average $(5.53 \pm 0.9) \times 10^8$ s^{-1}. Chen (1998) has calculated f-values for the higher series members.

For multiplet 1v of Be II, I have adopted the precise calculations of Yan et al. (1998), which included corrections for relativity and finite central mass. These differ little from the semiempirical Coulomb calculations by Theodosiou, Curtis, & El-Mekki (1991) and very little from the many-body theory of Johnson et al. (1996) and the multiconfiguration Breit-Pauli results of Froese Fischer et al. (1998), both normalized to the experimental transition energies. The BF lifetime of 0.93 ± 0.02 ns by Bergström et al. (1969) is consistent. Froese Fischer et al. also are the source of the A-value for multiplet 1u, which is very close to the results of Qu et al. (1999), who obtained excellent agreement between the length and velocity formulations.

6.5. *Boron* (B); $Z = 5$

Roig & Tondello (1976) did not measure the B I intersystem multiplet near 3463 Å, so that there is an uncertainty of 2 Å in the absolute wavelengths. The other levels for B I are from Johansson et al. (1993), who measured both isotopes, R. Engleman & U. Litzén (2001, private communication to W. C. Martin), and for the highest energies, Odintzova & Striganov (1979) increased by 0.05 cm^{-1} to match the previous reference. J. E. Sansonetti & W. C. Martin (2003, in preparation) concluded that the IP for ^{10}B I and ^{11}B I are essentially identical at 66,928.04 cm^{-1}. The levels for B II are from Ölme (1970), Litzén et al. (1998), and Jönsson et al. (1998) with $2s2p\ ^3P^o$ decreased by 0.5 cm^{-1} and the IP by 0.4 cm^{-1} following Sansonetti & Martin. Litzén & Kling (1998), Proffitt et al. (1999), and Ölme (1969), were the sources for B III, and Eidelsberg (1974) for B IV. Table 2 includes the isotopic wavelengths for the strongest lines of B I, B II, and B III. The measurements of Lew & Title (1960) and Harvey, Evans, & Lew (1972) show that the hfs in the B I $2p\ ^2P^o$ ground term produces maximum level separations of 0.025 cm^{-1} in both isotopes. The $^1S_0$ ground level of B II has no hfs and the calculations of Jönsson, Johansson, & Froese Fischer (1994) for $2s2p\ ^1P^o_1$ indicate that the total separations of the three levels are only 0.00141 and 0.0241 cm^{-1} for ^{10}B II and ^{11}B II, respectively. The somewhat larger splittings of B III are given in Table 4 from Proffitt et al.

The calculations of Tachiev & Froese Fischer (2000) accurately reproduce the TRLIF lifetimes of O'Brian & Lawler (1992) for multiplets 1, 2, and 3 of B I so that Table 2 quotes the theoretical results from the web site for these transitions and the intersystem multiplet, all scaled to laboratory wavelengths. The errors listed from the lifetime measurements probably are overestimates.

Träbert et al. (1999b) used a heavy-ion storage ring to obtain the $2s2p\ ^3P^o_1$ lifetime for B II. The corresponding $A/10^8 = 10.24 \pm 0.05$ s^{-1} is in good agreement with the calculated 10.27 of Froese Fischer & Gaigalas (1997) and 10.15 of Tachiev & Froese Fischer (1999), both scaled to the measured transition energy. Precise calculations of B II $f(\lambda 1362)$ by Weiss (1995), Godefroid et al. (1995), Fleming et al. (1996b), Jönsson, Froese Fischer, & Godefroid (1999), and Tachiev & Froese Fischer (1999) average 0.996 ± 0.005, while the ANDC beam-foil lifetime of Bashkin et al. (1985) with isoelectronic smoothing by Reistad & Martinson (1986) gave 0.965 ± 0.020 g, and the ANDC lifetime of Irving et al. (1999) gave 0.98 ± 0.06. I have adopted $f = 0.996 \pm 0.005$.

The A-values for the B III doublet are from the ab initio theory of Yan et al. (1998), which agree closely with Theodosiou et al. (1991) and very closely with Johnson et al. (1996) and Froese Fischer et al. (1998). The five experimental lifetimes listed by Kernahan et al. (1975) are consistent with the calculations but are not accurate enough to confirm them.

TABLE 4

ISOTOPES AND HYPERFINE STRUCTURE

Isotope Number	Air Wavelength (Å)	Vacuum (Å)	E_{low} (cm^{-1})	E_{up} (cm^{-1})	g_l	g_u	F_l	F_u	f	log λf (Å)	Error (dex)
LITHIUM = Li Z = 3 A = 6:7.5, 7:92.5% ^{6}Li:I = 1, ^{7}Li:I = 3/2											
Li I	2s 2S J = 1/2 GROUND		IP = 43487.150+−0.005 cm^{-1} Ref SRER95, REB95								
1v	2p 2Po		All Ref YTD98, JLS96								
Li I	6707.9265	6709.7784	0.	14903.62178	2	2	2.490E−01			3.223	22E−6
Li I	6707.7756	6709.6275	0.	14903.95712	2	4			4.980E−01	3.524	29E−6
^{6}Li I	6708.0728	6709.9248	0.	14903.29679	2	2			2.490E−01	3.223	22E−6
^{6}Li I	6707.9219	6709.7738	0.	14903.63212	2	4			4.980E−01	3.524	29E−6
^{7}Li I	6707.9147	6709.7666	0.	14903.64813	2	2			2.490E−01	3.223	22E−6
^{7}Li I	6707.7637	6709.6156	0.	14903.98347	2	4			4.980E−01	3.524	29E−6
^{6}Li I	6708.0740	6709.9259	0.002537	14903.29670	2	2	3/2	1/2, 3/2	2.490E−01	3.223	22E−6
^{6}Li I	6708.0704	6709.9224	−0.005075	14903.29699	2	2	1/2	1/2, 3/2	2.490E−01	3.223	22E−6
^{6}Li I	6707.9230	6709.7749	0.002537	14903.63208	2	4	3/2	1/2−5/2	4.980E−01	3.524	29E−6
^{7}Li I	6707.9201	6709.7720	0.010051	14903.64621	2	2	2	1	1.245E−01	2.922	22E−6
^{6}Li I	6707.9196	6709.7715	−0.005075	14903.63218	2	4	1/2	1/2, 3/2	4.980E−01	3.524	29E−6
^{7}Li I	6707.9187	6709.7706	0.010051	14903.64928	2	2	2	2	1.245E−01	2.922	22E−6
^{7}Li I	6707.9080	6709.7599	−0.016751	14903.64621	2	2	1	1	4.150E−02	2.445	22E−6
^{7}Li I	6707.9066	6709.7585 −	0.016751	14903.64928	2	2	1	2	2.075E−01	3.144	22E−6
^{7}Li I	6707.7683	6709.6202	0.010051	14903.98334	2	4	2	1, 2, 3	4.980E−01	3.524	29E−6
^{7}Li I	6707.7562	6709.6081	−0.016751	14903.98337	2	4	1	0, 1, 2	4.980E−01	3.524	29E−6
BERYLLIUM Be Z = 4 A = 9:100% ^{9}Be:I = 3/2											
Be II	2s 2S J = 1/2 GROUND		IP = 146882.84 cm^{-1} Ref VAZW76, BWWI85								
1v	2p 2Po		All Ref YTD98								
Be II	3131.0667	3131.9742	0.	31928.7436	2	2			1.660E−01	2.716	12E−5
Be II	3130.4219	3131.3292	0.	31935.3198	2	4			3.321E−01	3.017	12E−5
^{9}Be II	3131.0655	3131.9729 −	0.015636	31928.7406	2	2	2	2	8.300E−02	2.415	12E−5
^{9}Be II	3131.0647	3131.9721	−0.015636	31928.7485	2	2	2	1	8.300E−02	2.415	12E−5
^{9}Be II	3131.0696	3131.9770	+0.026060	31928.7406	2	2	1	2	1.384E−01	2.637	12E−5
^{9}Be II	3131.0688	3131.9762	+0.026060	31928.7485	2	2	1	1	2.767E−02	1.938	12E−5
^{9}Be II	3130.4204	3131.3277	−0.015636	31935.3198	2	4	2	1, 2, 3	3.321E−01	3.017	12E−5
^{9}Be II	3130.4245	3131.3318	+0.026060	31935.3198	2	4	1	0, 1, 2	3.321E−01	3.017	12E−5
BORON = B Z = 5 A = 10:19.9, 11:80.1% ^{10}B:I = 3, ^{11}B:I = 3/2											
B III	2s 2S J = 1/2 GROUND		IP = 305931.1+−0.6 cm^{-1} Ref LK98, PJLPW99								
	2s2p 2Po		All Ref YTD98								
B III	2067.236	2067.896	0.	48358.330	2	2			1.211E−01	2.399	23E−5
B III	2065.779	2066.439	0.	48392.430	2	4			2.424E−01	2.700	23E−5
^{10}B III	2067.2696	2067.9299	0.	48357.538	2	2			1.211E−01	2.399	23E−5
^{10}B III	2065.8128	2066.4728	0.	48391.636	2	4			2.424E−01	2.700	23E−5
^{11}B III	2067.2274	2067.8876	0.	48358.527	2	2			1.211E−01	2.399	23E−5
^{11}B III	2065.7705	2066.4305	0.	48392.627	2	4			2.424E−01	2.700	23E−5
^{10}B III	2067.2730	2067.9333	0.06031	48357.5198	2	2	7/2	5/2	6.919E−02	2.156	23E−5
^{10}B III	2067.2716	2067.9319	0.06031	48357.5516	2	2	7/2	7/2	5.189E−02	2.031	23E−5
^{10}B III	2067.2670	2067.9273	−0.08041	48357.5198	2	2	5/2	5/2	2.883E−02	1.775	23E−5
^{10}B III	2067.2656	2067.9259	−0.08041	48357.5516	2	2	5/2	7/2	9.225E−03	1.281	23E−5
^{11}B III	2067.2327	2067.8929	0.09005	48358.4931	2	2	2	1	6.054E−02	2.098	23E−5
^{11}B III	2067.2303	2067.8906	0.09005	48358.5473	2	2	2	2	6.054E−02	2.098	23E−5
^{11}B III	2067.2224	2067.8827	−0.15008	48358.4931	2	2	1	1	2.018E−02	1.620	23E−5
^{11}B III	2067.2201	2067.8803	−0.15008	48358.5473	2	2	1	2	1.009E−01	2.319	23E−5
^{10}B III	2065.8155	2066.4755	0.06031	48391.6342	2	4	7/2	5/2	2.164E−02	1.650	23E−5

TABLE 4—*Continued*

Isotope Number	Air Wavelength (Å)	Vacuum (Å)	E_{low} (cm^{-1})	E_{up} (cm^{-1})	g_l	g_u	F_l	F_u	f	log λf (Å)	Error (dex)
^{10}B III	2065.8154	2066.4754	0.06031	48391.6358	2	4	7/2	7/2	6.926E−02	2.156	23E−5
^{10}B III	2065.8153	2066.4753	0.06031	48391.6383	2	4	7/2	9/2	1.515E−01	2.496	23E−5
^{10}B III	2065.8095	2066.4695	−0.08041	48391.6332	2	4	5/2	3/2	8.080E−02	2.223	23E−5
^{10}B III	2065.8094	2066.4695	−0.08041	48391.6342	2	4	5/2	5/2	9.235E−02	2.281	23E−5
^{10}B III	2065.8094	2066.4694	−0.08041	48391.6358	2	4	5/2	7/2	6.926E−02	2.156	23E−5
^{11}B III	2065.7745	2066.4345	0.09005	48392.6229	2	4	2	1	1.212E−02	1.399	23E−5
^{11}B III	2065.7744	2066.4344	0.09005	48392.6257	2	4	2	2	6.060E−02	2.098	23E−5
^{11}B III	2065.7742	2066.4342	0.09005	48392.6304	2	4	2	3	1.697E−01	2.545	23E−5
^{11}B III	2065.7643	2066.4243	−0.15008	48392.6216	2	4	1	0	4.040E−02	1.922	23E−5
^{11}B III	2065.7643	2066.4243	−0.15008	48392.6229	2	4	1	1	1.010E−01	2.320	23E−5
^{11}B III	2065.7641	2066.4241	−0.15008	48392.6257	2	4	1	2	1.010E−01	2.320	23E−5
SODIUM = Na Z = 11 A = 23:100% ^{23}Na:I = 3/2											
Na I	3s 2S J = 1/2 GROUND		IP = 41449.44+−0.03 cm^{-1} Ref JPHC81, RA65, GINRV77, YSH93, AIV77								
1v	3p 2Po		LS Ref CJSF92, JJLPTW96, OVH96, TKR96, VMLSS96								
Na I	5895.9242	5897.5581	0.	16956.17025	2	2			3.201E−01	3.276	33E−5
Na I	5889.9510	5891.5833	0.	16973.36616	2	4			6.408E−01	3.577	33E−5
^{23}Na I	5895.9322	5897.5661	+0.022161	16956.16946	2	2	2	1, 2	3.201E−01	3.276	33E−5
^{23}Na I	5895.9109	5897.5448	−0.036934	16956.17156	2	2	1	1, 2	3.201E−01	3.276	33E−5
^{23}Na I	5889.9584	5891.5907	+0.022161	16973.36693	2	4	2	1, 2, 3	6.408E−01	3.577	33E−5
^{23}Na I	5889.9386	5891.5709	−0.036934	16973.36487	2	4	1	0, 1, 2	6.408E−01	3.577	33E−5
^{23}Na I	5895.9333	5897.5672	+0.022161	16956.16631	2	2	2	1	1.600E−01	2.975	33E−5
^{23}Na I	5895.9311	5897.5650	+0.022161	16956.17261	2	2	2	2	1.600E−01	2.975	33E−5
^{23}Na I	5895.9128	5897.5467	−0.036934	16956.16631	2	2	1	1	5.335E−02	2.498	33E−5
^{23}Na I	5895.9106	5897.5445	−0.036934	16956.17261	2	2	1	2	2.668E−01	3.197	33E−5
^{23}Na I	5889.9592	5891.5915	+0.022161	16973.36448	2	4	2	1	3.204E−02	2.276	33E−5
^{23}Na I	5889.9588	5891.5911	+0.022161	16973.36563	2	4	2	2	1.602E−01	2.975	33E−5
^{23}Na I	5889.9582	5891.5905	+0.022161	16973.36757	2	4	2	3	4.486E−01	3.422	33E−5
^{23}Na I	5889.9389	5891.5712	−0.036934	16973.36396	2	4	1	0	1.068E−01	2.799	33E−5
^{23}Na I	5889.9387	5891.5710	−0.036934	16973.36448	2	4	1	1	2.670E−01	3.197	33E−5
^{23}Na I	5889.9383	5891.5706	−0.036934	16973.36563	2	4	1	2	2.670E−01	3.197	33E−5
2v	4p 2Po		LS Ref FP29								
Na I	3302.978	3303.929	0.	30266.99	2	2			4.597E−03	1.181	
Na I	3302.369	3303.319	0.	30272.58	2	4			9.195E−03	1.483	
^{23}Na I	3302.981	3303.932	+0.022161	30266.99	2	2	2	1, 2	4.597E−03	1.182	
^{23}Na I	3302.974	3303.925	−0.036934	30266.99	2	2	1	1, 2	4.597E−03	1.182	
^{23}Na I	3302.371	3303.322	+0.022161	30272.58	2	4	2	1, 2, 3	9.195E−03	1.483	
^{23}Na I	3302.365	3303.315	−0.036934	30272.58	2	4	1	0, 1, 2	9.195E−03	1.483	
MAGNESIUM = Mg Z = 12 A = 24:78.99, 25:10.00, 26:11.01% ^{25}Mg:I = 5/2											
Mg II	3s 2S J = 1/2 GROUND		IP = 121267.64+−0.05 cm^{-1} Ref PTW98, DWB80, IW81								
1u	3p 2Po		All Ref ALP89								
Mean II	2802.7056	2803.5315	0.	35669.298	2	2			3.058E−01	2.933	0.003
Mean II	2795.5301	2796.3543	0.	35760.848	2	4			6.155E−01	3.236	0.004
^{24}Mg II	2802.7065	2803.5324	0.	35669.286	2	2			3.058E−01	2.933	0.003
^{24}Mg II	2795.5311	2796.3553	0.	35760.835	2	4			6.155E−01	3.236	0.004
^{25}Mg II	2802.7023	2803.5283	0.	35669.339	2	2			3.058E−01	2.933	0.003
^{25}Mg II	2795.5270	2796.3511	0.	35760.888	2	4			6.155E−01	3.236	0.004
^{25}Mg II	2802.7004	2803.5263	−0.02486	35669.339	2	2	3	3, 2	3.058E−01	2.933	0.003
^{25}Mg II	2802.7051	2803.5310	+0.03481	35669.339	2	2	2	3, 2	3.058E−01	2.933	0.003
^{25}Mg II	2795.5250	2796.3492	−0.02486	35760.888	2	4	3	4, 3, 2	6.155E−01	3.236	0.004
^{25}Mg II	2795.5297	2796.3539	+0.03481	35760.888	2	4	2	3, 2, 1	6.155E−01	3.236	0.004
^{26}Mg II	2802.6985	2803.5244	0.	35669.388	2	2			3.058E−01	2.933	0.003
^{26}Mg II	2795.5231	2796.3473	0.	35760.937	2	4			6.155E−01	3.236	0.004

TABLE 4—*Continued*

Isotope Number	Air Wavelength (Å)	Vacuum (Å)	$E_{\rm low}$ (cm^{-1})	$E_{\rm up}$ (cm^{-1})	g_l	g_u	F_l	F_u	f	log λf (Å)	Error (dex)
ALUMINIUM = Al Z = 13 A = 27:100% ^{27}Al:I = 5/2											
Al III	3s 2S J = 1/2 GROUND		IP = 229445.7 = −0.2 cm^{-1} Ref GK00								
1u	3p 2Po		All Ref TC88, JLS96, SMK98								
Al III		1862.7910	0.	53682.888	2	2			2.780E−01	2.714	
Al III		1854.7184	0.	53916.542	2	4			5.590E−01	3.016	
27 Al		1862.7986	+0.2192	53682.8884	2	2	3	2, 3	2.780E−01	2.714	
27 Al		1862.7803	−0.3069	53682.8884	2	2	2	2, 3	2.780E−01	2.714	
27 Al		1854.7247	+0.2192	53916.5766	2	4	3	2, 3, 4	5.590E−01	3.016	
27 Al		1854.7090	−0.3069	53916.5080	2	4	2	1, 2, 3	5.590E−01	3.016	
POTASSIUM = K Z = 19 A = 39:93.2581, 40:0.01167, 41:6.7302% ^{39}K,^{41}K: I = 3/2											
K I	4s 2S J = 1/2 GROUND		IP = 35009.8140+−0.0007 Ref SC85, E99, AIV77								
1v	4p 2Po		All Ref VS96, WLWWGS97								
K I	7698.9645	7701.0835	0.	12985.1858	2	2			3.327E−01	3.409	7E−4
K I	7664.8991	7667.0089	0.	13042.8960	2	4			6.682E−01	3.710	7E−4
^{39}K I	7698.9681	7701.0870	+0.005775	12985.1856	2	2	2	1, 2	3.327E−01	3.409	7E−4
^{39}K I	7698.9586	7701.0775	−0.009626	12985.1862	2	2	1	1, 2	3.327E−01	3.409	7E−4
^{39}K I	7664.9024	7667.0121	+0.005775	13042.8963	2	4	2	1, 2, 3	6.682E−01	3.710	7E−4
^{39}K I	7664.8937	7667.0035	−0.009626	13042.8956	2	4	1	0, 1, 2	6.682E−01	3.710	7E−4
3v	5p 2Po		All Ref SK84								
K I	4047.2132	4048.3565	0.	24701.382	2	2			2.641E−03	1.029	
K I	4044.1422	4045.2847	0.	24720.139	2	4			5.680E−03	1.361	
^{39}K I	4047.2141	4048.3574	+0.005775	24701.382	2	2	2	1, 2	2.641E−03	1.029	
^{39}K I	4047.2116	4048.3549	−0.009626	24701.382	2	2	1	1, 2	2.641E−03	1.029	
^{39}K I	4044.1431	4045.2856	+0.005776	24720.139	2	4	2	1, 2, 3	5.680E−03	1.361	
^{39}K I	4044.1406	4045.2831	−0.009626	24720.139	2	4	1	0, 1, 2	5.680E−03	1.361	

NOTE.—Table 4 is also available in machine-readable form in the electronic edition of the *Astrophysical Journal Supplement*.

6.6. *Carbon* (C); $Z = 6$

Moore (1970b) has tabulated the energy levels for all the ion states of carbon. In the case of C I, Table 2 lists the improved data by Chang & Geller (1998) including most of the new levels from Feldman et al. (1976). The relative accuracy of some levels warrants quoting them to 0.001 cm^{-1}, but their separation from the ground state is an order of magnitude or more uncertain. Three additional levels noted with *M* are from a 1975 private communication by C. E. Moore corroborating Morton's (1978) observation of the corresponding interstellar lines toward ζ Oph. Precise measurement by Yamamoto & Saito (1991) and Klein et al. (1998) place the excited fine-structure levels of the ground term of ^{12}C I at 16.416712 (2) and 43.413454 (2) cm^{-1} and those of ^{13}C I at 16.416787 (6) and 43.413667 (12) cm^{-1}. Similarly, Cooksy, Blake, & Saykally (1986) found ^{12}C II at 63.39509 (4) and ^{13}C II at 63.39538 (7) cm^{-1}. These papers also give the hyperfine splittings for ^{13}C I and II, the largest being 0.027 cm^{-1} for ^{13}C II $2p\ ^2P^o_{1/2}$. Table 2 includes isotopic wavelengths for multiplet 1 of ^{13}C I from the measurements of Bernheim & Kittrell (1980) and for multiplets 2, 3, and 4 of ^{13}C I and 1 of ^{13}C II from Haridass & Huber (1994). New FTS wavelengths for the C IV doublet by Griesmann & Kling (2000) and an IP by Tunklev et al. (1997) supersede previous measurements.

Table 2 quotes the multiconfiguration Hartree-Fock Breit-Pauli calculations of Tachiev & Froese Fischer (2001) for multiplets 1, 2, 2.01, 3, and 4 of C I and the spline frozen-cores results of Zatsarinny & Froese Fischer (2002) for the higher transitions, also with the Breit-Pauli approximation, which avoids the assumption of strict *LS* coupling. The second method is an extension of the close-coupling approach and hence is particularly suitable for the higher Rydberg transitions. Both sets of calculations predict the energy levels very well and have remarkably good consistency between length and velocity *f*-values in all but a few cases. These results are within 2 σ of the wall-stabilized–arc measurements of *f* by Goldbach & Nollez (1987) and Goldbach, Martin, & Nollez (1989) for multiplets 2, 3, 4, 5, 6, and 9 except for λ1279.5 of multiplet 6, two blends at $\lambda\lambda$1277.5, 1277.3 of multiplet 7, and λ1261.4 of multiplet 9. The adopted calculations combined with branch *A*-values from Wiese et al. (1996) also agree within 2 σ with the BF lifetimes of Haar et al. (1991) for multiplets 2, 3, 5, 7, and 9 and the TRLIF results of Li et al. (2000) for multiplet 2. However, the comparison is less conclusive for multiplet 4, for which the branches contribute only 1.2×10^6 s^{-1}. Tachiev & Froese Fischer derived $\tau = 3.5$ ns, and Zatsarinny & Froese Fischer obtained 5.8, whereas Haar et al. measured 4.5 ± 0.2, Brooks, Rohrlich, & Smith (1977) found 4.2 ± 0.4 by the same technique, and the *f*-values of Goldbach &

Nollez correspond to 4.2 ± 0.5 ns. Note that the last authors normalized to $f(\lambda 1560.3) = 0.82$ based on a mean $\tau = 7.4 \pm 0.1$ ns from five experiments, whereas Haar et al. found 7.8 ± 0.3. The new calculations are consistent with the results of Mendoza, Zeippen, & Storey (1999) for the intersystem multiplet 1, are close to many of the theoretical values by Luo & Pradhan (1989) and Hibbert et al. (1993) adopted by Wiese et al. and should be a significant improvement for the weaker transitions to higher levels.

Zsargó, Federman, & Cardelli (1997) and Federman & Zsargó (2001) estimated astrophysical *f* for many C I lines by adopting the values quoted by Morton (1991) for multiplets 5, 7, and 9. The new scale adopted here increases these *f* by only 0.035 dex. Zatsarinny & Froese Fischer (2002) have noted significant discrepancies with their theoretical results in half these determinations. Jenkins & Tripp (2001) have published astrophysical *f*-values from 1330 to 1188 Å that are systematically larger than those in Table 2. However, the sums of their *A*-values from the upper levels of multiplets 4, 5, 7, and 9, are too large for the lifetimes measured by Haar et al. (1991).

The heavy-ion storage-ring lifetimes of Träbert et al. (1999a) for the intersystem multiplet 0.01 of C II supersede the ion-trap data of Fang et al. (1993b) and Smith, Chutjian, & Greenwood (1999) and agree well with the calculations of Tachiev & Froese Fischer (2000) and Corrégé & Hibbert (2002). Their theoretical branching fractions and the latest measurements gave the *A*-values in Table 2. Multiplets 1 and 2 are from the calculations of Jönsson, Froese Fischer, & Godefroid (1996) rather than the OP results of Yan, Taylor, & Seaton (1987). Experiments by Goly & Weniger (1982), Glenzer et al. (1994), and Huber, Sandeman, & Tozzi (1984) show that the assumption of *LS* ratios is valid. The ANDC beam-foil lifetime of 0.44 ± 0.02 ns by Reistad et al. (1986) matches the theory for multiplet 2.

Doerfert et al. (1997) have measured $A(\lambda 1909) = 102.94 \pm 0.14$ s^{-1} from the decay of C III in a heavy-ion storage ring, a significant improvement over 121 ± 7 s^{-1}, which Kwong et al. (1993) obtained with a radio-frequency ion trap. The new result is supported by the isoelectronic prediction of 102.4 s^{-1} by Curtis & Ellis (1996) and the relativistic calculations of 103.0 s^{-1} by Froese Fischer & Gaigalas (1997), 102.9 s^{-1} by Jönsson & Froese Fischer (1998), and 101.6 s^{-1} by Chen, Cheng, & Johnson (2001). The papers by Froese Fischer & Gaigalas and Jönsson & Froese Fischer obtained $A(\lambda 977)/10^8 = 17.62$ and 17.65 s^{-1} for the strong line, consistent with the ANDC lifetime of 0.57 ± 0.02 ns by Reistad et al. (1986), and very close to the calculations of Fleming, Hibbert, & Stafford (1994), Tachiev & Froese Fischer (1999), and Froese Fischer (2000).

The *A*-values for the C IV doublet are from the calculations of Yan et al. (1998), who included corrections for relativity and the finite nuclear mass. These results match the theoretical values of Johnson et al. (1996) and Froese Fischer et al. (1998) and are only slightly smaller than those of Peach et al. (1988) adopted by Wiese et al. (1996). The BF lifetimes of Knystautas et al. (1971) are consistent with all these values.

6.7. *Nitrogen* (N); $Z = 7$

The levels for N I, III, and IV are from Moore (1975), N II from Eriksson (1983), and the higher ions from Moore (1971). All the IPs are from the Moore references. The hfs constants of Holloway, Lüscher, & Novick (1962) for the ground state of ^{14}N I correspond to a spread of 0.0014 cm^{-1}. The precise measurements of Brown et al. (1994b) placed the fine-structure levels for the ground term of ^{14}N II at 48.73811 and 130.77420 cm^{-1} and showed that the hfs spread is only 0.00042 cm^{-1} for $2p^2\ ^3P_1$ and 0.016 cm^{-1} for $2p^2\ ^3P_2$. There appears to be no information about the excited terms of either N I or II and nothing on N III, IV, or V.

The multiconfiguration Hartree-Fock Breit-Pauli calculations of Tachiev & Froese Fischer (2002a) adopted for N I in Table 2 supersede the earlier results of Hibbert et al. (1991a) and others quoted by Wiese et al. (1996). Goldbach et al. (1986,1992) measured relative *gf*-values of N I with a wall-stabilized arc and deduced absolute values from a mean lifetime of 2.35 ± 0.96 ns adopted from six measurements of the $2p^2 3s\ ^4P$ upper levels, ignoring decays to $2p^3\ ^2D^o$ and $2p^3\ ^2P^o$. The experimental data agree with the calculated lifetime of 2.47 ns and match the *f*-values of multiplets 1, 2, 3, 3.05, and 3.06 within 0.09 dex. The astrophysical *f*-values of Lugger et al. (1978) for the *LS* multiplets 3.05 and 3.06 also are within 0.09 dex of the calculations. Unfortunately, the larger errors for the intersystem multiplets prevent critical checks on the weaker lines. Thus, a thorough evaluation of the theoretical uncertainties is important for the weak intersystem lines at 1160.9 and 1159.8 Å, which can give the interstellar abundance of N I without correction for saturation. The *f*-values of Lugger et al. are larger than Tachiev & Froese Fischer by 0.31 dex while earlier calculations by Hibbert, Dufton, & Keenan (1985) are smaller by 0.06 dex.

The data quoted for multiplet 0.01 of N II depend on the accurate $\tau = 5.88 \pm 0.03$ ms measured by Träbert et al. (1998) using a heavy-ion storage ring, and the mean branching ratio 2.32 ± 0.12 from the measurements of Musielok et al. (1996), Bridges, Wiese, & Griesmann (1998), and Curry, Gibson, & Lawler (1997). Brage, Hibbert, & Leckrone (1997), Mendoza et al. (1999), and Tachiev & Froese Fischer (2001) calculated ratios of 2.44, 2.36, and 2.46 and lifetimes of 5.43, 5.41, and 5.61 ns, respectively. The accurate calculations of the last authors are quoted for multiplets 1 and 2; they are consistent with the measured lifetimes summarized by Dumont, Biémont, & Grevesse (1974).

The N III storage-ring lifetimes for the intersystem multiplet 0.01 by Träbert et al. (1999a) supplant the ion-trap results of Fang, Kwong, & Parkinson (1993a). The new measurements also are close to the calculations of Tachiev & Froese Fischer (2000) and Corrégé & Hibbert (2002), so that their branching fractions were adopted to obtain the individual *A*-values. With a different theoretical approach Tachiev & Froese Fischer also obtained *A*-values for multiplet 1 which are essentially the same as those of Wiese et al. (1996) quoted here from Yan et al. (1987) and Bell et al. (1995).

Wiese et al. (1996) adopted $A(\lambda 1486) = 580 \pm 10$ s^{-1} for the intersystem line of N IV from the ab initio calculations by Fleming et al. (1995) scaled to experimental energies. This is very close to 577.3 s^{-1} from the multiconfiguration calculations of Nussbaumer & Storey (1979), 585 s^{-1} from the isoelectronic prediction of Curtis & Ellis (1996), 578.4 s^{-1} from the Breit-Pauli calculations of Tachiev & Froese Fischer (1999), and 577.2 s^{-1} from the direct Dirac results of Froese Fischer (2000), and it is consistent with the storage-ring measurements of 625^{+200}_{-125}

s^{-1} by Doerfert et al. (1995) and 500^{+90}_{-65} by Träbert, Wolf, & Gwinner (2002). A new measurement with improved accuracy is needed.

For the N V doublet I have adopted the precise calculations of Yan et al. (1998), which differ very little from Peach et al. (1988) adopted by Wiese et al. (1996), or from Johnson et al. (1996) or Froese Fischer et al. (1998). The corresponding lifetime of 2.96 ns is shorter than any of the 12 measurements listed by Baudinet-Robinet et al. (1975), which average 3.19 ± 0.08 ns. Cascades may have biased these early data. A modern measurement by laser excitation would be a useful check.

6.8. *Oxygen* (O); $Z = 8$

The energy levels and IP for oxygen are from the compilations of Moore (1976) for O I, Martin, Kaufman, & Musgrove (1993) for O II, Moore (1985) for O III, Moore (1983) for O IV, and Moore (1980) for O V. However, for the O VI resonance doublet, I adopted the wavelengths proposed by Kaufman & Martin (1989) and listed only the IP from Moore (1979). Zink et al. (1991) and De Natale et al. (1993) measured the excited fine-structure levels of the ^{16}O I ground term at 158.268741 (4) and 226.985244 (5) cm^{-1}.

For the intersystem multiplet 1 of O I, Wiese et al. (1996) averaged the lifetimes of Johnson (1972), Wells & Zipf (1974), Nowak, Borst, & Fricke (1978), and Mason (1990) and split the branches according to the theoretical ratio of Biémont & Zeippen (1992). The next five multiplets are from the multiconfiguration Hartree-Fock Breit-Pauli calculations of Tachiev & Froese Fischer (2002a), which are an improvement on the theoretical results adopted by Wiese et al. (1996) for multiplets 2, 3, and 4 and agree with the measurements of Goldbach & Nollez (1994) within 1.5 σ for 3 and 4. However, the accuracy of the intersystem lines in 2.01 and 3.01 is questionable because Tachiev & Froese Fischer predict a lifetime for multiplet 1 longer by 0.48 dex and all three have large length-velocity differences. The remaining transitions are from the calculations of Butler & Zeippen (1991) from the Opacity Project and Hibbert et al. (1991b) or the earlier results of Zeippen, Seaton, & Morton (1977), which agree closely with Butler & Zeippen. As O I approaches its ionization limit, many of the J levels are not resolved, so that the ^3P–$^3D^o$ multiplets have two or three lines with the same wavelengths. Table 2 sums the superposed f-values, quotes the total statistical weights of the upper levels, and omits the meaningless A-values.

The accurate calculations of Fleming & Brage (1997) and Mendoza et al. (1999) for the intersystem lines of O III reproduced the ion-trap and storage-ring lifetimes of Johnson, Smith, & Knight (1984) and Träbert et al. (2000) and provided the branching ratio of 2.47 adopted here with the weighted mean of the two experiments. Johnson et al. showed that the branch to $^1D_2$ is negligible.

The A-values for the O IV intersystem lines are the averages from the calculations of Tachiev & Froese Fischer (2000) and Corégé & Hibbert (2002), whose results for C II and N III agree with the lifetimes of Träbert et al. (1999a). The theoretical results of Brage, Judge, & Brekke (1996) adopted by Wiese et al. (1996) are essentially the same.

For multiplet 0.01 of O V, Träbert et al. (2002) measured $A(\lambda 1218) = 2180 \pm 70\ \mathrm{s}^{-1}$ from a storage ring, very close to the calculated values of 2280 by Fleming et al. (1996a), 2276 by Tachiev & Froese Fischer (1999), and 2271 by Froese Fischer (2000). Earlier Nussbaumer & Storey (1979) obtained 2246 s^{-1} and Curtis & Ellis (1996) predicted 2331 from their isoelectronic analysis.

Like the other members of the Li I isoelectronic sequence, the relativistic calculations of Yan et al. (1998) are listed for the O VI doublet. They are very close to Peach et al. (1988) quoted by Wiese et al. (1996), Johnson et al. (1996), and Froese Fischer et al. (1998) and are consistent with the BF lifetimes of Knystautas et al. (1971) and Pinnington et al. (1974).

6.9. *Fluorine* (F); $Z = 9$

The energy levels of F I are from the compilation of J. E. Sansonetti & W. C. Martin (2003, in preparation), based on the hfs measures of the ground term by Laguana & Beatty (1982) and the reoptimization of the results of Lidén (1949) for the higher levels by V. I. Azarov (1995, private communication to W. C. Martin). The hfs spread in the ^{19}F I ground level $2p^5\ ^2P^o_{3/2}$ is a significant 0.135 cm^{-1}, and the spread of $2p^5\ ^2P^o_{1/2}$ is 0.342 cm^{-1} according to Harvey (1965), but I have found no data on the higher levels. Palenius (1969, 1970, 1971) analyzed F II, III, and F IV+V, and Engström (1985, 1984) did F VI and VII. Brown, Zink, & Evenson (1998) studied the hfs of the ground term of F II.

The multiconfiguration Hartree-Fock Breit-Pauli calculations of Tachiev & Froese Fischer (2002b) listed for F I predict a lifetime of 1.40 ns for multiplet 1 consistent with the BF measurements of 1.4 ± 0.1 by Irwin & Livingston (1973) and 1.28 ± 0.07 by Pinnington et al. (1976). The absorption f-values of Clyne & Nip (1977) are too small by 0.23 dex.

The theoretical values quoted here for the intersystem multiplets of F IV, F V, and VI are, respectively, from Tachiev & Froese Fischer (2001, 2000, 1999). These differ little from Mendoza et al. (1999) or Aggarwal, Keenan, & Msezane (2001) for F IV and Nussbaumer & Storey (1979) for F V and VI. The result for F VI also agrees also with the prediction of Curtis & Ellis (1996) in their analysis of the Be I isoelectronic sequence.

6.10. *Neon* (Ne); $Z = 10$

Kaufman & Minnhagen (1972), Persson (1971), Persson et al. (1991), and Kramida et al. (1999a) have published spectral analyses and IP for Ne I, II, III, and IV, respectively. The wavelengths of the intersystem lines of Ne V and IV are from the energy levels of Kramida et al. (1999b) and (1999c).

The calculations of Tachiev & Froese Fischer (2001, 2000) corrected to the measured wavelengths provided the A-values quoted here for the Ne V and VI lines. Mendoza et al. (1999) obtained similar results for Ne V as did Dankwort & Trefftz (1978) for Ne VI. Laboratory lifetimes would be useful tests.

6.11. *Sodium* (Na); $Z = 11$

The energy levels and IP are mainly from the compilation of Martin & Zalubas (1981). However, Juncar et al. (1981) made very accurate measurements of the D lines and Ciocca et al. (1992) and Baugh et al. (1998) improved the IP for Na I. The hfs levels in Table 4, which were calculated from the experimental parameters of Ramsey & Anderson (1965), Griffith et al. (1977), and Yei, Sieradzan, & Havey (1993), agree closely with the results of McNutt & Mack

(1963). The data which Arimondo, Inguscio, & Violino (1977) listed for 4p $^2P^o_{3/2}$ show that the ground-level separations dominate the hfs of multiplet 2v.

Like Li I, the D lines of Na I provide a test for experimentalists and theorists to find agreement in their results. Recent high-precision lifetime measurements by Carlsson et al. (1992), Tiemann, Knöckel, & Richling (1996), Jones et al. (1996), Oates, Vogel, & Hall (1996), and Volz et al. (1996) give a weighted average $f_M = 0.9609 \pm 0.0007$. The combination of these lifetimes from one or both upper levels depends on the assumption of *LS* coupling, for which the ratio of line strengths is exactly 0.5 compared with 0.50014 (44) measured by Volz et al. The latest calculations, including the relativistic correction, are very close to the measured *f*-values. Brage, Froese Fischer, & Jönsson (1994) obtained 0.9612, Johnson et al. (1996) 0.9609, Jönsson et al. (1996) 0.9602, Safronova, Derevianko, & Johnson (1998) 0.9635, and Siegel, Migdalek, & Kim (1998) 0.9650 when corrected to the measured wavelengths. This last paper, McEachran & Cohen (1983), and Lowe & Biémont (1994) all report calculated *f*-values for the much weaker transitions to higher levels of the series, but Lowe & Biémont differ from the other two. Consequently, for Table 2, I have preferred the relative f_M measured by Filippov & Prokofiev (1929), normalized to $f_M = 0.9609$ for the D lines and split according to *LS* coupling. Siegel et al. have predicted a decrease in the line-strength ratio with increasing np to 0.475 at $n = 18$. The Faraday rotation data of Nawaz et al. (1992) are within 2% for $n = 9$ and 10 but diverge for higher n. Since these weak lines are very important for determining Na I abundances, some modern measurements are most desirable.

6.12. *Magnesium* (Mg); $Z = 12$

Pickering, Thorne, & Webb (1998b) measured precise FTS wavelengths for both the mean isotopic mix and ^{24}Mg for multiplets 1u of Mg I and Mg II. Kelly (1957), Hallstadius (1979), and Beverini et al. (1990) provided additional isotopic and hfs data for Mg I and Drullinger, Wineland, & Bergquist (1980) and Itano & Wineland (1981) for Mg II. Otherwise the energy levels and IP are from the tabulations of Martin & Zalubas (1980) and Kaufman & Martin (1991a), who also listed observed wavelengths. These are close to the Ritz values in Table 2 except for $\lambda\lambda$1240.395 and 1239.925, which are observed at 1240.399 and 1239.936 Å.

Lifetime measurements for the Mg I intersystem transition 1v by Furcinitti, Wright, & Balling (1975b), Kwong, Smith, & Parkinson (1982), and Godone & Novero (1992) have given 4.5 ± 0.5, 4.6 ± 0.6, and 5.1 ± 0.7 ms, respectively, each with a different technique. The weighted mean corresponds to $A = 214 \pm 0.15$ s^{-1}. The calculations of Laughlin & Victor (1979), Chou, Chi, & Huang (1993), Stanek, Glowacki, & Migdalek (1996), and Jönsson & Froese Fischer (1997) are within 2 σ. There are at least 10 lifetime measurements for the upper state of λ2852 (using five different techniques) by Lurio (1964), Smith & Gallagher (1966), Andersen et al. (1970), Smith & Lizt (1971), Lundin et al. (1973), Marek & Richter (1973), Kelly & Mathur (1978), Liljeby et al. (1980), Schade (1987), and Larsson & Svanberg (1993). They range from 1.9 to 2.2 ns and have a weighted mean of 2.00 ± 0.03, giving $A = 5.00 \times 10^8$ s^{-1} adopted in Table 2. Recent calculations by Jönsson & Froese Fischer (1997) and Jönsson et al. (1999) predict a slightly longer lifetime of 2.14 ns. The relative hook measurements of Mitchell (1975) for the higher ^1S–$^1P^o$ transitions corrected to $f(\lambda 2853) = 1.83$ are very close to the calculated values of Mendoza & Zeippen (1987), Moccia & Spizzo (1988), and Chang & Tang (1990). Larsson & Svanberg (1993) and Larsson et al. (1993) measured LIF lifetimes for these levels, but they lack branching fractions.

The accurate BL measurements of Ansbacher, Li, & Pinnington (1989) for both the 3p $^2P^o_{1/2}$ and 3p $^2P^o_{3/2}$ levels of Mg II are very close to *LS* coupling and to the *J*-dependent calculations of Theodosiou & Curtis (1988) (semiempirical), Johnson et al. (1996) (many-body perturbation), and Siegel et al. (1998) (single-configuration Dirac-Fock), as well as the multiplet results of Fleming et al. (1998) (superposition of configurations), Godefroid & Froese Fischer (1999) (multiconfiguration Hartree Fock), Theodosiou & Federman (1999) (self-consistent Hartree-Kohn-Sham potential), and Majumder et al. (2002) (relativistic coupled cluster). The last four theoretical papers also found $f_M = 8.33 \times 10^{-4}$, 7.43×10^{-4}, 9.88×10^{-4}, and 9.302×10^{-4}, respectively, for the weaker doublet at 1240 Å and appear to have overcome the severe cancellation of terms which affected several earlier calculations. Fitzpatrick (1997) had estimated $f_M = 9.6 \times 10^{-4}$ using an astrophysical approach. Table 2 quotes the results of Theodosiou & Federman. After years of widely differing theoretical results this convergence is encouraging. However, a difficulty remains. Godefroid & Froese Fischer (1999), Theodosiou & Federman (1999), and Majumder et al. found the ratio $f(\lambda 1239.9)/f(\lambda 1240.4) = 2.54$, 1.78, and 1.80, respectively, compared with the *LS* ratio of 2.0008. (Fleming et al. calculated only the multiplet value.) Fitzpatrick, as quoted by Theodosiou & Federman, and Sofia, Fabian, & Howk (2000) reanalyzed their observations of Mg II interstellar absorption lines and found $f_M = (9.6 \pm 0.6) \times 10^{-4}$ and $(9.71 \pm 0.32) \times 10^{-4}$ and ratios of 1.82 ± 0.08 and 1.74 ± 0.06, respectively. Reliable *f*-values for both components of this doublet are very important because multiplet 1 of Mg II usually is too saturated to determine the abundance of this prevalent ion. The two shortest wavelength doublets in Table 2 are a little stronger, but calculations such as those by Butler, Mendoza, & Zeippen (1984) (close coupling) also may be affected by cancellation of terms and deviations from *LS* coupling. Consequently, I have quoted the results of Majumder et al.

6.13. *Aluminum* (Al); $Z = 13$

Most of the energy levels and IP in Table 2 are from Martin & Zalubas (1979) or preferably Kaufman & Martin (1991b). The latter authors relabeled the Martin-Zalubas 4d ^2D levels of Al I as $nd\,y$ ^2D and reduced n by 1 on all the higher terms of this series. Chang (1990) and Brown & Evenson (1999) have tabulated the hfs levels for ^{27}Al I, and the latter authors found 112.06495 (6) cm^{-1} for the separation of $J = 1/2, 3/2$ in the ground term. Griesmann & Kling (2000) have published precise FTS wavelengths for multiplets 2 of Al II and 1 of Al III, including the hyperfine components of the latter quoted in Table 4.

The *A*-values for multiplets 1v and 3v of Al I correspond to the weighted mean lifetimes, which Doidge (1995) calculated from many consistent measurements. Additional entries are from the LIF lifetimes of Buurman et al. (1986) and Davidson, Volten, & Dönszelmann (1990) and their estimates of the branching fractions. The remainder are from the hook measurements of Penkin & Shabanova (1965) rescaled to $f_M(\lambda3956) = 0.0116$. Accurate measurements of the branching fractions are needed for Al I. Kohl & Parkinson (1973) and Lombardi, Cardon, & Kurucz (1981) investigated two of the autoionizing multiplets.

Lifetime measurements of the $\lambda2669$ intersystem line of Al II with an ion trap by Johnson, Smith, & Parkinson (1986) and with a storage ring by Träbert et al. (1999b) give a mean $A = 3300 \pm 80$ s^{-1}. The closest theoretical results are 3450 by Laughlin & Victor (1979), 3500 by Hibbert & Keenan (1987), 2896 by Chou et al. (1993), 3067 by Zou & Froese Fischer (2000), and 3340 by Tachiev & Froese Fischer (2002c). Recent calculations have given $f(\lambda1671) = 1.779$ by Chou et al., 1.751 by Jönsson & Froese Fischer (1997), 1.746 by Zou & Froese Fischer (2000), and 1.743 by Tachiev & Froese Fischer (2002c). I have adopted 1.74 consistent with 1.75 ± 0.27 from the BF lifetime of Kernahan et al. (1979). A new precise measurement would provide a test of the calculations. Table 2 lists $f(\lambda935) = 2.52 \times 10^{-3}$ from the OP calculation of Butler, Mendoza, & Zeippen (1993), which is close to $f = 2.7 \times 10^{-3}$ by Victor, Stewart, & Laughlin (1976) but very different from 6.3×10^{-3} by Tayal & Hibbert (1984) and 0.382×10^{-3} by Tachiev & Froese Fischer (2002c).

The calculated *f*-values of Theodosiou & Curtis (1988), Johnson et al. (1996), and Siegel et al. (1998), corrected to laboratory wavelengths, agree very closely for both components of the Al III doublet so that Table 2 quotes the means. The corresponding lifetime of 1.87 ns is consistent with the BF result of 2.1 ± 0.2 ns by Berry, Bromander, & Buchta (1970a).

6.14. *Silicon* (Si); $Z = 14$

W. C. Martin (2002, private communication) has revised the energy levels for Si I and published some in J. E. Sansonetti & W. C. Martin (2003, in preparation). Griesmann & Kling (2000) obtained FTS wavelengths of the ground-state transitions of multiplets 1 and 2 of Si II and multiplet 1 of Si IV. Otherwise the levels and IP are from Martin & Zalubas (1983). Laser-magnetic-resonance measurements by Inguscio et al. (1984) and Brown, Zink, & Evenson (1994c) placed the excited levels of the ground term of Si I at 77.111871 (4) cm^{-1} for $J = 1$ and 223.15717 (6) for $J = 2$.

O'Brian & Lawler (1991) published *A*-values for Si I based on their TRLIF lifetimes and the branching fractions that Smith et al. (1987) obtained from emission and absorption measurements. These *A*-values are more accurate than those quoted by Smith et al., who normalized to BF lifetimes. O'Brian & Lawler listed lifetimes for many levels, but they avoided using any of the branching fractions above $4s\ ^1P^o$ at 53,387 cm^{-1} because of possible infrared decays. Instead Table 2 quotes additional *A* from the OP calculations of Nahar (1993) distributed according to pure *LS* coupling. For the three resonance multiplets in common, these results agree with O'Brian & Lawler within 0.06 dex, but she cautions against trusting her calculations if $f_M < 0.01$.

Calamai, Smith, & Bergeson (1993) measured branching fractions and ion-trap lifetimes for the intersystem muliplet 0.01 of Si II. These results supersede the theoretical calculations of Nussbaumer (1977) and Dufton et al. (1991), which are reasonably close for the stronger components.

The many discrepancies between the theoretical *f*-values for the permitted Si II lines and the lifetime measurements or the observed interstellar line strengths are gradually being resolved, with much more confidence now attributable to the theoretical results. Dufton et al. (1992) and Hibbert, Ojha, & Stafford (1992) overcame the severe cancellation of terms in the calculations and deduced $f_M(\lambda1814) = 0.0018 \pm 0.0004$, while Bergeson & Lawler (1993c) measured 0.00189 ± 0.00019 by TRLIF as well as the branching fraction. Table 2 quotes these last results. The calculations for multiplets 2, 3, 4, and 5, and to a lesser extent those for 5.1 and 6, have always given consistent results and showed good agreement between length and velocity forms where both were provided. Consequently, the data for these multiplets in Table 2 are based on *LS* coupling and the averages of the recent calculations by Hibbert et al. (1992) (configuration interaction), Nahar (1998) (close coupling), and Charro & Martín (2000) (relativistic quantum defect). Schectman, Povolny, & Curtis (1998) measured a BF lifetime for multiplet 2 that corresponds to $f_M = 0.130 \pm 0.006$, in excellent agreement with the theoretical value. However, the earlier beam-foil lifetimes appear to be untrustworthy. In multiplets 4 and 5 the lifetimes are somewhat longer than expected from the calculations, possibly because of incomplete correction for cascades, but for multiplets 3, 5.01, and 6, the published lifetimes are shorter than predicted. A few more modern lifetime measurements would be very useful to confirm the theoretical values adopted here and reduce the uncertainties in the last two multiplets.

The ion-trap lifetime of Kwong et al. (1983) gave $A(\lambda1892) = 16,700 \pm 500$ s^{-1} for the intersystem Si III line, very close to the theoretical 16,070 of Chou et al. (1993) and 16,450 of Zou & Froese Fischer (2000). The last two papers also reported $f(\lambda1206) = 1.647$ and 1.606, respectively, for the strong line, so that I quoted 1.63, which is consistent with the BF results of 1.60 ± 0.12 by Irwin & Livingston (1973) and 1.60 ± 0.18 by Livingston et al. (1976).

The calculations of Theodosiou & Curtis (1988), Johnson et al. (1996), and Siegel et al. (1998) adopted here for the Si IV doublet are in excellent agreement with the new ANDC beam-foil lifetimes by Maniak, Träbert, & Curtis (1993).

6.15. *Phosphorus* (P); $Z = 15$

Martin, Zalubas, & Musgrove (1985) have compiled energy levels and IPs. The hfs in the $3p^3\ ^4S^o_{3/2}$ ground level of ^{31}P I has a spread of 0.0037 cm^{-1} according to Pendlebury & Smith (1964). Brown et al. (1996) found that the $3p^2\ ^3P_1$ level of ^{31}P II is 164.92853 (6) cm^{-1} above the ground and has an hfs spread of 0.0014 cm^{-1}, while the $3p^2\ ^3P_2$ level has a spread of 0.21 cm^{-1}.

The phase-shift and BF lifetimes of the $4s\ ^4P$ state of P I by Savage & Lawrence (1966), Curtis, Martinson, & Buchta (1971b), and Livingston et al. (1975) have a weighted mean of 4.17 ± 0.23 ns. The relative intensities of the triplet lines measured by Mazzoni & Ricci (1996) give their contributions to the observed signal and hence the *A*-values for multiplet 1 in Table 2. The relativistic Hartree-Fock calculations of Fawcett (1986) provided data for two more multiplets. His results for the first multiplet are about 0.07 dex smaller than the experimental values. Further laboratory measurements are needed for the numerous resonance lines of P I.

The *A*-values for the ^3P–$^5S^o$ intersystem transitions of P II are based on the ion-trap lifetime of Calamai, Han, & Parkinson (1992) and the theoretical branching fractions of

Brage & Froese Fischer (1993) and LaJohn & Luke (1993a, 1993b). Hibbert (1993) discussed the theoretical sophistication necessary to calculate such a lifetime. Most of the other *f*-values are quoted from the length results of the extensive configuration-interaction calculations of Hibbert (1988), which agree well with the velocity values. The BF lifetimes of Livingston et al. (1975) are consistent with the calculations for multiplets 2 and 3 and $\lambda964$, but the error on 2 is large and the $\lambda967$ multiplet probably was not resolved from $\lambda964$. The phase-shift lifetimes of Savage & Lawrence (1966) and the BF results of Curtis et al. (1971b) differ considerably from the adopted calculations. New measurements are needed.

The BF lifetimes of Curtis et al. (1971b) and Livingston et al. (1975) were averaged for the *LS* transitions of P III, which have no branches. For P IV Table 2 quotes the means of nearly identical theoretical results by Chou et al. (1993) and Zou & Froese Fischer (2000) for both $\lambda1467$ and $\lambda951$. Thus, $\tau(\lambda951) = 0.27$ ns compared with the BF lifetimes of 0.22 ± 0.02 by Curtis et al. (1971b) and 0.35 ± 0.02 by Livingston et al. (1975). A new lifetime measurement would be helpful.

The means of the very similar results from the calculations of Theodosiou & Curtis (1988), Johnson et al. (1996), and Siegel et al. (1998) quoted here for the P V doublet imply a lifetime of 0.800 ns compared with 0.70 ± 0.15 measured by Curtis et al. (1971b) and 0.95 ± 0.05 by Livingston et al. (1975). A lifetime derived from laser excitation would provide a useful check on whether cascades affected the beam-foil data.

6.16. *Sulfur* (S); $Z = 16$

The energy levels and IP are from Martin, Zalubas, & Musgrove (1990) updated with the useful compilation of Kaufman & Martin (1993), who included laboratory wavelengths for many transitions. In the particular case of S II, W. C. Martin (2002, private communication) has recommended the measured wavelengths rather than the Ritz values deduced from the energy levels. Accordingly, in Table 2, I have adjusted the quoted levels wherever measurements are available. Brown, Evenson, & Zink (1994a) have measured 177.53925 (9) cm^{-1} for the separation of $J = 0$ and 1 in the ground term of S I.

The *A*-values for multiplet 1 of S I are from the lifetime and branching fractions measured by Delalic, Erman, & Källne (1990). The *f*-values calculated by Biémont, Storey, & Zeippen (1996) for multiplets 1 and 2 are within 0.12 dex of those adopted here. Beideck et al. (1994) published BF lifetimes for the upper levels of multiplets 2 and 9 of S I. Their experimental branching fractions for multiplet 9 and those of Ricci & Mazzoni (1994) for multiplet 2 then give the *A* values in Table 2. Oscillator strengths for multiplets 3 and 5 follow from Doering's (1990) ratios of $f_M(\lambda1479)$ and $f_M(\lambda1429)$ to $f_M(\lambda1814)$ and the assumption of *LS* coupling. Berzinsh et al. (1997) and Li et al. (1998) measured TRLIF lifetimes for several levels, which Biémont et al. (1998) combined with their theoretical branching fractions. Comparison of these data with the early measurements from a wall-stabilized arc by Müller (1968) indicates corrections within 0.14 dex in most cases so that his values are quoted for multiplets 4 and 7. The close-coupling calculations of Zatsarinny & Tayal (2002) agree reasonably well with the experimental values. Federman & Cardelli (1995) used observations of interstellar absorption lines toward ζ Oph to derive astrophysical *f*-values for many S I lines normalized to $f(\lambda1474.6) = 0.00133$. However, since *LS* coupling seems appropriate for multiplet 3, $f(\lambda1474.6) = 0.00099$, requiring a correction of -0.13 dex. With or without this correction the astrophysical *f*-values are within 0.13 dex of the values adopted here from 1808 to 1262 Å, but deviate seriously for 1247 and 1242 Å.

For multiplets 1 and 2 of S II, Table 2 adopts the intermediate-coupling configuration-interaction calculations with relativistic correction by Ojha & Hibbert (1989). The resulting theoretical $f_M(\lambda1256) = 0.0329$, agrees with 0.032 ± 0.003 obtained from the pulsed-electron lifetimes of Lawrence (1969). The ab initio close-coupling calculations by Nahar (1997) gave 0.0377. An accurate modern lifetime measurement would provide a valuable check on the calculations.

The *A*-values for the intersystem multiplet of S III are from the ion-trap lifetime of Heise, Smith, & Calamai (1995) and branching fractions averaged from the calculations of Hayes (1986) and Brage & Froese Fischer (1993). LaJohn & Luke (1993b) obtained similar theoretical values. The *f*-values for multiplets 1 and 2 of S III are the averages of the close-coupling calculations of Nahar & Pradhan (1993) and the configuration-interaction calculations of Tayal (1995), and for multiplet 1 agree with the BF lifetimes of Berry et al. (1970b) and Livingston et al. (1976) as well as the configuration-interaction results of Ho & Henry (1987). However, the lifetime for multiplet 2 by Livingston et al. is 23% too long for the adopted calculations but agrees with Ho & Henry. A laser-excited lifetime would be useful to check whether the discrepancy could be due to cascades.

The configuration-interaction calculations of Hibbert, Brage, & Fleming (2002) adopted for S IV are within 0.12 dex of the relativistic calculations of Froese Fischer (2002) for the intersystem lines and 0.030 dex for multiplet 1u. There are no experimental lifetimes to check the first one, and the BF results by Reistad & Engström (1989) gave $\tau(^2D_{3/2}) = 4.84 \pm 0.15$ and $\tau(^2D_{5/2}) = 4.86 \pm 0.15$ ns compared with 5.92 and 6.15 ns by Hibbert et al. New measurements are required for these frequently observed lines.

Since there is no experimental lifetime for the ^1S–$^3P^o$ transition of S V, I adopted $A = 1.60 \times 105\ \mathrm{s}^{-1}$ from the calculations of Chou et al. (1993) and Zou & Froese Fischer (2000) because they are consistent with the measurements for lower isoelectronic species. The recent results confirm the calculations of Laughlin & Victor (1979).

The *f*-values for the S VI doublet are the means of the nearly identical theoretical results by Theodosiou & Curtis (1988), Johnson et al. (1996), and Siegel et al. (1998), which agree with the ANDC beam-foil lifetimes of Ekberg et al. (1983).

6.17. *Chlorine* (Cl); $Z = 17$

Radziemski & Kaufman (1969, 1974) have derived the energy levels and IP for Cl I and II. These are quoted in Table 2 with some revised Cl I assignments from the NIST Web site and a Cl I fine-structure excitation of 882.353 cm^{-1} from the weighted mean of the precision measurements by Uehara & Horiai (1987) for the two isotopes. The hfs constants summarized by Uslu, Code, & Harvey (1974) indicate a total spread of 0.039 cm^{-1} in the $3p^5\,^2P^o_{3/2}$ ground state of ^{35}Cl I and 0.033 cm^{-1} in ^{37}Cl I. Raassen et al. (1992) have tabulated wavelengths for Cl iii and iv, Ellis & Martinson (1984) estimated the upper level of the Cl iv intersystem lines, and Feuchtgruber, Lutz, & Beintema (2001) determined ground-term fine-structure levels for Cl iv and Cl v from observations of planetary nebulae with the *Infrared Space Observatory*, while Jupén & Curtis (1996) provided the Cl v wavelengths and Levashov (1991) the energy level for Cl vi.

Schectman et al. (1993) measured BF lifetimes and branching fractions for the lines at 1347, 1363, 1097, and 1088 Å. Their *f*-values for the first two in multiplet 1 are 40%–70% larger than the absorption results of Clyne & Nip (1977) and Schwab & Anderson (1982), but agree well with the relativistic calculations of Biémont, Gebarowski, & Zeippen (1994). Since their length and velocity results are similar except for $\lambda\lambda 1373$, 1098, 1092, 1085.717, 1085.304, and 1109, I have adopted their length values for most of the other Cl i lines. Ojha & Hibbert (1990), published an extensive list of Cl i *f*-values, which differ from Biémont et al. except for multiplets 1 and 2 and show poor agreement between length and velocity results.

The Cl i transitions at 1097 and 1088 Å deserve special consideration. The measurements of Schectman et al. (1993) confirm the interstellar observations of Jura & York (1978) and Federman (1986) that $\lambda 1088$ is significantly stronger than $\lambda 1097$, contrary to any of the theoretical results. Keenan & Dufton (1990) and Biémont et al. (1994) have proposed that the spectroscopic assignments of Radziemski & Kaufman used by theoreticians should be reversed so that $\lambda 1088$ is the $3p^5\,{}^2P^o_{3/2}$–$3d\,{}^2D_{5/2}$ component of an *LS* multiplet, while $\lambda 1097$ is $3p^5\,{}^2P^o_{3/2}$–$3d\,{}^2F_{5/2}$, whose strength depends on spin-orbit mixing. Further experimental *f*-values are needed for this atom and a reanalysis of the terms in question.

The *A*-value for multiplet 1 of Cl ii is based on the weighted mean of the lifetimes of Lawrence (1969) (pulsed electrons) and Bashkin & Martinson (1971) (beam-foil). The latter authors also published measurements for Cl iii ${}^4S^o$–${}^4P$ and Cl iv ${}^3P$–${}^3D^o$. I have preferred the calculations of LaJohn & Luke (1993b) for Cl iv ${}^3P$–${}^5S^o$ rather than Ellis & Martinson (1984) because the former results agree much better with the lifetime experiments for P ii and S ii. Froese Fischer (2002) has calculated transition probabilities for the intersystem lines of Cl v. The theoretical $f(\lambda 1014) = 1.76 \times 10^{-4}$ adopted here for Cl vi from Chou et al. (1993) is close to the earlier 1.79×10^{-4} of Laughlin & Victor (1979) and the semiempirical 1.605×10^{-4} of Curtis (1991).

6.18. *Argon* (Ar); $Z = 18$

Velchev, Hogervorst, & Ubachs (1999) have published very accurate values for the IP and the wavenumbers for the Ar i transition near 1048 Å for the three stable isotopes. Minnhagen's (1973) level difference then gave the line near 1067 Å. The energy levels in Table 2 are for ^{40}Ar i, the most abundant isotope in air; they are lower by only 0.018 cm^{-1} for ^{38}Ar i and 0.035 cm^{-1} for ^{36}Ar i. The solar wind is 84.2% ^{36}Ar and 15.8% ^{38}Ar (Anders & Grevesse 1989). Minnhagen (1971) measured the levels adopted here for Ar ii and Yamada, Kanamori, & Hirota (1985) confirmed the ground-state fine-structure separation at 1431.5831 ± 0.0007 cm^{-1}. Kaufman & Whaling (1996) determined the IP for Ar iii. The levels for the intersystem lines of Ar v and vi are based on the ground-term separations that Kelly & Lacy (1995) and Feuchtgruber et al. (2001) observed in planetary nebulae and the laboratory wavelengths reported by Träbert et al. (1988).

The summary by Chan et al. (1992) shows a wide range in the measured *f*-values for both multiplets 1 and 2 of Ar i. I have adopted the accurate results of $f(\lambda 1067) = 0.06747 \pm 0.00067$ and $f(\lambda 1048) = 0.2628 \pm 0.0022$ from the electron-energy-loss spectroscopy of Lang et al. (1998). They confirmed the measurements of Chan et al. by a similar technique, and the BF lifetime of Federman et al. (1992) for $\lambda 1048$. Lauer et al. (1999) measured the Ar ii lifetime from pulsed monochromatic synchrotron radiation, and Jans et al. (1997) obtained the branching fraction from electron impact.

For the ${}^3P$–${}^5S^o$ transitions of Ar v, I have quoted the mean *A* from the calculations of Brage & Froese Fischer (1993) and Kohstall et al. (1998) rather than the much smaller values of LaJohn & Luke (1993b), though their results are consistent with the lifetime measurements of the S iii multiplet. The theoretical *A*-values for Ar vi are from Froese Fischer (2002).

6.19. *Potassium* (K); $Z = 19$

The energy levels and IP for potassium to nickel are from the compilation of Sugar & Corliss (1985) except as noted for particular cases.

R. Engleman (1999) in a private communication has kindly provided improved energy levels for multiplet 1v. The ^{39}K i hfs in Table 4 is based on the parameters recommended by Arimondo et al. (1977).

The *A*-values for multiplet 1v of K i are the weighted means of the precise lifetimes of Volz & Schmoranzer (1996) (BL), and Wang et al. (1997) (binding of ^{39}K$_2$). The resulting *f* are within 0.4% of the theoretical results of Liaw (1992) and are consistent with the ratio 2.1 ± 0.1 measured by Gamalii (1996). The *f*-values for the higher series numbers are based on the renormalized hook measurements of Shabanova & Khlyustalov (1985) and for $n \geq 10$, depend on the ratios from the relativistic calculations of Migdalek & Kim (1998), who included core polarization. The Faraday rotation measurements of Nawaz et al. (1992) for $n \geq 10$ are significantly smaller.

6.20. *Calcium* (Ca); $Z = 20$

U. Litzén (1999, private communication) kindly provided new measurements of the wavelengths of the H and K lines. The quoted values are only 0.001 and 0.002 Å less than those given by Morton (1991), but now are reliable to 3×10^{-4} Å ($3\,\sigma$), or 0.02 km s^{-1}.

The lifetimes for $4s4p\,{}^3P^o_1$ of Ca i by Furcinitti, Balling, & Wright (1975a), Giusfredi et al. (1975), Whitkop & Wiesenfeld (1980), Pasternack et al. (1980), Husain & Schifino (1983), Husain & Roberts (1986), and Drozdowski (1997) range from 0.33 to 0.55 ms, while the hook measurement of Parkinson, Reeves, & Tompkins (1976a) implies $\tau = 0.41$ ms and the theory of Brage et al. (1993) gives 0.40 ms. Pending a defining experiment, I have adopted $\tau = 0.40$. Doidge (1995) obtained $f(\lambda 4227) = 1.77 \pm 2\%$ from the mean of 10 lifetime measurements. The higher series members are from Parkinson et al. normalized to $f(\lambda 4227) = 1.75$. Ahmad, Baig, & Hormes (1994) extended these results to $n = 25$.

Jin & Church (1994), with laser excitation, measured accurate lifetimes for the two upper levels of the Ca II H and K lines. The ab initio calculations of Liaw (1995) confirm these within 1.3% and provide the branching fractions 0.0639 and 0.0654 to $3d\,^2D_{3/2,\,5/2}$, which are needed to derive the *A*-values quoted in Table 2. The less accurate lifetimes of Gosselin, Pinnington, & Ansbacher (1988) and Rosner, Holt, & Scholl (1997) are consistent with Jin & Church. The *f*-values for the higher series numbers are from the calculations of Theodosiou, Curtis, & Nicoliades (1995), who used the Coulomb approximation with a central potential for the core. They also confirmed the theoretical branching fractions used for the H and K lines.

6.21. *Scandium* (Sc); $Z = 21$

Fricke et al. (1959) and Aboussaïd et al. (1996) have measured hfs constants for ^{45}Sc I, while Arnesen et al. (1982), Young et al. (1988), Mansour et al. (1989), and Villemoes et al. (1992) have done so for ^{45}Sc II.

TRLIF lifetimes by Marsden et al. (1988) and FTS branching fractions by Lawler & Dakin (1989) provided many of the *A*-values for Sc I and II. Additional entries for Sc I came from the relative hook measures of Parkinson, Reeves, & Tomkins (1976b), whose scale on average is identical with Marsden et al. In multiplet 6v of Sc I, Lawler & Dakin did not separate the decays of the very close $^2P^o_{1/2}$ and $^2P^o_{3/2}$ levels to $^2D_{3/2}$. However, in a private communication, J. E. Lawler (2002) has derived the *A*-values in Table 2 using the reasonable assumption that collisions in the light source populated the upper fine-structure levels in proportion to their statistical weights. The Hartree-Fock theoretical *f* for multiplet 1 of Sc III by Weiss (1967) was adopted by Martin, Fuhr, & Wiese (1988).

6.22. *Titanium* (Ti); $Z = 22$

The wavelengths in Table 2 are derived from the energy levels of Forsberg (1991) for Ti I and those of I. Zapadlik, S. Johansson, & U. Litzén (2001, private communication) for Ti II. The IP for Ti I is from Sohl, Zhu, & Knight (1990).

The majority of the *f*-values for Ti I are based on the relative absorption measurements of Blackwell et al. (1982a) and Blackwell, Menon, & Petford (1983) with the Oxford furnace. Grevesse, Blackwell, & Petford (1989), revised their absolute scale to $\log gf(\lambda 3949) = -0.412 \pm 0.018$ using the reliable LIF lifetimes of Rudolph & Helbig (1982) in place of earlier beam-foil data. Later LIF measurements by Salih & Lawler (1990), with some revisions by Lawler (1991), and by Lowe & Hannaford (1991) confirmed these results. According to the last paper, the means of all three sets of lifetimes showed that $\log gf(\lambda 3949) = -0.406 \pm 0.011$. Table 2 adopts this normalization, with its error, and the 1% or smaller errors on the relative *f*. Nitz, Wickliffe, & Lawler (1998), with their measurements of nonresonance lines, have questioned the exceptional accuracy claimed for the Oxford data. Alternative *f*-values for visual multiplets 12, 13, 16, and 19 are available from the same means of lifetimes and the branching fractions of Whaling, Scalo, & Testerman (1977). Their errors are larger for some transitions, but the results are consistent with the values in Table 2 within 2 σ. A correction of +0.09 dex to the relative hook values of Smith & Kühne (1978) brings them on to the present scale and provides additional data for the shorter wavelength lines, though with large errors in some cases.

Pickering, Thorne, & Perez (2001, 2002b), have published *A*-values for Ti II based on the TRLIF lifetimes of Bizzarri et al. (1993) and FTS branching fractions from both papers. Thus, Pickering et al. have confirmed the estimate for *f* (λ3073) in multiplet 5v by Ferderman, Weber, & Lambert (1996). Wiese, Fedchak, & Lawler (2001) determined *f*-values for the lines at 1911.0 and 1910.6 Å by comparing their absorption equivalent widths in a synchrotron beam with the lines at 3383.8 and 3066.3 Å and calibrating the first of these using the accurate relative *f* of Blackwell, Menon, & Petford (1982b) and the absolute *f* of eight transitions they had in common with Bizzarri et al. TRLIF lifetimes by Langhans, Schade, & Helbig (1995) confirm those of Bizzari et al. for eight levels. Further lifetime measurements of the odd levels between 52,329 and 63,375 cm^{-1} could take advantage of the additional branching fractions of Pickering et al.

The orthogonal-operator calculations of Raassen & Uylings (1998) provided the *f*-values for Ti III.

6.23. *Vanadium* (V); $Z = 23$

James et al. (1994) measured the IP for V I and Iglesias, Cabeza, & de Luis (1988) revised the energy levels and IP for V II. Palmeri et al. (1995, 1997) and Lefèbvre, Garnir, & Biémont (2002) published extensive hfs measurements for V I, which can have large splittings.

Most of the V I *A*-values are from Martin et al. (1988) based on the TRLIF lifetimes and FTS branching fractions of Whaling et al. (1985) supplemented by hook measurements of Ostrovskii & Penkin (1958) and absorption data by King (1947), both renormalized to the newer lifetimes. Table 2 lists additional *f*-values from Doerr et al. (1985) from LIF, emission, and hook measurements. Blending in the busy spectrum of V I may explain why their *f* for $\lambda\lambda$4368, 4356, 4353, 3925 in multiplets 5v and 8v differ from Whaling et al. by more than 0.2 dex. Table 2 includes some shorter wavelength multiplets that are exceptionally strong in Kurucz's (1998) calculations. He has reproduced the experimental results for many of the lower permitted transitions, but not some of the higher ones nor any of the intersystem lines. Consequently, no theoretical *f*-values are listed.

Karamatskos et al. (1986) measured TRLIF lifetimes and FTS branching fractions for three multiplets of V II and determined *f*-values, which Martin et al. (1988) adopted. Biémont et al. (1989) confirmed these results with branching fractions from the same FTS and the additional TRLIF lifetimes by Schade, Langhans, & Helbig (1987). Table 2 quotes the first paper except for the lines at 2742.4 and 2739.7 Å, which were measured by only Biémont et al. The remaining entries for V II from Kurucz (1998), but only if $\log gf > -1.2$ for at least one line in a multiplet because weaker transitions deviate from Karamatskos et al. by more than 0.2 dex. Kurucz (1998) is the only source for V III.

6.24. *Chromium* (Cr); $Z = 24$

Pickering et al. (2000) have measured very accurate wavelengths for multiplet 1 of Cr II; they are 0.002 to 0.003 Å longer than those derived from Sugar & Corliss (1985). Ekberg (1997) has revised the analysis of Cr III.

The *f*-values for Cr I are from Martin et al. (1988), who found good agreement among various measurements. Recent lifetimes by Reinhardt et al. (1995) and Cooper, Gibson, & Lawler (1997) do not change these results and should be useful for additional transitions if more branching fractions become available.

The A-values for multiplet 1 of Cr II are based on the weighted means of the TRLIF lifetimes of Schade, Mundt, & Helbig (1990) and Bergeson & Lawler (1993a) and the BL lifetimes of Pinnington et al. (1993) combined with the branching fractions of Bergeson & Lawler. The theoretical results of Kurucz (1998) are larger by 0.23 dex, those of Aashamar & Luke (1994) by 0.16 dex, and those of Raassen & Uylings (1998) by 0.09 dex. Additional f-values are quoted from this last source for multiplets with at least one line having $\log gf > -2.5$. The experimental papers list more lifetimes, but unfortunately they lack branching fractions. For Cr III we have only the Kurucz (1998) calculations, which are the same as his 1988 results.

6.25. *Manganese* (Mn); $Z = 25$

The Mn I multiplet numbers are from Adelman et al. (1989). The hfs parameters of Davis, Wright, & Balling (1971) and Handrich, Steudel, & Walther (1969) for ^{55}Mn I indicate separations of 0.037 cm^{-1} in the $a\,^6S_{5/2}$ ground level and 0.17 to 0.29 cm^{-1} in the $z\,^6P^o_{3/2,5/2,72}$ excited term.

Martin et al. (1988) adopted the Oxford absorption measurements of the first three multiplets of Mn I by Booth et al. (1984) normalized to the phase-shift and laser-excited lifetimes of Marek & Richter (1973) and Marek (1975). The relative hook measures of Ostrovskii & Penkin (1957) were the basis for multiplet 1u. As yet, there are no branching-fraction measurements to use with the TRLIF lifetimes of Schnabel, Bard, & Kock (1995). The calculations of Kurucz (1998) for the first four multiplets agree with the experimental results within ±0.06 dex. Table 2 lists his values for the remaining lines, omitting multiplets that have $\log gf \leq -3.0$ for all lines.

Kling & Griesmann (2000) combined their experimental branching fractions for multiplets 1 and 2 of Mn II with the weighted means of the TRLIF lifetimes of Kwiatkowski et al. (1982) and Schnabel et al. (1995), and the BL results of Pinnington et al. (1992). Additional accurate TRLIF lifetimes by Kling, Schnabel, & Griesmann (2001) confirm the adopted values for multiplet 1. The remaining lines are quoted directly from the calculations of Kurucz (1998), with most having $\log gf \leq -4.0$ omitted. For 21 experimental f-values with $-3.4 \leq \log gf \leq 0.4$ Kling & Griesmann found that the corrections to Kurucz ranged from -0.17 to $+0.10$ dex. De Boer et al. (1974) and Lugger et al. (1982) estimated astrophysical f-values for multiplet 3, with considerable differences from star to star. If one increases these by 0.10 dex to correct the values they adopted for multiplet 1 from Morton & Smith (1973) and ignores the results for the line at 1199 Å, which is blended with N I absorption, the results of de Boer et al. and Lugger et al. are smaller than Kurucz by 0.24 and 0.12 dex, respectively. Similarly, Allen, Snow, & Jenkins (1990) and Welty et al. (1999) have published astrophysical values for multiplet 4 relative to the f-values for multiplet 3 by Lugger et al. The results quoted by Welty et al., after correction to the new standard for multiplet 1, are 0.47 dex larger than the values of Kurucz in Table 2. Experimental data are much needed for both multiplets 3 and 4, which are prominent in spectra from the *Far Ultraviolet Spectroscopic Explorer*.

6.26. *Iron* (Fe); $Z = 26$

Nave et al. (1994) have published a revised multiplet table for Fe I and the new multiplet numbers quoted here. Note their abbreviated designations such as Hsp^3 for new terms in place of the traditional lowercase letter. The energy levels for Fe II are from Johansson (1978), with a few more between 106,361 and 108,373 cm^{-1} labeled J added at the shortest wavelengths from S. Johansson (1984, and 1999, private communication), which I have revised using the precision wavelengths of Nave, Johansson, & Thorne (1997). Brown, Körsgen & Evenson (1998) measured the $J = 1/2$–$3/2$ and $3/2$–$5/2$ fine-structure splittings of the ground term of Fe II and estimated the remainder from the data of Nave et al. (1997). These results imply $E(9/2) = 0.0$, $E(7/2) = 384.7869$, $E(5/2) = 667.6830$, $E(3/2) = 862.6112$, and $E(1/2) = 977.0495$ cm^{-1}, very close to the values adopted in Table 2 for calculating the Ritz wavelengths. Ekberg (1993) has published new energy levels for Fe III. Brown et al. (1988), and Page & Gudeman (1990) confirmed the IP of Fe I adopted here from Worden et al. (1984).

The most accurate Fe I f-values are the relative measurements from the Oxford furnace by Blackwell et al. (1979). Their normalization to $\log gf(\lambda 3720) = -0.430$ is essentially unchanged by modern TRLIF lifetimes of $z\,^5F^o_5$ by Hannaford & Lowe (1981), O'Brian et al. (1991), and Engelke, Bard, & Kock (1993). Following J. R. Fuhr & W. L. Wiese (2003, private communication) I have given double weight for the first two because they considered the effect of polarization disalignment and made a small correction for the branches to a $^5F_{4,\ 5}$, thus obtaining $A(\lambda 3720) = 1.62 \times 10^7$ s^{-1} and $\log gf = -0.432 \pm 0.008$. Consequently, Table 2 quotes Blackwell's results with the original normalization and an error of 0.01 dex. Many other transitions are available from the lifetimes and FTS branching fractions of O'Brian et al. LIF lifetimes by Carlsson, Sturesson, & Svanberg (1989) for multiplet 14 and Langhans et al. (1995) for 17 and 19 confirm those adopted here. The hook measurements of Banfield & Huber (1973), corrected by +0.02 dex to match the Oxford normalization at 3720 Å, are quoted as a third choice. The mean differences are O'Brian − Blackwell = $+0.017 \pm 0.030$ dex for 57 resonance lines in common and Banfield + 0.02− Blackwell = -0.0050 ± 0.050 for 25 lines.

The f-values for multiplets 1 to 5 of Fe II are based primarily on the branching fractions from Bergeson et al. (1996) (FTS) or Bergeson, Mullman, & Lawler (1994) (echelle) and the accurate BL lifetimes of Biémont et al. (1991) or Guo et al. (1992), which agree well with the earlier TRLIF results of Hannaford et al. (1992), Schade, Mundt, & Helbig (1988), Schultz-Johanning, Schnabel, & Kock (1999), and Schnabel & Kock (2000). The f-values have changed little from Morton (1991), who used many of the same lifetimes with branching fractions from Nussbaumer, Pettini, & Storey (1981), but now we have more confidence in the results. Pickering, Johansson, & Smith (2001) and Pickering et al. (2002a) combined their FTS branching fractions with the TRLIF lifetimes of Sikström et al. (1999) and Li et al. (2000) to determine A-values for the ground-state transitions at 1611 and 1608 Å and eight more lines in multiplet 8. The resulting A-values for this multiplet agree closely with the absorption measurements of Mullman, Sakai, & Lawler (1997).

Table 2 also lists results for multiplet 9 and the one preceding it for which Johansson et al. (1995) estimated *f*-values for the perturbed upper $J = 3/2$ levels and revised the 1981 *f*-values of Kurucz using experimental intensity ratios. Wiese, Bonvallet, & Lawler (2002) obtained $f(\lambda 1145)$ in multiplet 10 by absorption.

Comparisons of these experimental *gf*-values with various theoretical calculations give the best fit with Raassen & Uylings (1998) (RU98) (orthogonal operators), a good fit with most of Kurucz (1999) (semi-empirical Hartree-Fock), poorer fits with Fawcett (1988) and Nussbaumer et al. (1981), and poorest with Nahar (1995) (Iron Project close coupling). The specific calculations by Donnelly & Hibbert (1999) for multiplet 8 also are close to the measurements. For multiplets 1, 2, 3, 4, and 8 the maximum deviations of RU98 from the experimental data are ±0.080 dex over a range of +0.5 to −2.0 in log *gf*, while RU98 is larger by 0.12 dex for λ1145. In the FERRUM project, Sikström et al. (1999) found that RU98 differed from their measured *gf* for 18 lines with excited lower terms by at most 0.15 dex. However, in one case of an experimental $\log gf = -2.61$ for λ2269.525 in multiplet 5, RU98 is smaller by 0.31 dex, while Kurucz is larger by 0.38 dex. At the shortest wavelengths where there are no RU98 data for the new Johansson transitions, I have listed *f*-values from Kurucz (1999). To save space, Table 2 omits many weak multiplets if all the transitions from the ground state have $\log gf \geq -5.0$ and many from excited levels of the ground term that have $\log gf \geq -3.0$. Some blank entries occur where RU98 list no value, presumably because $\log gf \geq -5.0$.

The astrophysical *f*-values that Cardelli & Savage (1995) derived for the ground-state transitions of Fe II between 2600 and 1608 Å with normalization to $f(\lambda 2260)$ and $f(\lambda 2249)$ from Table 2 are consistent with the other experimental results except $f(\lambda 1611)$, but Welty et al. (1999) did find agreement for that line. However, the analysis of Cardelli & Savage does suggest a correction of +0.46 dex to the theoretical $f(\lambda 2368)$ quoted from RU98. Betweeen 1145 and 1055 Å the astrophysical *f* of Lugger et al. (1982), Shull, Van Steenberg, & Seab (1983), Howk et al. (2000), and Mallouris et al. (2001) support the adopted values of RU98 except for a correction of −0.17 dex to $f(\lambda 1122)$. Further experimental checks on a few of the far-UV lines, including some weaker than $\log gf = -2.0$, would enhance confidence in Fe II abundances based on the calculated *f*-values.

The *A*-values for Fe III are from the calculations of Raassen & Uylings (1998), which are close to those of Ekberg (1993). An experimental check on the frequently observed line at 1123 Å would be very worthwhile.

6.27. *Cobalt* (Co)*;* $Z = 27$

The energy levels for Co I, II, and III, respectively, are from Pickering & Thorne (1996), Pickering et al. (1998a), and Raassen & Ortin (1984). Pickering (1996) has analyzed the hfs of Co I, and Page & Gudeman (1990) measured the IP.

Nitz et al. (1999) determined *A*-values for Co I from their FTS branching fractions and the TRLIF lifetimes of Nitz, Bergeson, & Lawler (1995). In most cases of overlap these agree well with the results of Cardon et al. (1982), which were adopted by Fuhr, Martin, & Wiese (1988). Table 2 quotes these where there are no data from Nitz et al. (1999) and omits many weak multiplets with intensities less than 2.0 according to Pickering & Thorne.

The Co II data are from the TRLIF lifetimes and FTS branching fractions of Mullman, Cooper, & Lawler (1998a), the absorption spectroscopy of Mullman et al. (1998b), and the orthogonal-operator theory of Raassen & Uylings (1998) and Raassen, Pickering, & Uylings (1998) where experimental results are absent. In most cases the calculations deviate from the measurements by 0.1 dex or less, but the lines at 1481, 1466, and 1448 Å reported by Mullman et al. imply corrections to Raassen et al. of −0.37, −0.44, and −0.47 dex. The last one was an astrophysical determination with considerable uncertainty so that Table 2 quotes Raassen et al. for the whole multiplet. The table omits multiplets with $\log gf \leq -3.0$ for all lines. Kurucz (1998) is the only source of *f*-values for the transitions of Co III quoted here.

6.28. *Nickel* (Ni)*;* $Z = 28$

Litzén, Brault, & Thorne (1993) have published a new analysis of the Ni I spectrum, and Page & Gudeman (1990) provided the IP. Table 2 includes transitions of Ni I involving the excited $3d^9 4s\ a\ ^3D$ term whose lowest level is only 205 cm^{-1} above ground. A few Ni II lines quoted to 0.0001 Å are from the precise FTS measurements by Pickering et al. (2000).

All the Ni I *f*-values with an error of 0.009 dex are from the accurate absorption measurements of Blackwell et al. (1989) corrected by +0.015 dex according to Bergeson & Lawler (1993c), who obtained improved TRLIF lifetimes. In Table 2 these data are supplemented by the hook values of Huber & Sandeman (1980) or the results of Doerr & Kock (1985) as quoted by Fuhr et al. (1988). With some exceptions the three data sets agree well in cases of overlap. Figure 2 of Blackwell et al. indicates that the values of Huber & Sandeman may be systematically too high for $\log gf < -2.0$ and the errors of Doerr & Kock may be larger than quoted.

Fedchak & Lawler (1999) have derived *A*-values for Ni II from TRLIF lifetimes and spectrophotometric branching fractions, and Fedchak, Wiese, & Lawler (2000a) extended these with relative *f* from a UV absorption experiment. These data also show that the relative astrophysical *f*-values of Zsargó & Federman (1998) are reliable if corrected by -0.272 ± 0.044 dex. The theoretical *f*-values of Kurucz (2000) are identical with those quoted in Paper I. The new experimental and astrophysical results indicate corrections ranging from −0.38 to +0.08 dex so that the Kurucz data are omitted from Table 2, but they have been useful in indicating potential strong lines to leave in the compilation. Improved calculations are needed for Ni II as well as additional branching fractions to use with the lifetimes of Fedchak & Lawler.

6.29. *Copper* (Cu)*;* $Z = 29$

The compilation of Sugar & Musgrove (1990) provided the energy-level and IP data for copper. Longmire, Brown, & Ginter (1980) and Loock, Beaty, & Simard (1999) have determined nearly identical IPs for Cu I.

Doidge (1995) adopted the accurate delayed-coincidence lifetimes of Carlsson et al. (1989) and the branching fractions of Koch & Richter (1968) to obtain the *f*-values quoted here for multiplet 1v of Cu I. The theoretical calculations by

Migdalek & Baylis (1979) and Curtis & Theodosiou (1989) reproduce these results very closely. The relative absorption measures of Hannaford & McDonald (1978) provided the f-values for the higher transitions normalized to $f(\lambda 3248) = 0.43$ compared with 0.434 adopted here.

Donnelly, Hibbert, & Bell (1999) have published the relativistic calculations for Cu II adopted in Table 2. Although their length and velocity results disagree, the summation of their length A-values over all branches gives lifetimes of 2.78 and 1.39 ns for $4p\ ^3P^o_1$ and $4p\ ^1P^o_1$, respectively, consistent with the BL measurements of 2.36 ± 0.05 and 1.34 ± 0.22 ns by Pinnington et al. (1997), but not with the relativistic calculations of these authors. Also, the new data for 1359 are significantly different from those quoted in Paper I from the Coulomb approximation by Theodosiou (1986). Thus, experimental branching fractions, a lifetime of $4p\ ^3D^o_1$, and a more accurate one for $4p\ ^1P^o_1$ are needed before one can have confidence in the transition probabilities of Cu II.

6.30. *Zinc* (Zn)*;* $Z = 30$

The lowest levels of Zn I and II are from the accurate measurements of Gullberg & Litzén (2000), while the higher levels and the IP are from the compilation of Sugar & Musgrove (1995). The Zn II results of Pickering et al. (2000) agree with Gullberg & Litzén within 0.001 cm^{-1}.

I have adopted the weighted mean $\tau = 26.7 \pm 2.4\ \mu$s from two LIF lifetimes for $4p\ ^3P^o_1$ of Zn I that Czajkowski, Bobkowski, & Krause (1991) measured using different techniques rather than the shorter $20.4 \pm 1.6\ \mu$s by Umemoto et al. (1989) using LIF. Doidge (1995) quoted the weighted mean of five lifetimes for $4p\ ^1P^o_1$. Zerne et al. (1994) have published lifetimes for four higher levels, but there is no branching information.

The A-values for multiplet 1 of Zn II are based directly on the TRLIF lifetimes of Bergeson & Lawler (1993a). They agree within 8% of the relativistic calculations of Migdalek & Baylis (1979) and the nonrelativistic ones of Curtis & Theodosiou (1989), both of which include core polarization. There are no data on multiplet 2 at 987 and 984 Å.

6.31. *Gallium* (Ga)*;* $Z = 31$

The revision of the $5s\ ^2S_{1/2}$ level in Ga I by Neijzen & Dönszelmann (1982) requires a correction of +0.02 cm^{-1} to some of the energy levels derived by Johansson & Litzén (1967). Table 2 includes three multiplets with less certain upper levels from Moore (1952) because they have known f-values. Isberg & Litzén (1985, 1986) provided the data for Ga II and III, respectively, and Karlsson & Litzén (2000) published isotopic and hfs data for Ga I and II as well as the wavelengths of the intersystem lines.

There are many lifetime measurements using various techniques for $5s\ ^2S_{1/2}$ of Ga I, with considerable scatter. I have adopted the simple mean $\tau = 6.99 \pm 0.49$ ns from Cunningham & Link (1967) (7.6 ± 0.4 phase shift), Norton & Gallagher (1971) (6.8 ± 0.3 Hanle), Andersen & Sørensen (1972) (6.9 ± 0.5 BF), Erdevdi & Shimon (1976) (6.8 ± 0.5 delayed coincidence), Havey, Balling, & Wright (1977) (7.0 ± 0.4 LIF), Lindgärd et al. (1981) (BF), Tursunov & Eshkobilov (1984) (6.2 ± 0.3 laser photoionization), and Verolainen, Komarovskii, & Penkin (1989) (7.6 ± 0.8 delayed coincidence), along with the f ratio from the hook data of Penkin & Shabanova (1965). BF measurements by Lindgärd et al. (1981, 1982) give τ in the range 5.4 to 5.7 ns, but they report different results in the two papers for the decay at 4172 Å. Several of the above authors as well as Carlsson et al. (1986), and Lee, Goo, & Ku (1993) have measured the lifetimes of the $4d\ ^2D_{3/2,\ 5/2}$ states, but the scatter is even larger. Consequently, I have preferred the f ratios of Penkin & Shabanova (1965), implying lifetimes of 7.5 ns for $4d\ ^2D_{5/2}$ and 7.0 ns for $4d\ ^2D_{3/2}$, which are both within the range of the data. Measurements by P. S. Doidge (2002, private communication) have confirmed the branching fractions adopted here for multiplets 1v and 1u. Hook ratios by Penkin & Shabanova provided f-values for the higher transitions.

For the Ga II intersystem line at 2091 Å, I have adopted the calculation of Fleming & Hibbert (1995), which agrees with the semiempirical estimate of Curtis (2000). Since their A-value is 0.23 dex more than the theoretical result of Chou, Chi, & Huang (1994), an experimental check would be worthwhile. The A-value for the stronger transition of 1414 Å follows from the weighted mean $\tau = 0.440 \pm 0.024$ ns of the BF lifetimes of Andersen et al. (1979), Engstrom (1982), and Ansbacher et al. (1985). The predictions of Chou et al., Curtis, and Fleming & Hibbert were longer by 0.013, 0.016, and 0.054 dex, respectively.

The Ga III lines are from the calculations of Curtis & Theodosiou (1989), which agree with the BF lifetimes of Ansbacher et al. (1985).

7. ISOTOPIC SHIFT AND HYPERFINE STRUCTURE

7.1. *Isotope Shift* (*IS*)

The wavelength data in Table 2, in most cases, represent the centroids for the isotopic mixtures found on Earth, as listed in the header for each element. At high resolution the spectral lines can be asymmetric or split into components owing to the presence of multiple isotopes or hyperfine structure.

For the elements of low atomic numbers the differing masses of each isotope can be important, leading to a normal mass shift of an energy level and a second specific mass shift resulting from the coupling between electrons, which can be large enough to double or cancel the first term and can be significant in some heavy-element transitions. Table 2 includes 19 lines of deuterium and a few lines of lithium, boron, carbon, and magnesium isotopes.

7.2. *Hyperfine Structure* (*hfs*)

The hyperfine splitting of a spectral line is caused by the magnetic field of the electrons interacting with the relatively weak magnetic moment of the nucleus, which is proportional to the nuclear angular momentum I. There also is an electrostatic hfs resulting from the nonspherical distribution of nuclear charge, which can be different for different isotopes. Since $I = 0$ for all atomic species with an even number of protons and an even number of neutrons, and these same conditions tend to define the peaks in cosmic abundances, hyperfine structure often is ignored in the analysis of interstellar and stellar spectra. A notable exception for interstellar absorption is Na I, where the splitting of the D lines can be seen with resolutions exceeding about 2×10^5. Even if hfs or isotope separation is not resolved, neglecting them can affect the analysis of astronomical spectra through asymmetries giving radial-velocity errors, increased line widths giving temperature errors, and reduced saturation giving abundance errors.

When $I \neq 0$, it combines with J to form the new quantum number $F = I + J, I + J - 1, \ldots, |I - J|$. The selection rule between lower F and upper F' is $\Delta F = 0, \pm 1$ but not 0 to 0. The energies of hyperfine levels can be calculated from the fine-structure level $E_{\rm fs}\,(J)$ by

$$E_{\rm hfs} = E_{\rm fs}(J) + \Delta E_{\rm M1}(I,\ J,\ F) + \Delta E_{\rm E2}(I,\ J,\ F)\ , \quad (17)$$

where the magnetic dipole interaction is

$$\Delta E_{\rm M1} = AK/2\ , \quad (18)$$

and, if $I > 1/2$, $J > 1/2$, the electric quadrupole interaction is

$$\Delta E_{\rm E2} = B\frac{3K(K+1) - 4I(I+1)J(J+1)}{8I(2I-1)J(2J-1)}\ , \quad (19)$$

with

$$K = F(F+1) - J(J+1) - I(I+1)\ . \quad (20)$$

See Schwartz (1955), who includes higher multipole terms. Precise wavelength measurements give the parameters A and B. Often upper levels are close enough together that a mean energy is acceptable, but it can differ for each lower level depending on the strengths of the contributing hyperfine transitions.

The J–I coupling usually is strong enough that, as discussed by Welty, Hobbs, & Kulkarni (1994), the strengths of the hyperfine components follow the rules of LS coupling with $L \rightarrow J$, $S \rightarrow I$, and $J \rightarrow F$. Thus,

$$S(IJF,\ IJ'F') = (2F+1)(2F'+1)\begin{pmatrix} J & I & F \\ F' & 1 & J' \end{pmatrix}^2 S(J,\ J')\ , \quad (21)$$

where the Wigner $6j$ symbol can be evaluated using the formulae quoted by Cowan (1981, pp. 147, 510) or directly from the Weizmann Institute site.[1] Since there are $(2I+1)(2F+1)$ hyperfine states in a level, the normalization is such that

$$\sum_{F'}\sum_{F} S(IJF,\ IJ'F') = (2I+1)S(J,\ J')\ , \quad (22)$$

but otherwise the analogs of equations (11) to (15) are valid so that

$$f(IJF,\ IJ'F') = (2J+1)(2F'+1)\begin{pmatrix} J & I & F \\ F' & 1 & J' \end{pmatrix}^2 f(J,\ J')\ . \quad (23)$$

As with LS multiplets, where the sum of all f from a lower level equals the multiplet f-value, so the sum from a lower hyperfine level equals the line f-value. Consequently, the relative populations of the hyperfine levels weighted by $2F + 1$ will determine the observed line strengths.

Table 4 includes the wavelengths, energy levels, and f-values of the hyperfine components of ^{6}Li I, ^{7}Li I, ^{9}Be I, ^{10}B III, ^{11}B III, ^{23}Na I, ^{25}Mg II, ^{27}Al III, and ^{39}K I.

TABLE 5

Finding List

Wavelength (Å)	Ion	No.	$E_{\rm low}$ (cm^{-1})	log lf (Å)
912.159	O I	47u	0	−1.894
912.321	O I	45u	0	−1.837
912.321	O I	46u	0	−1.153
912.498	O I	44u	0	−1.093
912.500	O I	43u	0	−1.775
912.589	Cr III		575.73	0.813
912.662	Cr III		0	−0.141
912.703	H I	30u	0	−1.318
912.723	O I	42u	0	−1.711
912.729	O I	41u	0	−1.029

Note.—Table 5 is available in its entirety in the electronic edition of the *Astrophysical Journal Supplement*. A portion is shown here for guidance regarding its form and content.

8. FINDING LIST

Table 5 orders all the lines in Table 2 by increasing wavelength and lists log λf if it is known.

9. DATA NEEDS

Users of atomic data would welcome the publication of multiplet tables with numerical labels on each multiplet following the tradition of Charlotte Moore Sitterly. In astrophysics a simple check on the identification of a line is whether other components of a multiplet are present. With so much recent progress in atomic spectroscopy many multiplets lack the numbers that facilitate easy reference. We need more compilations like that of Nave et al. (1994) for Fe I.

9.1. *Energy Levels and Wavelengths*

B I: The absolute wavelengths of the $^2P^o$–^4P intersystem multiplet are uncertain.

B II: Similarly, the ^1S–$^3P^o$ transition has not yet been measured directly in the laboratory.

Cl I: Laboratory and astrophysical observations indicate that the spectroscopic assignments of the lines at 1097 and 1088 Å may be reversed.

Cl IV, V, VI: More accurate measurements are needed for the intersystem lines.

Ar V, VI: These intersystem lines also lack precise wavelengths.

9.2. *Hyperfine Structure and Isotope Shifts*

The hfs is known for the ground terms of most neutral atoms and some excited terms, but N I, F I, P I, and Cl I appear to lack any measurements of the higher terms so that the precise structure of their resonance lines is not known. For ions there are data on the ground terms of Be II, B II, N II, F II, and P II, but not for Cl II, Mn II, or Co II, nor for most excited levels, though Mn II has a measurement of $z\ ^7P^o_2$ by Holt, Scholl, & Rosner (1999). Among higher ions only B III and Al III seem to have measurements. I have not found data on the isotopic shifts in any of the UV transitions of chlorine.

9.3. *Ionization Potentials*

Most IP of the lower ion stages of the lighter elements are now known with errors less than 0.1%. The exceptions

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[1] See http://plasma.gate.weizmann.ac.il/369j.html.

among stages I to IV requiring better measurements are S III, Cl III, Ar IV, K II, Ca IV, Cr IV, Mn IV, Fe IV, Co III and IV, and Ni IV. For higher ions with transitions in this compilation, the IP of Ne V and Cl V could be improved.

9.4. *Transition Probabilities*

Li I: The Faraday rotation measurement of $2s$–$9p$ by Nawaz et al. (1992) is 0.14 dex larger than the adopted calculation of Qu et al. (1999).

C I: Additional experimental data are needed to check whether the astrophysical results of Jenkins & Tripp (2001) are more reliable than the theoretical values adopted here.

N I: Where the stronger lines are saturated, the weak intersystem transitions at 1161 and 1160 Å are important for abundance determinations. Laboratory measurements and additional calculations are required because the astrophysical values of Lugger et al. (1978) are 0.4 dex smaller than the adopted results from Tachiev & Froese Fischer (2002a).

O I: Modern calculations without the assumption of pure *LS* coupling are needed for the many transitions shortward of 952 Å.

Na I: It is time for a modern experimental check on the pioneering relative hook measurements of the UV lines by Filippov & Prokofiev (1929), particularly the weak doublet at 3303 Å.

Mg II: The *f*-values of the weak doublet lines at 1240 Å, so essential for abundances, remain uncertain. Recent calculations and astrophysical results have converged on a value for the multiplet but disagree on the ratio. Measurements will be difficult but are necessary to obtain dependable data.

Al II: Further calculations are needed for $\lambda 935$ because the existing ones range over 1.2 dex.

P I: Most lines lack either experimental or theoretical *f*-values.

P II: New measurements are needed to test the calculated *f* adopted in Table 2.

Cl I: Many lines need laboratory *f*-values.

K I: The adopted calculations of Migdalek & Kim (1998) for $n \geq 10$ disagree with the Faraday rotation measurements of Nawaz et al. (1992).

Mn II: Experimental *f*-values are needed for the frequently observed multiplets 3u and 4u near 1199 and 1163 Å.

Fe II: More laboratory tests are desirable for the calculations adopted from Raassen & Uylings (1998), particularly at far-UV wavelengths.

Fe III: Only the line at 1123 Å is detected in the ISM; an experimental check is needed.

Zn II: The doublet at 986 Å has neither experimental nor theoretical *f*-values.

9.5. *Lifetimes*

N IV: A more accurate measurement of the intersystem transition would provide a further test of the theoretical results.

N V: A measurement by laser excitation could resolve a discrepancy between calculations and beam-foil data.

Ne V and VI: There are no experimental lifetimes to check the calculations for the intersystem transitions.

Mg I: Ten lifetime measurements for $\lambda 2852$ average 2.00 ± 0.03 ns, while the best calculations predict 2.14 ns.

Si II: New lifetimes for multiplets 3, 4, 5, 5.01, and 6 would be an important test of the adopted theoretical *f*-values.

P IV: The existing BF lifetimes differ significantly.

S II, III: Modern measurements are needed to check the adopted calculations for multiplet 1 of S II and 2 of S III.

S IV: There is no measurement for the intersystem lines, and the BF data for $3s3p^2\ ^2D$ are inconsistent with the adopted calculations.

Ca I: An accurate experimental lifetime for $4s4p\ ^3P_1^o$ is required to test the adopted calculation.

Ti II: Additional lifetimes for the odd levels from 52,329 to 63,375 cm^{-1} could be used with the branching fractions of Pickering, Thorne, & Perez (2001, 2002b).

Cu II: The $4p\ ^3D_1^o$ level lacks a lifetime and $4p\ ^1P_1^o$ needs a more accurate one.

Ga II: New lifetimes could resolve discrepancies in earlier measurements.

9.6. *Branching Fractions*

Al I: Accurate measurements are needed for use with the available lifetimes.

Si I: If the infrared decays could be included, experimental branching fractions for the levels above 53,387 cm^{-1} could be used with available lifetimes in place of theoretical estimates.

S I: Experimental branching fractions would be preferable to the theoretical ones used for several lines.

Cr I, Cr II: The experimental papers listed in § 6.24 contain many lifetimes that lack the corresponding branching data.

Mn I: The lifetimes of Schnabel et al. (1995) have no branching fractions.

Ni II: Additional measurements could take advantage of the lifetimes of Fedchak & Lawler (1999).

Cu II: All three upper levels in Table 2 need measured branching data.

Zn I: Branching fractions combined with the lifetimes of Zerne et al. (1994) would provide additional *A*-values.

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APPENDIX

ELEMENTS GERMANIUM TO URANIUM

This Appendix reports new information and corrections relevant to the data in Paper II for these elements.

Krypton (Kr), $Z = 36$: Brandi, Hogervorst, & Ubachs (2002) have reported very accurate measurements of the IP and some levels of Kr I. The formal publication of the Kr II lifetimes has appeared as Lauer et al. (1999).

Yttrium (Y), $Z = 39$: Jakubek & Simard (2000) have measured the IP of Y I to be 50146.6 ± 0.8 cm^{-1} or 6.21739 eV.

Zirconium (Zr), $Z = 40$: Charro, López-Ayuso, & Martín (1999) have calculated *f*-values for Zr III that confirm and extend the adopted numbers.

Molybdenum (Mo), $Z = 42$: Sikström et al. (2001) have measured branching fractions in Mo II and derived *f*-values using existing lifetimes.

Silver (Ag), $Z = 47$: The IP of 61106.52 ± 0.5 cm^{-1} for Ag I by Loock et al. (1999) confirms the value quoted in Paper II. Kalus et al. (2002) have published a significant improvement to the energy levels of Ag II.

Indium (In), $Z = 49$: Karlsson & Litzén (2001) have given improved energy levels for In I and II.

Tin (Sn), $Z = 50$: The measured lifetimes and branching fractions of Schectman et al. (2000) for multiplet 3u of Sn II corroborate the adopted value for $\lambda1400$.

Xenon (Xe), $Z = 54$: Brandi et al. (2001) have measured hyperfine splittings, isotope shifts, and the IP for many isotopes of Xe I. The formal publication of the Xe II lifetimes has appeared as Lauer et al. (1999).

Barium (Ba), $Z = 56$: Klose, Fuhr, & Wiese (2002) have critically evaluated *A*-values for Ba I and II. They agree with Paper II in most cases.

Lanthanum (La), $Z = 57$: Lawler, Bonvallet, & Sneden (2001) have reported *f*-values for La II from their measures of LIF lifetimes and FTS branching fractions.

Cerium (Ce), $Z = 58$: Palmeri (2000b) calculated *A*-values for Ce II that should be more reliable than those in Paper II. The LIF lifetimes of Zhang et al. (2001b) for Ce IV imply *A*-values about 80% of the theoretical ones adopted by Morton (2000).

Praseodymium (Pr), $Z = 59$: Scholl et al. (2002) have measured lifetimes and branching fractions for Pr II and determined *A*-values which differ significantly from Paper II in some cases. Palmeri et al. (2000a) have calculated *f*-values for Pr III.

Neodymium (Nd), $Z = 60$: The *A*-values Zhang et al. (2002b) derived from their calculations for Nd III normalized to LIF lifetimes agree closely with the theoretical results adopted in Paper II.

Europium (Eu), $Z = 63$: Den Hartog, Wickliffe, & Lawler (2002) have tabulated *A*-values for Eu I from their LIF lifetimes and branching fractions, and Zhiguo et al. (2000) and Lawler et al. (2001b) have done the same for Eu II. The new results confirm and extend the adopted data.

Gadolinium (Gd), $Z = 64$: The calculatiions of Biémont, Kohnen, & Quinet (2002) for Gd III suggest a correction of -0.12 dex to those presented in Paper II.

Terbium (Tb), $Z = 65$: Lawler et al. (2001a) have published *A*-values for Tb II based on LIF lifetimes and FTS branching fractions.

Dysprosium (Dy), $Z = 66$: Zhang et al. (2002c) measured LIF lifetimes and calculated oscillator strengths for Dy III.

Holmium (Ho), $Z = 67$: Zhang et al. (2002a) reported LIF lifetimes and theoretical *f*-values for Ho III.

Erbium (Er), $Z = 68$: The calculated *f*-values for Er III by Biémont et al. (2001) are close to those adopted in Paper II in most cases.

Ytterbium (Yb), $Z = 70$: Li et al. (1999) have reported some LIF lifetimes for Yb II, and Zhang et al. (2001a) measured LIF lifetimes and calculated *f*-values for three lines of Yb III. Wyart et al. (2001) have revised the analysis of Yb IV and calculated *A*-values.

Lutetium (Lu), $Z = 71$: Fedchak et al. (2000b) have measured branching fractions and LIF lifetimes for Lu I and lifetimes for Lu II and Lu III.

Tantalum (Ta), $Z = 73$: Eriksson et al. (2002) have revised the energy levels of Ta II.

Platinum (Pt), $Z = 78$: Jakubek & Simard (2000) have measured the IP of Pt I to be 72257.8 ± 0.8 cm^{-1} or 8.95882 eV.

Gold (Au), $Z = 79$: The IP of 74409.0 ± 0.2 cm^{-1} by Loock et al. (1999) confirms the value quoted in Paper II.

Bismuth (Bi), $Z = 83$: Wahlgren et al. (2001) have quoted improved wavelengths and hfs data for Bi I, II, and III, and Dolk, Litzén, & Wahlgren (2002) have provided new levels for Bi II. Palmeri, Quinet, & Biémont (2001) and Wahlgren et al. have calculated *f*-values for Bi II that do not always agree with each other or with Paper II.

Thorium (Th), $Z = 90$: Nilsson et al. (2002) have reported LIF lifetimes and FTS branching fractions giving *f*-values for many Th II lines. Biémont et al. (2002b) obtained *f*-values for Th III from LIF lifetimes and theoretical branching fractions.

Uranium (U), $Z = 92$: The LIF U II lifetimes of Lundberg et al. (2001) are consistent with those adopted in Paper II. Biémont et al. (2002a) measured LIF lifetimes for U III.

Paper II failed to mention the important source of energy levels and wavelengths for Th and U and other actinides by Blaise & Wyart (1992).

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