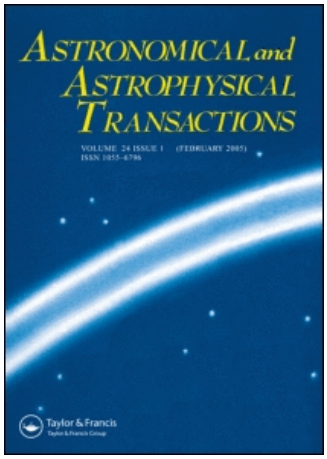

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Catalogue of atomic data for low-density astrophysical plasma

V. V. Golovatyj [a]; A. Sapar [b]; T. Feklistova [b]; A. F. Kholtygin [c]
[a] Lvov University Astronomical Observatory, Lvov, Ukraine
[b] Tartu Astrophysical Observatory, Töravere, Estonia
[c] Astronomical Institute, St. Petersburg University, St. Petersburg, Petrodvoretz, Russia

Online Publication Date: 01 January 1997
To cite this Article: Golovatyj, V. V., Sapar, A., Feklistova, T. and Kholtygin, A. F. (1997) 'Catalogue of atomic data for low-density astrophysical plasma', Astronomical & Astrophysical Transactions, 12:2, 85 - 241
To link to this article: DOI: 10.1080/10556799708232079
URL: http://dx.doi.org/10.1080/10556799708232079

Astronomical and Astrophysical Transactions, 1997, Vol. 12, pp. 85–241
Reprints available directly from the publisher
Photocopying permitted by license only

CATALOGUE OF ATOMIC DATA FOR LOW-DENSITY ASTROPHYSICAL PLASMA

V. V. GOLOVATYJ[1], A. SAPAR[2], T. FEKLISTOVA[2], and A. F. KHOLTYGIN[3]

[1] *Lvov University Astronomical Observatory, Kirilla i Mefodia 8, Lvov 290005, Ukraine*
[2] *Tartu Astrophysical Observatory, Töravere, EE2444, Estonia,*
[3] *Astronomical Institute, St.Petersburg University, 198904, St.Petersburg, Petrodvoretz, Russia*

(Received March 27, 1996)

1 INTRODUCTION

This catalogue contains mainly the atomic data needed in astrophysical investigations of low-density plasma. It is a revised and extended version of the *Catalogue of Atomic Data for the Rarefied Astrophysical Plasma* (Golovatyj *et al.*, 1991).

1.1 Low-Density Plasma

Different forms of the low-density astrophysical plasma include the intergalactic and interstellar media, the matter of gaseous nebulae (planetary and diffuse), regions in the vicinity of active galaxies and quasars, the solar and stellar coronae and several other astronomical subjects. The ion concentration in the plasma varies within broad limits from about 10^{-7} cm^{-3} to 10^{9} cm^{-3} and kinetic temperature from 5×10^{3} K to 10^{7} K. In these plasma objects generation of emission spectral lines occurs. The low-density astrophysical plasma is practically transparent in all spectral lines excluding the series of resonance lines which arise due to electron transitions to the ground state of most abundant ions of abundant elements. The bound state populations and corresponding line intensities of such targets are predominantly determined by the cascade processes which populate the states. The preceding absorption processes in the radiative transfer are photoionization and excitation in optically thick resonance spectral lines. In the low-density astrophysical plasma the majority of atoms and ions are placed in the ground state. In calculations of spectra generated by such plasma structures besides probabilities of

spontaneous transitions only the induced transition rates to the low excited states and to continua are needed. This circumstance reduces essentially the atomic data set indispensable in computations of the spectra of the low-density plasma targets compared with the set needed in calculations of spectra of essentially denser stellar atmospheres.

We shall use the following notations: A^i and B^i are the i-fold ions of elements A and B, the notations $n(A^i)$ we use for number density of corresponding atoms or ions and the symbols n_k denote the number densities of an ion in the atomic state k (the occupation number). The excited states we denote by adding a prime to the ion symbol, say $A^{i\prime}$, but the autoionization states are doubly primed ($A^{i\prime\prime}$). As usual we shall use a standard notation XI for a neutral atom, XII for its singly ionized ion etc. This means, for example, that symbols N^{3+} and N IV for triple ionized nitrogen are identical.

1.2 The Cross-Sections and Rates of Physical Processes in a Low-Density Astrophysical Plasma

The full list of physical processes, proceeding in a rarefied astrophysical plasma includes the impact, fusion and decay processes which are accompanied by electron transitions from one state to another. In the present paper we confine our analysis with the following most important processes:

(1) the radiation transitions between discrete bound levels ($A^i + \gamma \leftrightarrow A^{i\prime}$),

(2) the photoionization and the photorecombination ($A^i + \gamma \leftrightarrow A^{i+1} + e$),

(3) the excitation and deactivation (de-excitation) by electron impacts ($A^i + e \leftrightarrow A^{i\prime} + e$),

(4) the dielectronic recombination and autoionization ($A^{i\prime\prime} \leftrightarrow A^{i\prime} + e$),

(5) the charge transfer ($A^{i+1} + B^j \leftrightarrow A^i + B^{j+1}$),

(6) the electron impact ionization ($A^i + e \rightarrow A^{i+1} + 2e$).

The reversed process of the last process in the list – the triple impact recombination is negligible in conditions of a rarefied astrophysical plasma. More detailed description of physical processes studied by us is given in the corresponding sections of the explanatory text to the atomic data tables. Here we only mention that for reactions of the type $A + B \rightarrow A' + B'$ the transition rate per unit time and unit volume is given by the expression $\langle \sigma v \rangle n(A)n(B)$. The averaged reaction rate in this expression is defined by

$$q = \langle \sigma v \rangle = \int \sigma(v) v f(v)\, dv,$$

where $f(v)$ is the velocity distribution of colliding particles taken to be the Maxwellian one, characterized by temperature T. If one of the colliding particles is a

photon we have to integrate over the photon frequency distribution of the external radiation field. The external radiation field distribution in most cases we shall assume to be the diluted Planckian one, specified by the effective stellar temperature T_*.

1.3 Units of Measurement

For convenience we shall give here the units of measure for quantities, describing the cross-sections and rates of elementary processes.

(1) *The energy units.* In the atomic spectroscopy the energy of particles and photons usually is expressed in electron-volts (eV), erg, wave numbers (cm^{-1}), Kelvin degrees (K) and Rydberg units (Ry). The transformation coefficients between the quantities are illustrated by the following table:

unit of measurement	*eV*	*erg*	cm^{-1}	*K*	*Ry*
1 eV	1	1.602–12	8065.48	11604.5	7.350–2
1 erg	6.242+11	1	5.034+15	7.243+15	4.587+10
1 cm^{-1}	1.240–4	1.986–16	1	1.439	9.113–6
1 K	8.617–5	1.381–16	6.950–1	1	6.334–6
1 Ry	13.606	2.180–11	1.097+5	1.579+5	1

(2) *The cross-section units.* The cross-sections in atomic physics are usually measured in cm^2, megabarns (Mb = 10^{-18} cm^2), or the hydrogen ground-state Bohr orbit areas ($\pi a_0^2 = 8.797 \times 10^{-17}$ cm^2).

(3) *The process rates.* In two-particle collisions the rate is measured in cm^3 s^{-1} units. The higher-order impacts for conditions of rarefied astrophysical plasma media can be ignored.

In the present manual only the data concerning elementary processes, which proceed in rarefied astrophysical plasma media are given. Both the numerical values and the approximate half-empirical formulae for cross-sections and process rates, compiled from different published papers, are presented.

The formulae for computation of intensities of spectral lines and continua of rarefied plasma have been given. The computation results are given for different mechanisms of line formation. In the present study we represent only the atomic data for computation of spectra of low-density astrophysical plasma (most known kinds of it are gaseous nebulae), their thermal and ionization structure.

2 MAIN KNOWLEDGE ABOUT ATOMIC SPECTROSCOPY

2.1 Classification of Levels

The standard classification scheme of atomic state levels is the single configuration approximation (SCA) and the LS-coupling of the angular momenta.

In the single configuration approximation one assumes that every electron is moving in the effective central-symmetric field generated by the nucleus and by all other electrons. To all electrons one can ascribe definite quantum numbers, starting with the principle quantum number ($n = 1, 2, 3, \ldots$) and the orbital quantum number ($l = 0, 1, \ldots, n-1$). The orbital angular momentum of an electron nl equals to $l\hbar$, where $\hbar = h/2\pi$ and h is the Planck constant. The electrons with the same n and l values differ by the values of projections of orbital angular momentum m_l and of the electron spin momentum m_s. The feasible values for m_l and m_s are $m_l = -l, -l+1, \ldots, l-1, l$, and $m_s = -1/2, +1/2$. Electrons which have the orbital quantum number values $l = 0, 1, 2, 3 \ldots$ are denoted in the atomic spectroscopy, respectively, by minuscules s, p, d, f and further in the alphabetic order. The atomic electrons with equal values of n and l are named to be equivalent ones. A set q of equivalent electrons builds up an electron shell $(nl)^q$ in which the maximal number of electrons is $2(2l+1)$. If $q = 2(2l+1)$ then such a shell is said to be filled.

The distribution of electrons in electron shells is termed the electron configuration. The energetically lowest state in which all electrons of the atom or of the ion have minimal possible values of n and l is called the ground configuration, all other configurations are termed excited. The population of electron shells follows definite rules. First, the electron shell $n = 1$ will be populated, thereafter electron shells with $n = 2$, etc. At a given value of n the shells with $l = 0$ will be filled first (s-shell), thereafter $l = 1$ (p-shell), $l = 2$ (d-shell) etc. The order of population of electron shells with $n \leq 3$ is the following: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} \ldots$. For instance, the ground configuration of a carbon atom is $1s^2 2s^2 2p^2$. Here $1s^2$ and $2s^2$ are the filled shells, but the shell $2p^2$ is unfilled. The regularity in shell filling order is violated for d-shells and f-shells. So, for K and Ca atoms the $4s$-shell will be filled first and thereafter the $3d$-shell. The electron configurations of atomic and ion ground states are given, for example, in monographs by Moore (1949), Sobelman (1977), Allen (1973) and in a manual by Radtsig and Smirnov (1986).

For classification of atomic states of the same configuration several approximate methods, so-called coupling schemes of momenta, have been used, among which the most widely use is LS-coupling. According to this scheme the atomic states have different values of L (the total atomic orbital momentum) and S (the total atomic spin). The rule of momentum addition we shall illustrate using the example of two electrons. The values of total momentum L cover a range from $\mid l_1 - l_2 \mid$ to $\mid l_1 + l_2 \mid$. A similar rule holds for total spin : if $s_1 = s_2 = 1/2$ then the total value of spin can be 0 or 1. The sum $J = L + S$ (called the total atomic momentum) according to general rules of addition of momenta can take values $|L - S| \leq J \leq L + S$. A definite value of J belongs to a definite energy level LSJ. The statistical weight corresponding to J is given by $g(J) = 2J + 1$ and it is the number of atomic states with the same energy, but different values of projection M_J. In the case of three or more electrons the addition of momenta must be carried out step by step – first for two electrons, thereafter the third electron will be added, etc.

The set of levels belonging to one configuration with given values of L and S forms a spectral term (notation ${}^{2S+1}L_J$, where $2S+1$ specifies the term multiplicity, J describes its fine structure and LSJ the energy level. If $S \leq L$ then the number of

term energy levels equals its multiplicity, but if $S > L$ then the term has $2L+1$ levels. Each level consists of $2J+1$ states. The values of L are specified by latin majuscules: $L = 0$ (S-term), 1 (P-term), 2 (D-term), 3 (F-term), etc. The terms which have $2S+1 = 1, 2, 3, 4, 5 \ldots$ are named, respectively, singlets, doublets, triplets, quartets, quintets, etc.

In addition to values of LS the terms differ by configuration parity $\pi = (-1)^{\sum l_i}$, where $\sum l_i$ is the algebraic sum of all electron orbital momenta, i.e. $\sum l_i = l_1 + l_2 + \ldots + l_N$. If $\pi = -1$ (odd terms) then superscript o is added to the term notation on its right-hand side. For three and more electrons with different values of nl in order to give an unambiguous description of energy levels the additional quantum numbers are needed. Usually the genealogy of the term, i.e. the intermediary values of L and S, are given. For instance, the excited configuration $1s^2 2s2pnl$ of C II can have two groups of terms: $2s2p(^1P^0)nlLS$ and $2s2p(^3P^0)nlLS$. The last group of terms has energy values about 6 eV lower than the first group.

A special case are shells with equivalent electrons $(nl)^q$. The number of terms of the $(nl)^q$ shell is limited by the Pauli principle. Thus, for configuration $2p^2$ the three possible terms are $^3P^0$, ^1S and ^1D, while ignoring the Pauli principle for this configuration also terms $^1P^0$, ^3S and ^3D were also possible. The terms of shells $(nl)^q$ are given, for example, in a monograph by Sobelman (1977). In the case of shells d^q and f^q there are various terms with equal L and S values. To discriminate them from each other the seniority quantum number $v = 1, 2, 3 \ldots$ (left subscript to the term notation) is added. The real atomic states πLSJ due to the approximate nature of the single configuration and LS-coupling concepts are in fact mixtures of the pure states with equal π and J values, which belong to different configurations and terms. In many cases instead of LS-coupling other types of coupling, namely, jj, LS_0 and LK (see monographs by Nikitin and Rudzikas, 1983; Rudzikas *et al.*, 1990) are used.

2.2 Radiative Transitions: Line Strengths and Oscillator Strengths: Transition Probabilities

The most important characteristic of radiative transition in atoms is its probability A_{li} defined in such a manner, that $n_l A_{li}$ is the number of transitions in spectral line $l - i$ per unit volume and per unit time. The value of A_{li} is strongly dependent on the transition type. If in transition $l - i$ a photon is emitted having momentum k (in $\hbar$ units) relative to the atom, where $k = 1, 2, \ldots$, and with parity $\pi = (-1)^k$, then we term it the electric (E) radiative transition of multipolity k (Ek-radiation), but in the case of parity $\pi = (-1)^{k+1}$ we term the transition as the magnetic (M) radiative transition of multipolity k (Mk-radiation). The probabilities of Mk and $Ek + 1$ transitions are about 10^{-4}–10^{-6} times less than these of corresponding Ek transitions. Thus, the largest transition probabilities have electric dipole ($E1$) transitions for which $A_{li} \simeq 10^8$ s^{-1} which are followed by electric quadruple ($E2$) transitions and magnetic dipole transitions for both of which $A_{li} \simeq 10^2$–10^4 s^{-1}. Transitions of higher multipolity in the spectra of astrophysical objects have not

been observed. The transition probabilities can be expressed by the use of line strengths S_{li}, namely (see Levinson and Nikitin, 1962; Sobelman, 1977)

$$g_l\, A_{li}^{E1,M1} = 2.67 \times 10^9\, \Delta e^3\, S_{li}, \quad g_l\, A_{li}^{E2} = 1.78 \times 10^3\, \Delta e^5\, S_{li}, \tag{1}$$

where the ratio $\Delta e = E_{li}/Ry$ is the transition energy expressed in Rydbergs ($Ry =$ 13.606 eV). The line strengths are connected with dimensionless quantities — the oscillator strengths f_{il} by

$$g_i\, f_{il}^{E1,M1} = \frac{1}{3}\, \Delta e\, S_{li}, \quad g_i\, f_{il}^{E2} = 2.22 \cdot 10^{-7}\, \Delta e^3\, S_{li}, \tag{2}$$

Thus, the transition probabilities can be expressed by oscillator strengths in the form

$$g_l\, A_{li}^{E1,M1} = 8.01 \times 10^9\, \Delta e^2\, g_i\, f_{il}, \quad g_l\, A_{li}^{E2} = 8.02 \times 10^9\, \Delta e^2\, g_i\, f_{il}, \tag{3}$$

Taking into account the conservation laws of momentum, angular momentum and parity, it follows that each process of type $E1, E2$ and $M1$ can take place only if there are definite selection rules specifying the possible differences of quantum numbers in the initial and final states of the transition. Let us consider now the selection rules for Ek and $M1$ transitions in the LS-coupling and single configuration approximation. For Ek-transition $\beta nlLSJ \to \beta' n'l'L'S'J'$ the selection rules are

$$\Delta J = 0, \pm 1, \ldots, \pm k,\ J + J' \geq k; \quad \Delta L = 0, \pm 1, \ldots, \pm k,\ L + L' \geq k; \quad \Delta S = 0, \tag{4}$$

where only the quantum numbers of one definite electron undergo changes, β and β' are the additional quantum numbers needed to describe the levels J and J' for which the selection rule $\beta = \beta'$ holds. Further, for $E1$-transitions $\Delta l = \pm 1$ holds and for $E2$-transitions $\Delta l = 0, \pm 2$. For $M1$-transitions $LSJ \to L'S'J'$ the selection rules are

$$\Delta J = 0, \pm 1;\ \Delta L = 0,\ \Delta S = 0,\ \Delta l = 0. \tag{5}$$

It has been taken into account that the magnetic dipole transitions can take place only between the levels of the same term ($\Delta l = 0$). Owing to the approximate nature of LS-coupling and single configuration assumptions the selection rules given above are not the exact ones, i.e. these selection rules can be violated in transitions which have essentially smaller probabilities. In atomic spectroscopy the transitions in which the selection rules hold, are termed the allowed transitions, but in the opposite case they are termed the forbidden transitions.

In the table below we give the classification of radiative transitions used in astrophysics in the case of selection rule violation. The classification differs somewhat from that used in atomic spectroscopy. For instance, all $E2$ transitions in astrophysics are treated as forbidden, independent of whether the selection rules hold or not. The typical values of the transition probabilities for the transitions under consideration are given in column 3 of the table. In the first column the transition type notations are also given (p, permitted; f, forbidden; i, intercombination; 2e,

dielectronic). The typical values of A_{li} given correspond to transitions in the visible and near-infrared regions of spectra of light elements and low-charge ions.

Classification of the transition types

Transition type	*Selection rule violation*	A_{ki} (s^{-1})
$E1$, p	No	10^7–10^9
$E1$, i	$\Delta S \neq 0$	10^2–10^4
$E1$, 2e	Quantum number change of two(three) electrons	10^6–10^8
$E2$, f	No	1–10^2
$E2$, f	$\Delta S \neq 0$	10^{-4}–1
$M1$, f	No	1–10
$M1$, f	Transition between levels of different terms	10^{-4}–1

To illustrate several types of electron transitions we give the scheme of lower levels of O III. In Figure 1 the wavelengths of most important observed spectral lines together with the transition type are given. The simbol ~ denotes that the transition is intercombinational. For atoms with $Z \geq 50$ and for multiple ions the selection rules do not hold exactly due to relativistic effects. For such atoms and ions the difference between the allowed and forbidden transitions weakens and can even be vanishing.

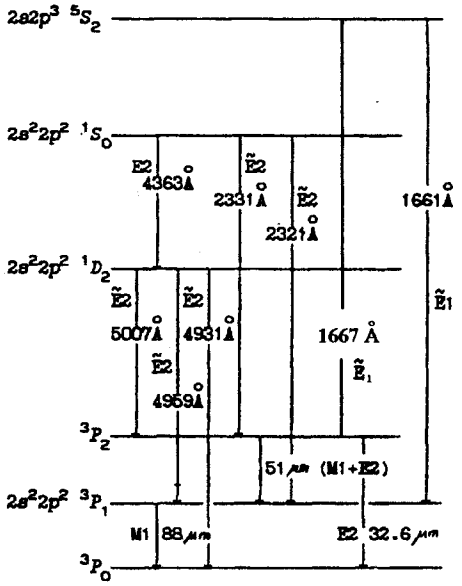

Figure 1 The types and the wavelengths of most important observed spectral lines O III. Symbol ~ denotes that the transition is an intercombination one.

Table 1. Transition probabilities for H I

$k-i$	λ_{ki} (Å)	A_{ki} (s^{-1})	$k-i$	λ_{ki} (Å)	A_{ki} (s^{-1})
1 – 2	1215.67	4.699+8	2 – 8	3889.05	2.215+5
1 – 3	1025.72	5.575+7	2 – 9	3835.38	1.216+5
1 – 4	972.537	1.278+7	2 – 10	3797.90	7.122+4
1 – 5	949.743	4.125+6	2 – 11	3770.63	4.397+4
1 – 6	937.803	1.644+6	2 – 12	3750.15	2.834+4
1 – 7	930.748	7.568+5	2 – 13	3734.37	1.893+4
1 – 8	926.226	3.869+5	2 – 14	3721.94	1.303+4
1 – 9	923.150	2.143+5	2 – 15	3711.97	9.210+3
1 – 10	920.963	1.263+5	2 – 16	3703.85	6.658+3
1 – 11	919.351	7.834+4	2 – 17	3697.15	4.910+3
1 – 12	918.129	5.068+4	2 – 18	3691.55	3.685+3
1 – 13	917.181	3.393+4	2 – 19	3686.83	2.809+3
1 – 14	916.429	2.341+4	2 – 20	3682.81	2.172+3
1 – 15	915.824	1.657+4	3 – 4	18751.0	8.966+6
1 – 16	915.329	1.200+4	3 – 5	12818.1	2.201+6
1 – 17	914.919	8.858+3	3 – 6	10938.1	7.783+5
1 – 18	914.576	6.654+3	3 – 7	10049.4	3.358+5
1 – 19	914.286	5.077+3	3 – 8	9545.97	1.651+5
1 – 20	914.039	3.928+3	3 – 9	9229.02	8.905+4
2 – 3	6562.80	4.410+7	3 – 10	9014.91	5.156+4
2 – 4	4861.32	8.419+6	3 – 11	8862.79	3.156+4
2 – 5	4340.46	2.530+6	3 – 12	8750.48	2.021+4
2 – 6	4101.73	9.732+5	3 – 13	8665.02	1.343+4
2 – 7	3970.07	4.389+5	3 – 14	8598.40	9.211+3
			3 – 15	8545.39	6.490+3

3 RADIATIVE TRANSITIONS AND PHOTOPROCESSES

3.1 Transition Probabilities, Oscillator Strengths and Mean Lifetimes

The relations between the transition probabilities and oscillator strengths are determined by equations (1)–(4). When only one of the values (transition probability) or (oscillator strength) are given in the table under consideration the remainder can be calculated using equations (2) and (3) as soon as the type of the transition is known. Using the experimental energy differences Δe from the last mentioned relations is preferable (see discussion in Rudzikas *et al.*, 1990).

Neglecting the induced transitions the spontaneous transition probabilities A_{ki} are connected to the mean lifetimes of level k via the relation:

$$\tau_k = \left(\sum_{i<k} A_{ki} \right)^{-1}$$

The probability that an atom in the state k emits a line $k \rightarrow i$ is called the branching ratio and it can be expressed by

$$B_{ki} = \tau_k A_{ki}.$$

Table 2. Transition probabilities for He I

Transition	λ_{ki} (Å)	A_{ki} (s^{-1})	*Transition*	λ_{ki} (Å)	A_{ki} (s^{-1})
$1s^1S - 2p^1P$	584.33	1.8000+9	$3p^1P - 6d^1D$	11048.01	1.8466+6
$1s^1S - 3p^1P$	537.03	5.6539+8	$4p^1P - 5d^1D$	41227.23	1.5250+6
$1s^1S - 4p^1P$	522.21	2.4300+8	$4p^1P - 6d^1D$	26538.84	8.6835+5
$1s^1S - 5p^1P$	515.62	1.2541+8	$5p^1P - 6d^1D$	75855.03	4.6592+5
$1s^1S - 6p^1P$	512.10	7.2939+7	$3d^1D - 3p^1P$	957880.50	1.5399+2
$2s^1S - 2p^1P$	20586.90	1.9688+6	$3d^1D - 4p^1P$	18560.66	2.9581+5
$2s^1S - 3p^1P$	5017.08	1.3153+7	$3d^1D - 5p^1P$	12759.17	1.2731+5
$2s^1S - 4p^1P$	3965.85	6.8331+6	$3d^1D - 6p^1P$	10905.16	6.6464+4
$2s^1S - 5p^1P$	3614.67	3.7368+6	$4d^1D - 4p^1P$	2162022.00	5.7302+1
$2s^1S - 6p^1P$	3448.57	2.2295+6	$4d^1D - 4p^1P$	40063.93	1.6316+5
$3s^1S - 3p^1P$	74375.16	2.5146+5	$4d^1D - 6p^1P$	26120.02	8.1814+4
$3s^1S - 4p^1P$	15087.78	1.3995+6	$5d^1D - 5p^1P$	4136180.00	2.2412+1
$3s^1S - 5p^1P$	11016.08	9.2043+5	$5d^1D - 6p^1P$	73711.16	8.3902+4
$3s^1S - 6p^1P$	9606.05	5.7975+5	$6d^1D - 6p^1P$	7059355.00	9.9013+0
$4s^1S - 4p^1P$	181001.70	5.8240+4			
$4s^1S - 5p^1P$	33308.48	2.9262+5	$2s^3S - 2p^3P$	10833.15	1.0183+7
$4s^1S - 6p^1P$	23069.61	2.1991+5	$2s^3S - 3p^3P$	3889.75	9.1179+6
$5s^1S - 5p^1P$	358496.30	1.8738+4	$2s^3S - 4p^3P$	3188.67	5.4238+6
$5s^1S - 6p^1P$	62057.34	8.8001+4	$2s^3S - 5p^3P$	2945.96	3.0791+6
$6s^1S - 6p^1P$	624843.80	8.8001+4	$2s^3S - 6p^3P$	2829.91	1.8639+6
$2p^1P - 3s^1S$	7283.36	1.8084+7	$3s^3S - 3p^3P$	42958.96	1.0703+6
$2p^1P - 4s^1S$	5049.15	6.6665+6	$3s^3S - 4p^3P$	12530.94	7.0306+5
$2p^1P - 5s^1S$	4438.80	3.2118+6	$3s^3S - 5p^3P$	9466.18	5.6331+5
$2p^1P - 6s^1S$	4170.14	1.7956+6	$3s^3S - 6p^3P$	8363.99	3.7725+5
$3p^1P - 4s^1S$	21137.79	4.5819+6	$4s^3S - 4p^3P$	108823.00	2.2783+5
$3p^1P - 5s^1S$	13415.33	2.0509+6	$4s^3S - 5p^3P$	28550.27	1.2031+5
$3p^1P - 6s^1S$	11228.98	1.1127+6	$4s^3S - 6p^3P$	20430.30	1.1475+5
$4p^1P - 5s^1S$	46065.65	1.4946+6	$5s^3S - 5p^3P$	220402.40	6.9994+4
$4p^1P - 6s^1S$	27607.62	7.5348+5	$5s^3S - 6p^3P$	54176.60	3.1375+4
$5p^1P - 6s^1S$	85292.94	5.9282+5	$6s^3S - 6p^3P$	389579.90	2.6970+4
$2p^1P - 3d^1D$	6679.99	6.3712+7	$2p^3P - 3s^3S$	7067.20	2.7375+7
$2p^1P - 4d^1D$	4923.30	1.9932+7	$2p^3P - 4s^3S$	4714.49	9.3052+6
$2p^1P - 5d^1D$	4389.16	9.0365+6	$2p^3P - 5s^3S$	4122.00	4.3396+6
$2p^1P - 6d^1D$	4144.93	4.9126+6	$2p^3P - 6s^3S$	3868.59	2.3805+6
$3p^1P - 4d^1D$	19094.57	7.1137+6	$3p^3P - 4s^3S$	21125.93	6.4846+6
$3p^1P - 5d^1D$	12971.98	3.3620+6	$3p^3P - 5s^3S$	12849.51	2.7173+6
$3p^3P - 6s^3S$	10670.62	1.4384+6	$4p^3P - 4d^3D$	439661.50	4.1607+3
$4p^3P - 5s^3S$	46949.36	2.0189+6	$4p^3P - 5d^3D$	37035.60	1.2776+6
$4p^3P - 6s^3S$	26888.35	9.5711+5	$4p^3P - 6d^3D$	24733.94	8.1001+5
$5p^3P - 6s^3S$	88073.67	7.7595+5	$5p^3P - 5d^3D$	858850.60	1.5199+3
$2p^3P - 3d^3D$	5877.29	7.0483+7	$5p^3P - 6d^3D$	68523.34	3.6572+5
$2p^3P - 4d^3D$	4472.76	2.4571+7	$6p^3P - 6d^3D$	1486839.00	6.4106+2
$2p^3P - 5d^3D$	4027.35	1.1612+7	$3d^3D - 4p^3P$	19548.49	6.4390+5
$2p^3P - 6d^3D$	3820.71	6.4472+6	$3d^3D - 5p^3P$	12988.44	2.7216+5
$3p^3P - 3d^3D$	186233.70	1.2923+4	$3d^3D - 6p^3P$	10999.58	1.4200+5
$3p^3P - 4d^3D$	17007.12	6.5950+6	$4d^3D - 5p^3P$	42440.82	3.2689+5
$3p^3P - 5d^3D$	11972.39	3.4722+6	$4d^3D - 6p^3P$	26678.60	1.5958+5
$3p^3P - 6d^3D$	10314.09	1.9917+6	$5d^3D - 6p^3P$	78390.48	1.5946+5

Owing to the limited volume of our catalogue we must exclude a great deal of transition probability and oscillator strength data. Such data are given only for H I

(Table 1) and He I (Table 2). The much more complete data for H I can be found in the review paper by Omidvar (1983) and for He in the paper by Theodosiou (1987). References on the numerous transition probability and oscillator strength compilations and tables can be found in Appendix A and also may be taken from the atomic data catalogue and banks described in Appendix B.

The largest database for spectral lines of atoms and two-atomic molecules has been calculated and composed by Kurucz. His current list includes data for more than 58 million spectral lines, more than 42 million of them belonging to atoms and their ions (Kurucz, 1992, 1995). A somewhat smaller former set of data by Kurucz is available on CD-ROM.

A large international project named the Opacity Project has been undertaken under the leadership of Seaton. The results have been compiled as the TOPBASE atomic database. The exact data for spectral lines and photoionization rates, including the autoionizational resonances have been compiled for all ions of 14 elements, namely, for H, He, C, N, O, Ne, Na, Mg, Al, Si, S, Ar, Ca and Fe. Some of the results have been published in a special issue of Revista Mexicana de Astronomía y Astrofísika Vol. 23, 1992, devoted to calculation of astrophysical opacities (see Seaton *et al.*, 1992; Cunto and Mendoza, 1992, and other papers in the issue). A large number of data concerning absorption lines with $\lambda > 912$Å compiled by Morton (1991). Even more vast is the list of lines including those in the region $\lambda > 228$Å presented by Verner *et al.* (1994).

To obtain the values A_{ki} and f_{ik} for hydrogenic ions with $Z > 1$ we can use the following scaling relations (see e.g. Rudzikas *et al.*, 1990):

$$A^Z_{ki} = Z^4 A^{\mathrm{H\,I}}_{ki},$$

and

$$f^Z_{ki} = f^{\mathrm{H\,I}}_{ki}.$$

The latter relation means that the oscillator strengths are the same for all hydrogenic ions. These relations are exact only within the framework of the non-relativistic approximation. For ions with $Z \gg 1$ the relativistic corrections should be taken into account. A recent study of the problem (see Rudzikas *et al.*, 1990, for details) showed that the relativistic corrections are significant only for higly stripped H-like ions ($Z > 50$) and for all astrophysically important hydrogenic ions one can use the non-relativistic scaling relations.

3.2 Photoionization

Photoionization is the main mechanism of ionization of atoms in low-density plasma. The ions of type X^i absorb photons having energies $h\nu \geq n\nu_0(X^i)$, i.e. energies which exceed the threshold value of releasing the electrons which usually belong to the external shell

$$X^i(\alpha\, nlLS) + h\nu \rightarrow X^{i+1}(\alpha\, L'S') + e,$$

where n is the main quantum number, l is the azimuthal quantum number of photoelectrons, L and S are, respectively, the total orbital and spin moment of ion X^i

and α is an unspecified set of all other quantum numbers which fix the state of the atomic residue. The number of photoionizations in unit volume per unit time is

$$\dot{N} = n(X^i) \int_{\nu_0(X^i)}^{\infty} \sigma_{nc}(\nu, X^i)\, 4\pi J_\nu \frac{d\nu}{h\nu}, \tag{6}$$

where J_ν is the mean intensity of the ionizing radiation (both the stellar and the diffuse one) at the given point of the ionized medium and σ_{nc} is the effective cross-section of photoionization of ion X^i from level n.

In the conditions of astrophysical low-density plasma (gaseous nebulae) due to large radiation dilution and low gas densities the electrons of atoms are mainly in the ground state. Consequently, for computations primarily the photoionization cross-sections from the ground state are needed. Formation of free electrons due to the photoionization processes takes place from the outermost atomic layer. However, there are special cases, say, in modelling of radiative transfer in the vicinity of quasars and active galactic nuclei which are the intensive X-ray sources, where the photoionization from inner electron shells is important. This holds, for instance, for N I, O III and S II. Determination of the cross-sections of photoionization σ_{nc} for all atoms, the lines of which are observed in nebular spectra, has been the topic of numerous experimental and theoretical investigations. A detailed list of such studies has been given in papers by Davidson and Netzer (1979), Mendoza (1983), Stasinska (1984) and Verner *et al.* (1993).

At the present time the values of σ_{1c} are known for most of atoms and ions, the lines of which are observed in the spectra of nebulae. The values can usually be given to within an accuracy about 10% (excluding the contribution of the resonances) by the following formula which is convenient for the photoionization and recombination rate computations:

$$\sigma_{1c}(X^i) = \sigma_0 \left[ax^{-s} + bx^{-s-1} + cx^{-s-2}\right] \text{cm}^2, \tag{7}$$

where $a + b + c = 1$. Here s is the approximation parameter in the law, describing the dependence of σ_{1c} on frequency ν or on the energy near the ionization threshold which is denoted by subscript 0 and $x = \nu/\nu_0(X^i) = E/E_0(X^i)$. The data on cross-sections of photoionization from the ground and excited states, which have been compiled by us from different published papers, for atoms and ions of elements from H to Si, for S and Ar are given in Table 3, where only the most reliable data were used. The most complete lists of photoionization cross-sections for atoms and ions having the nuclear charge number $Z \leq 30$ are given in the papers by Reilman and Manson (1979) and Verner *et al.* (1993), where the values of σ_{1c}, found in the Hartree–Slater approximation for energies 5 eV $\leq E \leq$ 5 keV are given. Unhappily in the first paper the dependence $\sigma(\nu)$ has been given in the form of a table. Nevertheless, Table 3 gives the values of approximation parameters, found based on the results of Reilman and Manson (1979) in the case where in the other papers the corresponding data were lacking. Though the lines of Li, Be and B in nebular spectra have not been detected yet, their inclusion in Table 3 may be useful. References to the calculations of the photoionization cross-sections for individual atoms and ions can be found in Appendix A.

Table 3. Parameters of photoionization cross-sections from the ground and excited states (equation (7))

Ion	*Transition*	σ_0	*a*	*b*	*c*	*s*	*Ref*
H^0	$H^0(^2S) - H^+(^1S)$	6.3	1.34	−0.34	0	2.99	O74
He^0	$He^0(^1S) - He^+(^2S)$	7.83	1.66	−0.66	0	2.05	O74
He^+	$He^+(^2S) - He^{2+}(^1S)$	1.58	1.34	−0.34	0	2.99	O74
Li^0	$Li^0(^2S) - Li^+(^1S)$	1.3	3.5	−2.5	0	1.4	F67
Be^0	$Be^0(^1S) - Be^+(^2S)$	1.93	0.027	−0.373	1.345	2.25	RM79
Be^+	$Be^+(^2S) - Be^{2+}(^1S)$	1.4	2.2	−1.2	0	2.0	F67
B^0	$B^0(^2P) - B^+(^1S)$	8.94	−0.020	0.075	0.945	1.0	RM79
B^+	$B^+(^1S) - B^{2+}(^2S)$	3.0	2.6	−1.6	0	3.0	F67
B^{2+}	$B^{2+}(^2S) - B^{3+}(^1S)$	0.98	1.0	0	0	1.8	F67
C^0	$C^0(^3P) - C^+(^2P)$	12.2	3.317	−2.317	0	2.0	H70
	$^1D - ^2P$	10.3	2.789	−1.789	0	1.5	H70
	$^1S - ^2P$	9.59	3.501	−2.501	0	1.5	H70
C^+	$C^+(^2P) - C^{2+}(^1S)$	4.60	1.95	−0.95	0	3.0	H70
C^{2+}	$C^{2+}(^1S) - C^{3+}(^2S)$	1.84	3.0	−2.0	0	2.6	SB71
	$2s2p\ ^3P^0 - ^2S$	2.15	1.0	0	0	2.45	SW78
	$2p^2\ ^3P - ^2S$	4.22	1.0	0	0	2.27	SW78
	$2s3s\ ^3S - ^2S$	0.95	1.0	0	0	1.19	SW78
	$2s3p\ ^3P^0 - ^2S$	3.09	1.0	0	0	2.10	SW78
	$2s3d\ ^3D - ^2S$	2.90	1.0	0	0	3.22	SW78
	$2p3s\ ^3P^0 - ^2S$	1.21	1.0	0	0	1.57	SW78
	$2s4s\ ^3S - ^2S$	1.22	1.0	0	0	1.37	SW78
	$2s4p\ ^3P^0 - ^2S$	4.13	1.0	0	0	2.03	SW78
	$2s4d\ ^3D - ^2S$	3.42	1.0	0	0	2.60	SW78
	$2s4f\ ^3F^0 - ^2S$	2.66	1.0	0	0	3.61	SW78
	$2p3p\ ^3S - ^2S$	2.47	1.0	0	0	2.33	SW78
	$2p3p\ ^3P - ^2S$	3.40	1.0	0	0	2.12	SW78
	$2p3d\ ^3F^0 - ^2S$	2.05	1.0	0	0	3.08	SW78
	$2p3d\ ^3D^0 - ^2S$	2.34	1.0	0	0	3.36	SW78
	$2p3d\ ^3P^0 - ^2S$	2.06	1.0	0	0	3.29	SW78
	$2p5g\ ^3G - ^2S$	1.96	1.0	0	0	4.41	SW78
C^{3+}	$C^{3+}(^2S) - C^{4+}(^1S)$	0.71	2.7	−1.7	0	2.2	SB71
	$2p\ ^2P^0 - ^1S$	0.93	1.5	−0.5	0	3.5	L72
N^0	$N^0(^4S) - N^+(^3P)$	11.42	4.287	−3.287	0	2.0	H70
	$^2D - ^3P$	4.41	3.847	−2.847	0	1.5	H70
	$^2D - ^1D$	5.02	4.826	−3.826	0	2.0	H70
	$^2P - ^3P$	4.20	4.337	−3.337	0	1.5	H70
	$^2P - ^1D$	2.87	5.112	−4.112	0	2.0	H70
	$^2P - ^1S$	2.03	4.727	−3.727	0	2.0	H70
N^+	$N^+(^3P) - N^{2+}(^2P)$	6.65	2.860	−1.860	0	3.0	H70
	$^1D - ^2P$	6.65	2.789	−1.789	0	2.5	H70
	$^1S - ^2P$	6.75	3.101	−2.101	0	2.5	H70
N^{2+}	$N^{2+}(^2P) - N^{3+}(^1S)$	2.0	0.9	0.1	0	2.0	S58
N^{3+}	$N^{3+}(^1S) - N^{4+}(^2S)$	1.08	−0.108	1.63	−0.522	0.93	RM79
N^{4+}	$N^{4+}(^2S) - N^{5+}(^1S)$	0.91	−0.081	1.70	−0.62	1.21	RM79
O^0	$O^0(^3P) - O^+(^4S)$	2.94	2.661	−1.661	0	1.0	H70
	$^3P - ^2D$	3.85	4.378	−3.378	0	1.5	H70
	$^3P - ^2P$	2.26	4.311	−3.311	0	1.5	H70

Table 3. Continued

Ion	*Transition*	σ_0	a	b	c	s	*Ref*
	$^1D - {}^2D$	4.64	6.829	−5.829	0	1.5	H70
	$^1D - {}^2P$	1.95	4.800	−3.800	0	1.5	H70
	$^1S - {}^2P$	7.65	5.124	−4.124	0	1.5	H70
O^+	$O^+(^4S) - O^{2+}(^3P)$	7.32	3.837	−2.837	0	2.5	H70
	$^2D - {}^3P$	3.53	3.808	−2.808	0	2.5	H70
	$^2D - {}^1D$	3.97	3.033	−2.033	0	2.5	H70
	$^2P - {}^3P$	3.43	4.174	−3.174	0	2.5	H70
	$^2P - {}^1D$	2.32	3.110	−2.110	0	2.5	H70
	$^2P - {}^1S$	1.68	3.751	−2.751	0	2.5	H70
O^{2+}	$O^{2+}(^3P) - O^{3+}(^2P)$	3.65	2.014	−1.014	0	3.0	H70
	$^1D - {}^2P$	3.79	2.777	−1.777	0	3.0	H70
	$^1S - {}^2P$	3.97	2.780	−1.780	0	3.0	H70
O^{3+}	$O^{3+}(^2P) - O^{4+}(^1S)$	1.20	1.82	−0.82	0	3.0	S58
O^{4+}	$O^{4+}(^1S) - O^{5+}(^2S)$	0.77	−0.104	1.647	−0.543	1.02	RM79
F^0	$F^0(^2P) - F^+(^3P)$	3.7	4.1	−3.1	0	1.0	S58
F^+	$F^+(^3P) - F^{2+}(^4S)$	2.84	3.1	−2.1	0	2.0	S58
F^{2+}	$F^{2+}(^4S) - F^{3+}(^3P)$	4.5	1.7	−0.7	0	2.0	S58
F^{3+}	$F^{3+}(^3P) - F^{4+}(^2P)$	2.06	1.0	0	0	2.0	S58
F^{4+}	$F^{4+}(^2P) - F^{5+}(^1S)$	0.8	1.0	0	0	2.3	S58
F^{5+}	$F^{5+}(^1S) - F^{6+}(^2S)$	0.58	2.6	−1.6	0	3.0	F67
Ne^0	$Ne^0(^1S) - Ne^+(^2P)$	5.35	3.769	−2.769	0	1.0	H70
Ne^+	$Ne^+(^2P) - Ne^{2+}(^3P)$	4.16	2.717	−1.717	0	1.5	H70
	$^2P - {}^1D$	2.71	2.148	−1.148	0	1.5	H70
	$^2P - {}^1S$	0.52	2.126	−1.126	0	1.5	H70
Ne^{2+}	$Ne^{2+}(^3P) - Ne^{3+}(^4S)$	1.80	2.277	−1.277	0	2.0	H70
	$^3P - {}^2D$	2.50	2.346	−1.346	0	2.5	H70
	$^3P - {}^2P$	1.48	2.225	−1.225	0	2.5	H70
	$^1D - {}^2D$	4.17	2.074	−1.074	0	2.0	H70
	$^1D - {}^2P$	1.39	2.792	−1.792	0	2.5	H70
	$^1S - {}^2P$	5.49	3.000	−2.000	0	2.5	H70
Ne^{3+}	$Ne^{3+}(^4S) - Ne^{4+}(^3P)$	3.11	1.963	−0.963	0	3.0	H70
	$^2D - {}^3P$	1.69	1.841	−0.841	0	2.5	H70
	$^2D - {}^1D$	1.65	2.277	−1.277	0	3.0	H70
	$^2P - {}^3P$	1.69	1.937	−0.937	0	2.5	H70
	$^2P - {}^1D$	0.93	2.455	−1.455	0	3.0	H70
	$^2P - {}^1S$	0.73	1.486	−0.486	0	2.5	H70
Ne^{4+}	$Ne^{4+}(^3P) - Ne^{5+}(^2P)$	1.40	1.471	−0.471	0	3.0	H70
	$^1D - {}^2P$	1.53	2.021	−1.021	0	3.0	H70
	$^1S - {}^2P$	1.54	2.104	−1.104	0	3.0	H70
Ne^{5+}	$Ne^{5+}(^2P) - Ne^{6+}(^1S)$	0.49	1.145	−0.145	0	3.0	H70
Na^0	$Na^0(^2S) - Na^+(^1S)$	1.560	1.000	−2.55	1.62	1.35	Kh95
Na^+	$Na^+(^1S) - Na^{2+}(^2P)$	8.0	4.2	−3.2	0	2.0	S58
Na^{2+}	$Na^{2+}(^2P) - Na^{3+}(^3P)$	3.2	2.4	−1.4	0	2.0	S58
Na^{3+}	$Na^{3+}(^3P) - Na^{4+}(^4S)$	1.2	1.0	0	0	2.0	S58
Na^{4+}	$Na^{4+}(^4S) - Na^{5+}(^3P)$	2.0	1.0	0	0	2.3	S58
Mg^0	$Mg^0(^1S) - Mg^+(^2S)$	1.2	3.0	−2.0	0	14	DM53
Mg^+	$Mg^+(^2S) - Mg^{2+}(^1S)$	0.24	3.71	−2.71	0	0.91	DM53
Mg^{2+}	$Mg^{2+}(^1S) - Mg^{3+}(^2P)$	5.2	2.65	−1.65	0	2.0	S58
Mg^{3+}	$Mg^{3+}(^2P) - Mg^{4+}(^3P)$	3.74	1.225	3.39	−3.62	2.25	RM79
Mg^{4+}	$Mg^{4+}(^3P) - Mg^{5+}(^4S)$	2.84	0.726	2.42	−2.14	2.22	RM79

Table 3. Continued

Ion	*Transition*	σ_0	a	b	c	s	*Ref*
Al^0	$Al^0(^2P) - Al^+(^1S)$	28.2	0.049	−0.529	1.48	1.0	CH72
Al^+	$Al^+(^1S) - Al^{2+}(^2S)$	4.65	2.6	−1.6	0	2.7	SB71
Al^{2+}	$Al^{2+}(^2S) - Al^{3+}(^1S)$	1.36	2.4	−1.4	0	2.1	SB71
Al^{3+}	$Al^{3+}(^1S) - Al^{4+}(^2P)$	3.8	1.0	0	0	2.0	S58
Al^{4+}	$Al^{4+}(^2P) - Al^{5+}(^3P)$	1.8	1.0	0	0	2.3	S58
Si^0	$Si^0(^3P) - Si^+(^2P)$	39.2	4.42	0.094	−3.51	5.0	CH72
	$^1D - ^2P$	34.5	6.46	−7.78	2.32	3.0	CH72
	$^1S - ^2P$	33.6	10.01	−14.53	5.52	3.0	CH72
Si^+	$Si^+(^2P) - Si^{2+}(^1S)$	1.41	2.31	−6.72	5.41	1.5	CH72
Si^{2+}	$Si^{2+}(^1S) - Si^{3+}(^2S)$	0.62	0.064	−0.549	1.485	1.70	RM79
Si^{3+}	$Si^{3+}(^2S) - Si^{4+}(^1S)$	0.32	0.083	−0.611	1.528	1.34	RM79
Si^{4+}	$Si^{4+}(^1S) - Si^{5+}(^2P)$	3.81	0.928	1.89	−1.82	2.30	RM79
S^0	$S^0(^3P) - S^+(^4S)$	12.6	21.6	−40.1	19.5	3.0	CH71
	$^3P - ^2D$	19.1	0.135	5.365	−4.5	2.5	CH71
	$^3P - ^2P$	12.7	1.16	2.425	−2.585	3.0	CH71
	$^1D - ^2D$	21.0	0.66	4.875	−4.535	1.5	CH71
	$^1D - ^2P$	7.87	0.543	6.347	−5.89	2.0	CH71
	$^1S - ^2P$	22.6	−1.148	9.27	−7.122	1.0	CH71
S^+	$S^+(^4S) - S^{2+}(^3P)$	0.93	−0.21	1.86	−0.65	1.05	RM79
	$^2D - ^3P$	16.1	0.562	−2.574	3.012	1.0	CH71
	$^2D - ^1D$	7.25	1.064	−3.936	3.872	1.5	CH71
	$^2P - ^3P$	16.0	0.530	−2.492	2.962	1.0	CH71
	$^2P - ^1D$	3.81	0.868	−3.421	3.553	1.0	CH71
	$^2P - ^1S$	2.53	1.286	−3.917	3.631	1.0	CH71
S^{2+}	$S^{2+}(^3P) - S^{3+}(^2P)$	0.38	18.43	−36.26	18.83	2.0	CH71
	$^1D - ^2P$	0.98	10.06	−23.39	14.33	2.0	CH71
	$^1S - ^2P$	0.75	14.65	−33.40	19.75	2.0	CH71
S^{3+}	$S^{3+}(^2P) - S^{4+}(^1S)$	0.76	2.8	−1.8	0	2.4	SB71
S^{4+}	$S^{4+}(^1S) - S^{5+}(^2S)$	5.18	−0.073	1.539	−0.466	0.59	RM79
Ar^0	$Ar^0(^1S) - Ar^+(^2P)$	32.7	4.2	−3.2	0	1.6	SB71
Ar^+	$Ar^+(^2P) - Ar^{2+}(^3P)$	28.6	0.082	−0.83	1.75	0.5	CH72
	$^2P - ^1D$	15.3	0.623	−2.77	3.15	1.0	CH72
	$^2P - ^1S$	3.07	0.570	−2.59	3.02	1.0	CH72
Ar^{2+}	$Ar^{2+}(^3P) - Ar^3+(^4S)$	2.23	5.93	−16.09	11.16	2.5	CH72
	$^3P - ^2D$	0.86	9.375	−22.95	14.58	2.0	CH72
	$^3P - ^2P$	0.92	7.825	−19.74	12.92	2.5	CH72
	$^1D - ^2D$	5.43	5.403	−14.84	10.44	2.5	CH72
	$^1D - ^2P$	2.01	4.823	−13.44	9.62	2.5	CH72
	$^1S - ^2P$	8.75	4.861	−13.68	9.82	2.5	CH72
Ar^{3+}	$Ar^{3+}(^4S) - Ar^{4+}(^3P)$	0.59	10.80	−15.91	6.11	2.0	CH72
	$^2D - ^3P$	0.23	32.56	−63.76	32.20	2.5	CH72
	$^2D - ^1D$	0.28	23.10	−42.98	20.88	2.5	CH72
	$^2P - ^3P$	0.25	34.23	−68.38	35.15	2.5	CH72
	$^2P - ^1D$	0.11	20.70	−33.46	13.76	2.0	CH72
	$^2P - ^1S$	0.11	25.39	−47.60	23.21	2.5	CH72
Ar^{4+}	$Ar^{4+}(^3P) - Ar^{5+}(^2P)$	0.63	7.45	−10.67	4.22	2.5	CH72
	$^1D - ^2P$	0.56	10.11	−15.35	6.24	2.5	CH72
	$^1S - ^2P$	0.55	11.84	−18.55	7.71	2.5	CH72
Ar^{5+}	$Ar^{5+}(^2P) - Ar^{6+}(^1S)$	0.34	2.438	−1.639	0.201	2.0	CH72

Table 3. Continued

Ion	*Transition*	σ_0	*a*	*b*	*c*	*s*	*Ref*
Ca^0	$Ca^0(^1S) - Ca^+(^2S)$	14.4	1.000	0.000	0.000	4.0	Kh95
Ca^+	$Ca^+(^2S) - Ca^{2+}(^1S)$	0.1	6.680	−3.240	−1.350	1.5	Kh95

Note. References: DM53, Ditchburn and Marr (1953); CH71, CH72, Chapman and Henry (1971, 1972); F67, Flower (1967); H70, Henry (1970); Kh95, Kholtygin *et al.* (1995); L72, Leibowitz (1972); O74, Osterbrock (1974); RM79, Reilman and Manson (1979); SW78, Sakhibullin and Willis (1978); S58, Seaton (1958); SB71, Silk and Brown (1971).

3.2.1 Photoionization from K and L shells

The common formulae have been derived for an idealized model picture for the photoionization cross-sections from K and L shells. These cross sections can be simply expressed using the functions

$$f_n(\nu) = \frac{2^7 \pi \sigma_T}{\alpha^3 Z^2} \left(\frac{I_n}{h\nu}\right)^4$$

and

$$\Phi_n(\nu) = \frac{\exp[-4\eta^{2-n}\, ctn^{-1}(\eta/n)]}{1 - \exp(-2\pi\eta)},$$

where σ_T is the Thompson scattering cross section, $\eta^2 = I_n/(h\nu - I_n)$ and I_n is the ionization energy from the shell with principal quantum number n. For the K-shell electrons we can write (Lang, 1974; Akhiezer and Berestetsky, 1969)

$$\sigma_{1s} = f_1(\nu)\, \Phi_1(\nu)\,,$$

for the L-shell electrons in the $2s$ state

$$\sigma_{2s} = 8 \left(1 + 3\frac{I_2}{h\nu}\right) f_2(\nu)\, \Phi_2(\nu),$$

and in the $2p$ state by

$$\sigma_{2p} = 16\frac{I_2}{h\nu} \left(3 + 8\frac{I_2}{h\nu}\right) f_2(\nu)\, \Phi_2(\nu)\,.$$

Daltabuit and Cox (1972) have represented the effective cross-sections of photoionization from the K-shell of H, He, C, N, O and Ne as a special case of equation (7) in the form

$$\sigma_{1c}(X^i) = \sigma_0 \left[a x^{-s} + (1-a) x^{-s-1}\right] \text{cm}^2. \tag{8}$$

This approximation is applicable in the region of ionization threshold and at moderate energies. The values of approximation parameters for these atoms and some of their ions (in units of 10^{-18} cm^2) are given in Table 4.

Table 4. Parameters of photoionization cross-sections from the K – shell (equation (8))

Ion	E_0 (eV)	σ_0 (10^{-18} cm^2)	α	s
C I	280	1.06	1	2.47
C II	296	0.997	1	2.48
C III	317	0.930	1	2.49
C IV	347	0.850	1	2.51
C V	392	0.526	1.325	2.76
C VI	490	0.194	1.287	2.95
N I	395	0.747	1	2.53
N II	412	0.717	1	2.54
N III	432	0.683	1	2.54
N IV	459	0.643	1	2.55
N V	496	0.595	1	2.57
N VI	552	0.371	1.314	2.79
N VII	666	0.142	1.287	2.95
O I	533	0.554	1	2.58
O II	550	0.537	1	2.59
O III	570	0.518	1	2.59
O IV	595	0.496	1	2.60
O V	627	0.470	1	2.61
O VI	672	0.439	1	2.62
O VII	739	0.275	1.308	2.81
O VIII	870	0.109	1.287	2.95
Ne I	878	0.336	1	2.67
Ne II	896	0.329	1	2.68
Ne III	916	0.322	1	2.68
Ne IV	940	0.314	1	2.69
Ne V	968	0.305	1	2.69
Ne VI	1000	0.295	1	2.70
Ne VII	1050	0.282	1	2.71
Ne VIII	1100	0.267	1	2.72
Ne IX	1195	0.180	1.28	2.95
Ne X	1360	0.075	1.25	2.90

The photoionization cross-section for the atoms of H and for the hydrogenic ions from the states with the principal quantum number n can be written in the form

$$\sigma_n = \frac{2^4\, e^2\, I_z^2}{3\sqrt{3}\, mch^2\, n^5\, \nu^3}\, g_n(\nu). \tag{9}$$

Here $g_n(\nu)$ is the Gaunt correction factor to the Kramers approximation and I_z is the ionization energy of ion with charge number Z from its ground state.

A simple approximation formula to the complicated exact formulae found by Karzas and Latter (1961) and Goldwire (1968) for the Gaunt factor of H and hydrogenic ions has been found by Sapar and Kuusik (1974). It has high precision (more than 1%) for a wide energy range for all states with $n > 2$ and only for $n = 1$ does it reach 3% in a narrow energy interval. The formula has the form:

$$g_n = g_n^I / \left[1 + 0.02494 \left(2.4 - \frac{0.014\, x^y}{1 + 0.01\, x^y}\right) x^{5/6}\right], \tag{10}$$

where g_n^I is the Gaunt factor in the well-known first approximation found by Menzel and Pekeris (1935)

$$g_n^I = 1 - 0.1728\, x^{1/3} \left(\frac{2}{n^2 x} - 1\right).$$

In these formulae $x = h\nu/I_z$ and

$$y = 0.43 + 0.6 \log (x + 10).$$

At large energies σ_n is proportional to $\nu^{-3.5}$.

In the determination of photoionization cross-sections for different atoms it is necessary to take into account not only the direct photoionization, but also ionization from intermediary autoionization states. The autoionization states are dielectronic excited states with excitation energy exceeding the ionization energy of the outermost single electron from the ground state of the atomic particle. However, the energy of each excited electron is less than the ionization energy. From the autoionization state an electron can transit to lower bound states with photon emission (this process is called radiative stabilization) or autoionizational stabilization can occur, where one electron is liberated from the atom but the other goes to some bound state. Owing to the presence of autoionization states autoionizational resonances of photoionization cross-sections appear. This circumstance must be taken into account in the modelling of ionization states and the structure of gaseous nebulae and other low-density astrophysical objects. If we ignore the autoionization phenomena then we can obtain the results but with only 20–30% precision. The autoionizational resonances have been studied in detail within the framework of the above-mentioned Opacity Project (see Seaton *et al.*, 1992).

3.3 Photorecombination

Free electrons can recombine on a level of ion X^{i+1} forming the ion X^i. The process of recombination can be radiative, dielectronic or triple. The latter process is usually negligible in conditions of low-density astrophysical plasma. The photorecombination rate can be easily obtained using the condition of its detailed equilibrium (see, for example, Sobolev, 1985) with the photoionization rates in the case of complete thermodynamical equilibrium. The processes of radiative and dielectronic recombination and their inverse processes can be described by the following schemes (see, for example, Nikitin *et al.*, 1988) for photorecombination

$$X^{i+1}(n_0 l_0) + e \longleftrightarrow X^i(n_0 l_0 n l) + h\nu \tag{11}$$

and for dielectronic recombination

$$X^{i+1}(n_0 l_0) + e \longleftrightarrow X^i(n_1 l_1 n' l') \longleftrightarrow \begin{cases} X^i(n_0 l_0 n' l') + h\nu' \\ X^i(n_1 l_1 n'' l'') + h\nu'' \end{cases}, \tag{12}$$

where the quantum numbers of type nl specify the ion states. Electron capture by neutral atoms leads to the formation of negative ions. Such processes, however, are negligible for nebulae.

In photorecombination processes the electrons are captured on the discrete levels nl with emission of photons having energies $h\nu_{ic} = E + I_i$ where E is the energy of the recombining electron and I_i is the ionization potential of the level $i = nl\gamma$, where γ denotes the set complementary to nl quantum numbers of the state i. The radiative cascade transitions between the discrete levels following recombination generate the recombinational spectral lines.

The most important quantity determining the ionization degree of the atom is the sum of the recombination rates to all atomic states (total recombination rate):

$$\alpha^{\mathrm{rad}} = \alpha^A = \sum_{n=1}^{\infty} \alpha_n(T_e)$$

and the same value excluding the recombinations onto the ground state:

$$\alpha^B = \sum_{n=2}^{\infty} \alpha_n(T_e) = \alpha^{\mathrm{rad}} - \alpha_1(T_e).$$

Here $\alpha_n(T_e)$ is the recombination rate to level n.

For hydrogen and hydrogenic ions about one half of all recombination acts proceed straight into the ground state of ion X^{i+1}, and the rest of them recombine to the excited states.

The total number of recombinations in a unit volume per unit time is

$$\dot{N}_r = n(X^{i+1})\, n_e\, \alpha^{\mathrm{rad}}(X^{i+1})\ \mathrm{cm^3 s^{-1}}. \tag{13}$$

The total recombination rate is often approximated by the expression

$$\alpha^{\mathrm{rad}}(X^{i+1}) = A_{\mathrm{rad}}\, [T_e/10^4\ \mathrm{K}]^{\chi_{\mathrm{rad}}}. \tag{14}$$

The numerical values of recombination rates α^{rad} for a large number of ions have been found by Aldrovandi and Pequignot (1973, 1976), Woods *et al.* (1981), and Shull and Van Steenberg (1982). The values of parameters A_{rad} and χ_{rad} for all ions of elements from C to Ni taken from the last mentioned paper are given in Table 5. The numerical values of these parameters for ions of Ar, Ca and Ni not included in the last-mentioned paper have been found by interpolation of the values in the corresponding isoelectronic sequences using the scaling relations as given in Section 2.5. To study an ionization balance in cold low-density plasma ($T \ll 10^4$ K (for example H I regions of the interstellar medium) the values of

Table 5. Parameters of approximation for the collisional ionization, radiative and dielectronic recombination rates (equations (14), (36) and (56))

Ion	A_{col}	T_{col}	A_{rad}	χ_{rad}	A_{di}	B_{di}	T_0	T_1
C	1.44–10	1.31+5	4.70–13	0.624	2.54–3	4.42–2	1.57+5	3.74+5
C^+	4.20–11	2.83+5	2.30–12	0.645	6.15–3	5.88–2	1.41+5	1.41+5
C^{2+}	1.92–11	5.56+5	3.20–12	0.770	1.62–3	3.43–1	8.19+4	1.59+5
C^{3+}	5.32–12	7.48+5	7.50–12	0.817	4.78–2	3.62–1	3.44+6	5.87+5
C^{4+}	2.87–13	4.55+6	1.70–11	0.721	3.22–2	3.15–1	4.06+6	8.31+5
C^{5+}	9.16–14	5.68+6	1.47–11	0.726	0	0	0	0
N	7.08–11	1.68+5	4.10–13	0.608	2.98–3	0	2.20+5	0
N^+	4.55–11	3.43+5	2.20–12	0.639	7.41–4	7.64–2	2.01+5	7.37+4
N^{2+}	1.83–11	5.50+5	5.00–12	0.676	1.13–2	1.64–1	1.72+5	2.25+5
N^{3+}	7.16–12	8.99+5	6.50–12	0.743	2.62–3	2.43–1	1.02+5	1.25+5
N^{4+}	2.30–12	1.14+6	1.50–11	0.850	7.50–2	3.50–1	4.75+6	8.35+5
N^{5+}	1.44–13	6.41+6	2.90–11	0.750	4.61–2	3.09–1	5.44+6	1.14+6
N^{6+}	4.93–14	7.74+6	2.00–11	0.726	0	0	0	0
O	1.09–10	1.58+5	3.10–13	0.678	1.11–3	9.25–2	1.75+5	1.45+5
O^+	3.96–11	4.07+5	2.00–12	0.646	5.07–3	1.81–1	1.98+5	3.35+5
O^{2+}	1.67–11	6.37+5	5.10–12	0.660	1.48–2	3.05–1	2.41+5	2.83+5
O^{3+}	7.60–12	8.98+5	9.60–12	0.670	1.84–2	1.00–1	2.12+5	2.83+5
O^{4+}	3.33–12	1.32+6	1.20–11	0.779	4.13–3	1.62–1	1.25+5	2.27+5
O^{5+}	1.15–12	1.60+6	2.30–11	0.802	1.06–1	3.40–1	6.25+6	1.12+6
O^{6+}	7.90–14	8.57+6	4.10–11	0.742	6.23–2	3.04–1	7.01+6	1.47+6
O^{7+}	2.89–14	1.01+7	2.62–11	0.726	0	0	0	0
Ne	3.03–11	2.50+5	2.20–13	0.759	9.77–4	7.30–2	3.11+5	2.06+5
Ne^+	1.79–11	4.76+5	1.50–12	0.693	2.65–3	2.42–1	2.84+5	3.07+5
Ne^{2+}	1.61–11	7.37+5	4.40–12	0.675	3.69–3	1.01	2.24+5	2.94+5
Ne^{3+}	9.76–12	1.13+6	9.10–12	0.668	1.18–2	3.91–1	2.70+5	5.50+5
Ne^{4+}	4.48–12	1.47+6	1.50–11	0.684	2.44–2	2.52	3.09+5	9.91+5
Ne^{5+}	2.03–12	1.83+6	2.30–11	0.704	3.02–2	4.45–1	2.83+5	1.73+6
Ne^{6+}	1.02–12	2.40+6	2.80–11	0.771	6.10–3	2.54–1	1.68+5	6.13+5
Ne^{7+}	3.84–12	2.77+6	5.00–11	0.832	2.52–1	3.04–1	1.40+7	1.80+6
Ne^{8+}	3.05–14	1.39+7	8.60–11	0.769	1.44–1	2.96–1	1.50+7	2.24+6
Ne^{9+}	1.17–14	1.58+7	4.09–11	0.726	0	0	0	0
Mg	8.90–11	8.87+4	1.40–13	0.855	4.49–4	2.10–2	5.01+4	2.81+4
Mg^+	5.90–11	1.74+5	8.80–13	0.838	1.95–3	7.40–2	6.06+5	1.44+6
Mg^{2+}	1.10–11	9.30+5	3.50–12	0.734	5.12–3	3.23–1	4.69+5	7.55+5
Mg^{3+}	9.14–12	1.26+6	7.70–12	0.718	7.74–3	6.36–1	3.74+5	7.88+5
Mg^{4+}	5.02–12	1.64+6	1.40–11	0.716	1.17–2	8.07–1	3.28+5	1.02+6
Mg^{5+}	2.73–12	2.17+6	2.30–11	0.695	3.69–2	3.51–1	4.80+5	9.73+5
Mg^{6+}	1.47–12	2.61+6	3.20–11	0.691	3.63–2	5.48–1	3.88+5	7.38+5
Mg^{7+}	7.35–13	3.09+6	4.60–11	0.711	4.15–2	2.33–1	3.39+5	3.82+5
Mg^{8+}	4.11–13	3.81+6	5.80–11	0.804	8.86–3	3.18–1	2.11+5	1.54+6
Mg^{9+}	1.64–13	4.25+6	9.10–11	0.830	2.52–1	3.15–1	1.40+7	2.64+6
Mg^{10+}	1.42–14	2.07+7	1.50–10	0.779	1.44–1	2.91–1	1.50+7	3.09+6
Mg^{11+}	5.74–15	2.27+7	5.89–11	0.726	0	0	0	0
Si	3.92–10	9.46+4	5.90–13	0.601	1.10–3	0	7.70+4	0
Si^+	4.87–11	1.90+5	1.00–12	0.786	5.87–3	7.53–1	9.63+4	6.46+4
Si^{2+}	2.32–11	3.88+5	3.70–12	0.693	5.03–1	1.88–1	8.75+4	4.71+4
Si^{3+}	6.20–12	5.24+5	5.50–12	0.821	5.43–3	4.50–1	1.05+6	7.98+5
Si^{4+}	4.86–12	1.93+6	1.20–11	0.735	8.86–3	0	1.14+6	0
Si^{5+}	2.60–12	2.38+6	2.11–11	0.716	1.68–2	1.80	4.85+5	1.03+6

Table 5. Continued

Ion	A_{col}	T_{col}	A_{rad}	χ_{rad}	A_{di}	B_{di}	T_0	T_1
Si^{6+}	1.65–12	2.86+6	3.00–11	0.702	2.49–2	1.88	4.15+5	1.91+6
Si^{7+}	1.03–12	3.52+6	4.30–11	0.688	3.13–2	2.01	3.66+5	2.11+6
Si^{8+}	6.02–13	4.07+6	5.80–11	0.703	4.25–1	1.22	3.63+5	2.14+6
Si^{9+}	3.23–13	4.66+6	7.70–11	0.714	6.18–2	3.03–1	3.88+5	1.12+6
Si^{10+}	1.95–13	5.52+6	1.20–11	0.855	1.38–2	1.42	2.51+5	3.93+6
Si^{11+}	8.08–14	6.07+6	1.50–10	0.831	3.27–1	3.06–1	1.88+7	3.60+6
Si^{12+}	7.44–15	2.83+7	2.10–10	0.765	1.89–1	2.86–1	1.99+7	4.14+6
Si^{13+}	3.09–15	3.10+7	8.02–11	0.726	0	0	0	0
S	1.45–10	1.20+5	4.10–13	0.630	1.62–3	0	1.25+5	0
S^{+}	7.11–11	2.71+5	1.80–12	0.686	1.09–2	1.20–2	1.92+5	1.80+4
S^{2+}	2.12–11	4.06+5	2.70–12	0.745	3.35–2	6.59–2	1.89+5	1.59+5
S^{3+}	6.39–12	5.49+5	5.70–12	0.755	3.14–2	6.89–2	1.68+5	8.04+4
S^{4+}	6.43–12	8.47+5	1.20–11	0.701	1.27–2	1.87–1	1.38+5	1.71+5
S^{5+}	1.85–12	1.02+6	1.70–11	0.849	1.47–2	1.29–1	1.80+6	1.75+6
S^{6+}	1.71–12	3.26+6	2.70–11	0.733	1.34–2	1.04	6.90+5	2.15+6
S^{7+}	1.01–12	3.81+6	4.00–11	0.696	2.38–2	1.12	5.84+5	2.59+6
S^{8+}	6.97–13	4.40+6	5.50–11	0.711	3.19–2	1.40	5.17+5	2.91+6
S^{9+}	4.75–13	5.19+6	7.40–11	0.716	7.13–2	1.00	6.66+5	2.32+6
S^{10+}	2.90–13	5.86+6	9.20–11	0.714	8.00–2	5.55–1	6.00+5	2.41+6
S^{11+}	1.63–13	6.55+6	1.40–10	0.755	7.96–2	1.63	5.09+5	6.37+6
S^{12+}	1.04–13	7.56+6	1.70–10	0.832	1.34–2	3.04–1	2.91+5	1.04+6
S^{13+}	4.42–14	8.02+6	2.50–10	0.852	4.02–1	2.98–1	2.41+7	4.67+6
S^{14+}	4.25–15	3.74+7	3.30–10	0.783	2.41–1	2.81–1	2.54+7	5.30+6
S^{15+}	1.81–15	4.05+7	1.05–10	0.726	0	0	0	0
Ar	2.20–10	1.83+5	3.77–13	0.651	1.00–3	5.00–3	3.20+5	3.10+5
Ar^{+}	1.20–10	3.21+5	1.95–12	0.752	1.10–2	4.50–2	2.90+5	5.50+5
Ar^{2+}	3.50–11	4.75+5	3.23–12	0.869	3.40–2	5.70–2	2.39+5	6.00+5
Ar^{3+}	3.80–11	6.94+5	6.03–12	0.812	6.85–2	8.70–2	2.56+5	3.81+5
Ar^{4+}	6.47–12	8.70+5	9.12–12	0.811	9.00–2	7.69–2	2.50+5	3.30+5
Ar^{5+}	1.72–12	1.06+6	1.58–11	0.793	6.35–2	1.40–1	2.10+5	2.15+5
Ar^{6+}	2.20–12	1.44+6	2.69–11	0.744	2.60–2	1.20–1	1.80+5	2.15+5
Ar^{7+}	6.95–13	1.66+6	3.55–11	0.910	1.70–2	1.00–1	2.70+6	3.30+6
Ar^{8+}	7.57–13	4.90+6	4.90–11	0.801	2.10–2	1.92	8.30+5	3.50+6
Ar^{9+}	4.75–13	5.56+6	6.92–11	0.811	3.50–2	1.66	6.95+5	3.60+6
Ar^{10+}	3.45–13	6.25+6	9.55–11	0.793	4.30–2	1.67	6.05+5	3.80+6
Ar^{11+}	2.48–13	7.17+6	1.23–10	0.702	7.13–2	1.40	6.68+5	2.90+6
Ar^{12+}	1.57–13	7.96+6	1.58–10	0.790	9.60–2	1.31	6.50+5	3.60+6
Ar^{13+}	9.10–14	8.77+6	2.14–10	0.774	8.50–2	1.02	5.30+5	2.80+6
Ar^{14+}	6.05–14	9.92+6	2.63–10	0.907	1.70–2	2.45–1	3.55+5	1.10+6
Ar^{15+}	2.62–14	1.07+7	3.72–10	0.899	4.76–1	2.94–1	3.01+7	6.05+6
Ar^{16+}	2.60–15	4.78+7	4.95–10	0.816	2.97–1	2.77–1	3.13+7	6.54+6
Ar^{17+}	1.13–15	5.14+7	1.35–10	0.726	0	0	0	0
Ca	2.09–10	7.09+4	1.12–13	0.900	3.28–4	9.07–2	3.46+4	1.64+4
Ca^{+}	9.00–11	1.38+5	6.78–13	0.800	5.84–2	1.10–1	3.85+5	2.45+5
Ca^{2+}	5.35–11	5.94+5	3.96–12	0.700	1.12–1	1.74–2	4.08+5	4.27+5
Ca^{3+}	2.58–11	7.81+5	7.08–12	0.780	1.32–1	1.32–1	3.82+5	6.92+5
Ca^{4+}	1.31–11	9.79+5	1.07–11	0.840	1.33–1	1.14–1	3.53+5	8.78+5
Ca^{5+}	5.91–12	1.27+6	1.80–11	0.820	1.26–1	1.62–1	3.19+5	7.43+5
Ca^{6+}	2.86–12	1.49+6	2.40–11	0.820	1.39–1	8.78–2	3.22+5	6.99+5
Ca^{7+}	6.96–13	1.66+6	3.76–11	0.810	9.55–2	2.63–1	2.47+5	4.43+5
Ca^{8+}	9.56–13	2.18+6	5.04–11	0.780	4.02–1	6.27–2	2.29+5	2.81+5

Table 5. Continued

Ion	A_{col}	T_{col}	A_{rad}	χ_{rad}	A_{di}	B_{di}	T_0	T_1
Ca^{9+}	3.20–13	2.45+6	6.46–11	0.900	4.19–2	6.16–2	3.73+6	5.84+6
Ca^{10+}	3.86–13	6.87+6	8.51–13	0.820	2.57–2	2.77	9.26+5	4.89+6
Ca^{11+}	2.54–13	7.61+6	1.18–10	0.810	4.45–2	2.23	7.96+5	4.62+6
Ca^{12+}	1.90–13	8.43+6	1.58–10	0.800	5.48–2	2.00	6.90+5	4.52+6
Ca^{13+}	1.42–13	9.48+6	2.04–10	0.730	7.13–2	1.82	6.70+5	3.32+6
Ca^{14+}	9.25–14	1.04+7	2.60–10	0.800	9.03–2	4.24–1	4.72+5	1.37+6
Ca^{15+}	5.48–14	1.13+7	3.24–10	0.780	1.10–1	2.43–1	5.67+5	4.41+6
Ca^{16+}	3.74–14	1.26+7	3.81–10	0.850	2.05–2	1.85–1	4.21+5	2.27+6
Ca^{17+}	1.65–14	1.34+7	5.13–10	0.850	5.49–1	2.92–1	3.65+7	7.25+6
Ca^{18+}	1.68–15	5.95+7	6.46–10	0.830	3.55–1	2.75–1	3.78+7	7.68+6
Ca^{19+}	7.39–16	6.35+7	1.64–10	0.726	0	0	0	0
Fe	1.26–10	9.13+4	1.42–13	0.891	1.58–3	4.56–1	6.00+4	8.97+4
Fe^{+}	4.97–11	1.88+5	1.02–12	0.843	8.38–3	3.23–1	1.94+5	1.71+5
Fe^{2+}	1.49–10	3.56+5	3.32–12	0.746	1.54–2	3.10–1	3.31+5	2.73+5
Fe^{3+}	3.90–11	6.36+5	7.80–12	0.682	3.75–2	4.11–1	4.32+5	3.49+5
Fe^{4+}	1.66–11	8.70+5	1.51–11	0.699	1.17–1	3.59–1	6.28+5	5.29+5
Fe^{5+}	7.16–12	1.15+6	2.62–11	0.728	2.54–1	9.75–2	7.50+5	4.69+5
Fe^{6+}	3.00–12	1.45+6	4.12–11	0.759	2.91–1	2.29–1	7.73+5	6.54+5
Fe^{7+}	1.02–12	1.75+6	6.05–11	0.790	1.50–1	4.20	2.62+5	1.32+6
Fe^{8+}	2.54–12	2.73+6	8.13–11	0.810	1.40–1	3.30	2.50+5	1.33+6
Fe^{9+}	1.70–12	3.04+6	1.09–10	0.829	1.00–1	5.30	2.57+5	1.41+6
Fe^{10+}	1.11–12	3.37+6	1.33–10	0.828	2.00–1	1.50	2.84+5	1.52+6
Fe^{11+}	6.42–13	3.84+6	1.64–10	0.834	2.40–1	7.00–1	8.69+5	1.51+6
Fe^{12+}	3.59–13	4.19+6	2.00–10	0.836	2.60–1	6.00–1	4.21+5	1.82+6
Fe^{13+}	9.30–14	4.55+6	2.41–10	0.840	1.90–1	5.00–1	4.57+5	1.84+6
Fe^{14+}	1.62–14	5.30+6	2.89–10	0.846	1.20–1	1.00	2.85+5	2.31+6
Fe^{15+}	5.97–14	5.68+6	3.42–10	0.850	3.50–1	0	8.18+5	0
Fe^{16+}	8.44–14	1.47+7	3.87–10	0.836	6.60–2	7.80	1.51+6	9.98+6
Fe^{17+}	5.92–14	1.58+7	4.52–10	0.824	1.00–1	6.30	1.30+6	9.98+6
Fe^{18+}	4.72–14	1.69+7	5.25–10	0.816	1.30–1	5.50	1.19+6	1.00+7
Fe^{19+}	3.79–14	1.84+7	6.07–10	0.811	2.30–1	3.60	1.09+6	1.10+7
Fe^{20+}	2.60–14	1.96+7	6.98–10	0.808	1.40–1	4.90	9.62+5	8.34+6
Fe^{21+}	1.61–14	2.09+7	7.72–10	0.800	1.10–1	1.60	7.23+5	1.01+7
Fe^{22+}	1.16–14	2.26+7	7.86–10	0.718	4.10–2	4.20	4.23+5	1.07+7
Fe^{23+}	5.39–15	2.35+7	8.57–10	0.677	7.47–1	2.84–1	5.87+7	1.17+6
Fe^{24+}	5.67–16	1.02+8	9.46–10	0.732	5.19–1	2.79–1	6.01+7	9.97+6
Fe^{25+}	2.57–16	1.08+8	2.76–10	0.726	0	0	0	0
Ni	1.34–10	8.86+4	3.60–13	0.700	1.41–3	4.69–1	9.82+4	1.01+5
Ni^{+}	6.38–10	2.11+5	1.00–12	0.700	5.20–3	3.57–1	2.01+5	1.91+5
Ni^{2+}	1.51–10	4.08+5	1.40–12	0.700	1.38–2	2.81–1	3.05+5	2.32+5
Ni^{3+}	5.43–11	6.37+5	1.60–12	0.700	2.30–2	1.28–1	4.20+5	3.18+5
Ni^{4+}	2.46–11	8.76+5	3.85–12	0.746	4.19–2	4.17–2	5.56+5	4.55+5
Ni^{5+}	1.00–11	1.25+6	9.05–12	0.682	6.83–2	5.58–2	6.72+5	5.51+5
Ni^{6+}	5.29–11	1.54+6	1.75–11	0.699	1.22–1	3.46–2	7.93+5	5.28+5
Ni^{7+}	2.67–12	1.88+6	3.04–11	0.728	3.00–1	0	9.00+5	0
Ni^{8+}	1.26–12	2.24+6	8.91–11	0.759	1.50–1	1.90	1.00+6	5.50+5
Ni^{9+}	4.66–13	2.60+6	1.19–10	0.790	6.97–1	2.77–1	7.81+5	8.87+5
Ni^{10+}	1.36–12	3.73+6	1.50–10	0.810	7.09–1	1.35–1	7.64+5	1.80+6
Ni^{11+}	9.44–13	4.09+6	1.91–10	0.829	6.44–1	1.34–1	7.44+5	1.25+6
Ni^{12+}	6.35–13	4.46+6	2.29–10	0.828	5.25–1	1.92–1	6.65+5	1.89+6
Ni^{13+}	3.80–13	4.99+6	2.63–10	0.834	4.46–1	3.22–1	5.97+5	8.84+5

Table 5. Continued

Ion	A_{col}	T_{col}	A_{rad}	χ_{rad}	A_{di}	B_{di}	T_0	T_1
Ni^{14+}	2.17–13	5.39+6	3.16–10	0.836	3.63–1	3.37–1	5.24+5	1.29+6
Ni^{15+}	5.74–13	5.79+6	3.63–10	0.840	3.02–1	1.21–1	4.96+5	6.24+5
Ni^{16+}	1.04–13	6.63+6	4.03–10	0.846	1.02–1	5.14–2	4.46+5	1.59+6
Ni^{17+}	3.88–14	7.04+6	4.73–10	0.850	2.70–1	1.83–1	8.49+5	8.01+6
Ni^{18+}	5.65–14	1.80+7	5.25–10	0.836	4.67–2	7.56	1.36+6	9.32+6
Ni^{19+}	4.02–14	1.91+7	5.75–10	0.824	8.35–2	4.55	1.23+6	9.45+6
Ni^{20+}	3.25–14	2.04+7	6.38–10	0.816	9.96–2	4.87	1.06+6	9.45+6
Ni^{21+}	2.65–14	2.20+7	7.08–10	0.811	1.99–1	2.19	1.25+6	8.01+6
Ni^{22+}	1.83–14	2.33+7	7.94–10	0.808	2.40–1	1.15	1.23+6	7.57+6
Ni^{23+}	1.15–14	2.47+7	8.71–10	0.800	1.15–1	1.23	3.32+5	2.64+6
Ni^{24+}	8.39–15	2.66+7	8.91–10	0.718	3.16–2	1.32–1	6.45+5	1.93+6
Ni^{25+}	3.84–15	2.78+7	9.14–10	0.677	8.03–1	2.89–1	6.65+7	1.19+7
Ni^{26+}	4.21–16	1.19+8	1.06–09	0.732	5.75–1	2.86–1	6.81+7	9.08+6
Ni^{27+}	1.91–16	1.25+8	3.21–10	0.726	0	0	0	0

radiative recombination rates for such temperatures are needed. In this temperature range the equation

$$\alpha^{\rm rad}(X^{i+1}) = A_{100}\,[T_e/100\ {\rm K}]^{\chi_{\rm rad}} \tag{14a}$$

which is slightly different to equation (14) can be used. Fitted parameters A_{100} and $\chi_{\rm rad}$ for radiative recombinations rates of some singly ionized atoms with ionization potentials (< 13.6 eV) taken from Péquignot and Aldrovandi (1986) are given in the following table.

Fit parameters for radiative recombinations rates of singly ionized atoms with low ionization potentials in the interval 10–1000 K

Atom	A_{100}	χ_{rad}	*Atom*	A_{100}	χ_{rad}
C*	8.29–12	0.621	Cl*	8.10–12	0.607
Li*	9.60–12	0.606	K	5.54–12	0.683
Na	5.82–12	0.682	Ca	5.58–12	0.683
Mg	5.87–12	0.681	Ca+	2.79–11	0.647
Al*	1.54–11	0.567	Ti	5.50–12	0.684
Si*	8.42–12	0.617	Mn	5.45–12	0.686
P	6.98–12	0.645	Fe	5.45–12	0.686
S*	1.05–11	0.593	Ni	5.56–12	0.681

Note. All fits are better than 3% at 20–500 K and than 6% in 10–1000 K. Fits better than 2.5% at 10–1000 K are marked by an asterisk.

The recombination rates $\alpha^{\rm rad}$ for the hydrogenic ions have been approximated by Seaton (1959) in the form

$$\alpha^{\rm rad}(Te) = 5.197 \times 10^{-14} Z \beta^{1/2} S^A, \tag{15}$$

where Z is the nuclear charge, $\beta = I/kT_e = 157890Z^2/T_e$, where I is the atomic ionization potential and $S^A = 0.4288 + 0.5\ln\beta + 0.469\beta^{-1/3}$. The error of the

Table 6. Radiative recombination rates on the He I ion levels

Levels	*5000 K*	*10 000 K*	*15 000 K*	*20 000 K*
1^1S	2.23–13	1.62–13	1.14–13	1.15–13
2^1S	7.64–15	5.43–15	4.06–15	3.99–15
2^1P	2.11–14	1.32–14	8.16–15	7.95–15
3^1S	2.23–15	1.63–15	1.19–15	1.16–15
3^1P	8.92–15	5.65–15	3.34–15	3.16–15
3^1D	9.23–15	5.28–15	2.70–15	2.29–15
$\alpha^{\mathrm{B}}(n^1l)$	9.96–14	6.27–14	3.46–14	
2^3S	1.98–14	1.46–15	1.13–14	1.11–14
2^3P	8.78–14	5.77–14	3.59–14	3.59–14
3^3S	4.88–15	3.73–15	2.97–15	3.00–15
3^3P	3.20–14	1.95–14	1.30–14	1.25–14
3^3D	2.84–14	1.30–14	8.46–15	6.92–15
$\alpha^{\mathrm{B}}(n^3l)$	3.26–13	2.10–13	1.29–13	
$\alpha^{\mathrm{B}}(\mathrm{He}^+)$	4.26–13	2.73–13	1.55–13	

Note. Data for T_e = 5000–15 000 K are taken from a paper by Osterbrock (1974), for T_e = 20 000 K and 10 000 K (1^1S, 2^1S, 2^1P, 2^3S, 2^3P) from a paper by Ilmas and Nugis (1982).

approximation equation (15) does not exceed about 3% if $T_e \leq 10^6 Z^2$ and do not exceed about 30% if $T_e \leq 5 \times 10^6 Z^2$.

The approximate formulae for α^{rad} and α^B, for non-hydrogenic ions have been derived by Tarter (1971). They have the same form as in equation (15), but

$$S^A = 0.431 + 0.501 \ln \beta + 0.460 \beta^{-1/3}, \tag{16}$$

and for the recombination rate α^B the expression S^A must be replaced by

$$S^B = -0.493 + 0.504 \ln \beta + 0.857 \beta^{-1/3}. \tag{17}$$

The error of the fit formula, equation (15), for non-hydrogenic ions is estimated to be about 3% at characteristic temperatures of gaseous nebulae. Similar calculations of photorecombination rates for Fe ions have been carried out by Woods *et al.* (1981). The error of the numerical values obtained by them has been estimated to be about 10%.

An extensive compilation of recombination rates on the levels of hydrogenic, He-like and Li-like ions has been given in a paper by Arnaud and Rothenflug (1985) where the values of α^{rad} for some ions of these sequences have been improved and presented in the form equation (14).

Of considerable significance for calculating the line emission intensities in the spectra of gaseous nebulae are the recombination rates to the different levels of the most abundant species H^+, He^0 and He^+. In Table 6 the values of the recombination rates for lower states of He^+ are given.

3.4 Photoheating and Recombination Cooling

This section is based on the paper by Oskinova and Kholtygin (1996). The data for hydrogenic ions (H I and He II) which provide the main energy gains and losses for the astrophysical plasma are tabulated only here.

3.4.1 Photoheating rates

The mean energy gained by electrons per 1 cm^3 and per second due to photoionization of an atom (ion) species from level i is specified by the mean intensity of ionizing radiation $\bar{J}_\nu$ at photon frequency ν and by photoionization cross section for this level $\sigma_i^{\rm phi}(\nu)$:

$$n_i \Gamma_{ic} = n_i \int_{\nu_i^0}^{\infty} \sigma_i^{\rm phi}(\nu) \frac{4\pi \bar{J}_\nu(T_*)}{h\nu} (h\nu - h\nu_i^0) d\nu. \tag{18}$$

Here Γ_{ic} is the heating rate, index c holds for designation of the continuum state, n_i is the level i occupation number, and ν_i^0 is the treshold value of the frequency for ionization from level i.

Intensity of the ionizing radiation at a given point is determined both by the frequency distribution of the source of radiation and by the optical distances τ_ν of the screening medium. As a model we consider a point source of the ionizing radiation in the spherically-symmetric gaseous envelope. This model is good both for the gaseous nebulae and for stellar envelopes. The Planck function is usually a good approximation for radiation of the astrophysical sources. Taking into account the dilution and extinction of radiation in the medium we have

$$\bar{J}_\nu = \bar{J}_\nu(T_*) = W B_\nu(T_*) e^{-\tau_\nu}, \tag{19}$$

where W is the dilution coefficient and τ_ν the optical distance at frequency ν to the ionizing source. The dilution coefficient is

$$W = \frac{1}{2} \left(1 - \sqrt{(1 - \left(\frac{R_*}{R}\right)^2} \right). \tag{20}$$

Here R is the distance to the ionizing source and R_* is the radius of the ionizing source. The optical distance τ_ν is connnected with the value τ_i^0 of this quantity at the threshold frequency $\nu = \nu_i^0$ via relation

$$\tau_\nu = \tau_i^0 \frac{\sigma_i^{\rm phi}(\nu)}{\sigma_i^0} = \tau_i^0 f_i(\nu), \tag{21}$$

where $\sigma_i^0 = \sigma_i^{\rm phi}(\nu_i^0)$ and

$$\tau_i^0 = \int_{R_*}^{R} \sigma_i^0 n_i(R) dR. \tag{22}$$

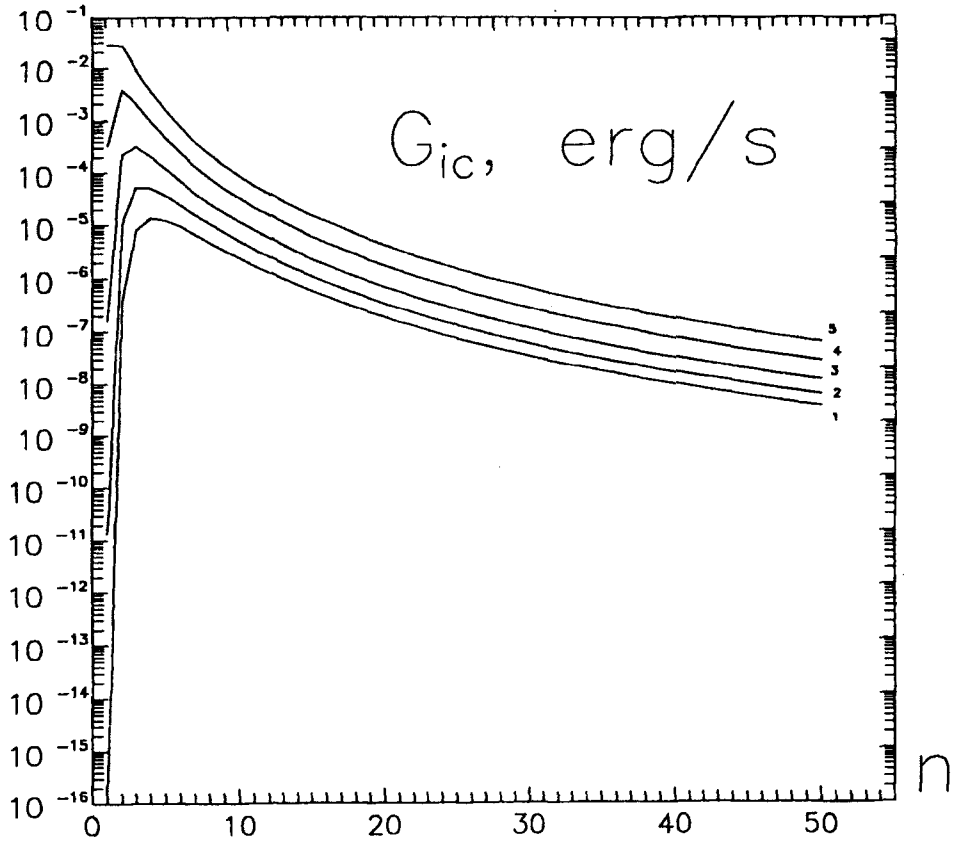

Figure 2 The dependence of He I heating rates on the level number n for values of Planck temperatures of an extrnal undiluted radiation field: *1*, $T_* = 20000$ K; *2*, $T_* = 30000$ K; *3*, $T_* = 50000$ K; *4*, $T_* = 100000$ K; *5*, $T_* = 200000$ K.

The energy of photoelectron E can be expressed in dimensionless threshold units $u = (h\nu - I_i)/I_i = E/I_i$, where $h\nu$ is the photon energy, $E = mv^2/2$ is the photoelectron energy and I_i is the ionization potential from level i. The frequency ν of an ionizing photon can be written in threshold units as $\nu = \nu_i^0(1+u)$. Substituting expression (19) into equation (18) and using the threshold units, one obtains

$$\Gamma_{ic} = W\, G_{ic} = W \frac{1}{8\pi^2} \frac{c\alpha^3}{a_0^3} \left[\frac{I_i}{Ry}\right]^3 I_i\, \mathcal{J}(\beta_i^*, \tau_i^0). \tag{23}$$

Here $\beta_i^* = I_i/kT_*$, and

$$\mathcal{J}(\beta_i^*, \tau_i^0) = \int_0^\infty \frac{u(1+u)^2 \sigma_i^{\mathrm{phi}}(\nu)\, e^{-\tau_i^0 f_i(u)}}{e^{\beta_i^*(u+1)} - 1} du. \tag{24}$$

Table 7. Photoheating rates G_{nc}(erg/s) for H I and He II levels ionized by the Planckian radiation field ($I_\nu = B_\nu(T_*)$) at optical depth $\tau = 0$ and $W = 1$, T_* is expressed in 10^4K

	H I				*He II*			
T_*	$n=1$	$n=2$	$n=3$	$n=4$	$n=1$	$n=2$	$n=3$	$n=4$
0.1	0.00+00	0.00+00	5.36-15	4.52-12	0.00+00	0.00+00	0.00+00	0.00+00
0.5	2.57-18	5.94-09	1.27-07	2.12-07	0.00+00	1.40-18	1.75-11	3.14-09
1.0	7.09-11	1.08-06	2.43-06	1.85-06	0.00+00	3.83-11	7.05-08	5.65-07
2.0	7.09-07	2.63-05	1.89-05	9.54-06	1.64-16	3.80-07	8.10-06	1.36-05
3.0	2.08-05	1.02-04	4.97-05	2.15-05	1.35-11	1.11-05	5.28-05	5.24-05
4.0	1.31-04	2.33-04	9.18-05	3.66-05	4.53-09	6.91-05	1.55-04	1.18-04
5.0	4.30-04	4.13-04	1.43-04	5.41-05	1.63-07	2.26-04	3.23-04	2.10-04
6.0	1.01-03	6.40-04	2.02-04	7.36-05	1.90-06	5.27-04	5.57-04	3.23-04
7.0	1.93-03	9.07-04	2.68-04	9.49-05	1.14-05	1.01-03	8.54-04	4.58-04
8.0	3.24-03	1.21-03	3.40-04	1.18-04	4.53-05	1.68-03	1.21-03	6.10-04
9.0	4.97-03	1.55-03	4.17-04	1.42-04	1.36-04	2.57-03	1.63-03	7.80-04
10.0	7.12-03	1.92-03	4.98-04	1.67-04	3.33-04	3.68-03	2.09-03	9.65-04
12.0	1.27-02	2.75-03	6.74-04	2.20-04	1.33-03	6.55-03	3.18-03	1.38-03
15.0	2.44-02	4.17-03	9.65-04	3.07-04	5.73-03	1.25-02	5.14-03	2.08-03
20.0	5.21-02	6.95-03	1.51-03	4.65-04	2.75-02	2.64-02	9.16-03	3.46-03
30.0	1.34-01	1.37-02	2.75-03	8.19-04	1.62-01	6.75-02	1.94-02	6.79-03
50.0	3.81-01	3.03-02	5.66-03	1.63-03	9.23-01	1.90-01	4.61-02	1.50-02
100.0	1.31+00	8.27-02	1.44-02	4.00-03	5.69+00	6.49-01	1.35-01	4.07-02

Here $\alpha = 1/137.036$ is the fine structure constant, $a_0 = 5.2918 \times 10^{-9}$ is the Bohr radius and c is the velocity of light.

In the case of photoheating and recombination cooling processes the level splitting of hydrogenic ions on to nl sublevels is not essential, so one can use the cross-sections averaged over values l:

$$\sigma_n(\nu) = \frac{1}{n^2} \sum_l (2l+1)\, \sigma_{nl}(\nu).$$

Confining our expressions with the second-order Gaunt correction terms, the averaged photoionization cross-sections from level n can be written in the form

$$\sigma_n(\nu) = \sigma_n^0 \frac{1}{(1+u)^3} \sum_{k=0}^{2} \frac{B_k^{(n)}}{(1+u)^k}. \tag{25}$$

Here $\sigma_n^0 = n\ \mathcal{G}_n\ 7.930 \times 10^{-18}/Z^2\mathrm{cm}^2$ is the threshold value of the cross-section from level n, where Z is the ion charge; $B_k^{(n)} = g_k^{(n)}/\mathcal{G}_n$ where the quantities $g_k^{(n)}$ are the coefficients of expansion of the Gaunt factor $g_n(\nu)$ for level n to the powers of $1/(1+u)$, given by Johnson (1972). The sum $\mathcal{G}_n = g_0^{(n)} + g_1^{(n)} + g_2^{(n)}$. Substituting the expansion (25) into equation (24) we find

$$\mathcal{J}(\beta_n^*, \tau_n^0) = \sigma_0 \sum_{k=0}^{2} B_k^{(n)} \left[\mathcal{Q}_k^f(\beta_n^*, \tau_n^0) - \mathcal{Q}_{k+1}^f(\beta_n^*, \tau_n^0) \right],$$

Table 8. Dependence of heating rate parameter $k_1(\tau)$ in G_{1c} of equation (26) on τ_n^0 and (T_*) in Planckian radiation

$log(1+\tau) \setminus T_*(K)$	5000	10 000	15 000	20 000	30 000	50 000
			H I			
0.0	0.8576	0.7531	0.6724	0.6080	0.5112	0.3902
0.2	0.8554	0.7476	0.6644	0.5981	0.4992	0.3774
0.4	0.8517	0.7386	0.6513	0.5823	0.4807	0.3582
0.6	0.8454	0.7236	0.6300	0.5572	0.4527	0.3311
0.8	0.8344	0.6980	0.5957	0.5189	0.4129	0.2955
1.0	0.8143	0.6552	0.5437	0.4648	0.3619	0.2540
1.2	0.7760	0.5893	0.4745	0.3988	0.3050	0.2109
1.4	0.7076	0.5051	0.3969	0.3295	0.2489	0.1705
1.6	0.6108	0.4157	0.3213	0.2645	0.1981	0.1349
1.8	0.5042	0.3328	0.2538	0.2076	0.1547	0.1049
2.0	0.4032	0.2596	0.1968	0.1604	0.1190	0.0805
2.2	0.3150	0.1996	0.1504	0.1222	0.0904	0.0611
2.4	0.2420	0.1514	0.1136	0.0921	0.0680	0.0459
2.6	0.1834	0.1137	0.0850	0.0688	0.0508	0.0343
2.8	0.1375	0.0846	0.0631	0.0510	0.0376	0.0254
3.0	0.1022	0.0626	0.0465	0.0376	0.0277	0.0187
3.2	0.0755	0.0460	0.0342	0.0276	0.0203	0.0137
3.4	0.0554	0.0336	0.0249	0.0201	0.0148	0.0100
3.6	0.0405	0.0245	0.0181	0.0146	0.0108	0.0073
3.8	0.0294	0.0178	0.0132	0.0106	0.0078	0.0053
4.0	0.0213	0.0128	0.0095	0.0077	0.0056	0.0038
$log(1+\tau) \setminus T_*(K)$	25 000	35 000	50 000	75 000	100 000	150 000
			He II			
0.0	0.8287	0.7766	0.7104	0.6229	0.5552	0.4574
0.2	0.8256	0.7719	0.7035	0.6134	0.5441	0.4448
0.4	0.8205	0.7642	0.6923	0.5982	0.5266	0.4256
0.6	0.8119	0.7511	0.6738	0.5739	0.4995	0.3974
0.8	0.7969	0.7287	0.6431	0.5362	0.4597	0.3588
1.0	0.7697	0.6901	0.5944	0.4823	0.4066	0.3114
1.2	0.7208	0.6278	0.5254	0.4153	0.3452	0.2606
1.4	0.6426	0.5434	0.4439	0.3439	0.2831	0.2116
1.6	0.5445	0.4504	0.3617	0.2765	0.2261	0.1679
1.8	0.4438	0.3616	0.2870	0.2174	0.1769	0.1309
2.0	0.3518	0.2836	0.2233	0.1680	0.1363	0.1005
2.2	0.2731	0.2186	0.1710	0.1281	0.1037	0.0763
2.4	0.2088	0.1661	0.1294	0.0966	0.0780	0.0574
2.6	0.1576	0.1249	0.0970	0.0722	0.0583	0.0428
2.8	0.1178	0.0931	0.0721	0.0535	0.0432	0.0317
3.0	0.0874	0.0689	0.0532	0.0395	0.0318	0.0234
3.2	0.0644	0.0506	0.0391	0.0289	0.0233	0.0171
3.4	0.0472	0.0370	0.0285	0.0211	0.0170	0.0125
3.6	0.0345	0.0270	0.0208	0.0154	0.0124	0.0091
3.8	0.0250	0.0196	0.0151	0.0111	0.0090	0.0066
4.0	0.0181	0.0142	0.0109	0.0080	0.0065	0.0048

where

$$Q_k^f(\beta^*, \tau) = \int_1^\infty \frac{e^{-\tau f(x)}}{x^k(e^{\beta^* x} - 1)} dx,$$

where $x = 1 + u$ and function $f(x)$ describes the frecuency dependence of the photoionization cross-section, given by equation (21).

Figure 2 illustrates the dependence of He I heating rates on the level number n. Similar dependence holds for H I and the other H-like ions. The calculated heating rates for the $n = 1$–4 levels of H I and He II at $\tau = 0$ are presented in Table 7.

For the case if $\tau \neq 0$ we should take into account the dependence of the values G_{nc} on τ. This dependence can be presented in the form

$$G_{nc}(\tau) = e^{-k_n \tau_n^0} G_{nc}(0), \tag{26}$$

where $G_{nc}(0)$ is the heating rate at $\tau_n^0 = 0$, and k_n is a slowly varying function of τ.

Values of parameter $k_1(\tau)$ for the ground ($n = 1$) levels of H I and He II are compiled in Table 8. Calculations by Kholtygin (1988) have demonstrated that the occupation numbers for $n > 2$ levels of H I and He II are very small even for dense outflowing envelopes of WR stars. As a result, the corresponding total optical depths of the envelopes are also small ($\tau_n^0 < 0.01$ for $n \geq 2$). These optical depth values are even smaller for envelopes (atmospheres) of other kinds of stars and gaseous nebulae. This means that one can use the heating rates presented in Table 7 for all $n > 2$ levels of H I and He II.

3.4.2 Recombination cooling rates

Cooling by spontaneous recombinations. Mean energy lost by electrons per 1 cm^3 and per second due to spontaneous electron recombinations with an ion X^+ to the level i of atom (or ion) X is determined by photorecombination cross-section to level $\sigma_i^{\rm phr}(\nu)$:

$$n_e L_i(T_e) = n_e \int_0^\infty \sigma_i^{\rm phi}(v) v f(v) \frac{mv^2}{2} dv. \tag{27}$$

Here $L_i(T_e)$ is the partial cooling rate for recombination on to level i. Adopting for the electron velocity distribution the Maxwell function and using threshold units, we can write:

$$L_i(T_e) = \frac{c\alpha^3}{2\sqrt{\pi}} \frac{g_i}{g^+} \left[\frac{I_i}{Ry}\right]^{3/2} \beta_i^{3/2} I_i \mathcal{L}(\beta_i), \tag{28}$$

where

$$\mathcal{L}(\beta_i) = \int_0^\infty u(1+u)^2 e^{-\beta u} \sigma_i^{\rm phi}(u) du.$$

Analytical presentation of the cross-sections (25) gives

$$\mathcal{L}(\beta) = \sigma_0 e^{-\beta} \sum_k B_k \left[E_k(\beta) - E_{k+1}(\beta)\right].$$

Table 9. Total cooling rates for spontaneous and stimulated recombination of H I and He II in units 10^{-25} erg s^{-1}

T_e (K)	Spontaneus	Stimulated, T_* (10^4 K)			
		1.00	2.00	5.00	10.00
		H I			
5000	3.78	1.48	2.03	2.81	3.48
10000	4.49	1.40	2.07	3.10	4.02
15000	4.90	1.30	2.03	3.20	4.30
20000	5.18	1.22	1.96	3.23	4.47
25000	5.39	1.14	1.89	3.23	4.57
30000	5.55	1.08	1.82	3.21	4.64
		He II			
5000	20.26	6.03	8.30	11.56	13.98
10000	24.95	5.67	8.43	12.75	16.06
15000	27.96	5.26	8.25	13.15	17.08
20000	30.33	4.93	7.97	13.27	17.68
25000	31.98	4.63	7.67	13.25	18.03
30000	33.48	4.38	7.45	13.16	18.24

Here $E_q(\beta)$ is the integral exponent (for details see Abramowitz and Stegun, 1964). The total recombinational cooling rate $L(T_e)$ is the sum of the partial rates (28). The calculated rates are given in Table 9.

Cooling by stimulated recombinations. For original Planck radiation, which is diluted and weakened by extinction (see equation (14), the cooling rate due to the stimulated recombination to level i is

$$R_{ci}^{\rm st} = W\, L_i^{\rm st} = W\, \frac{c\alpha^3}{2\sqrt{\pi}}\, \frac{g_i}{g^+} \left[\frac{I_i}{Ry}\right]^{3/2} \beta_i^{3/2} I_i e^{\beta} \sum_k B_k\, \mathcal{H}(\beta_i, \beta_i^*, \tau_i^0), \qquad (29)$$

where

$$\mathcal{H}(\beta_i, \beta_i^*, \tau_i^0) = \int_0^\infty \frac{u\,(u+1)^2 \sigma_i^{\rm phi}(u) e^{(-\beta_i u + \tau_i^0 f_i(u))}}{e^{\beta_i^*(u+1)} - 1} du.$$

Using the analytical expression of the photoionization cross-sections (25) we have

$$\mathcal{H}(\beta, \beta^*, \tau_i^0) = \sigma_i^0 \sum_{k=0}^{2} B_k^{(i)} \left(\mathcal{S}_k(\beta, \beta^*, \tau_i^0) - \mathcal{S}_{k+1}(\beta, \beta^*, \tau_i^0)\right),$$

where

$$\mathcal{S}_k(\beta, \beta^*, \tau) = e^{\beta} \int_1^\infty \frac{e^{-(\beta x + \tau f(x))}}{x^k (e^{\beta^* x} - 1)} dx.$$

The total stimulated photorecombination cooling rate $R^{\rm st}(T_e, T_*)$ or $L^{\rm st}(T_e, T_*)$ is the sum of all partial rates $R_{ci}^{\rm st}$ or $L_{ci}^{\rm st}$, respectively. Calculations (Oskinova and Kholtygin, 1996) show that the total stimulated photorecombination cooling rates depend very weakly on the optical depth of the ionized plasma.

The total recombination cooling rate. Total cooling rates is the sum of the spontaneous recombination and stimulated recombination cooling rates given above, i.e.

$$L^{\rm tot}(T_e) = L(T_e) + W\ L^{\rm st}(T_e, T_*).$$

Table 9 incorporates the total cooling rates for both spontaneous and stimulated photorecombinations. From the table one sees the evident circumstance that the contribution of stimulated recombination to the total cooling rates is important only for regions close to the ionizing source ($W > 0.1$).

3.5 Scaling Relations for Photoionization and Photorecombination rates

Some important scaling properties for recombination and ionization rates as well as for cooling and heating rates can be easily obtained for hydrogenic ions using the dependence of their photoionization cross-sections and level energies on the nuclear charge Z (see, Oskinova and Kholtygin, 1996). Then we have for photoionization rates

$$B_{ic} = B_{ic}(Z, T_e, \tau_i^0) = Z^4\ B_{ic}(1, T_e/Z^2, \tau_i^0), \tag{30}$$

and for photoheating rates

$$G_{ic} = G_{ic}(Z, T_e, \tau_i^0) = Z^6\ G_{ic}(1, T_e/Z^2, \tau_i^0). \tag{31}$$

Similar equalities hold also for photorecombination (spontaneous) rates

$$\alpha_i(T_e) = \alpha_i(Z, T_e) = Z\ \alpha_i(1, T_e/Z^2), \tag{32}$$

and for spontaneuos recombination cooling rates

$$L_i(T_e) = L_i(Z, T_e) = Z^3\ L_i(1, T_e/Z^2), \tag{33}$$

for stimulated photorecombination

$$\alpha_i^{\rm st}(T_e, T_*) = \alpha_i^{\rm st}(Z, T_e) = Z\ \alpha_i^{\rm st}(1, T_e/Z^2, T_*/Z^2), \tag{34}$$

and for stimulated photorecombination cooling rates

$$L_i^{st}(T_e, T_*) = L_i^{\rm st}(Z, T_e, T_*) = Z^3\ L_i^{\rm st}(1, T_e/Z^2, T_*/Z^2), \tag{35}$$

and taking into account equations (32)–(35) similar equations hold for the total recombination and cooling rates.

4 COLLISION PROCESSES

4.1 Electron Impact Ionization

Collisions of atoms and ions with electrons, protons and other particles can also have an effect upon the gas ionization degree in nebulae. The collisional ionization

rate increases rapidly at higher values of gas temperature. In planetary nebulae the most effective are the electron impacts in which an essential fraction of the kinetic energy will be wasted for the atom ionization:

$$X^i(\alpha\, nl) + e \rightarrow X^{i+1}(\alpha) + e' + e'',$$

where e and e' are the electron states before and after the ionizing collision with ions X^i. Here e'' is the removal electron, α is the quantum number set of the atomic remnant and nl is the same for the removal electron. For nebulae the rate of collisional ionization in atom impacts with heavy particles is relatively small and can be neglected.

The number of collisional ionization events resulting from the ion X^i impacts with electrons per unit volume and unit time is given by

$$\dot{N} = n(X^i) n_e q_{1c}(T_e),$$

where $q_{1c} = \langle v\sigma_{1c} \rangle$ is the collisional ionization rate. The ionization cross-section σ_{1c} and, consequently, the ionization rate for different atoms have been determined by numerous authors. Most often are used the approximation expressions for q_{1c} found by Lotz (1967a, b, 1968) for atoms from H to Ca. Shull and Van Steenberg (1982) using the experimental and theoretical cross-sections of collisional ionization have found simple approximation formula for collisional ionization of all ionization stages of C, N, O, Ne, Mg, Si, Ar, Ca, Fe and Ni in the form

$$q_{1c}(T_e) = \frac{A_{\rm col}\sqrt{T_e}\beta \exp(-\beta)}{\alpha I}\ {\rm cm}^3\ {\rm s}^{-1}, \tag{36}$$

where as in the previous section $\beta = I/kT_e = T_{\rm col}/T_e$; $I = kT_{\rm col}$ is the ionization energy from the ground state. For most cases $a \approx 0.1$. The last value holds always if $kT_e > 1$ eV. The values of $A_{\rm col}$ and $T_{\rm col}$ are given in Table 5. The formula for the collisional ionization rates for atoms and ions of isoelectronic series from H to Ni have been generalized in the paper by Arnaud and Rothenflug (1985) and they give the form

$$q_{1c}(T_e) = \frac{6.69 \times 10^{-7}}{(kT_e)^{3/2}} \sum_j F(\beta_j) \frac{\exp(-\beta_j)}{\beta_j}\ {\rm cm}^3\ {\rm s}^{-1}, \tag{37}$$

where $\beta_j = I_j/kT_e$ and I_j is the ionization energy from level j and

$$\begin{aligned} F(\beta_j) &= A_j\{1 - \beta_j\, f_1(\beta_j)\} + B_j\{1 + \beta_j - \beta_j(2 + \beta_j)\, f_1(\beta_j)\} \\ &+ C_j\, f_1(\beta_j) + D_j\, \beta_j\, f_2(\beta_j), \\ f_1(\beta) &= e^{\beta} E_1(\beta), \quad f_2(\beta) = e^{\beta} \int_1^{\infty} \frac{e^{-t\beta}}{t} \ln t\, dt. \end{aligned} \tag{38}$$

The numerical values of I_j, A_j, B_j, C_j and D_j are given in Table 10. Integral exponential function $E_1(\beta)$ can be calculated by the usual manner (see, e.g. Abramowitz and Stegun, 1964). The function $f_2(\beta)$ can be expressed with an error of about 1% in the following form (Hummer, 1983):

$$f_2(\beta) = P(\beta)/(Q(\beta)\beta^2), \tag{39}$$

Table 10. Parameters for electron collision ionization (equation (38))

Sequence	*Ion*	*Shell*	I_j (*eV*)	A_j	B_j	C_j	D_j
H	H^0	$1s$	13.6	22.8	−12.0	1.9	−22.6
	He^{1+}	$1s$	54.4	14.4	−5.6	1.9	−13.3
	C^{5+}	$1s$	490.0	12.2	−3.9	1.9	−10.3
	N^{6+}	$1s$	667.0	12.3	−4.0	1.9	−10.3
	O^{7+}	$1s$	871.0	12.3	−4.0	1.9	−10.3
	Ne^{9+}	$1s$	1362.0	12.5	−4.1	1.9	−10.4
	Na^{10+}	$1s$	1649.0	12.5	−4.1	1.9	−10.4
	Mg^{11+}	$1s$	1963.0	12.6	−4.2	1.9	−10.4
	Al^{12+}	$1s$	2304.0	12.6	−4.2	1.9	−10.4
	Si^{13+}	$1s$	2673.0	12.7	−4.3	1.9	−10.4
	S^{15+}	$1s$	3493.0	12.8	−4.3	1.9	−10.4
	Ar^{17+}	$1s$	4426.0	12.8	−4.4	1.9	−10.5
	Ca^{19+}	$1s$	5470.0	12.9	−4.4	1.9	−10.5
	Fe^{25+}	$1s$	9278.0	13.0	−4.5	1.9	−10.6
	Ni^{27+}	$1s$	10790.0	13.0	−4.5	1.9	−10.6
He	He^0	$1s^2$	24.6	17.8	−11.0	7.0	−23.2
	C^{4+}	$1s^2$	392.0	20.4	−6.1	4.5	−18.0
	N^{5+}	$1s^2$	552.0	20.8	−6.3	4.4	−18.2
	O^{6+}	$1s^2$	739.0	21.2	−6.5	4.3	−18.4
	Ne^{8+}	$1s^2$	1196.0	21.9	−6.8	4.2	−18.7
	Na^{9+}	$1s^2$	1465.0	22.2	−7.0	4.2	−18.8
	Mg^{10+}	$1s^2$	1762.0	22.4	−7.1	4.1	−18.9
	Al^{11+}	$1s^2$	2086.0	22.7	−7.2	4.1	−19.0
	Si^{12+}	$1s^2$	2438.0	22.9	−7.3	4.0	−19.1
	S^{14+}	$1s^2$	3224.0	23.3	−7.6	4.0	−19.3
	Ar^{16+}	$1s^2$	4121.0	23.7	−7.8	3.9	−19.5
	Ca^{18+}	$1s^2$	5129.0	24.0	−7.9	3.9	−19.6
	Fe^{24+}	$1s^2$	8828.0	24.8	−8.4	3.8	−20.0
	Ni^{26+}	$1s^2$	10280.0	25.0	−8.5	3.7	−20.1
Li	C^{3+}	$2s$	64.5	8.2	−2.7	1.4	−6.6
		$1s^2$	343.0	20.0	−5.6	4.1	−18.0
	N^{4+}	$2s$	97.9	10.5	−3.3	1.4	−7.7
		$1s^2$	493.0	20.5	−5.8	4.1	−18.0
	O^{5+}	$2s$	138.0	10.4	−3.3	1.4	−7.4
		$1s^2$	670.0	20.8	−6.0	4.1	−18.0
	Ne^{7+}	$2s$	239.0	10.1	−3.1	1.4	−7.1
		$1s^2$	1107.0	21.5	−6.4	4.1	−18.0
	Na^{8+}	$2s$	300.0	10.0	−3.0	1.4	−6.9
		$1s^2$	1366.0	21.7	−6.5	4.1	−18.0
	Mg^{9+}	$2s$	367.0	10.0	−3.0	1.4	−6.8
		$1s^2$	1653.0	22.0	−6.7	4.1	−18.0
	Al^{10+}	$2s$	442.0	9.9	−3.0	1.4	−6.7
		$1s^2$	1967.0	22.2	−6.8	4.1	−18.0
Li	Si^{11+}	$2s$	523.0	9.8	−2.9	1.4	−6.6
		$1s^2$	2309.0	22.4	−6.9	4.1	−18.0
	S^{13+}	$2s$	707.0	9.7	−2.8	1.4	−6.4
		$1s^2$	3075.0	22.8	−7.1	4.1	−18.0
	Ar^{15+}	$2s$	918.0	9.6	−2.8	1.4	−6.2
		$1s^2$	3951.0	23.1	−7.3	4.1	−18.0
	Ca^{17+}	$2s$	1157.0	9.5	−2.7	1.4	−6.1
		$1s^2$	4939.0	23.4	−7.4	4.1	−18.0

Table 10. Continued

Sequence	*Ion*	*Shell*	I_j (*eV*)	A_j	B_j	C_j	D_j
	Fe^{23+}	$2s$	2045.0	9.3	−2.6	1.4	−5.8
		$1s^2$	8580.0	24.1	−7.9	4.1	−18.0
	Ni^{25+}	$2s$	2399.0	9.2	−2.6	1.4	−5.7
		$1s^2$	10020.0	24.3	−8.0	4.1	−18.0
Be	C^{2+}	$2s^2$	47.9	23.2	−7.4	2.5	−19.4
		$1s^2$	325.0	20.0	−5.6	4.1	−18.0
	N^{3+}	$2s^2$	77.5	17.6	−3.8	2.8	−13.6
		$1s^2$	471.0	20.5	−5.8	4.1	−18.0
	O^{4+}	$2s^2$	114.0	16.4	−3.0	2.9	−12.0
		$1s^2$	644.0	20.8	−6.0	4.1	−18.0
	Ne^{6+}	$2s^2$	207.0	16.5	−3.1	2.8	−11.4
		$1s^2$	1073.0	21.5	−6.4	4.1	−18.0
	Na^{7+}	$2s^2$	264.0	16.8	−3.4	2.8	−11.4
		$1s^2$	1328.0	21.7	−6.5	4.1	−18.0
	Mg^{8+}	$2s^2$	328.0	17.1	−3.6	2.7	−11.5
		$1s^2$	1611.0	22.0	−6.7	4.1	−18.0
	Al^{9+}	$2s^2$	399.0	17.4	−3.8	2.7	−11.6
		$1s^2$	1921.0	22.2	−6.8	4.1	−18.0
	Si^{10+}	$2s^2$	476.0	17.7	−4.0	2.7	−11.7
		$1s^2$	2259.0	22.4	−6.9	4.1	−18.0
	S^{12+}	$2s^2$	652.0	18.1	−4.4	2.7	−11.8
		$1s^2$	3017.0	22.8	−7.1	4.1	−18.0
	Ar^{14+}	$2s^2$	855.0	18.4	−4.6	2.7	−12.0
		$1s^2$	3885.0	23.1	−7.3	4.1	−18.0
	Ca^{16+}	$2s^2$	1087.0	18.6	−4.6	2.7	−12.1
		$1s^2$	4865.0	23.4	−7.4	4.1	−18.0
	Fe^{22+}	$2s^2$	1950.0	19.2	−5.3	2.7	−12.3
		$1s^2$	8482.0	24.1	−7.9	4.1	−18.0
	Ni^{24+}	$2s^2$	2295.0	19.3	−5.4	2.7	−12.3
		$1s^2$	9914.0	24.3	−8.0	4.1	−18.0
B	C^{1+}	$2p$	24.4	16.0	−9.0	2.5	−10.5
		$2s^2$	30.9	23.7	−7.6	2.5	−21.7
	N^{2+}	$2p$	47.4	16.0	−7.5	2.3	−10.0
		$2s^2$	55.8	18.1	−4.0	2.8	−15.8
	O^{3+}	$2p$	77.4	15.0	−5.0	2.2	−10.5
		$2s^2$	87.6	16.8	−3.3	2.8	−14.1
	Ne^{5+}	$2p$	158.0	14.5	−4.6	1.9	−8.5
		$2s^2$	172.0	16.9	−3.4	2.8	−13.2
	Na^{6+}	$2p$	208.0	14.5	−4.6	1.8	−8.5
		$2s^2$	224.0	17.2	−3.7	2.8	−13.1
	Mg^{7+}	$2p$	266.0	14.5	−4.6	1.8	−8.5
		$2s^2$	283.0	17.5	−4.0	2.8	−13.0
	Al^{8+}	$2p$	330.0	14.0	−4.6	1.7	−8.5
		$2s^2$	350.0	17.9	−4.1	2.8	−13.0
	Si^{9+}	$2p$	401.0	14.0	−4.6	1.6	−8.5
		$2s^2$	423.0	18.0	−4.3	2.8	−12.9
	S^{11+}	$2p$	564.0	14.0	−4.6	1.5	−8.5
		$2s^2$	589.0	18.3	−4.7	2.8	−12.8
	Ar^{13+}	$2p$	755.0	14.0	−4.6	1.4	−8.5
		$2s^2$	784.0	18.5	−5.0	2.8	−12.6

Table 10. Continued

Sequence	*Ion*	*Shell*	I_j (*eV*)	A_j	B_j	C_j	D_j
	Ca^{15+}	$2p$	974.0	14.0	−4.6	1.3	−8.5
		$2s^2$	1006.0	18.7	−5.3	2.8	−12.4
	Fe^{21+}	$2p$	1799.0	13.7	−4.4	1.0	−8.3
		$2s^2$	1842.0	19.2	−5.5	2.8	−12.3
	Ni^{23+}	$2p$	2131.0	13.7	−4.4	1.0	−8.3
		$2s^2$	2178.0	19.4	−5.7	2.8	−12.3
C	C^0	$2p^2$	11.3	6.0	−16.0	12.0	−15.1
		$2s^2$	16.6	24.3	−7.8	2.5	−24.0
	N^{1+}	$2p^2$	29.6	21.0	−9.0	5.3	−22.5
		$2s^2$	36.7	18.5	−4.3	2.8	−18.0
	O^{2+}	$2p^2$	54.9	25.0	−7.0	5.0	−18.0
		$2s^2$	63.8	17.3	−3.5	2.9	−16.1
	Ne^{4+}	$2p^2$	126.0	25.5	−8.5	4.5	−16.8
		$2s^2$	139.0	17.4	−3.8	2.8	−14.9
	Na^{5+}	$2p^2$	172.0	25.5	−8.5	4.2	−16.8
		$2s^2$	186.0	17.6	−4.0	2.8	−14.7
	Mg^{6+}	$2p^2$	225.0	25.5	−8.5	4.1	−16.8
		$2s^2$	241.0	18.0	−4.3	2.8	−14.5
	Al^{7+}	$2p^2$	285.0	27.0	−8.5	3.9	−16.8
		$2s^2$	302.0	18.2	−4.5	2.8	−14.3
	Si^{8+}	$2p^2$	351.0	27.0	−8.5	3.8	−16.8
		$2s^2$	371.0	18.3	−4.7	2.8	−14.1
	S^{10+}	$2p^2$	505.0	27.0	−8.5	3.3	−16.8
		$2s^2$	528.0	18.6	−5.1	2.8	−13.7
	Ar^{12+}	$2p^2$	686.0	27.0	−8.5	3.0	−16.8
		$2s^2$	713.0	18.7	−5.4	2.8	−13.3
	Ca^{14+}	$2p^2$	894.0	27.0	−8.5	2.7	−16.8
		$2s^2$	925.0	18.9	−5.8	2.8	−12.8
	Fe^{20+}	$2p^2$	1689.0	27.4	−8.8	2.0	−16.6
		$2s^2$	1731.0	19.2	−5.5	2.8	−12.3
	Ni^{22+}	$2p^2$	2011.0	27.4	−8.8	2.0	−16.6
		$2s^2$	2056.0	19.4	−5.7	2.8	−12.3
N	N^0	$2p^3$	14.5	19.5	−30.5	15.0	−29.0
		$2s^2$	20.3	19.0	−4.5	2.8	−20.2
	O^{1+}	$2p^3$	35.1	25.0	−8.0	8.4	−29.5
		$2s^2$	42.6	17.8	−3.8	2.9	−18.1
	Ne^{3+}	$2p^3$	97.1	34.0	−10.0	7.5	−25.0
		$2s^2$	108.0	17.8	−4.0	2.8	−16.7
	Na^{4+}	$2p^3$	138.0	35.1	−12.4	7.2	−25.1
		$2s^2$	151.0	18.0	−4.3	2.8	−16.3
	Mg^{5+}	$2p^3$	187.0	35.1	−12.4	6.9	−25.1
		$2s^2$	201.0	18.2	−4.6	2.8	−16.0
	Al^{6+}	$2p^3$	241.0	38.3	−12.4	6.7	−25.1
		$2s^2$	258.0	18.4	−4.8	2.8	−15.7
	Si^{7+}	$2p^3$	303.0	38.3	−12.4	6.4	−25.1
		$2s^2$	321.0	18.6	−5.1	2.8	−15.4
	S^{9+}	$2p^3$	447.0	38.3	−12.4	5.5	−25.1
		$2s^2$	469.0	18.8	−5.5	2.8	−14.7
	Ar^{11+}	$2p^3$	618.0	38.3	−12.4	4.8	−25.1
		$2s^2$	644.0	18.9	−5.9	2.8	−14.0

Table 10. Continued

Sequence	*Ion*	*Shell*	I_j (*eV*)	A_j	B_j	C_j	D_j
	Ca^{13+}	$2p^3$	818.0	38.3	−12.4	4.3	−25.1
		$2s^2$	847.0	19.0	−6.3	2.8	−13.2
	Fe^{19+}	$2p^3$	1582.0	41.1	−13.2	3.1	−24.9
		$2s^2$	1622.0	19.2	−5.5	2.8	−12.3
	Ni^{21+}	$2p^3$	1894.0	41.1	−13.2	2.9	−24.9
		$2s^2$	1938.0	19.4	−5.7	2.8	−12.3
O	O^0	$2p^4$	13.6	9.5	−17.5	12.5	−19.5
		$2s^2$	28.5	18.2	−4.0	2.8	−20.2
	Ne^{2+}	$2p^4$	63.5	33.0	−17.5	11.2	−33.0
		$2s^2$	86.2	18.2	−4.4	2.8	−18.4
	Na^{3+}	$2p^4$	99.0	43.3	−16.3	10.7	−33.4
		$2s^2$	126.0	18.4	−4.7	2.8	−18.0
	Mg^{4+}	$2p^4$	141.0	43.3	−16.3	10.3	−33.4
		$2s^2$	172.0	18.6	−4.9	2.8	−17.5
	Al^{5+}	$2p^4$	190.0	49.5	−16.3	9.9	−33.4
		$2s^2$	225.0	18.9	−5.2	2.8	−17.1
	Si^{6+}	$2p^4$	246.0	49.5	−16.3	9.6	−33.4
		$2s^2$	285.0	19.0	−5.4	2.8	−16.6
	S^{8+}	$2p^4$	379.0	49.5	−16.3	8.0	−33.4
		$2s^2$	426.0	19.1	−5.9	2.8	−15.6
	Ar^{10+}	$2p^4$	539.0	49.5	−16.3	6.9	−33.4
		$2s^2$	594.0	19.2	−6.4	2.8	−14.6
	Ca^{12+}	$2p^4$	727.0	49.5	−16.3	6.1	−33.4
		$2s^2$	790.0	19.2	−6.8	2.8	−13.7
	Fe^{18+}	$2p^4$	1456.0	54.8	−17.6	4.1	−33.2
		$2s^2$	1548.0	19.2	−5.5	2.8	−12.3
O	Ni^{20+}	$2p^4$	1756.0	54.8	−17.6	3.9	−33.2
		$2s^2$	1858.0	19.4	−5.7	2.8	−12.3
F	Ne^{1+}	$2p^5$	41.1	37.0	−33.0	15.5	−46.0
		$2s^2$	66.4	18.6	−4.6	2.8	−20.2
	Na^{2+}	$2p^5$	71.7	50.1	−20.2	14.8	−41.7
		$2s^2$	102.0	18.8	−5.0	2.8	−19.6
	Mg^{3+}	$2p^5$	109.0	50.1	−20.2	14.2	−41.7
		$2s^2$	144.0	19.0	−5.3	2.8	−19.0
	Al^{4+}	$2p^5$	154.0	60.8	−20.2	13.7	−41.7
		$2s^2$	194.0	19.1	−5.5	2.8	−18.4
	Si^{5+}	$2p^5$	205.0	60.8	−20.2	13.2	−41.7
		$2s^2$	250.0	19.3	−5.8	2.8	−17.8
	S^{7+}	$2p^5$	328.0	60.8	−20.2	10.9	−41.7
		$2s^2$	384.0	19.3	−6.3	2.8	−16.6
	Ar^{9+}	$2p^5$	479.0	60.8	−20.2	9.3	−41.7
		$2s^2$	545.0	19.4	−6.8	2.8	−15.3
	Ca^{11+}	$2p^5$	657.0	60.8	−20.2	8.1	−41.7
		$2s^2$	734.0	19.4	−7.3	2.8	−14.1
	Fe^{17+}	$2p^5$	1358.0	68.5	−22.0	5.1	−41.5
		$2s^2$	1471.0	19.2	−5.5	2.8	−12.3
	Ni^{19+}	$2p^5$	1648.0	68.5	−22.0	4.9	−41.5
		$2s^2$	1775.0	19.4	−5.7	2.8	−12.3
Ne	Ne^0	$2p^6$	21.6	40.0	−42.0	18.0	−56.0
		$2s^2$	48.5	19.0	−4.9	2.8	−22.0

Table 10. Continued

Sequence	*Ion*	*Shell*	I_j (*eV*)	A_j	B_j	C_j	D_j
	Na^{1+}	$2p^6$	47.3	40.0	−28.0	19.4	−60.0
		$2s^2$	80.1	19.2	−5.3	2.8	−21.2
	Mg^{2+}	$2p^6$	80.1	55.5	−24.1	18.7	−65.0
		$2s^2$	119.0	19.3	−5.6	2.8	−20.5
	Al^{3+}	$2p^6$	120.0	72.0	−24.1	18.0	−50.0
		$2s^2$	164.0	19.5	−5.9	2.8	−19.8
	Si^{4+}	$2p^6$	167.0	72.0	−24.1	17.4	−50.0
		$2s^2$	217.0	19.6	−6.2	2.8	−19.0
	S^{6+}	$2p^6$	281.0	72.0	−24.1	14.2	−50.0
		$2s^2$	343.0	19.6	−6.8	2.8	−17.5
	Ar^{8+}	$2p^6$	423.0	72.0	−24.1	11.9	−50.0
		$2s^2$	498.0	19.6	−7.3	2.8	−16.0
	Ca^{10+}	$2p^6$	592.0	72.0	−24.1	10.3	−50.0
		$2s^2$	680.0	19.5	−7.8	2.8	−14.5
	Fe^{16+}	$2p^6$	1265.0	82.2	−26.4	6.1	−49.8
		$2s^2$	1397.0	19.2	−5.5	2.8	−12.3
	Ni^{18+}	$2p^6$	1546.0	82.2	−26.4	5.9	−49.8
		$2s^2$	1694.0	19.4	−5.7	2.8	−12.3
Na	Na^0	$3s$	5.1	16.0	−1.0	0.2	−13.5
		$2p^6$	34.0	63.9	−27.0	33.0	−80.0
	Mg^{1+}	$3s$	15.0	9.0	−3.6	0.3	−5.4
		$2p^6$	65.0	37.7	−30.0	24.8	−62.0
		$2s^2$	104.5	17.6	−5.2	3.3	−19.0
	Al^{2+}	$3s$	28.4	6.3	−2.4	0.5	−4.1
		$2p^6$	103.0	31.3	−22.7	21.0	−44.1
		$2s^2$	145.6	12.1	−3.5	3.3	−13.1
	Si^{3+}	$3s$	45.1	9.0	−3.0	0.6	−5.8
		$2p^6$	148.0	66.7	−24.8	18.7	−65.0
		$2s^2$	193.5	22.0	−7.2	3.3	−20.9
	S^{5+}	$3s$	88.1	9.0	−2.8	0.7	−5.4
		$2p^6$	257.0	73.2	−27.0	15.8	−61.1
		$2s^2$	309.7	23.1	−8.0	3.3	−19.5
	Ar^{7+}	$3s$	143.0	9.0	−2.7	0.8	−5.4
		$2p^6$	394.0	74.8	−27.0	14.1	−58.6
		$2s^2$	453.1	23.4	−8.3	3.3	−18.5
	Ca^{9+}	$3s$	211.0	9.0	−2.6	0.9	−5.4
		$2p^6$	559.0	76.1	−27.0	12.8	−56.6
		$2s^2$	623.7	23.5	−8.4	3.3	−17.8
	Fe^{15+}	$3s$	490.0	9.0	−2.6	1.0	−5.4
		$2p^6$	1223.0	78.9	−27.0	10.6	−52.8
		$2s^2$	1298.6	23.5	−7.8	3.3	−16.5
	Ni^{17+}	$3s$	608.0	9.0	−2.6	1.0	−5.4
		$2p^6$	1500.0	79.6	−27.0	10.1	−51.9
		$2s^2$	1578.0	23.5	−7.8	3.3	−16.2
Mg	Mg^0	$3s^2$	7.6	18.0	−1.0	0.6	−4.0
		$2p^6$	54.0	37.7	−30.0	24.8	−62.0
		$2s^2$	92.2	17.6	−5.2	3.3	−19.0
	Al^{1+}	$3s^2$	18.8	17.0	−6.0	1.0	−8.0
		$2p^6$	90.0	31.3	−22.7	21.0	−44.1
		$2s^2$	131.0	12.1	−3.5	3.3	−13.1

Table 10. Continued

Sequence	*Ion*	*Shell*	I_j (*eV*)	A_j	B_j	C_j	D_j
	Si^{2+}	$3s^2$	33.5	19.8	−5.7	1.3	−11.9
		$2p^6$	133.0	66.7	−24.8	18.7	−65.0
		$2s^2$	176.6	22.0	−7.2	3.3	−20.9
	S^{4+}	$3s^2$	72.7	19.8	−5.7	1.6	−11.9
		$2p^6$	239.0	73.2	−27.0	15.8	−61.1
		$2s^2$	288.2	23.1	−8.0	3.3	−19.5
	Ar^{6+}	$3s^2$	125.0	19.8	−5.7	1.9	−11.9
		$2p^6$	373.0	74.8	−27.0	14.1	−58.6
		$2s^2$	427.0	23.4	−8.3	3.3	−18.5
	Ca^{8+}	$3s^2$	189.0	19.8	−5.7	1.8	−11.9
		$2p^6$	534.0	76.1	−27.0	12.8	−56.6
		$2s^2$	593.1	23.5	−8.4	3.3	−17.8
Mg	Fe^{14+}	$3s^2$	457.0	19.8	−5.7	2.1	−11.9
		$2p^6$	1185.0	78.9	−27.0	10.6	−52.8
		$2s^2$	1254.3	23.5	−7.8	3.3	−16.5
	Ni^{16+}	$3s^2$	571.0	19.8	−5.7	2.2	−11.9
		$2p^6$	1458.0	79.6	−27.0	10.1	−51.9
		$2s^2$	1529.0	23.5	−7.8	3.3	−16.2
Al	Al^0	$3p$	6.0	47.0	−26.0	0.6	−39.0
		$3s^2$	10.6	55.1	−37.2	1.4	−41.0
	Si^{1+}	$3p$	16.3	50.4	−33.4	0.6	−36.9
		$3s^2$	22.9	55.1	−37.2	1.4	−41.0
	S^{3+}	$3p$	47.3	50.4	−33.4	0.6	−36.9
		$3s^2$	57.6	55.1	−37.2	1.4	−41.0
	Ar^{5+}	$3p$	91.2	50.4	−33.4	0.6	−36.9
		$3s^2$	105.0	55.1	−37.2	1.4	−41.0
	Ca^{7+}	$3p$	148.0	11.1	−3.4	1.3	−7.3
		$3s^2$	165.0	22.7	−8.6	1.9	−15.5
	Fe^{13+}	$3p$	392.0	9.1	−2.6	1.4	−5.6
		$3s^2$	421.0	28.2	−12.5	2.3	−19.4
	Ni^{15+}	$3p$	499.0	9.1	−2.6	1.4	−5.6
		$3s^2$	531.0	28.2	−12.5	2.3	−19.4
Si	Si^0	$3p^2$	8.1	74.5	−49.4	1.3	−54.6
		$3s^2$	13.5	53.8	−35.8	1.4	−40.7
	S^{2+}	$3p^2$	35.0	74.5	−49.4	1.3	−54.6
		$3s^2$	43.8	53.8	−35.8	1.4	−40.7
	Ar^{4+}	$3p^2$	75.2	74.5	−49.4	1.3	−54.6
		$3s^2$	87.6	53.8	−35.8	1.4	−40.7
	Ca^{6+}	$3p^2$	128.0	22.9	−7.4	2.8	−15.9
		$3s^2$	144.0	21.9	−7.7	1.9	−14.9
	Fe^{12+}	$3p^2$	361.0	21.3	−5.9	3.0	−12.6
		$3s^2$	388.0	26.4	−11.2	2.3	−18.1
	Ni^{14+}	$3p^2$	464.0	21.3	−5.9	3.0	−12.6
		$3s^2$	494.0	26.4	−11.2	2.3	−18.1
P	S^{1+}	$3p^3$	23.4	98.7	−65.4	1.9	−72.3
		$3s^2$	30.7	52.5	−34.5	1.4	−40.5
	Ar^{3+}	$3p^3$	59.7	98.7	−65.4	1.9	−72.3
		$3s^2$	70.4	52.5	−34.5	1.4	−40.5
	Ca^{5+}	$3p^3$	109.0	40.9	−13.6	3.4	−30.1
		$3s^2$	123.0	20.4	−6.3	2.1	−13.8

Table 10. Continued

Sequence	*Ion*	*Shell*	I_j (*eV*)	A_j	B_j	C_j	D_j
	Fe^{11+}	$3p^3$	331.0	33.4	−9.7	4.6	−20.8
		$3s^2$	356.0	24.6	−9.8	2.3	−16.8
	Ni^{13+}	$3p^3$	430.0	33.4	−9.7	4.6	−20.8
		$3s^2$	458.0	24.6	−9.8	2.3	−16.8
S	S^0	$3p^4$	10.4	6.0	−22.0	20.0	−20.0
		$3s^2$	20.2	51.3	−33.2	1.4	−40.2
	Ar^{2+}	$3p^4$	40.9	122.8	−81.4	2.6	−90.0
		$3s^2$	55.5	51.3	−33.2	1.4	−40.2
	Ca^{4+}	$3p^4$	84.5	47.1	−14.5	4.8	−35.5
		$3s^2$	104.0	18.9	−5.1	1.6	−13.2
	Fe^{10+}	$3p^4$	290.0	45.6	−13.9	6.2	−30.0
		$3s^2$	324.0	22.8	−8.4	2.3	−15.4
	Ni^{12+}	$3p^4$	384.0	45.6	−13.9	6.2	−30.0
		$3s^2$	423.0	22.8	−8.4	2.3	−15.4
Cl	Ar^{1+}	$3p^5$	27.6	147.0	−97.4	3.2	−107.7
		$3s^2$	41.7	50.0	−31.8	1.4	−40.0
	Ca^{3+}	$3p^5$	67.3	55.8	−15.8	6.4	−44.5
		$3s^2$	86.4	16.2	−3.2	1.8	−11.6
	Fe^{9+}	$3p^5$	262.0	57.7	−18.6	7.8	−40.3
		$3s^2$	297.0	21.0	−7.1	2.3	−14.1
	Ni^{11+}	$3p^5$	352.0	57.7	−18.6	7.8	−40.3
		$3s^2$	393.0	21.0	−7.1	2.3	−14.1
Ar	Ar^0	$3p^6$	15.8	171.1	−78.0	3.8	−169.0
		$3s^2$	29.2	48.7	−30.5	1.4	−39.7
	Ca^{2+}	$3p^6$	51.2	74.3	−24.2	7.0	−63.0
		$3s^2$	70.1	17.6	−3.8	1.9	−13.8
	Fe^{8+}	$3p^6$	235.0	69.9	−23.7	9.5	−51.7
		$3s^2$	271.0	19.2	−5.7	2.3	−12.7
	Ni^{10+}	$3p^6$	321.0	69.9	−23.7	9.5	−51.7
		$3s^2$	363.0	19.2	−5.7	2.3	−12.7
K	Ca^{1+}	$4s$	11.9	7.9	−2.0	0.2	−6.0
		$3p^6$	37.0	74.3	−24.2	7.0	−63.0
		$3s^2$	45.2	17.6	−3.8	1.9	−13.8
	Fe^{7+}	$3d$	151.0	11.6	−3.7	0.4	−5.6
		$3p^6$	213.0	69.9	−23.7	9.5	−51.7
		$3s^2$	249.0	19.2	−5.7	2.3	−12.7
	Ni^{9+}	$3d$	225.0	12.5	−4.0	0.4	−6.0
		$3p^6$	296.0	69.9	−23.7	9.5	−51.7
		$3s^2$	338.0	19.2	−5.7	2.3	−12.7
Ca	Ca^0	$4s^2$	6.1	2.5	−2.5	8.0	−5.5
		$3p^6$	28.0	74.3	−24.2	7.0	−63.0
		$3s^2$	40.3	17.6	−3.8	1.9	−13.8
	Fe^{6+}	$3d^2$	125.0	22.1	−7.0	0.7	−10.7
		$3p^6$	190.0	69.9	−23.7	9.5	−51.7
		$3s^2$	227.0	19.2	−5.7	2.3	−12.7
	Ni^{8+}	$3d^2$	193.0	24.1	−7.7	0.7	−11.7
		$3p^6$	271.0	69.9	−23.7	9.5	−51.7
		$3s^2$	313.0	19.2	−5.7	2.3	−12.7

Table 10. Continued

Sequence	*Ion*	*Shell*	I_j (*eV*)	A_j	B_j	C_j	D_j
Sc	Fe^{5+}	$3d^3$	99.0	30.6	−9.7	1.0	−14.8
		$3p^6$	169.0	69.9	−23.7	9.5	−51.7
		$3s^2$	205.0	19.2	−5.7	2.3	−12.7
	Ni^{7+}	$3d^3$	162.0	34.5	−10.9	1.1	−16.7
		$3p^6$	246.0	69.9	−23.7	9.5	−51.7
		$3s^2$	288.0	19.2	−5.7	2.3	−12.7
Ti	Fe^{4+}	$3d^4$	75.0	36.5	−11.6	1.1	−17.6
		$3p^6$	147.0	69.9	−23.7	9.5	−51.7
		$3s^2$	184.0	19.2	−5.7	2.3	−12.7
	Ni^{6+}	$3d^4$	133.0	43.2	−13.7	1.3	−20.9
		$3p^6$	221.0	69.9	−23.7	9.5	−51.7
		$3s^2$	264.0	19.2	−5.7	2.3	−12.7
V	Fe^{3+}	$3d^5$	54.8	39.9	−12.7	1.2	−19.3
		$3p^6$	125.0	69.9	−23.7	9.5	−51.7
		$3s^2$	162.0	19.2	−5.7	2.3	−12.7
	Ni^{5+}	$3d^5$	108.0	50.8	−16.1	1.6	−24.6
		$3p^6$	196.0	69.9	−23.7	9.5	−51.7
		$3s^2$	239.0	19.2	−5.7	2.3	−12.7
Cr	Fe^{2+}	$3d^6$	30.7	32.7	−10.4	1.0	−15.8
		$3p^6$	103.0	69.9	−23.7	9.5	−51.7
		$3s^2$	141.0	19.2	−5.7	2.3	−12.7
	Ni^{4+}	$3d^6$	75.5	49.9	−15.9	1.6	−24.1
		$3p^6$	171.0	69.9	−23.7	9.5	−51.7
		$3s^2$	215.0	19.2	−5.7	2.3	−12.7
Mn	Fe^{1+}	$4s$	16.2	90.0	−60.0	0.2	−86.0
		$3d^6$	17.5	18.6	−5.9	0.6	−0.9
		$3p^6$	81.0	69.9	−23.7	9.5	−51.7
	Ni^{3+}	$3d^7$	54.9	50.3	−16.0	1.6	−24.3
		$3p^6$	146.0	69.9	−23.7	9.5	−51.7
		$3s^2$	190.0	19.2	−5.7	2.3	−12.7
Fe	Fe^0	$4s^2$	7.9	3.9	−1.3	0.4	−1.9
		$3d^6$	9.0	9.6	−3.0	0.3	−4.6
		$3p^6$	59.0	69.9	−23.7	9.5	−51.7
	Ni^{2+}	$3d^8$	35.2	44.4	−14.1	1.4	−21.5
		$3p^6$	122.0	69.9	−23.7	9.5	−51.7
		$3s^2$	166.0	19.2	−5.7	2.3	−12.7
Co	Ni^{1+}	$3d^9$	18.2	32.0	−10.0	1.0	−15.4
		$3p^6$	97.0	69.9	−23.7	9.5	−51.7
		$3s^2$	142.0	19.2	−5.7	2.3	−12.7
Ni	Ni^0	$4s^2$	8.7	2.5	−0.8	0.2	−1.2
		$3d^8$	10.0	12.6	−4.0	0.4	−6.1
		$3p^6$	73.0	69.9	−23.7	9.5	−51.7

where

$$P(\beta) = \sum_{j=0}^{13} \beta^{-j} p_j, \quad Q(\beta) = \sum_{j=0}^{14} \beta^{-j} q_j.$$

The values of parameters p_j and q_j are in series expansion of $f_2(\beta)$ given in the above-cited paper.

Table 11. Parameters A and χ in equation (40) for the different shells

Type of Shell	*Shell*	A	χ
Outer shell	$1s^q$	5.08	0.477
	$2s^q$	5.23	0.594
	$2p^q$	6.23	0.697
	$3s^q$	4.85	0.640
	$3p^q$	5.33	0.738
	$4s^q$	4.15	0.720
Inner shell	$1s^2$	4.81	0.393
	$2s^2$	5.13	0.562
	$2p^6$	6.33	0.666
	$3s^2$	4.98	0.652
	$3p^6$	5.33	0.734

Shevelko *et al.* (1983) using the cross-sections of collisional ionization calculated in the Coulomb–Born approximation found a more simple analytical expression for the collisional ionization rate $q_{1c}(T_e)$ for the outermost shell $(nl)^q$, namely,

$$q_{1c}(T_e) = \frac{10^{-8} q\,[I_H/I]^{3/2} \exp(-\beta)\,\sqrt{\beta} A}{\beta + \chi}, \tag{40}$$

where as before, $\beta = I/kT_e$ and I is the ionization energy (from the ground level) and the quantities A and χ are the parameters, the values of which for some atomic shells are presented in Table 11. The error estimation of this approximation for collision ionization rate is about 6% for $0.1 < \beta < 10$. Equation (40) is applicable for all elements, but at small values of Z the error increases.

The rate of collisional ionization (in units of $\mathrm{cm}^3\ \mathrm{s}^{-1}$) for complex ions can also be calculated using the formula of Burgess and Chidichimo (1983)

$$q_{1c}(T_e) = 2.17 \times 10^{-8} \bar{C} \sum_j q_j (I_H/I_j)^{3/2}\, \beta_j^{1/2} E_1(\beta_j)\, \omega,$$

$$\omega = [\ln(I/I_j + \beta_j^{-1})]^{\tau/((I+kT_e)/I_j)}, \tag{41}$$

$$\tau = (1/4)\,\{[(100Z + 91)/(4Z + 3)]^{1/2} - 5\}. \tag{42}$$

In equation (41) q_j is the number of electrons in shell j and I_j is the corresponding ionization energy. Summation over all shells of the atomic configuration takes into account also the electron excitation from internal shells and the processes of autoionization. The values of parameters $\bar{C}, I_j$ and q_j are given in Table 12. If the autoionization contribution is negligible then the letter a has been added to the ion symbol and if it is essential then the letter b. Symbol (i) added to q_j values denotes the presence of strong resonances in ionization cross-sections for corresponding shells, but symbol (ii) denotes the presence of a large number of weak resonances. For light ions with $2 \le Z \le 5$ we can take $\bar{C} = 2.30\ (\pm 19\%)$. This value is well consistent with the value of 2.2 found by Seaton (1964). If we incorporate

Table 12. Parameters q_j, I_j and $\bar{C}$ in equation (41) for determination of the collisional ionization rates

Ion	*Shell*	q_j	I_j (*eV*)	$\bar{C}$
B^{+3}(a)	$1s^2$	2	259.4	2.34±19%
C^{+4}(a)	$1s^2$	2	392.1	2.28±32%
N^{+5}(a)	$1s^2$	2	552.1	3.28±11%
C^{+3}(b)	$1s^22s$	2(*i*),1	300, 64.5	1.82±7%
N^{+4}(b)	$1s^22s$	2(*i*),1	420, 97.9	2.38±5%
O^{+5}(b)	$1s^22s$	2(*i*),1	530, 138.1	2.61±10%
C^{+2}(b)	$2s^2$	2	47.9	2.56±10%
N^{+3}(b)	$2s^2$	2	77.5	2.44±12%
O^{+4}(b)	$1s^22s^2$	2(*i*),2	550, 113.9	2.87±3%
N^{+2}(b)	$2s^22p$	2(*ii*)+1	47.4	2.18±3%
O^{+3}(b)	$2s^22p$	2(*ii*)+1	77.4	2.25±5%
O^{+2}(b)	$2s^22p^2$	2(*ii*)+2	54.9	2.36±5%
Mg^{+2}(b)	$2s^22p^6$	2(*i*),6	105.1, 80.1	1.71±22%
Al^{+2}(b)	$2p^63s$	6(*i*),1	80.0, 28.4	1.23±8%
Si^{+3}(b)	$2p^63s$	6(*i*),1	112.0, 45.1	1.92±16%
Ar^{+}(b)	$3s^23p^5$	2(*i*),5	30.6, 27.6	1.86±11%
Ar^{+2}(b)	$3s^23p^4$	2(*i*),4	44.5, 40.7	2.40±20%
Ar^{+3}(b)	$3s^23p^3$	2(*ii*)+3	250.0, 59.8	2.11±12%
Ar^{+4}(b)	$3s^23p^2$	2(*ii*)+2	250.0, 75.0	2.40±15%
Ar^{+5}(b)	$3s^23p$	2(*ii*)+1	250.0, 91.0	2.72±14%

Note. The letter *a* has been added to the ion symbol if the contribution of autoionization is negligible and if it is essential then the letter *b* follows, symbol (*i*) added to q_j values denotes the presence of strong resonances in ionization cross sections for corresponding shells, but symbol (*ii*) denotes the presence of a large number of weak resonances.

approximately the contributions of autoionization then $\bar{C}$=2.70, which is close to the value of 2.77 found by Lotz (1968). Comparison of the collision ionization rates given by Arnaud and Rothenflug (1985) with corresponding data by other authors showed that the discrepancy with the data by Summers (1974) and by Burgess and Chidichimo can reach from 1.2 to 2 times, but the consistency with reformulated results by Lotz (1967a, b; 1968) is good.

References to the many modern collision ionization data for astrophysically important ions are given by Butler (1992) (see also Appendix A).

4.2 The Electron Impact Excitation

Excitation of atoms by electron impacts is the main mechanism of formation of the spectral lines between low excited levels in the spectra of gaseous nebulae. The electron impact excitation rates usually are expressed via the effective collision strengths γ_{ij}:

$$q_{ij} = \frac{8.6287 \times 10^{-6}}{g_i T_e^{1/2}} \gamma_{ij} \exp(-\beta_{ij}). \tag{43}$$

Table 13. Coefficients of polynomial fit to the effective collision strengths for H I and He II (equation (47)). Low-temperature (500 K $\leq T_e \leq$ 72 000 K) coefficients for H I are listed in the first line, and the high-temperature one (55 000 K $\leq T_e \leq$ 500 000 K) below

Transition	*a*	*b*	*c*	*d*
	Coefficients of polynomial fit for H I			
$1s-2s$	2.297−01	5.318−06	−1.180−10	8.636−16
	2.694−01	7.883−07	−1.394−12	1.451−18
$1s-2p$	3.435−01	1.297−05	2.178−12	7.928−17
	3.162−01	1.472−05	−8.275−12	−8.794−19
$1s-3s$	6.250−02	−1.299−06	2.666−11	−1.596−16
	3.337−02	2.223−07	−2.794−13	1.516−19
$1s-3p$	9.941−02	−3.714−07	6.134−11	−3.973−16
	6.985−02	2.538−06	−8.729−13	−1.291−18
$1s-3d$	5.030−02	7.514−07	−2.826−13	−1.098−17
	5.051−02	7.876−07	−2.072−12	1.902−18
$1s-4s$	1.909−04	1.983−07	−8.325−13	1.128−18
	2.867−03	1.222−07	−2.323−13	1.865−19
$1s-4p$	1.527−03	1.001−06	−2.192−12	9.348−18
	1.958−03	9.525−07	−9.668−13	4.807−19
$1s-4d$	1.339−03	6.470−07	−4.397−12	1.736−17
	1.007−02	3.508−07	−8.024−13	6.764−19
$1s-4f$	3.266−03	3.908−07	−8.778−12	6.171−17
	9.103−03	−6.105−09	−6.191−15	1.268−20
$1s-5$	2.035−02	6.076−07	−2.175−13	−2.459−18
	2.002−02	6.325−07	−7.070−13	4.096−19
$1s-6$	1.136−02	3.428−07	−1.467−13	−1.300−18
	1.123−02	3.549−07	−3.998−13	2.331−19
$1s-7$	6.999−03	2.126−07	−9.963−14	−7.672−19
	6.940−03	2.194−07	−2.483−13	1.453−19
$1s-8$	4.624−03	1.410−07	−6.969−14	−4.927−19
	4.593−03	1.453−07	−1.648−13	9.667−20
$1s-9$	3.217−03	9.836−08	−5.031−14	−3.361−19
	3.199−03	1.012−07	−1.150−13	6.758−20
$1s-10$	2.329−03	7.135−08	−3.737−14	−2.400−19
	2.318−03	7.334−08	−8.349−14	4.910−20
$1s-11$	1.741−03	5.342−08	−2.845−14	−1.775−19
	1.727−03	5.493−08	−6.270−14	3.695−20
$1s-12$	1.336−03	4.103−08	−2.213−14	−1.351−19
	1.326−03	4.213−08	−4.821−14	2.844−20
$1s-13$	1.048−03	3.220−08	−1.754−14	−1.053−19
	1.040−03	3.310−08	−3.786−14	2.236−20
$1s-14$	8.369−04	2.574−08	−1.413−14	−8.368−20
	8.305−04	2.645−08	−3.028−14	1.790−20
$1s-15$	6.791−04	2.090−08	−1.154−14	−6.763−20
	6.740−04	2.147−08	−2.460−14	1.455−20
$2s-3s$	1.326+00	−1.727−05	8.914−10	−6.101−15
	6.311−01	2.881−05	−5.372−11	4.095−17
$2s-3p$	2.040+00	−1.580−05	1.908−09	−1.027−14
	−1.334+00	1.229−04	−9.676−11	2.842−17
$2s-3d$	6.342−01	3.090−04	−2.205−09	8.592−15
	5.567+00	1.494−04	−3.692−10	3.280−16

Table 13. Continued

Transition	*a*	*b*	*c*	*d*
$2s-4s$	1.762−02	8.683−06	−4.800−11	1.810−16
	1.210−01	5.439−06	−1.103−11	9.116−18
$2s-4p$	6.398−02	2.578−05	−8.551−11	6.504−16
	−2.905−02	2.640−05	−3.072−11	1.769−17
$2s-4d$	1.125−01	4.732−05	−4.285−10	1.971−15
	9.485−01	1.785−05	−4.590−11	4.181−17
$2s-4f$	1.140−01	5.154−05	−4.757−10	1.989−15
	1.191+00	1.544−05	−4.739−11	4.605−17
$2s-5$	3.647−01	7.145−05	−5.516−10	2.257−15
	1.483+00	3.251−05	−7.279−11	6.337−17
$2s-6$	1.793−01	3.599−05	−2.848−10	1.189−15
	7.466−01	1.605−05	−3.611−11	3.149−17
$2s-7$	1.027−01	2.090−05	−1.675−10	7.056−16
	4.333−01	9.222−06	−2.081−11	1.817−17
$2s-8$	6.476−02	1.330−05	−1.073−10	4.546−16
	2.755−01	5.832−06	−1.318−11	1.151−17
$2s-9$	4.366−02	9.020−06	−7.313−11	3.108−16
	1.868−01	3.940−06	−8.916−12	7.790−18
$2s-10$	3.092−02	6.415−06	−5.217−11	2.223−16
	1.328−01	2.795−06	−6.329−12	5.531−18
$2s-11$	4.162−02	8.661−06	−7.060−11	3.013−16
	1.793−01	3.766−06	−8.534−12	7.458−18
$2s-12$	3.155−02	6.580−06	−5.373−11	2.295−16
	1.362−01	2.857−06	−6.477−12	5.661−18
$2s-13$	2.450−02	5.121−06	−4.186−11	1.790−16
	1.059−01	2.221−06	−5.036−12	4.402−18
$2s-14$	1.943−02	4.066−06	−3.327−11	1.424−16
	8.411−02	1.762−06	−3.996−12	3.493−18
$2s-15$	1.567−02	3.283−06	−2.689−11	1.151−16
	6.791−02	1.422−06	−3.225−12	2.820−18
$2p-3s$	1.690+00	4.563−05	−6.605−10	4.445−15
	2.325−00	1.361−05	−2.702−11	2.397−17
$2p-3p$	4.923+00	1.525−04	4.370−11	−3.914−15
	6.984+00	1.260−04	−3.014−10	2.655−16
$2p-3d$	4.540+00	7.943−04	5.831−09	−5.106−14
	2.922+00	1.089−03	−1.705−09	1.237−15
$2p-4s$	5.237−02	2.123−05	−2.176−10	1.027−15
	4.788−01	5.979−06	−1.667−11	1.605−17
$2p-4p$	1.798−01	8.300−05	−6.927−10	2.843−15
	1.738+00	3.133−05	−8.425−11	7.825−17
$2p-4d$	1.591−02	1.673−04	9.135−10	−1.037−14
	1.004+00	1.889−04	−3.433−10	2.692−16
$2p-4f$	2.254−01	1.365−04	−7.926−10	1.760−15
	2.785+00	6.406−05	−1.773−10	1.638−16
$2p-5$	1.094+00	2.143−04	−1.655−09	6.771−15
	4.449+00	9.754−05	−2.184−10	1.901−16
$2p-6$	5.379−01	1.080−04	−8.544−10	3.566−15
	2.240+00	4.814−05	−1.083−10	9.448−17
$2p-7$	3.080−01	6.270−05	−5.024−10	2.117−15
	1.300+00	2.767−05	−6.243−11	5.450−17

Table 13. Continued

Transition	*a*	*b*	*c*	*d*
$2p-8$	1.943−01	3.989−05	−3.220−10	1.364−15
	8.266−01	1.750−05	−3.955−11	3.454−17
$2p-9$	1.310−01	2.706−05	−2.194−10	9.325−16
	5.604−01	1.182−05	−2.675−11	2.337−17
$2p-10$	9.276−02	1.925−05	−1.565−10	6.668−16
	3.984−01	8.384−06	−1.899−11	1.659−17
$2p-11$	4.935−02	1.027−05	−8.372−11	3.572−16
	2.126−01	4.466−06	−1.012−11	8.844−18
$2p-12$	3.741−02	7.803−06	−6.371−11	2.722−16
	1.615−01	3.388−06	−7.680−12	6.713−18
$2p-13$	2.906−02	6.072−06	−4.964−11	2.123−16
	1.256−01	2.634−06	−5.972−12	5.220−18
$2p-14$	2.304−02	4.821−06	−3.945−11	1.688−16
	9.973−02	2.089−06	−4.738−12	4.142−18
$2p-15$	1.858−02	3.893−06	−3.188−11	1.365−16
	8.053−02	1.686−06	−3.825−12	3.344−18
$3s-4s$	−3.207−01	9.244−05	2.640−09	−2.373−14
	5.697−01	1.740−04	−3.941−10	3.383−16
$3s-4p$	−3.391−01	1.439−04	6.033−09	−3.777−14
	−9.335+00	5.521−04	−5.967−10	3.066−16
$3s-4d$	−7.739−01	3.623−04	5.026−09	−5.334−14
	5.641+00	4.317−04	−1.094−09	9.844−16
$3s-4f$	5.916−01	8.966−04	−1.047−08	5.520−14
	1.721+01	2.360−04	−6.574−10	6.176−16
$3s-5$	2.928+01	6.550−04	−8.590−09	4.996−14
	3.970+01	1.720−04	−3.724−10	3.239−16
$3s-6$	5.342−01	3.320−04	−3.031−09	1.350−14
	6.269+00	1.223−04	−2.925−10	2.617−16
$3s-7$	2.760−01	1.686−04	−1.584−09	7.202−15
	3.203+00	6.023−05	−1.451−10	1.301−16
$3s-8$	1.633−01	9.909−05	−9.445−10	4.340−15
	1.888+00	3.482−05	−8.421−11	7.561−17
$3s-9$	1.055−01	6.385−05	−6.139−10	2.838−15
	1.219+00	2.221−05	−5.384−11	4.839−17
$3s-10$	7.256−02	4.383−05	−4.239−10	1.967−15
	8.377−01	1.515−05	−3.678−11	3.307−17
$3s-11$	5.223−02	3.153−05	−3.061−10	1.425−15
	6.030−01	1.085−05	−2.636−11	2.371−17
$3s-12$	3.895−02	2.351−05	−2.289−10	1.067−15
	4.497−01	8.059−06	−1.960−11	1.764−17
$3s-13$	2.988−02	1.803−05	−1.759−10	8.214−16
	3.451−01	6.166−06	−1.501−11	1.350−17
$3s-14$	2.346−02	1.415−05	−1.383−10	6.466−16
	2.709−01	4.831−06	−1.176−11	1.059−17
$3s-15$	1.877−02	1.133−05	−1.108−10	5.185−16
	2.169−01	3.860−06	−9.403−12	8.463−18
$3p-4s$	−6.866−04	2.012−04	−7.084−10	1.046−15
	2.290+00	1.391−04	−2.365−10	1.857−16

Table 13. Continued

Transition	*a*	*b*	*c*	*d*
$3p - 4p$	−8.174−01	7.898−04	3.420−09	−5.299−14
	1.220+01	6.924−04	−1.698−09	1.512−15
$3p - 4d$	−2.328+00	1.173−03	2.980−08	−2.176−13
	−2.813+01	2.839−03	−4.071−09	2.739−15
$3p - 4f$	2.395−01	3.736−03	−2.458−08	6.950−14
	7.244+01	1.596−03	−4.378−09	4.085−15
$3p - 5$	9.375+01	2.382−03	−3.124−08	1.817−13
	1.316+02	6.255−04	−1.354−09	1.178−15
$3p - 6$	1.729+00	1.075−03	−9.810−09	4.370−14
	2.029+01	3.957−04	−9.468−10	8.471−16
$3p - 7$	8.934−01	5.457−04	−5.125−09	2.331−14
	1.037+01	1.950−04	−4.696−10	4.212−16
$3p - 8$	5.286−01	3.207−04	−3.057−09	1.405−14
	6.112+00	1.127−04	−2.725−10	2.447−16
$3p - 9$	3.416−01	2.066−04	−1.987−09	9.187−15
	3.945+00	7.189−05	−1.734−10	1.566−16
$3p - 10$	2.348−01	1.419−04	−1.372−09	6.368−15
	2.711+00	4.903−05	−1.190−10	1.070−16
$3p - 11$	1.690−01	1.020−04	−9.908−10	4.611−15
	1.952+00	3.511−05	−8.533−11	7.675−17
$3p - 12$	1.261−01	7.608−05	−7.407−10	3.454−15
	1.456+00	2.608−05	−6.345−11	5.708−17
$3p - 13$	9.671−02	5.835−05	−5.694−10	2.659−15
	1.117+00	1.996−05	−4.857−11	4.371−17
$3p - 14$	7.593−02	4.580−05	−4.477−10	2.093−15
	8.769−01	1.563−05	−3.807−11	3.426−17
$3p - 15$	6.076−02	3.665−05	−3.587−10	1.678−15
	7.019−01	1.249−05	−3.043−11	2.739−17
$3d - 4s$	4.602−01	3.451−04	−6.086−09	3.823−14
	6.804+00	1.948−05	−7.904−11	8.451−17
$3d - 4p$	1.456+00	1.303−03	−2.048−08	1.240−13
	2.532+01	1.621−04	−4.722−10	4.641−16
$3d - 4d$	1.424−01	2.943−03	−1.984−08	5.541−14
	5.947+01	1.183−03	−3.338−09	3.153−15
$3d - 4f$	−1.121+01	8.600−03	8.986−08	−8.662−13
	2.948+01	1.147−02	−2.131−08	1.690−14
$3d - 5$	2.332+02	4.300−03	−5.639−08	3.279−13
	3.016+02	1.129−03	−2.445−09	2.126−15
$3d - 6$	3.481+00	2.163−03	−1.975−08	8.799−14
	4.085+01	7.967−04	−1.906−09	1.705−15
$3d - 7$	1.799+00	1.099−03	−1.032−08	4.693−14
	2.087+01	3.925−04	−9.455−10	8.479−16
$3d - 8$	1.064+00	6.457−04	−6.155−09	2.828−14
	1.231+01	2.269−04	−5.487−10	4.927−16
$3d - 9$	6.877−01	4.160−04	−4.000−09	1.850−14
	7.942+00	1.447−04	−3.508−10	3.153−16
$3d - 10$	4.728−01	2.856−04	−2.762−09	1.282−14
	5.458+00	9.872−05	−2.397−10	2.155−16

Table 13. Continued

Transition	*a*	*b*	*c*	*d*
$3d-11$	3.403−01	2.055−04	−1.995−09	9.283−15
	3.929+00	7.068−05	−1.718−10	1.545−16
$3d-12$	2.538−01	1.532−04	−1.491−09	6.954−15
	2.931+00	5.252−05	−1.277−10	1.149−16
$3d-13$	1.947−01	1.175−04	−1.146−09	5.353−15
	2.249+00	4.018−05	−9.779−11	8.800−17
$3d-14$	1.529−01	9.222−05	−9.013−10	4.213−15
	1.766+00	3.148−05	−7.665−11	6.899−17
$3d-15$	1.223−01	7.380−05	−7.222−10	3.379−15
	1.413+00	2.515−05	−6.127−11	5.515−17
$4s-5$	2.555+02	1.523−02	−2.326−07	1.438−12
	3.560+02	5.331−03	−1.698−08	1.837−14
$4s-6$	7.880+01	2.140−03	−3.123−08	1.896−13
	1.131+02	4.513−04	−1.007−09	8.872−16
$4s-7$	7.059−01	9.385−04	−9.491−09	4.473−14
	1.757+01	2.978−04	−7.355−10	6.671−16
$4s-8$	4.012−01	4.747−04	−4.937−09	2.371−14
	8.960+00	1.452−04	−3.616−10	3.289−16
$4s-9$	2.497−01	2.796−04	−2.952−09	1.432−14
	5.301+00	8.379−05	−2.096−10	1.909−16
$4s-10$	1.667−01	1.810−04	−1.928−09	9.410−15
	3.440+00	5.355−05	−1.343−10	1.225−16
$4s-11$	1.174−01	1.249−04	−1.340−09	6.562−15
	2.379+00	3.665−05	−9.214−11	8.407−17
$4s-12$	8.609−02	9.041−05	−9.735−10	4.781−15
	1.724+00	2.636−05	−6.637−11	6.058−17
$4s-13$	6.518−02	6.781−05	−7.324−10	3.604−15
	1.294+00	1.968−05	−4.961−11	4.530−17
$4s-14$	5.063−02	5.231−05	−5.664−10	2.791−15
	9.990−01	1.513−05	−3.817−11	3.487−17
$4s-15$	4.018−02	4.130−05	−4.479−10	2.210−15
	7.890−01	1.191−05	−3.007−11	2.747−17
$4p-5$	9.393+02	5.559−02	−8.491−07	5.251−12
	1.306+03	1.946−02	−6.199−08	6.707−14
$4p-6$	2.445+02	7.474−03	−1.091−07	6.621−13
	3.645+02	1.576−03	−3.518−09	3.099−15
$4p-7$	2.363+00	3.142−03	−3.177−08	1.498−13
	5.881+01	9.968−04	−2.462−09	2.233−15
$4p-8$	1.343+00	1.589−03	−1.653−08	7.939−14
	3.000+01	4.862−04	−1.211−09	1.101−15
$4p-9$	8.359−01	9.359−04	−9.882−09	4.794−14
	1.775+01	2.805−04	−7.017−10	6.392−16
$4p-10$	5.582−01	6.058−04	−6.456−09	3.150−14
	1.152+01	1.793−04	−4.497−10	4.101−16
$4p-11$	3.931−01	4.183−04	−4.484−09	2.197−14
	7.966+00	1.227−04	−3.085−10	2.815−16
$4p-12$	2.882−01	3.027−04	−3.259−09	1.601−14
	5.771+00	8.825−05	−2.222−10	2.028−16

Table 13. Continued

Transition	*a*	*b*	*c*	*d*
$4p - 13$	2.182−01	2.270−04	−2.452−09	1.207−14
	4.332+00	6.589−05	−1.661−10	1.517−16
$4p - 14$	1.695−01	1.751−04	−1.896−09	9.345−15
	3.344+00	5.066−05	−1.278−10	1.167−16
$4p - 15$	1.345−01	1.383−04	−1.499−09	7.399−15
	2.641+00	3.988−05	−1.007−10	9.197−17
$4d - 5$	1.469+03	1.284−01	−1.962−06	1.213−11
	2.317+03	4.497−02	−1.432−07	1.550−13
$4d - 6$	4.677+02	1.487−02	−2.170−07	1.317−12
	7.064+02	3.136−03	−7.000−09	6.166−15
$4d - 7$	4.527+00	6.019−03	−6.087−08	2.869−13
	1.127+02	1.910−03	−4.716−09	4.278−15
$4d - 8$	2.573+00	3.044−03	−3.166−08	1.521−13
	5.746+01	9.314−04	−2.319−09	2.109−15
$4d - 9$	1.601+00	1.793−03	−1.893−08	9.183−14
	3.399+01	5.374−04	−1.344−09	1.224−15
$4d - 10$	1.069+00	1.160−03	−1.237−08	6.034−14
	2.206+01	3.434−04	−8.615−10	7.856−16
$4d - 11$	7.529−01	8.012−04	−8.590−09	4.208−14
	1.526+01	2.351−04	−5.909−10	5.392−16
$4d - 12$	5.521−01	5.798−04	−6.243−09	3.066−14
	1.106+01	1.691−04	−4.256−10	3.885−16
$4d - 13$	4.180−01	4.349−04	−4.697−09	2.311−14
	8.299+00	1.262−04	−3.181−10	2.905−16
$4d - 14$	3.247−01	3.355−04	−3.632−09	1.790−14
	6.406+00	9.705−05	−2.448−10	2.236−16
$4d - 15$	2.577−01	2.648−04	−2.872−09	1.417−14
	5.060+00	7.640−05	−1.928−10	1.762−16
$4f - 5$	1.475+03	2.653−01	−4.053−06	2.506−11
	3.225+03	9.290−02	−2.959−07	3.201−13
$4f - 6$	1.003+03	1.995−02	−2.911−07	1.767−12
	1.323+03	4.207−03	−9.389−09	8.270−15
$4f - 7$	7.765+00	1.032−02	−1.044−07	4.920−13
	1.932+02	3.275−03	−8.090−09	7.338−15
$4f - 8$	4.413+00	5.222−03	−5.431−08	2.609−13
	9.856+01	1.598−03	−3.977−09	3.618−15
$4f - 9$	2.747+00	3.075−03	−3.247−08	1.575−13
	5.831+01	9.217−04	−2.306−09	2.100−15
$4f - 10$	1.834+00	1.991−03	−2.121−08	1.035−13
	3.784+01	5.890−04	−1.478−09	1.347−15
$4f - 11$	1.291+00	1.374−03	−1.473−08	7.218−14
	2.617+01	4.032−04	−1.014−09	9.248−16
$4f - 12$	9.470−01	9.945−04	−1.071−08	5.260−14
	1.896+01	2.900−04	−7.300−10	6.664−16
$4f - 13$	7.169−01	7.459−04	−8.056−09	3.965−14
	1.423+01	2.165−04	−5.457−10	4.983−16
$4f - 14$	5.570−01	5.755−04	−6.230−09	3.071−14
	1.099+01	1.665−04	−4.199−10	3.835−16
$4f - 15$	4.420−01	4.543−04	−4.927−09	2.431−14
	8.678+00	1.310−04	−3.308−10	3.022−16

Table 13. Continued

Transition	*a*	*b*	*c*	*d*
5 – 6	−9.122+02	1.260+00	−1.070−05	4.290−11
	2.166+04	4.690−01	−1.122−06	1.008−12
5 – 7	3.959+01	2.108−01	−2.162−06	1.020−11
	3.874+03	6.443−02	−1.596−07	1.452−13
5 – 8	3.691+01	7.806−02	−8.485−07	4.166−12
	1.465+03	2.207−02	−5.556−08	5.082−14
5 – 9	2.352+01	3.911−02	−4.365−07	2.179−12
	7.410+02	1.062−02	−2.698−08	2.476−14
5 – 10	1.542+01	2.296−02	−2.601−07	1.310−12
	4.374+02	6.096−03	−1.556−08	1.430−14
5 – 11	1.062+01	1.487−02	−1.699−07	8.608−13
	2.841+02	3.889−03	−9.962−09	9.167−15
5 – 12	7.642+00	1.029−02	−1.183−07	6.014−13
	1.969+02	2.663−03	−6.838−09	6.297−15
5 – 13	5.695+00	7.464−03	−8.621−08	4.394−13
	1.431+02	1.918−03	−4.935−09	4.547−15
5 – 14	4.368+00	5.617−03	−6.508−08	3.323−13
	1.078+02	1.436−03	−3.698−09	3.409−15
5 – 15	3.430+00	4.348−03	−5.051−08	2.583−13
	8.353+01	1.107−03	−2.854−09	2.632−15
6 – 7	−3.431+03	4.116+00	−3.853−05	1.679−10
	7.146+04	1.379+00	−3.346−06	3.023−12
6 – 8	4.397+01	6.434−01	−7.008−06	3.431−11
	1.187+04	1.794−01	−4.501−07	4.118−13
6 – 9	8.927+01	2.325−01	−2.667−06	1.350−11
	4.380+03	5.990−02	−1.527−07	1.405−13
6 – 10	6.153+01	1.152−01	−1.354−06	6.957−12
	2.192+03	2.846−02	−7.324−08	6.759−14
6 – 11	4.165+01	6.729−02	−8.024−07	4.156−12
	1.288+03	1.621−02	−4.197−08	3.881−14
6 – 12	2.923+01	4.349−02	−5.232−07	2.724−12
	8.351+02	1.031−02	−2.678−08	2.480−14
6 – 13	2.130+01	3.008−02	−3.641−07	1.902−12
	5.790+02	7.050−03	−1.837−08	1.702−14
6 – 14	1.603+01	2.185−02	−2.656−07	1.391−12
	4.213+02	5.079−03	−1.326−08	1.229−14
6 – 15	1.239+01	1.647−02	−2.008−07	1.054−12
	3.179+02	3.804−03	−9.944−09	9.226−15
7 – 8	−9.280+03	1.116+01	−1.122−04	5.167−10
	1.954+05	3.426+00	−8.397−06	7.624−12
7 – 9	6.658+01	1.651+00	−1.884−05	9.487−11
	3.057+04	4.266−01	−1.080−06	9.917−13
7 – 10	2.172+02	5.833−01	−6.977−06	3.615−11
	1.103+04	1.392−01	−3.582−07	3.309−13
7 – 11	1.535+02	2.858−01	−3.499−06	1.838−11
	5.458+03	6.530−02	−1.696−07	1.572−13
7 – 12	1.049+02	1.660−01	−2.060−06	1.090−11
	3.189+03	3.693−02	−9.653−08	8.966−14

Table 13. Continued

Transition	*a*	*b*	*c*	*d*
7 – 13	7.412+01	1.070−01	−1.339−06	7.118−12
	2.062+03	2.338−02	−6.136−08	5.707−14
7 – 14	5.428+01	7.389−02	−9.304−07	4.963−12
	1.429+03	1.595−02	−4.200−08	3.910−14
7 – 15	4.103+01	5.366−02	−6.786−07	3.629−12
	1.039+03	1.148−02	−3.029−08	2.282−14
8 – 9	−2.069+04	2.637+01	−2.802−04	1.342−09
	4.651+05	7.527+00	−1.859−05	1.694−11
8 – 10	2.055+02	3.731+00	−4.420−05	2.276−10
	6.930+04	9.038−01	−2.302−06	2.121−12
8 – 11	5.123+02	1.292+00	−1.599−05	8.442−11
	2.450+04	2.891−01	−7.487−07	6.939−13
8 – 12	3.578+02	6.265−01	−7.922−06	4.235−11
	1.200+04	1.340−01	−3.505−07	3.260−13
8 – 13	2.438+02	3.616−01	−4.633−06	2.494−11
	6.970+03	7.523−02	−1.981−07	1.846−13
8 – 14	1.721+02	2.322−01	−3.000−06	1.622−11
	4.493+03	4.741−02	−1.254−07	1.170−13
8 – 15	1.260+02	1.601−01	−2.081−06	1.129−11
	3.106+03	3.226−02	−8.559−08	7.997−14
9 – 10	−4.032+04	5.614+01	−6.231−04	3.073−09
	9.956+05	1.506+01	−3.741−05	3.418−11
9 – 11	6.989+02	7.655+00	−9.352−05	4.903−10
	1.425+05	1.754+00	−4.489−06	4.146−12
9 – 12	1.141+03	2.605+00	−3.313−05	1.777−10
	4.949+04	5.510−01	−1.435−06	1.333−12
9 – 13	7.755+02	1.250+00	−1.624−05	8.808−11
	2.401+04	2.526−01	−6.645−07	6.196−13
9 – 14	5.234+02	7.175−01	−9.437−06	5.153−11
	1.386+04	1.408−01	−3.729−07	3.485−13
9 – 15	3.677+02	4.590−01	−6.087−06	3.338−11
	8.904+03	8.835−02	−2.305−07	2.200−13
10 – 11	−7.097+04	1.101+02	−1.266−03	6.390−09
	1.961+06	2.798+01	−6.982−05	6.394−11
10 – 12	2.018+03	1.455+01	−1.824−04	9.708−10
	2.715+05	3.175+00	−8.158−06	7.551−12
10 – 13	2.383+03	4.875+00	−5.348−05	3.449−10
	9.279+04	9.821−01	−2.567−06	2.390−12
10 – 14	1.569+03	2.319+00	−3.081−05	1.691−10
	4.460+04	4.458−01	−1.178−06	1.100−12
10 – 15	1.046+03	1.323+00	−1.779−05	9.830−11
	2.561+04	2.468−01	−6.566−07	6.150−13
11 – 12	−1.150+05	2.020+02	−2.392−03	1.231−08
	3.613+06	4.898+01	−1.227−04	1.125−10
11 – 13	4.988+03	2.601+01	−3.334−04	1.797−09
	4.861+05	5.434+00	−1.401−05	1.299−11
11 – 14	4.675+03	8.595+00	−1.142−04	6.273−10
	1.638+05	1.658+00	−4.348−06	4.054−12

Table 13. Continued

Transition	*a*	*b*	*c*	*d*
11 – 15	2.986+03	4.054+00	−5.491−05	3.046−10
	7.810+04	7.456−01	−1.976−06	1.850−12
12 – 13	−1.737+05	3.511+02	−4.263−03	2.227−08
	6.300+06	8.163+01	−2.051−04	1.884−10
12 – 14	1.094+04	4.419+01	−5.774−04	3.146−09
	8.271+05	8.881+00	−2.296−05	2.131−11
12 – 15	8.673+03	1.442+01	−1.950−04	1.082−09
	2.753+05	2.676+00	−7.037−06	6.571−12
13 – 14	−2.459+05	5.829+02	−7.233−03	3.830−08
	1.049+07	1.305+02	−3.288−04	3.025−10
13 – 15	2.191+04	7.194+01	−9.561−04	5.259−09
	1.348+06	1.396+01	−3.617−05	3.361−11
14 – 15	−3.273+05	9.312+02	−1.178−02	6.306−08
	1.680+07	2.016+02	−5.089−04	4.687−10
Coefficients of polynomial fit to the effective collision strenghts for He II				
$1s - 2s$	1.435−01	−1.156−03	7.442−05	−6.725−06
$1s - 2p$	2.908−01	2.657−02	−1.736−03	7.498−05
$1s - 3s$	5.042−02	6.663−03	−1.037−03	4.835−05
$1s - 3p$	8.002−02	1.669−02	−1.448−03	5.509−05
$1s - 3d$	6.212−02	−1.441−03	−4.799−05	5.412−06
$2s - 3s$	4.700−01	1.759−01	−1.228−02	4.193−04
$2s - 3p$	2.156	1.521−01	−7.095−03	3.125−04
$2s - 3d$	1.998	3.513−01	−2.075−02	6.523−04
$2p - 3s$	2.388	−1.361−01	7.334−03	−1.569−04
$2p - 3p$	5.906	2.648−01	−2.352−02	9.556−04
$2p - 3d$	11.35	2.584	−1.873−01	7.257−03

Here g_i is the statistical weight of the lower state i. The coefficient of collisional deactivation can be written in the form

$$q_{ji} = \frac{8.6287 \times 10^{-6}}{g_i T_e^{1/2}} \gamma_{ij}, \tag{44}$$

and it is interrelated to the coefficient of collisional excitation by the relation

$$q_{ij} = \frac{g_j}{g_i} \exp(-\beta_{ij}), \tag{45}$$

The quantity γ_{ij} is determined by integrating the collision strength Ω_{ij} over the Maxwell electron velocity distribution :

$$\gamma_{ij} = \int_0^\infty \Omega_{ij} \exp(-\beta_{ij} u) d(\beta_{ij} u). \tag{46}$$

In equations (42)–(45) $\beta_{ij} = E_{ij}/kT_e$ and $u = E/E_{ij} - 1$ is the energy E of the removed electron in ionization threshold units.

Table 14. Electron impact excitation rates for atomic hydrogen (equation (43))

T_e (K)	$q(1\text{-}2)$	$q(1\text{-}3)$	$q(1\text{-}4)$	$q(1\text{-}5)$	$q(1\text{-}6)$	$q(1\text{-}7)$	$q(1\text{-}8)$
6000	1.03-16	8.20-19	2.09-20	1.45-20	5.86-21	2.98-21	1.74-21
8000	1.29-14	2.46-16	1.04-17	7.25-18	3.19-18	1.70-18	1.02-18
10000	2.33-13	7.37-15	4.40-16	3.00-16	1.38-16	7.60-17	4.66-17
12000	1.59-12	7.03-14	5.40-15	3.58-15	1.70-15	9.55-16	5.93-16
14000	6.29-12	3.49-13	3.26-14	2.10-14	1.02-14	5.81-15	3.64-15
16000	1.76-11	1.16-12	1.26-13	7.91-14	3.92-14	2.25-14	1.42-14
18000	3.90-11	2.93-12	3.63-13	2.22-13	1.12-13	6.46-14	4.10-14
20000	7.39-11	6.16-12	8.47-13	5.07-13	2.58-13	1.50-13	9.57-14
25000	2.33-10	2.35-11	3.93-12	2.25-12	1.17-12	6.89-13	4.42-13
30000	5.03-10	5.76-11	1.10-11	6.12-12	3.22-12	1.91-12	1.23-12
35000	8.72-10	1.10-10	2.31-11	1.25-11	6.66-12	3.98-12	2.58-12
40000	1.32-09	1.81-10	4.04-11	2.16-11	1.15-11	6.92-12	4.49-12
45000	1.83-09	2.67-10	6.25-11	3.30-11	1.77-11	1.07-11	6.95-12
50000	2.38-09	3.67-10	8.90-11	4.65-11	2.51-11	1.51-11	9.87-12

T_e (K)	$q(1\text{-}9)$	$q(1\text{-}10)$	$q(1\text{-}11)$	$q(1\text{-}12)$	$q(1\text{-}13)$	$q(1\text{-}14)$	$q(1\text{-}15)$
6000	1.11-21	7.55-22	5.39-22	4.00-22	3.05-22	2.39-22	1.90-22
8000	6.67-19	4.61-19	3.33-19	2.49-19	1.92-19	1.51-19	1.21-19
10000	3.08-17	2.15-17	1.56-17	1.18-17	9.08-18	7.16-18	5.75-18
12000	3.95-16	2.78-16	2.03-16	1.53-16	1.18-16	9.36-17	7.53-17
14000	2.44-15	1.72-15	1.26-15	9.56-16	7.41-16	5.87-16	4.73-16
16000	9.58-15	6.78-15	4.99-15	3.78-15	2.93-15	2.32-15	1.87-15
18000	2.77-14	1.97-14	1.45-14	1.10-14	8.55-15	6.78-15	5.47-15
20000	6.50-14	4.62-14	3.41-14	2.59-14	2.02-14	1.60-14	1.29-14
25000	3.02-13	2.15-13	1.59-13	1.21-13	9.45-14	7.51-14	6.07-14
30000	8.44-13	6.04-13	4.48-13	3.41-13	2.66-13	2.12-13	1.71-13
35000	1.77-12	1.27-12	9.41-13	7.18-13	5.60-13	4.46-13	3.61-13
40000	3.09-12	2.22-12	1.65-12	1.26-12	9.83-13	7.83-13	6.34-13
45000	4.78-12	3.44-12	2.56-12	1.95-12	1.53-12	1.22-12	9.85-13
50000	6.81-12	4.90-12	3.64-12	2.78-12	2.18-12	1.74-12	1.41-12

T_e (K)	$q(2\text{-}3)$	$q(2\text{-}4)$	$q(2\text{-}5)$	$q(2\text{-}6)$	$q(2\text{-}7)$	$q(2\text{-}8)$	$q(2\text{-}9)$
6000	1.65-08	8.17-10	3.44-10	1.24-10	5.89-11	3.29-11	2.04-11
8000	3.96-08	3.03-09	1.38-09	5.41-10	2.70-10	1.56-10	9.87-11
10000	6.74-08	6.79-09	3.22-09	1.32-09	6.80-10	4.00-10	2.57-10
12000	9.69-08	1.18-08	5.70-09	2.42-09	1.27-09	7.57-10	4.91-10
14000	1.26-07	1.76-08	8.63-09	3.75-09	2.00-09	1.20-09	7.83-10
16000	1.55-07	2.39-08	1.18-08	5.23-09	2.81-09	1.70-09	1.12-09
18000	1.83-07	3.05-08	1.51-08	6.80-09	3.68-09	2.24-09	1.47-09
20000	2.10-07	3.72-08	1.85-08	8.39-09	4.58-09	2.80-09	1.84-09
25000	2.72-07	5.38-08	2.67-08	1.23-08	6.81-09	4.19-09	2.78-09
30000	3.28-07	6.93-08	3.42-08	1.60-08	8.90-09	5.51-09	3.66-09
35000	3.79-07	8.35-08	4.09-08	1.93-08	1.08-08	6.70-09	4.47-09
40000	4.26-07	9.64-08	4.68-08	2.22-08	1.25-08	7.77-09	5.19-09
45000	4.69-07	1.08-07	5.20-08	2.48-08	1.40-08	8.71-09	5.83-09
50000	5.08-07	1.18-07	5.65-08	2.71-08	1.53-08	9.54-09	6.39-09

Table 14. Continued

T_e (K)	q(2-10)	q(2-11)	q(2-12)	q(2-13)	q(2-14)	q(2-15)
6000	1.36-11	1.22-11	8.98-12	6.79-12	5.28-12	4.18-12
8000	6.69-11	6.08-11	4.50-11	3.43-11	2.68-11	2.13-11
10000	1.76-10	1.61-10	1.20-10	9.16-11	7.18-11	5.73-11
12000	3.38-10	3.11-10	2.32-10	1.78-10	1.40-10	1.12-10
14000	5.41-10	4.99-10	3.74-10	2.87-10	2.26-10	1.81-10
16000	7.74-10	7.16-10	5.37-10	4.13-10	3.25-10	2.61-10
18000	1.03-09	9.50-10	7.13-10	5.50-10	4.33-10	3.48-10
20000	1.29-09	1.19-09	8.97-10	6.92-10	5.46-10	4.38-10
25000	1.94-09	1.81-09	1.36-09	1.05-09	8.31-10	6.68-10
30000	2.57-09	2.40-09	1.81-09	1.40-09	1.10-09	8.89-10
35000	3.14-09	2.93-09	2.21-09	1.71-09	1.36-09	1.09-09
40000	3.65-09	3.41-09	2.58-09	2.00-09	1.58-09	1.27-09
45000	4.11-09	3.84-09	2.90-09	2.25-09	1.78-09	1.43-09
50000	4.51-09	4.21-09	3.19-09	2.47-09	1.96-09	1.57-09

T_e (K)	q(3-4)	q(3-5)	q(3-6)	q(3-7)	q(3-8)	q(3-9)
6000	5.18-07	1.03-06	5.09-08	2.14-08	1.11-08	6.55-09
8000	8.50-07	1.47-06	9.46-08	4.16-08	2.23-08	1.34-08
10000	1.17-06	1.79-06	1.40-07	6.31-08	3.44-08	2.10-08
12000	1.48-06	2.02-06	1.83-07	8.42-08	4.64-08	2.86-08
14000	1.77-06	2.19-06	2.23-07	1.04-07	5.79-08	3.59-08
16000	2.04-06	2.32-06	2.60-07	1.22-07	6.86-08	4.27-08
18000	2.30-06	2.41-06	2.94-07	1.39-07	7.84-08	4.90-08
20000	2.54-06	2.48-06	3.24-07	1.55-07	8.75-08	5.49-08
25000	3.09-06	2.59-06	3.90-07	1.88-07	1.07-07	6.74-08
30000	3.58-06	2.64-06	4.42-07	2.15-07	1.22-07	7.74-08
35000	4.01-06	2.65-06	4.83-07	2.36-07	1.35-07	8.54-08
40000	4.40-06	2.65-06	5.16-07	2.52-07	1.45-07	9.18-08
45000	4.75-06	2.63-06	5.43-07	2.66-07	1.53-07	9.70-08
50000	5.06-06	2.60-06	5.64-07	2.77-07	1.59-07	1.01-07

T_e (K)	q(3-10)	q(3-11)	q(3-12)	q(3-13)	q(3-14)	q(3-15)
6000	4.23-09	2.90-09	2.09-09	1.56-09	1.20-09	9.43-10
8000	8.81-09	6.12-09	4.45-09	3.34-09	2.58-09	2.04-09
10000	1.39-08	9.74-09	7.11-09	5.36-09	4.16-09	3.29-09
12000	1.91-08	1.34-08	9.81-09	7.42-09	5.76-09	4.57-09
14000	2.40-08	1.69-08	1.24-08	9.42-09	7.32-09	5.82-09
16000	2.86-08	2.02-08	1.49-08	1.13-08	8.80-09	7.00-09
18000	3.30-08	2.33-08	1.72-08	1.31-08	1.02-08	8.10-09
20000	3.69-08	2.62-08	1.93-08	1.47-08	1.15-08	9.12-09
25000	4.55-08	3.24-08	2.39-08	1.82-08	1.42-08	1.13-08
30000	5.24-08	3.73-08	2.76-08	2.11-08	1.64-08	1.31-08
35000	5.79-08	4.13-08	3.06-08	2.33-08	1.82-08	1.45-08
40000	6.23-08	4.45-08	3.30-08	2.52-08	1.97-08	1.57-08
45000	6.59-08	4.70-08	3.49-08	2.66-08	2.08-08	1.66-08
50000	6.88-08	4.91-08	3.64-08	2.78-08	2.18-08	1.74-08

Table 14. Continued

T_e (K)	$\sum_j q(1-j)$	$\sum_j q(2-j)$	$\sum_j q(3-j)$
6000	1.03-16	1.79-08	1.65-06
8000	1.32-14	4.53-08	2.52-06
10000	2.41-13	8.07-08	3.26-06
12000	1.68-12	1.21-07	3.90-06
14000	6.72-12	1.62-07	4.46-06
16000	1.90-11	2.05-07	4.94-06
18000	4.25-11	2.47-07	5.37-06
20000	8.21-11	2.88-07	5.76-06
25000	2.66-10	3.86-07	6.58-06
30000	5.87-10	4.76-07	7.24-06
35000	1.04-09	5.57-07	7.79-06
40000	1.60-09	6.31-07	8.25-06
45000	2.24-09	6.98-07	8.65-06
50000	2.96-09	7.59-07	8.99-06

Using the experimental and theoretical excitation cross-sections for transitions between hydrogen states Giovanardi *et al.* (1987) determined the effective collision strengths $\gamma_{ij}(T_e)$ for 15 lower states. For the four lowest levels the transitions between sublevels with different orbital quantum numbers were considered. The effective collision strengths were approximated by the expression

$$\gamma_{ij} = a + bT_e + cT_e^2 + dT_e^3, \tag{47}$$

The values of polynomial fit parameters a, b, c and d are given in Table 13. The effective collision strengths for He II have been found by Hummer and Storey (1987). These can be well presented by the same polynomial fit for temperatures up to 10^5 K. The values of corresponding coefficients are also given in Table 13.

The values of q_{ij} computed for H I by using equations (43) and (45) (3.8) and (3.10) and data of Table 13 at different values of T_e are given in Table 14, which also gives the total coefficients of electron impact excitation summed over all levels $j \leq 15$. This quantity is useful for calculating the ionization state of H I atoms in the nebulae.

The coefficients of collisional excitation of complex ions have been given by Clark *et al.* (1982). The collisional strengths for different atoms and ions of isoelectronic sequences of H, He, Li, Be, B, Na, Mg have been presented by expression

$$\begin{aligned} \Omega(Z,X) &= (Z + b_1 + d_1/Z)^{-2}(c_0 + c_1/X + c_2/X^2) \\ &+ (Z + b_2 + d_2/Z)^{-2}(c_3 \ln(X) + c_4), \end{aligned} \tag{48}$$

where $X = E/E_{ij} = u + 1$, Z is the nuclear charge number and the values of parameters b_1, b_2, c_0, c_1, c_2, c_3, d_1 and d_2 are given in Table 15. Integrating over the Maxwellian velocity distribution of electrons the corresponding coefficient of collisional excitation can be written in the form

$$q_{ij}(T_e) = F_1(Z)C_E\left[\frac{c_0 \exp(-\beta)}{\beta} + c_1 E_1(\beta) + c_2 E_2(\beta)\right] +$$

Table 15. Approximation parameters for the electron impact excitation rates for some ions (equations (48)–(50))

Atom	*Transition*	b_1	d_1	b_2	d_1
H	$1s-2s$	3.0255−2	2.8721+0	1.5828−2	−6.8354−3
	$1s-2p$	−7.2121−1	7.9039−1	−2.8375−1	3.7837−1
He	$1s^2-1s2s\,^1S$	−3.9862−1	1.9305+0	−5.3181−1	1.0520+0
	$1s^2-1s2p\,^1P$	−8.7050−1	1.3427+0	−7.7148−1	1.3553+0
Li	$2s-2p$	−1.8357+0	6.7641+0	−1.4303+0	−1.0308+0
	$2s-3s$	7.6061−1	−2.9960−1	−1.4644+0	3.7946−1
	$2s-3p$	−2.3123+0	1.2005+1	−1.6955+0	1.1404+1
	$2s-3d$	−1.7336+0	2.6599+0	−1.5825+0	3.0934+0
Be	$2s^2-2s2p\,^1P$	−5.4701+0	4.1354+0	−1.9273+0	−3.7323−2
	$2s^2-2s3s\,^1S$	−1.5089+0	4.1170+0	−1.6947+0	−1.0008−1
	$2s^2-2s3p\,^1P$	−6.1290+0	2.8693+1	−5.9038+0	3.0727+1
	$2s^2-2s3d\,^1D$	−2.4614+0	7.2745+0	−2.0230+0	8.4731+0
B	$2p-2p^2\,^2D$	−2.5357+0	1.6273+1	2.2823−1	−1.2860+1
	$2p-2p^2\,^2S$	1.2389+0	−1.6709+0	2.2454+0	−2.5053+1
	$2p-2p^2\,^2P$	−5.5294+0	3.8336+1	−2.1885+0	−2.2321+0
	$2p-3s\,^2S$	−5.2852+0	6.2157+0	−7.1461+0	1.7524+1
	$2p-3d\,^2D$	−2.6613+0	6.1030+0	−2.6047+0	6.1124+0
Na	$3s-3p$	−6.2955+0	1.1678+1	−4.3993+0	−4.0964+1
Mg	$3s^2-3s3p\,^1P$	−1.0469+1	7.5316+1	−7.3671+0	−1.1696+1

Atom	*Transition*	c_0	c_1	c_2	c_3	c_4
H	$1s-2s$	0	−2.8348−1	1.4644−1	0	8.8632−1
	$1s-2p$	−3.1169+0	1.4595+0	1.1221+0	4.3571+0	3.4015+0
He	$1s^2-1s2s\,^1S$	0	−4.6688−1	7.9729−2	0	8.7561−1
	$1s^2-1s2p\,^1P$	−1.2663+1	1.3627+0	1.1779−1	4.1292+0	1.2640+1
Li	$2s-2p$	1.2644+2	2.2678+2	−7.7611+1	9.1550+1	−1.2483+1
	$2s-3s$	0	−2.6169+0	4.7124−1	0	1.0335+1
	$2s-3p$	−3.5391+1	2.6411+1	−5.9858+0	2.0986+1	2.2133+1
	$2s-3d$	0	−3.1967+1	1.7385+1	0	3.1034+1
Be	$2s^2-2s2p\,^1P$	4.8738+1	1.1374+2	−2.9936+1	6.4360+1	2.3304+1
	$2s^2-2s3s\,^1S$	0	−2.2488+0	−2.8697−1	0	1.0413+1
	$2s^2-2s3p\,^1P$	−1.7122+1	1.1138+1	−2.2600+0	1.0231+1	1.0797+1
	$2s^2-2s3d\,^1D$	0	−3.1033+1	1.2496+1	0	2.9371+1
B	$2p-2p^2\,^2D$	2.3051+2	3.0526+2	−1.1423+2	1.4200+2	−7.9871+1
	$2p-2p^2\,^2S$	1.1548+2	1.7294+2	−7.4270+1	6.9007+1	−3.7716+1
	$2p-2p^2\,^2P$	2.4309+2	3.5044+2	−1.0487+2	1.9704+2	−5.3362+1
	$2p-3s\,^2S$	−1.5911+0	5.1577+0	−8.1767−1	2.9391+0	−1.1354+0
	$2p-3d\,^2D$	−1.9081+3	1.2813+2	−1.4259+1	1.2072+2	1.8988+3
Na	$3s-3p$	1.0320+3	1.1301+3	−3.2897+2	5.0125+2	−3.8105+2
Mg	$3s^2-3s3p\,^1P$	6.4280+2	6.5293+2	−1.0841+2	3.5073+2	−2.2096+2

Atom	*Transition*	a_0	a_1	a_2	a_3	a_4
H	$1s-2s$	−2.4146−2	1.6733−2	1.0200+1	1.2581−4	1.1876−4
	$1s-2p$	2.2668−2	−2.3461−2	1.0210+1	−9.7361−4	1.8101−4
He	$1s^2-1s2s\,^1S$	4.1136−1	−1.0370+1	1.0155+1	2.3318−3	6.8920−5
	$1s^2-1s2p\,^1P$	−1.6465+0	−8.9437+0	1.0053+1	7.3500−3	2.5688−5

Table 15. Continued

Atom	*Transition*	a_0	a_1	a_2	a_3	a_4
Li	$2s-2p$	−4.6636+0	2.2833+0	−3.9025−2	1.7520−3	0
	$2s-3s$	2.8825+0	−5.4725+0	1.8648+0	1.6849−3	1.8420−6
	$2s-3p$	2.3189+0	−5.2566+0	1.9255+0	−2.5229−3	9.5942−5
	$2s-3d$	1.6400+0	−5.0109+0	1.9148+0	−1.5113−3	7.5428−5
Be	$2s^2-2s2p\,^1P$	−1.0050+1	4.1061+0	−6.7408−2	2.4015−3	0
	$2s^2-2s3s\,^1S$	4.6753+0	−6.9992+0	1.8838+0	5.8812−4	9.7093−6
	$2s^2-2s3p\,^1P$	3.4151+0	−6.5534+0	1.8861+0	3.8007−4	2.5128−5
	$2s^2-2s3d\,^1D$	4.5549−1	−5.7056+0	1.8864+0	5.9589−4	2.1710−5
B	$2p-2p^2\,^2D$	−1.1341+1	3.7007+0	−5.6339−2	2.0624−3	0
	$2p-2p^2\,^2S$	−1.3042+1	4.2204+0	−9.7416−3	3.4929−4	0
	$2p-2p^2\,^2P$	−1.4969+1	5.2729+0	−1.0270−1	3.4006−3	0
	$2p-3s\,^2S$	1.7830+1	−1.2243+1	1.9563+0	−1.7541−3	1.8977−5
	$2p-3d\,^2D$	7.1403+0	−9.5604+0	1.8991+0	−6.6362−4	3.0004−5
Na	$3s-3p$	−2.6149+1	3.0072+0	−5.0588−2	1.0321−3	0
Mg	$3s^2-3s3p\,^1P$	−3.5986+1	4.0890+0	−7.5769−2	1.3900−3	0

$$+ \quad F_2(Z)C_E\left[\frac{c_3E_1(\beta)}{\beta}+\frac{c_4\exp(-\beta)}{\beta}\right]\ \mathrm{cm^3\ s^{-1}}, \tag{49}$$

where $\beta = E_t/kT_e$, $C_E = 8.010\times10^{-8}\beta/[(2L+1)(2S+1)T_e^{1/2}]$, $F_1(Z) = [Z+b_1+d_1/Z]^{-2}$, $F_2(Z) = [Z+b_2+d_2/Z]^{-2}$ and $E_n(\beta)$ is the integro-exponential function of nth order:

$$E_n(\beta) = \int_1^\infty \frac{e^{-\beta t}}{t^n}\,dt.$$

For different atoms and ions of the above-mentioned sequences the energy E_{ij} has been expressed in the form

$$E_{ij} = a_0 + a_1Z + a_2Z^2 + a_3Z^3 + a_4Z^4, \tag{50}$$

Values of the parameters a_0, a_1, a_2, a_3 and a_4 are also given in Table 15.

The values of the transition probabilities and γ_{ij} for the large number of forbidden and intercombination lines which are observed in the spectra of planetary nebula are given in Table 16. An explication of used designations for the levels and their energies is given in Table 17. Owing to limited space in the catalogue we present data only for ions of Be, B, O and Mg sequence which are taken from Mendoza (1983). The modern data can be found in the original papers cited in Appendix A. The updated collision strengths are also available by *anonymons* **ftp** via ftp-server **urania.aispbu.spb.su** in the directory /usr/afk/CatAda under the name *cs.new*.

4.3 Excitation by Collision with Heavy Particles

The process of atom and ion excitation by heavy particle collisions differs essentially from that by electron impacts. Large mass particles move much more slowly than

Table 16. Transition probabilities and effective collision strengths γ_{ij} of selected atoms and ions for transitions between low excited lines

Ion	*Transition*	A_{ki} (s^{-1})	T_e (K)			
			5000	*10 000*	*15 000*	*20 000*
		Be sequence				
C III	1–2	0	1.12	1.01	0.990	0.996
	1–3	95.9	1.12	1.01	0.990	0.996
	1–4	5.19–3	1.12	1.01	0.990	0.996
	1–5	1.79+9	3.85	4.34	4.56	4.69
	2–3	2.39–7	0.848	0.911	0.975	1.03
	2–4	0	0.579	0.677	0.776	0.867
	3–4	2.41–6	2.36	2.66	2.97	3.23
N IV	1–2	0	0.904	0.852	0.817	0.798
	1–3	5.77+2	0.904	0.852	0.817	0.798
	1–4	1.15–2	0.904	0.852	0.817	0.798
	1–5	2.38+9	3.20	3.46	3.58	3.65
	2–3	4.53–6				
	3–4	4.03–5				
O V	1–2	0	0.733	0.721	0.674	0.639
	1–3	2.25+3	0.733	0.721	0.674	0.639
	1–4	2.16–2	0.733	0.721	0.674	0.639
	1–5	2.92+9	2.66	2.76	2.82	2.85
	2–3	4.54–5				
	3–4	3.89–4				
Ne VII	1–2	0	0.129	0.172	0.205	0.228
	1–3	1.98+4	0.129	0.172	0.205	0.228
	1–4	5.78–2	0.129	0.172	0.205	0.228
	1–5	4.08+9	1.39	1.56	1.63	1.66
	2–3	1.69–3				
	3–4	1.32–2				
		B sequence				
C II	2–1	2.29–6		1.25		
	3–1	5.53+1	3.25	3.17	3.09	2.97
	3–2	6.55+1	3.25	3.17	3.09	2.97
	4–1	1.71	3.25	3.17	3.09	2.97
	4–2	5.24				
	4–3	2.39–7				
	5–2	4.32+1				
	5–3	3.49–14				
	5–4	3.67–7				

Ion	*Transition*	A_{ki} (s^{-1})	T_e (K)					
			500	*1000*	*5000*	*10 000*	*15 000*	*20 000*
		O sequence						
O I	3–1	7.32–2	0.00065	0.00184	0.0153	0.0324		0.0607
	3–2	1.74–5	0.0008	0.0018	0.0112	0.0265		0.0693
	4–1	2.88–4	0.00065	0.00184	0.0153	0.0324		0.0607
	4–2		0.0006	0.0022	0.0148	0.0292		0.0536

Table 16. Continued

Ion	*Transition*	A_{ki} (s^{-1})	T_e (K)					
			500	*1000*	*5000*	*10 000*	*15 000*	*20 000*
	4–3	8.92–5	0.0027	0.0076	0.0474	0.0987		0.207
	5–1	1.22	0.0221	0.0310	0.0732	0.105		0.148
	5–2	7.23–7	0.0058	0.0151	0.124	0.266		0.501
	5–3	2.11–3	0.0058	0.0151	0.124	0.266		0.501
	5–4	6.34–3	0.0058	0.0151	0.124	0.266		0.501
Ne III	3–1	2.00			0.152	0.151	0.152	0.157
	3–2	1.15–3			0.185			
	4–1	3.94–3			0.152	0.151	0.152	0.157
	4–2	2.18–8			0.131			
	4–3	5.97–3			0.527			
	5–1	2.71			0.220	0.236	0.262	0.284
	5–2	8.51–6			1.35	1.34	1.33	1.32
	5–3	5.42–2			1.35	1.34	1.33	1.32
	5–4	1.71–1			1.35	1.34	1.33	1.32

Ion	*Transition*	A_{ki} (s^{-1})	T_e (K)			
			5000	*10 000*	*15 000*	*20 000*
Mg I	1–3	1.80+2				
	1–4	4.13–4				
	1–5	4.93+8				
	2–3	1.45–7				
	2–4	4.08–12				
	3–4	9.10–7				
Si III	1–2	0	6.90	5.43	4.80	4.41
	1–3	1.26+4	6.90	5.43	4.80	4.41
	1–4	1.20–2	6.90	5.43	4.80	4.41
	1–5	2.60+9	5.48	5.82	6.21	6.54
	2–3	3.82–5				
	2–4	3.20–9				
	3–4	2.42–4				
S V	1-2	0	0.911	0.910	0.914	0.905
	1–3	1.26+5	0.911	0.910	0.914	0.905
	1–4	6.59–2	0.911	0.910	0.914	0.905
	1–5	5.13+9	7.30	7.30	7.29	7.27
	2–3	9.07–4	0.272			
	2–4	1.63–7	0.400			
	3–4	5.96–3	1.24			

electrons and pass nearby the excited atom during a long time interval. If the energy of the transition ΔE in the target atom or ion is comparable with the kinetical energy E of the colliding particle then the excitation cross-sections are very small due to the fast oscillation of the target wavefunction with the phase $\Delta E t/h$. On the contrary, in the case if $\Delta E \ll E$ this phase is small and the total excitation cross-section by a heavy particle is not small and can exceed the appropriate cross-section for excitation by electron impacts. This means that the heavy particle collisions are

Table 17. Energies and designations for the ground and metastable levels of the selected atoms and ions (cm^{-1})

No.	*Conf.*	*Term*	*J*	*C III*	*N IV*	*O V*	*Ne VI*
				Be sequence			
1	$2s^2$	^1S	0	0.0	0.0	0.0	0.0
2	$2s2p$	$^3P^0$	0	52367.1	67209.2	81942.5	111264.9
3			1	52390.8	67272.3	82078.6	111717
4			2	52447.1	67416.3	82385.3	112711.5
5		$^1P^0$	1	102352.0	130693.9	158797.7	214951.6
No.	*Conf.*	*Term*	*J*	*C II*	*N III*	*O IV*	*Ne V*
				B sequence			
1	$2s^2\,2p$	$^2P^0$	1/2	0.0	0.0	0.0	0.0
2	$2s^2\,2p$		3/2	63.42	174.4	386.3	1306.6
3	$2s\,2p^2$	^4P	1/2	43003.3	57187.1	71440.0	
4	$2s\,2p^2$		3/2	42025.3	57246.8	71571.4	
5	$2s\,2p^2$		5/2	43053.6	57327.9	71755.9	
No.	*Conf.*	*Term*	*J*	*C I*	*N II*	*O III*	*Ne IV*
				C sequence			
1	$2p^2$	^3P	0	0.0	0.0	0.0	0.0
2	$2p^2$		1	16.4	48.7	113.2	412.4
3	$2p^2$		2	43.4	130.8	306.2	1110.1
4	$2p^2$	^1D	2	10192.6	15316.2	20273.3	30291.5
5	$2p^2$	^1S	0	21648.0	32688.8	43185.7	63913.6
6	$2p^3$	$^5S^0$	2	33735.2	46784.6	60325.0	88363.1
No.	*Conf.*	*Term*	*J*	*N I*	*O II*	*Ne IV*	*Na V*
				N sequence			
1	$2p^3$	$^4S^0$	3/2	0.0	0.0	0.0	0.0
2	$2p^3$	$^2D^0$	5/2	19224.5	26810.7	41234.6	48313.5
3	$2p^3$		3/2	19233.2	26830.2	41279.5	48359.3
4	$2p^3$	$^2P^0$	1/2	28838.9	40468.6(5)	62434.6	73201.9
5	$2p^3$	$^2P^0$	3/2	28839.3	40467.5(4)	62441.3	73236.4

the effective ones for excitation of the fine structure transitions or for orbital moment redistribution due to transitions between the high-excited Rydberg states.

Proton collisions are most effective for generating transitions if $\Delta E \ll E$. For such transitions the excitation rates of neutral targets by proton impacts are $(M_p/m_e)^{1/2}$ times larger than those by electron impacts (Seaton, 1955; see, also, Dalgarno, 1984). The proton collisions are effective for excitation of the fine structure levels and for excitation of the transitions between sublevels nl:

$$p + H(nl) \leftrightarrow p + H(nl').$$

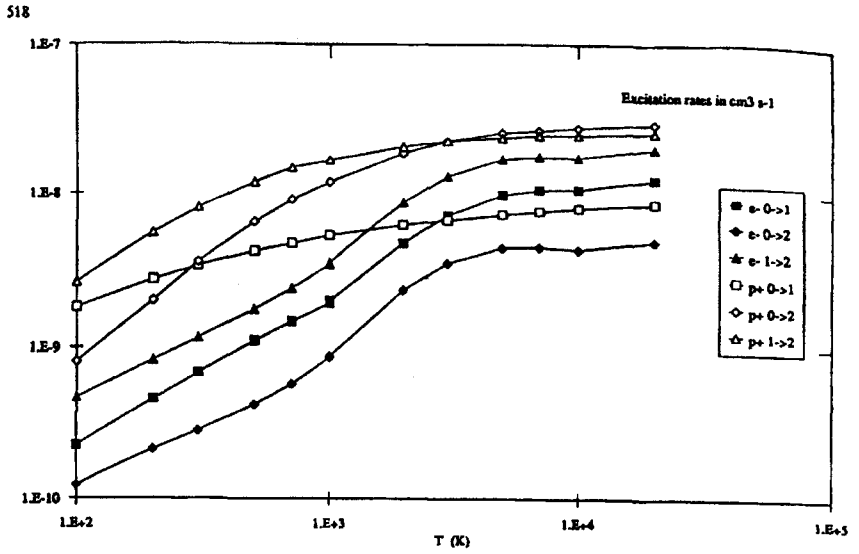

Figure 3 Collison excitation rates of C I ground state fine structure levels ($J = 0, 1, 2$) with phtotons (Rouef and Le Bourlot, 1990, white markers) and electrons (analytical fit of Johnson *et al.* (1987) filled markers).

Cross-sections for this process have been calculated by Pengelly and Seaton (1964) with in the framework of the semiclassical pertubation theory. At large values of n the proton collisions lead to the statistical equilibrium distribution of atoms on nl sublevels.

For large values of n and n' the proton impact excitations

$$p + H(n) \leftrightarrow p + H(n').$$

are also effective (Burgess and Summer (1976)).

For excitation of the positive ions by proton impacts the Coulomb interaction must be taken into account. This interaction diminishes the proton-impact excitation rates and in turn increases the excitation rates by electron impacts. The role of this effect is negligible if $n \gg 1$ as is typical in astrophysical object of $T_e \approx 10^4$ K.

Proton collisions are very effective for excitation of the fine structure levels of C I, O I, O II and of many other ions. Numerous references in the field are presented in Appendix A. At low temperatures ($T \leq 10^3$ K) excitation by proton collisions can by more than 10 times exceed the excitation by electron impacts (Roueff and Le Bourlot, 1990, see Table 18 and also Figure 3).

Excitation by collision with H I is effective for the fine structure levels. Collisions with *more heavier particles* are less effective than neutral hydrogen excitation due to their lower abundances. The references in the field can be found in Appendix A.

Table 18. Collision excitation rates ($cm^3\ s^{-1}$) of the C I fine structure levels due to proton impact (Roueff and Le Bourlot, 1990)

T (K)	$k_{0\to1}$	$k_{0\to2}$	$k_{1\to2}$
100	1.8–9	8.1–10	2.6–9
200	2.7–9	2.0–9	5.4–9
300	3.3–9	3.5–9	8.0–9
500	4.1–9	6.4–9	1.2–8
700	4.6–9	9.1–9	1.5–8
1000	5.2–9	1.2–8	1.7–8
2000	6.1–9	1.9–8	2.1–8
3000	6.6–9	2.3–8	2.3–8
5000	7.2–9	2.6–8	2.4–8
7000	7.6–9	2.7–8	2.5–8
10000	7.9–9	2.8–8	2.5–8
20000	8.5–9	3.0–8	2.6–8

4.4 Autoionization

The autoionization process comprises of collisional excitation of an atom or ion to autoionization states followed by autoionization decay. Similarly to the photoionization processes, autoionization by electron impacts generates the resonances in the cross-sections. Autoionization is usually essential at $T_e \geq 10^5$ K for atoms and ions having more than two electrons. The number of autoionization events per unit volume and unit time is

$$\dot{N}_\alpha = n(X^i) n_e\, q_\alpha(T_e), \tag{51}$$

where $q_\alpha(T_e)$ is the autoionization rate.

The most complete compilation of analytical expressions and corresponding data for determination of q_α is given in the paper by Arnaud and Rothenflug (1985) the results of which we reproduce here.

(1) The formula for lithium isoelectronic series is

$$q_\alpha(T_e) = 1.92 \times 10^{-7} \frac{b \exp(-\beta) G(\beta)}{Z_{\rm ef}^2 (kT_e)^{1/2}}\ \mathrm{cm^3\ s^{-1}}, \tag{52}$$

where $\beta = I_\alpha / kT_e$,
$G(\beta) = 2.22 f_1(\beta) + 0.67[1 - \beta f_1(\beta)] + 0.49\beta f_1(\beta) + 1.2\beta[1 - \beta f_1(\beta)]$,
$b = [1 + 2 \times 10^{-4} Z^3]^{-1}$, $Z_{\rm ef} = (Z - 0.43)$,
$I_\alpha = 13.6\{(Z - 0.835)^2 - 0.25(Z - 1.62)^2\}$ eV, and function $f_i(\beta)$ is given by equation (38).

Equation (52) corresponds to the $1s - 2p$ transition corrected for the contribution of other transitions by multiplying with coefficient 1.2. Comparison of the q_α values, given by equation (52) with existing measurements showed that the results can differ from them by not more than about twice.

(2) For ions of sodium isoelectronic series

$$q_\alpha(T_e) = 6.69 \times 10^{-7} \frac{\alpha\, I_\alpha}{(kT_e)^{1/2}} \exp(-\beta)\,\{1 + \Phi(\beta)\} \text{ cm}^3\,\text{s}^{-1}. \quad (53)$$

If $12 \leq Z \leq 16$ then $\Phi(\beta) = -\beta f_1(\beta)$, $I_\alpha = 26(Z - 10)$ eV and $\alpha = 2.28 \times 10^{-17}(Z - 11)^{-0.7}$ cm^2.
If $18 \leq Z \leq 28$ then

$$\Phi(\beta) = -0.5[\beta - \beta^2 + \beta^3 f_1(\beta)], \quad (54)$$

and $I_\alpha = 11(Z - 10)^{3/2}$ eV, $\alpha = 1.3 \times 10^{-14}(Z - 10)^{-3.73}$ cm^2.

(3) For the ions of isoelectronic series set from the magnesium series to the sulphur series ($Z < 16$) the expression for $\Phi(\beta)$ is given by equation (54) where $\alpha = 4.0 \times 10^{-13} Z^{-2}$ cm^2 and
$I_\alpha = 10.3(Z - 10)^{-1.52}$ eV for the Mg isoelectronic sequence,
$I_\alpha = 18.0(Z - 11)^{-1.33}$ eV for the Al isoelectronic sequence,
$I_\alpha = 18.4(Z - 12)^{-1.36}$ eV for the Si isoelectronic sequence,
$I_\alpha = 23.7(Z - 13)^{-1.29}$ eV for the P isoelectronic sequence,
$I_\alpha = 40.1(Z - 14)^{-1.10}$ eV for the S isoelectronic sequence.

For ions of other series the contribution of autoionization to the total collision excitation rate can be ignored.

4.5 Dielectronic Recombination

The process of dielectronic recombination, described by equation (12), proceeds in two stages. During the first stage the electron is captured in an autoionization state γ belonging to ion X^{i+1}. At the second stage radiative decay of the state γ occurs with generation of a bound state of ion X^i.

At high temperatures $T_e \geq 10^5$–10^6 K the main contribution to the dielectronic recombination rate is by the recombination processes to the autoionization states with large principal quantum numbers n. These states decay easily in electron collisions and due to the external radiation field. Thus, the dielectronic recombination rate depends heavily on the physical conditions in the plasma. At high electron densities $n_e > 10^{13}$–10^{15} cm^3 both the collisional ionization from autoionization states and collisional population of them are essential.

The photons irradiated in the processes of dielectronic recombination due to transitions between autoionization states are termed the dielectronic satellites.

The number of dielectronic recombination events for ion X^{i+1} per unit volume and unit time is

$$\dot{N}^{\text{di}} = n(X^{i+1}) n_e \alpha^{\text{di}}(X^{i+1}) \text{ cm}^3\,\text{s}^{-1}, \quad (55)$$

where $\alpha^{\text{di}}(T_e)$ is the dielectronic recombination rate.

The semiempirical formulae for dielectronic recombination rates have been given by Burgess (1965), Landini and Monsignori (1971), and Jain and Narain (1976).

The revised expression for $\alpha^{\rm di}(T_e)$ with the modified values of excitation cross-sections of ions X^{i+1} due to electron collisions have been given by Alam and Ansari (1985). The differences between $\alpha^{\rm di}(T_e)$ values found by various authors for many ion species reach 1 dec. This is caused by the difficulties in computing reliable values of excitation cross-sections, the main factor among these being the necessity to take into account transitions from all autoionization states and cascade transitions from these states.

Generally, the dielectronic recombination rate is computed in the Burgess (1965) approximation. This approximation holds for most ions at high electron temperatures $T_e > 10^5$ K. A simple approximation formula for $\alpha^{\rm di}(T_e)$ has been given in papers by Aldrovandi and Pequignot (1973, 1976) who modified the Burgess approximation to the form

$$\alpha_H^{\rm di} = A_{\rm di} T_e^{-3/2} \exp(-T_0/T_e)[1 + B_{\rm di} \exp(-T_1/T_e)]. \tag{56}$$

Here the index H marks the Burgess (High temperature) approximation. The same expression has been proposed also by Shull and Van Steenberg (1982), who also used the semiempirical formula by Burgess (1965) and improved the numerical values of approximation parameters $A_{\rm di}$, $B_{\rm di}$, T_0 and T_1 for all ions of chemical elements from C to Ni which are given in Table 5. The same expression holds also for He^+.

Arnaud and Rothenflug (1985) started from the expression of $\alpha_H^{\rm di}$ given in the paper by Aldrovandi and Pequignot (1973) and corrected by a factor proposed by Burgess and Tworkowski (1976). For Li-like ions they obtained the following formula:

$$\alpha_H^{\rm di} = 7.6 \times 10^{-11} A(z) \exp[-D(z)\beta] \beta^{3/2} \ {\rm cm^3\ s^{-1}}, \tag{57}$$

where

$$\beta = I_0/kT_e, \ z = Z - 2,$$

$$A(z) = (z+1)^3/z^2(z^2+13.4)^{1/2}[1 + 0.16(z+1) + 0.017(z+1)^2],$$

$$D(z) = 3.0\frac{(z+1)^2}{z^2}/[1 + 0.015z^3/(z+1)^2].$$

In these formulae I_0 is the ionization potential for the ion studied and Z is its nuclear charge. The values of coefficients $\alpha^{\rm di}(T_e)$ computed using equation (57) are smaller than the corresponding values found by Shull and Van Steenberg (1982), being multiplied by coefficients 0.19, 0.44, 0.36 and 0.41 for ions of O, Mg, Ca and Fe, respectively. For high-charge ions we can use the $\alpha^{\rm di}(T_e)$ values from paper by Shull and Van Steenberg (1982), multiplying the values by 0.30 for ions of Ne and by 0.40 for ions of Si, S and Ar. The values of $\alpha^{\rm di}(T_e)$ also based on the Burgess approximation for all ions of C–Ni and for some other isoelectronic sequences have been given in papers by Jacobs *et al.* (1977a, b, 1980), where the autoionization processes have also been incorporated. The results of the latter papers have been improved by Woods *et al.* (1981), Shull and Van Steenberg (1982).

A simple approximation formula for the total dielectronic recombination rate has been given by Romanik (1988) for ions of He, Li, Be and Ne sequences:

$$\alpha_H^{\rm di} = T_e^{-3/2} \sum_i a_i \exp(-T_i/T_e) \ {\rm cm^3\ s^{-1}}. \tag{58}$$

Table 19. Parameters α_i and T_i for total rates of dielectronic recombination (equation (58))

Sequence	*Ion*	t	T_i/Ry (K)	α_i
He	C V	1	20.9	2.98–10
	N VI	1	29.8	6.78–10
	O VII	1	39.2	1.05–9
	Ne IX	1	51.8	3.11–10
		2	63.9	1.56–9
	Mg XI	1	74.4	6.30–10
		2	92.9	2.42–9
	Si XIII	1	101.0	1.04–9
		2	127.0	3.13–9
	S XV	1	132.0	1.56–9
		2	167.0	4.07–9
	Ar XVII	1	167.0	2.04–9
		2	212.0	4.58–9
	Ca XIX	1	206.0	2.50–9
		2	263.0	5.07–9
	Fe XXV	1	339.0	4.17–9
		2	441.0	7.21–9
	Ni XXVII	1	404.0	4.44–9
		2	522.0	7.54–9
Li	C IV	1	0.0262	5.21–13
		2	0.231	3.16–13
		3	0.371	5.44–13
		4	0.579	5.47–11
	N V	1	0.0957	1.09–12
		2	0.295	6.90–13
		3	0.449	1.18–12
		4	0.720	7.74–11
	O VI	1	0.187	1.83–12
		2	0.368	1.22–12
		3	0.534	2.03–12
		4	0.860	1.00–10
		5	5.07	5.00–11
	Ne VIII	1	0.179	4.76–12
		2	0.412	3.14–12
		3	0.623	4.70–12
		4	0.859	8.44–12
		5	1.15	1.47–10
		6	7.13	2.73–11
		7	9.09	1.74–10
	Mg X	1	0.217	9.40–12
		2	0.480	6.36–12
		3	0.738	9.22–12
		4	0.999	1.16–11
		5	1.43	2.11–10
		6	5.81	3.65–11
		7	10.5	6.72–11
		8	13.8	5.07–10
	Si XII	1	0.306	1.58–11
		2	0.597	1.10–11
		3	0.871	1.60–11
		4	1.17	1.86–11

Table 19. Continued

Sequence	*Ion*	t	T_i/Ry (K)	α_i
	Si XII	5	1.73	2.82–10
		6	7.70	7.53–11
		7	14.5	1.38–10
		8	19.4	1.07–9
	S XIV	1	0.0255	3.02–11
		2	0.432	2.06–11
		3	0.813	2.90–11
		4	1.23	3.23–11
		5	2.01	4.33–10
		6	9.80	1.37–10
		7	19.1	2.52–10
		8	25.9	1.72–9
	Ar XVI	1	0.204	4.06–11
		2	0.584	2.81–11
		3	0.997	3.93–11
		4	1.41	3.38–11
		5	2.33	3.70–10
		6	11.8	2.32–10
		7	24.2	4.16–10
		8	33.3	2.74–9
	Ca XVIII	1	0.429	5.34–11
		2	0.801	3.81–11
		3	1.22	5.47–11
		4	1.75	4.59–11
		5	2.67	4.45–10
		6	15.1	3.68–10
		7	34.1	1.51–9
		8	43.6	3.01–9
	Fe XXIV	1	0.675	1.36–10
		2	1.20	9.80–11
		3	1.80	1.40–10
		4	2.68	1.24–10
		5	4.07	6.47–10
		6	25.0	1.15–9
		7	52.6	1.65–9
		8	72.8	5.58–9
	Ni XXVI	1	0.768	1.87–10
		2	1.39	1.35–10
		3	2.10	1.92–10
		4	2.94	1.29–10
		5	3.66	1.59–10
		6	4.83	7.93–9
		7	28.7	1.47–9
		8	61.3	2.00–9
		9	84.9	6.08–9
Be	C III	1	0.0326	3.70–13
		2	0.227	1.25–13
		3	0.334	9.12–14
		4	0.478	4.08–13
		5	0.738	1.41–12
		6	0.925	1.09–10
	N IV	1	0.0505	8.46–13

Table 19. Continued

Sequence	*Ion*	t	T_i/Ry (K)	α_i
	N IV	2	0.218	1.40–12
		3	0.440	6.39–13
		4	0.745	2.07–12
		5	1.17	1.56–10
		6	3.39	1.83–11
	O V	1	0.111	1.41–12
		2	0.307	7.90–13
		3	0.479	3.85–12
		4	0.916	4.22–12
		5	1.42	2.83–10
		6	4.79	5.97–11
	Ne VII	1	0.207	2.67–12
		2	0.532	1.27–11
		3	1.10	9.88–12
		4	1.90	4.76–10
		5	8.22	2.24–10
	Mg IX	1	0.292	5.59–12
		2	0.502	3.89–12
		3	0.742	2.38–11
		4	1.31	2.08–11
		5	2.38	6.96–10
		6	10.3	1.19–10
		7	13.0	5.98–10
	Si XI	1	0.228	2.96–11
		2	0.330	9.13–12
		3	0.560	6.60–12
		4	0.857	3.60–11
		5	1.61	3.23–11
		6	2.16	4.89–11
		7	2.91	8.45–10
		8	14.3	2.59–10
		9	18.4	1.14–9
	S XIII	1	0.0642	1.80–11
		2	0.402	1.30–11
		3	0.629	5.42–11
		4	0.907	1.33–11
		5	1.28	4.00–11
		6	1.93	5.09–11
		7	2.55	7.11–11
		8	3.44	1.04–9
		9	19.0	4.65–10
		10	24.8	2.25–9
	Ar XV	1	0.130	9.84–11
		2	0.496	1.55–11
		3	1.02	8.71–11
		4	1.89	7.73–11
		5	2.75	1.01–10
		6	3.93	1.32–9
		7	13.4	1.33–10
		8	24.2	7.49–10
		9	32.0	3.40–9

Table 19. Continued

Sequence	*Ion*	*t*	T_i/Ry (*K*)	α_i
Be	Ca XVII	1	0.271	2.28–11
		2	0.708	1.18–10
		3	0.965	2.46–11
		4	1.53	8.09–11
		5	2.37	1.10–10
		6	3.19	1.33–10
		7	4.49	1.54–9
		8	16.3	1.97–10
		9	30.1	1.15–9
		10	40.4	5.47–9
	Fe XXIII	1	0.101	3.21–11
		2	0.598	2.51–11
		3	0.978	2.89–10
		4	2.12	1.78–10
		5	3.20	2.50–10
		6	4.40	2.58–10
		7	6.50	2.11–9
		8	26.2	7.29–10
		9	51.8	2.96–9
		10	70.8	1.17–8
	Ni XXV	1	0.434	2.83–11
		2	0.615	3.49–10
		3	1.07	4.08–11
		4	2.00	2.43–10
		5	3.30	3.52–10
		6	4.71	3.31–10
		7	7.19	2.39–9
		8	30.0	9.90–10
		9	60.1	3.67–9
		10	82.6	1.34–8
Ne	Mg III	1	2.79	5.02–13
		2	3.88	4.17–11
	Si V	1	6.00	2.40–11
		2	7.53	8.68–11
		3	9.04	1.39–10
	S VII	1	8.80	6.59–11
		2	12.0	3.82–10
		3	14.5	1.03–9
	Ar IX	1	11.7	1.19–10
		2	14.5	1.78–10
		3	19.8	2.55–9
	Ca XI	1	16.7	6.37–10
		2	23.0	1.21–9
		3	27.7	3.92–9
	Fe XVII	1	29.0	2.83–9
		2	43.4	5.05–9
		3	54.8	1.67–8
	Ni XIX	1	33.7	3.79–9
		2	51.8	6.67–9
		3	62.8	1.14–8

In this expression all important radiative and autoionization processes have been taken into account. The numerical values of parameters T_i and a_i are given in Table 19.

At large electron temperature the high excited levels are populated predominantly by the dielectronic recombination. For most elements at 10^5–10^6 K the dielectronic recombination dominates over the radiative recombination. At temperatures $T_e \approx 10^4$ K the efficiency of captures into high excited states is low. For ions of C, N, O, Ne, Al and Si the dielectronic recombination can proceed via captures into lower autoionization states. Owing to the presence of such states the process of dielectronic recombination is essential also at low temperatures $T_e = 5000$–$20\,000$ K which are dominant in nebulae. The capture processes to lower autoionization states determine the rate of low-temperature dielectronic recombination. Some of the ions of the above-mentioned elements have low metastable states. The number of autoionization captures and thus the dielectronic recombination rate in these cases depend on the population of corresponding metastable states and, consequently, on the electron concentration and temperature of the nebula. The dielectronic recombination at low temperatures acts on the intensities of some emission lines observed in the spectra of nebulae.

The dielectronic recombination rate at low temperatures (applied to the conditions of gaseous nebulae) has been calculated by Storey (1981), Nussbaumer and Storey (1983, 1984, 1986, 1987). The corresponding coefficient $\alpha_L^{\rm di}(T_e)$ has been expressed by the following approximation

$$\alpha_L^{\rm di}(T_e) = (\frac{a}{t} + b + ct + dt^2)t^{-3/2}\exp(-f/t)10^{-12}\ {\rm cm}^3\ {\rm s}^{-1}. \qquad (59)$$

This expression describes the dielectronic recombination to the ground or the metastable states.

Table 20 gives the values of parameters a, b, c, d and f and values t_l and Y for ions of C, N, O, Ne, Mg, Al and Si taken from the papers by Nussbaumer and Storey (1984, 1986, 1987). In the table the quantity E_0 is the calculated excitation energy of the term, the value of t_l has been chosen such that the maximum errors in the fitted formula equation (59) were less than 20%. The value Y is the rate $\alpha^{\rm di}$ at $T_e = 10^4$ K in units of 10^{-12} ($\rm cm^3 s^{-1}$). For ions of Mg, Al, Si and Ne also the values of total dielectronic recombination rates $\alpha^{\rm di}({\rm total}) = \sum \alpha_{\rm eff}^{\rm di}(LS)$ are given in Table 20. In this formula the summation is carried out over both ground and metastable states.

More exact calculations of the dielectronic recombination rates for ions C II, N III and O IV have been carried out in the paper by Badnell (1988). These quantities do not differ from the results of Nussbaumer and Storey (1984, 1986, 1987) by more than 10–20%. That it is necessary to take into account the forbidden autoionization transitions in the calculation of dielectronic recombination rate has been demonstrated by Beigman and Chichkov (1980).

The total recombination rate can be written in the form

$$\alpha = \alpha^{\rm rad}(T_e) + \alpha_H^{\rm di}(T_e) + \alpha_L^{\rm di}(T_e). \qquad (60)$$

Table 20. Approximation parameters for dielectronic recombination rates (Nussbaumer and Storey (1984, 1986, 1987) (equation (59))

Term	E_0	*a*	*b*	*c*	*d*	*f*	t_l	*Y*
	C I							
^1S	21618	0.0000	0.0000	0.0000	0.0000	0.0000	0.10	0.000
^1D	10163	−0.0202	0.3799	0.0890	−0.0057	0.9237	0.10	0.176
^3P	0	0.0238	−0.0222	0.1722	−0.0154	2.7590	0.10	0.010
	C II							
$^2P^0$	0	1.9661	3.8179	5.0243	0.1934	0.6013	0.10	6.030
	C III							
$^3P^0$	52419	1.8790	5.0085	4.5530	−0.1453	0.4090	0.10	7.504
^1S	0	0.8361	5.2192	2.7046	−0.0856	0.4436	0.10	5.566
	N I							
$^2P^0$	28839	0.0000	0.1264	0.0273	−0.0031	0.4570	0.10	0.095
$^2D^0$	19228	0.0017	0.5661	0.1008	−0.0121	0.4443	0.10	0.421
$^4S^0$	0	0.0102	−0.0032	0.0754	−0.0068	3.1555	0.15	0.008
	N II							
^1S	32600	0.0090	−0.0111	0.0232	−0.0009	3.3623	0.15	0.001
^1D	15227	0.1851	0.3804	0.6203	−0.0321	3.2769	0.10	0.044
^3P	0	0.0324	−0.6695	4.0805	−0.0509	0.5569	0.10	1.944
	N III							
$^2P^0$	0	3.6446	16.6017	30.2077	−1.2409	0.8275	0.10	21.513
	N IV							
$^3P^0$	67345	0.3327	−2.1374	16.0006	−1.3683	0.2665	0.10	9.827
^1S	0	0.1065	−1.9371	10.4904	−0.9499	0.3468	0.10	5.450
	O I							
$^5S^0$	73690	0.9887	−2.1047	3.6416	−0.2442	12.4049	0.40	0.000
^3P	0	0.0051	0.0012	0.1377	−0.0135	0.6061	0.10	0.071
	O II							
$^2P^0$	40467	0.0000	0.2105	0.2768	−0.0238	0.3353	0.10	0.331
$^2D^0$	26817	−0.0002	1.0132	0.3488	−0.0199	0.3186	0.10	0.976
$^4S^0$	0	0.0629	−0.1823	0.3497	0.0085	1.8398	0.10	0.038
	O III							
^1S	42975	−0.0002	0.3726	0.3460	−0.0219	2.1618	0.15	0.080
^1D	20063	−0.0049	1.6231	2.6810	−0.1466	1.5497	0.10	0.882
^3P	0	0.2789	−4.8663	23.1182	−1.9408	0.5530	0.10	9.543
	O IV							
$^2P^0$	0	5.9556	−10.8824	60.9389	−1.8906	0.2173	0.10	43.551
	O V							
$^3P^0$	82234	0.3075	−4.6445	30.2563	−3.0843	1.8174	0.10	3.709
^1S	0	0.2155	−3.0795	19.7360	−1.9183	2.0666	0.10	1.893
	Mg I							
$^3P^0$	21885	0.5116	−2.8906	7.4450	−0.7234	2.4137	0.10	0.389
^1S	0	0.1028	−0.3270	1.3742	−0.0742	1.2735	0.10	0.301
Total	0	1.2044	−4.6836	7.6620	−0.5930	1.6260	0.15	0.706
	Al I							
^4P	29022	0.1290	0.1380	1.3088	−0.1254	2.0075	0.10	0.195
$^2P^0$	0	−0.0001	1.0652	1.5718	−0.1149	0.6513	0.10	1.315
Total	0	0.0219	−0.4528	2.5427	−0.1678	0.2276	0.10	1.548

Table 20. Continued

Term	E_0	*a*	*b*	*c*	*d*	*f*	t_l	*Y*
	Al II							
$^3P^0$	37517	1.7223	−4.5922	7.2682	0.1478	1.1321	0.10	1.465
^1S	0	0.3813	−1.4668	3.8543	−0.1085	0.3581	0.10	1.860
Total	0	0.7086	−3.1083	7.0422	0.5998	0.4194	0.10	3.447
	Si I							
^3P	0	−0.0219	0.4364	0.0684	−0.0032	0.1342	0.10	0.419
Total	0	−0.0219	0.4364	0.0684	−0.0032	0.1342	0.10	0.419
	Si II							
$^4F^0$	114224	0.2692	−0.7274	0.8477	0.0543	0.4070	0.15	0.223
^4P	42811	0.2899	−0.8854	1.7321	−0.1101	0.3248	0.10	0.742
$^2P^0$	0	3.0004	−11.8047	15.8005	−0.7492	0.7858	0.20	2.847
Total	0	3.2163	−12.0571	16.2118	−0.5886	0.5613	0.15	3.869
	Ne II							
^4P	219181	0.3073	−0.5251	1.7029	−0.0739	13.3271	0.45	0.000
$^2P^0$	0	0.0146	−0.1906	0.9996	−0.0970	0.4741	0.10	0.452
Total	0	0.0129	−0.1779	0.9353	−0.0682	0.4516	0.10	0.447
	Ne III							
$^5S^0$	313828	0.0004	2.9380	1.5448	−0.0820	3.0010	0.10	0.219
^1S	55427	0.5209	2.0127	1.0069	−0.0243	0.2447	0.10	2.753
^1D	25521	1.2277	5.5667	7.0485	−0.4427	0.2799	0.10	10.129
^3P	0	1.8736	7.6536	7.9371	−0.0495	0.2062	0.10	14.170
Total	0	3.6781	14.1481	17.1175	−0.5017	0.2313	0.10	27.330
	Ne IV							
$^2P^0$	62499	0.0374	−0.1777	2.9749	−0.2530	0.1819	0.10	2.152
$^2D^0$	41313	0.0523	−1.1191	7.9365	−0.7140	−0.0331	0.10	6.363
$^4S^0$	0	1.0446	4.6520	7.0880	0.1502	0.2842	0.10	9.735
Total	0	−0.0254	5.5365	17.0727	−0.7225	0.1702	0.10	18.440
	Ne V							
$^5S^0$	97713	0.7469	−3.2024	12.1163	−1.0379	1.8482	0.10	1.358
^1S	63900	0.0000	1.2354	0.3603	0.0245	0.7655	0.15	0.754
^1D	30294	−0.0283	21.5485	7.0314	−0.2801	0.4342	0.10	18.314
^3P	0	0.0435	25.1260	24.6502	−0.4953	0.1664	0.10	41.763
Total	0	−0.0141	33.8479	43.1608	−1.6072	0.1942	0.10	62.081
	Ne VI							
^4P	105390	23.8234	135.1852	85.8070	−1.2212	0.1231	0.10	215.380
$^2P^0$	0	1.1880	121.9472	56.3464	12.1953	0.2288	0.10	152.477
Total	0	19.9280	235.0536	152.5096	9.1413	0.1282	0.10	366.502
	Ne VII							
$^3P^0$	112196	4.2564	145.0547	59.8074	−5.1910	2.5046	0.20	16.663
^1S	0	0.0610	39.1376	37.6243	−3.7043	2.4254	0.15	6.467
Total	0	5.4751	203.9751	86.9016	−7.4568	2.5145	0.20	23.373

If $T_e \leq 10^3$ K then this rate is dominantly the radiative recombination $\alpha^{\rm rad}(T_e)$ and at $T_e > 10^5$ K dominates the dielectronic recombination via the captures to high excited autoionization states $\alpha_H^{\rm di}(T_e)$ (see equation (55)). For intermediate temperatures T_e=10^3–10^4 K for many ion species the dominating process is the dielectronic recombination via low excited autoionization states ($\alpha_L^{\rm di}(T_e)$). The

contribution of individual recombination transitions to the total recombination rate is visualized in Figure 10 of the monograph by Nikitin *et al.* (1988).

4.6 Charge Transfer Reactions

In charge transfer reactions an electron (usually the outermost one) is transported from atom or ion X to ion X^+:

$$X^+ + \mathrm{Y} \leftrightarrow X + \mathrm{Y}^+ \pm \Delta E. \tag{61}$$

The electron transition is realized via quasimolecular state $X^+\mathrm{Y}$ or $X\mathrm{Y}^+$. The energy defect ΔE equals to the difference between binding energies of atomic systems $X^+\mathrm{Y}$ and $X\mathrm{Y}^+$.

In the case of direct reaction an electron of atom Y is transferred to ion X^+. Such a charge transfer is ionization of Y and recombination to X^+. The opposite charge transfer is called the inverse charge transfer. The rates of direct and inverse reactions are not equal and the ratio depends on the gas temperature.

For energies of colliding particles $\Delta E \leq 100$ eV the most important process is the electron capture by the outermost shell. At large energies of colliding particles the processes of electron capture by internal shells are more effective. For atoms of alkali metals the electron capture by internal shells is essential already at $E > 20$ eV.

The reactions of type

$$X^+ + X^0 \leftrightarrow X^0 + X^+ \tag{62}$$

are termed the reactions of resonance charge transfer, the role of such processes is minor for gaseous nebulae.

Dominating in the conditions of gaseous nebulae are the reactions of charge transfer in collision with neutral hydrogen and helium:

$$X^{i+1} + \mathrm{H}^0 \leftrightarrow X^i + \mathrm{H}^+ \tag{63}$$

and

$$X^{i+1} + \mathrm{He}^0 \leftrightarrow X^i + \mathrm{He}^+. \tag{64}$$

However, in some cases also other reactions of type (61) for elements other than H and He can be important. The number of direct (or recombination) charge transfer events (equation (63) and equation (64)) in the unit volume per unit time is

$$\overrightarrow{N}_{\mathrm{ch}} = n(X^{i+1})n(\mathrm{Y}^0)\overrightarrow{k}(X^i, \mathrm{Y}^0) \tag{65}$$

and the same number for inverse (or ionization) charge transfer (see also equations (63) and (64)) is

$$\overleftarrow{N}_{\mathrm{ch}} = n(X^i)n(\mathrm{Y}^+)\overleftarrow{k}(X^i, \mathrm{Y}^+), \tag{66}$$

where Y^0 corresponds to H^0 or He^0 and Y^+ to H^+ or He^+. The quantites $\overrightarrow{k}$ and $\overleftarrow{k}$ are the corresponding charge transfer rates ($\mathrm{cm}^3\ \mathrm{s}^{-1}$).

Table 21a. Charge transfer rates (in cm^3s^{-1}) for collisions with H (T_e in 10^3 (K) $X^{i+1}+ + H^0 \leftrightarrow X^i + H^+ + \Delta E$

X^{i+1}	$\overrightarrow{k}$ (X^{i+1}, H^0)	T_e	*Meth.*	*Ref*	$\overleftarrow{k}$ (X^i, H^+)	T_e	*Meth.*	*Ref.*	ΔE (eV)
H^+	5.0–10	0.1		W78					0
He^+	8.0–16	0.1		W78					+11.0
	1.9–15			JD71					
He^{2+}	1.6–13	0.25–64		AH57					+40.8
	1.0–13			AD65					
Li^{2+}	3.0–9	10		W78					+62.0
C^+	1.4–17	10	DW	B80	2.8–16	10		B80	−2.33
					1.4–11	10		S75	
C^{2+}	1.0–14			MV76					+10.8
	1.3–11			S75b					
	1.0–12	10	QM	BD80					
	1.0–12	5	QM	BH80					
	1.0–12	10	QM	BH80					
	1.35–12	20	QM	BH80					
	3.53–12	30	QM	BH80					
	1.49–11	50	QM	BH80					
C^{3+}	2.0–9		**	PA78					+34.3
	1.0–9			B76					
	3.6–9	10	QM	BD80					
	2.9–9	10	LZ	BD80					
	3.09–9	5	QM	BH80					
	3.58–9	10	QM	BH80					
	4.22–9	20	QM	BH80					
	4.78–9	30	QM	BH80					
	5.46–9	50	QM	BH80					
C^{4+}	2.8–11	1.0	LZ	BD80					+50.9
	1.2–10	3.16	LZ	BD80					
	7.6–10	10	LZ	BD80					
	3.8–9	31.6	LZ	BD80					
N^+	5.0–10	10		SW71	4.0–10	10		SW71	+0.95
	1.0–12	10		M73	5.3–10	10		FS71	
	1.0–12	10	DW	BD79					
	3.7–10	10		FS71					
N^{2+}	3.96–9			S75a					+16.0
	2.0–9		**	PA78					
	8.6–10	10	QM	BD80					+16.0
	5.2–10	10	LZ	BD80					
	7.8–10	5	QM	BH80					
	8.6–10	10	QM	BH80					
	9.7–10	20	QM	BH80					
	1.05–9	30	QM	BH80					
	1.11–9	50	QM	BH80					
N^{3+}	1.11–9	3		MV79					+33.9
	3.56–9	10		MV79					
	7.90–9	30		MV79					
	3.0–9		**	PA78					
	2.9–9	10	QM	BD80					
	2.7–9	10	LZ	BD80					
	4.4–10	2.0		CW77					
	9.7–10	3.5		CW77					

Table 21a. Continued

X^{i+1}	$\overrightarrow{k}$ (X^{i+1}, H^0)	T_e	*Meth.*	*Ref*	$\overleftarrow{k}$ (X^i, H^+)	T_e	*Meth.*	*Ref.*	ΔE (eV)
N^{3+}	1.5–9	5.0		CW77					
	2.3–9	7.5		CW77					
	3.1–9	10.0		CW77					
	3.8–9	12.5		CW77					
	4.4–9	15.0		CW77					
	5.6–9	20.0		CW77					
	1.54–9	5	QM	BH80					
	2.93–9	10	QM	BH80					
	5.14–9	20	QM	BH80					
	7.10–9	30	QM	BH80					
	9.47–9	50	QM	BH80					
N^{4+}	6.4–11	1.0	LZ	BD80					+63.9
	2.7–11	3.16	LZ	BD80					
	1.6–10	10.0	LZ	BD80					
	8.7–10	31.6	LZ	BD80					
O^+	1.04–9	10		FS71	9.1–10	10		FS71	+0.02
	6.8–10	0.3		FF72	3.8–10	0.3		FF72	
	8.0–10	1.2		R63					
	3.8–10	1.2		HP63					
O^{2+}	3.96–9	10		S75					+21.5
	1.6–9		**	PA78					
	5.9–10		LZ	BB79					
	7.7–10	10	QM	BG77					
	7.7–10	10	LZ	BD80					
O^{2+}	6.0–10	5	QM	BH80					+21.5
	7.7–10	10	QM	BH80					
	1.03–9	20	QM	BH80					
	1.26–9	30	QM	BH80					
	1.62–9	50	QM	BH80					
O^{3+}	8.6–9	10	QM	BD80					+41.3
	2.1–9	10	LZ	BD80					
	6.34–9	5	QM	BH80					
	8.63–9	10	QM	BH80					
	1.18–8	20	QM	BH80					
	1.45–8	30	QM	BH80					
	1.76–8	50	QM	BH80					
O^{4+}	1.4–10	1.0	LZ	BD80					+63.8
	1.9–10	3.16	LZ	BD80					
	2.6–10	10.0	LZ	BD80					
	5.2–10	31.6	LZ	BD80					
Ne^{2+}	2.0–9	10		S75a					+27.4
	3.0–10		**	PA78					
	3.0–11		LZ	BB79					
	1.0–20			BG77					
	9.0–21	5	QM	BH80					
	1.0–20	10–50	QM	BH80					
Ne^{3+}	5.7–9	10	QM	BD80					+49.9
	3.8–9	10	LZ	BD80					
	4.0–9	5	QM	BH80					
	5.68–9	10	QM	BH80					
	8.28–9	20	QM	BH80					

Table 21a. Continued

X^{i+1}	$\vec{k}$ (X^{i+1}, H^0)	T_e	*Meth.*	*Ref*	$\overleftarrow{k}$ (X^i, H^+)	T_e	*Meth.*	*Ref.*	ΔE (eV)
Ne^{3+}	1.05–8	30	QM	BH80					
	1.30–8	50	QM	BH80					
Ne^{4+}	5.9–9	1.0	LZ	BD80					+83.5
	5.9–9	3.16	LZ	BD80					
	6.9–9	10	LZ	BD80					
	1.2–8	31.6	LZ	BD80					
Mg^{2+}	1.0–14			W78	7.4–14	10	LZ	BD80	+1.44
	8.7–14	1.0	LZ	BD80	7.6–14	31.6–316	LZ	BD80	
	8.6–14	3.16	LZ	BD80					
	8.6–14	10	LZ	BD80					
	8.6–14	31.6	LZ	BD80					
Mg^{3+}	7.0–21			BM54					+66.5
	4.4–9	1.0	LZ	BD80					
	4.4–9	3.16	LZ	BD80					
	6.5–9	10	LZ	BD80					
	1.2–8	31.6	LZ	BD80					
Mg^{4+}	5.9–9	1.0	LZ	BD80					+95.7
	5.9–9	3.16	LZ	BD80					
	6.5–9	10	LZ	BD80					
	1.2–8	31.6	LZ	BD80					
Si^{2+}	5.0–9	10		MV76					+2.74
	5.0–9	10		W78					
	1.98–9	0.01	QM	GM82					
	1.80–9	0.02	QM	GM82					
	1.75–9	0.05	QM	GM82					
	1.72–9	0.1	QM	GM82					
	1.74–9	0.2	QM	GM82					
	2.01–9	0.5	QM	GM82					
	2.50–9	1	QM	GM82					
	3.20–9	2	QM	GM82					
	4.34–9	5	QM	GM82	3.0–12	5	QM	GM82	
	5.28–9	10	QM	GM82	7.3–11	10	QM	GM82	
	6.26–9	20	QM	GM82	4.26–10	20	QM	GM82	
	6.87–9	30	QM	GM82	4.94–10	30	QM	GM82	
	7.70–9	50	QM	GM82	1.36–9	50	QM	GM82	
	9.10–9	100	QM	GM82	2.21–9	100	QM	GM82	
	1.12–8	200	QM	GM82	3.18–9	200	QM	GM82	
	1.60–8	500	QM	GM82	4.99–9	500	QM	GM82	
	2.18–8	1000	QM	GM82	7.03–9	1000	QM	GM82	
Si^{3+}	4.0–10	1.0	LZ	BD80					+19.9
	3.9–10	3.16	LZ	BD80					
	4.1–10	10	LZ	BD80					
	4.3–10	31.6	LZ	BD80					
Si^{4+}	2.4–9	1.0	LZ	BD80					+31.5
	2.2–9	3.16	LZ	BD80					
	2.3–9	10	LZ	BD80					
	2.7–9	31.6	LZ	BD80					
$S^+(^4S)$	3.0–15	10	DW	B80					–3.24
$S^+(^2P)$					1.0–9	10		DB78	+0.20
S^{2+}	0			PA78					+9.74
	1.0–14*	1–31.6	LZ	BD80					

Table 21a. Continued

X^{i+1}	$\overrightarrow{k}$ (X^{i+1}, H^0)	T_e	*Meth.*	*Ref*	$\overleftarrow{k}$ (X^i, H^+)	T_e	*Meth.*	*Ref.*	ΔE *(eV)*
S^{3+}	1.5–9		**	PA78					+21.2
	3.9–9	1.0	LZ	BD80					
	2.7–9	3.16	LZ	BD80					
	2.3–9	10	LZ	BD80					
	2.4–9	31.6	LZ	BD80					
S^{4+}	1.2–8	1.0	LZ	BD80					+33.7
	8.0–9	3.16	LZ	BD80					
	6.5–9	10	LZ	BD80					
	7.5–9	31.6	LZ	BD80					
Ar^{2+}	1.0–14*	1–31.6	LZ	BD80					+14.0
Ar^{3+}	2.1–9	1.0	LZ	BD80					+27.3
	3.0–9	3.16	LZ	BD80					
	4.4–9	10	LZ	BD80					
	6.2–9	31.6	LZ	BD80					
Ar^{4+}	5.8–9	1.0	LZ	BD80					+46.2
	5.8–9	3.16	LZ	BD80					
	6.5–9	10	LZ	BD80					
	1.7–9	31.6	LZ	BD80					
Fe^+					7.0–9	0.3		W78	–5.7

The values $\overrightarrow{k}$ and $\overleftarrow{k}$ for different ions, the lines of which are observed in the nebulae, are summarized by Table 21. Before the charge transfer reaction the ion X^{i+1} is predominantly in the ground state, but as a result of the charge transfer reaction the excited states of ion X^i can be populated.

The quantities $\overrightarrow{k}$ and $\overleftarrow{k}$ are interrelated by the following formula of statistical thermodynamics:

$$\overrightarrow{k} = \overleftarrow{k} \exp(-\Delta E/kT_e). \tag{67}$$

The main direct and inverse charge transfer reactions of types equation (63) and equation (64) are essential in the low-density astrophysical plasma conditions considered by Arnaud and Rothenflug (1985). They found the following approximation formula for computation of the charge transfer rates:

$$\overrightarrow{k} = A\,(T_e/10^4)^B\ \{1 + C\exp[D(T_e/10^4)]\}\ \mathrm{cm^3\ s^{-1}}. \tag{68}$$

In this expression the dependence of corresponding coefficients on T_e has been described analytically. The values of parameters A, B, C and D are given in Table 22, where in column 2 the range of T_e values has been given for which approximation equation (68) holds.

Some valuable data on charge transfer reactions are given by Suchkov and Shchekinov (1983). For reactions with H^0 and He^0 they used the approximation C=0, i.e. in their formulation

$$\overrightarrow{k} = k_0 T_e^{\alpha}.$$

Table 21b. Charge transfer rates (in cm^3s^{-1}) for collisions with He (T_e in 10^3 K) $X^{i+1}+$ $+He^0 \leftrightarrow X^i + He^+ + \Delta E$

X^{i+1}	$\overrightarrow{k}$ (X^{i+1}, He^0)	T_e	*Meth.*	*Ref*	$\overleftarrow{k}$ (X^i, He^+)	T_e	*Meth.*	*Ref.*	ΔE (eV)
Li^{2+}	3.0–9	10		D54					+51.1
	2.0–17	10		D54					
Li^{3+}	5.0–10	10		W78					+97.9
Be^{3+}	1.0–9	10		W78					+129.3
C^{2+}	8.13–15	0.2		B72	3.1–15	10	QM	BD80	–0.21
	4.26–13	0.3		B72	1.0–15	10	LZ	BD80	
	1.02–11	0.5		B72					
	3.31–11	0.7		B72					
	1.12–10	1.0		B72					
	3.63–10	2.0		B72					
	5.62–10	3.0		B72					
	7.41–10	5.0		B72					
	1.00–9	10.0		B72					
$C^{2+}(^3P^0)$	1.4–12	5	QM	BH80	5.0–16	5		BH80	+6.29
	6.1–12	10	QM	BH80	3.1–15	10		BH80	
	2.2–11	20	QM	BH80	4.2–13	20		BH80	
	4.8–11	30	QM	BH80	3.2–12	30		BH80	
	1.1–10	50	QM	BH80	1.8–11	50		BH80	
C^{3+}	4.7–13	1.0	LZ	BD80					+23.3
	4.6–12	3.16	LZ	BD80					
	5.1–11	10.0	LZ	BD80					
	3.5–10	31.6	LZ	BD80					
C^{4+}	1.0–14*	1.0–31.6	LZ	BD80					+39.9
N^{2+}	3.0–10	1.0	LZ	BD80	4.1–12	10	LZ	BD80	+5.03
	3.1–10	3.16	LZ	BD80	4.7–11	31.6	LZ	BD80	
	3.3–10	10.0	LZ	BD80	2.5–10	100	LZ	BD80	
	4.6–10	31.6	LZ	BD80	8.5–10	316	LZ	BD80	
N^{3+}	1.8–10	1.0	LZ	BD80					+22.9
	1.9–10	3.16	LZ	BD80					
	1.1–10	10.0	LZ	BD80					
	1.9–10	31.6	LZ	BD80					
	4.4–10	2.0		CW77					
	9.7–10	3.5		CW77					
	1.5–9	5.0		CW77					
	2.3–9	7.5		CW77					
N^{3+}	3.1–9	10.0		CW77					
	3.8–9	12.5		CW77					
	4.4–9	15.0		CW77					
	5.6–9	20.0		CW77					
N^{4+}	4.6–9	1.0	LZ	BD80					+52.9
	2.8–9	3.16	LZ	BD80					
	2.0–9	10.0	LZ	BD80					
	1.7–9	31.6	LZ	BD80					
O^{2+}	2.0–10			BG77					+10.5
	2.0–10	10	QM	BD80					
	3.2–10	10	LZ	BD80					
	1.0–10	5	QM	BH80					
	2.0–10	10	QM	BH80					
	3.9–10	20	QM	BH80					
	5.9–10	30	QM	BH80					
	8.9–10	50	QM	BH80					

Table 21b. Continued

X^{i+1}	$\overrightarrow{k}$ (X^{i+1}, He^0)	T_e	*Meth.*	*Ref*	$\overleftarrow{k}$ (X^i, He^+)	T_e	*Meth.*	*Ref.*	ΔE (eV)
O^{3+}	1.7–9	1.0	LZ	BD80					+30.3
	1.2–9	3.16	LZ	BD80					
	1.0–9	10.0	LZ	BD80					
	1.0–9	31.6	LZ	BD80					
O^{4+}	1.4–9	1.0	LZ	BD80					+52.8
	8.7–10	3.16	LZ	BD80					
	6.5–10	10.0	LZ	BD80					
	6.4–10	31.6	LZ	BD80					
Ne^{2+}	1.0–14			D80					+16.4
	5.0–15	0.3	exp	JB78					
	1.0–14*	1.0–31.6	LZ	BD80					
Ne^{3+}	1.0–14*	1.0–31.6	LZ	BD80					+38.9
Ne^{4+}	1.7–9	1.0	LZ	BD80					+72.5
	1.7–9	3.16	LZ	BD80					
	1.7–9	10.0	LZ	BD80					
	3.1–9	31.6	LZ	BD80					
Mg^{3+}	7.0–21	10.0		W78					+55.6
	1.2–9	1.0	LZ	BD80					
	8.6–10	3.16	LZ	BD80					
	7.4–10	10.0	LZ	BD80					
	7.7–10	31.6	LZ	BD80					
Mg^{4+}	1.8–9	1.0	LZ	BD80					+84.7
	1.8–9	3.16	LZ	BD80					
Mg^{4+}	2.2–9	10.0	LZ	BD80					
	3.2–9	31.6	LZ	BD80					
Al^{3+}	6.0–15			W78					+3.86
Si^{2+}					1.5–10	10.0	LZ	BD80	−8.24
					2.0–10	31.6	LZ	BD80	
					2.7–10	100	LZ	BD80	
					3.4–10	316	LZ	BD80	
Si^{3+}	1.7–10	1.0	LZ	BD80	3.0–10			B80	+8.88
	3.9–10	3.16	LZ	BD80	9.9–10	10	LZ	BD80	
	9.6–10	10.0	LZ	BD80	2.0–9	31.6	LZ	BD80	
	2.0–10	31.6	LZ	BD80	3.4–9	100	LZ	BD80	
					4.9–9	316	LZ	BD80	
Si^{4+}	1.4–9	0.001		OM85	5.0–15	50		OM85	+20.6 (^2S)
	7.0–10	0.01		OM85	6.0–13	100		OM85	+11.7 (^2P)
	4.0–10	0.1		OM85	2.5–10	500		OM85	
	5.0–10	1.0		OM85	1.0–9	1000		OM85	
	9.0–10	3.2		OM85					
	1.6–9	10.0		OM85					
	2.7–9	31.6		OM85					
	4.0–9	100		OM85					
S^{2+}					2.5–11	10.0	LZ	BD80	−1.25
					9.8–11	31.6	LZ	BD80	
					2.7–10	100	LZ	BD80	
					5.5–10	316	LZ	BD80	
S^{3+}	3.3–10	1.0	LZ	BD80	1.3–11	10.0	LZ	BD80	+10.4
	5.2–10	3.16	LZ	BD80	8.4–11	31.6	LZ	BD80	

Table 21b. Continued

X^{i+1}	$\overrightarrow{k}$ (X^{i+1}, He^0)	T_e	*Meth.*	*Ref*	$\overleftarrow{k}$ (X^i, He^+)	T_e	*Meth.*	*Ref.*	ΔE (eV)
S^{3+}	1.1–9	10.0	LZ	BD80	3.3–10	100	LZ	BD80	
	2.3–9	31.6	LZ	BD80	8.8–10	316	LZ	BD80	
S^{4+}	1.1–12	1.0	LZ	BD80					+22.7
	8.7–13	3.16	LZ	BD80					
	7.6–13	10.0	LZ	BD80					
	1.1–12	31.6	LZ	BD80					
Ar^{2+}	7.0–11	0.3	exp	JB78	1.1–10*	10–316	LZ	BD80	+3.04
	1.3–10*	1–31.6	LZ	BD80					
Ar^{3+}	1.0–14*	1–31.6	LZ	BD80					+16.3
Ar^{4+}	2.2–9	1.0	LZ	BD80					+35.2
	1.4–9	3.16	LZ	BD80					
	9.8–10	10.0	LZ	BD80					
	8.3–10	31.6	LZ	BD80					

Note. *, There is a dependence on T_e; **, empirical values obtained from the best fit of the observed NGC 7027 spectra; DW, distorted wave approximation; LZ, Landau–Zener approximation; QM, ab initio quantum mechanical calculation; exp, experimental data.

References: AH57, Arthurs and Hyslop (1957); AD65, Allison and Dalgarno (1965); B72, Brown (1972); B76, Blint *et al.* (1976); B80, Butler and Dalgarno (1980); BB79, Butler *et al.* (1979); BD79, Butler and Dalgarno (1979); BD80, Butler and Dalgarno (1980a); BG77, Butler *et al.* (1977); BH80, Butler *et al.* (1980); BM54, Bates and Moiseiwisch (1954); CW77, Christensen *et al.* (1977); D54, Dalgarno (1954); D80, Dalgarno *et al.* (1980); DB78, Dalgarno and Butler (1978); FF72, Fehsenfeld and Ferguson (1972); FS71, Field and Steigman (1971); GM82, Gargaud *et al.* (1982); HP63, Hanson *et al.* (1963); JB78, Johnson and Biondi (1978); JD71, Jura and Dalgarno (1971); M73, Melius (1973); MV76, McCarrol and Valiron (1976); MV79, McCarrol and Valiron (1979); OM85, Opradolse *et al.* (1985); PA78, Pequignot *et al.* (1978); R63, Rapp (1963); S75, Steigman (1975); S75a, Steigman (1975a); SW71, Steigman *et al.* (1971); W78, Watson (1978).

The values of coefficients k_0 and α are compiled in Table 23. The data for charge transfer rates in impacts between atoms and ions of heavy elements are given by Pequignot and Aldrovandi (1986). The values of $\overrightarrow{k}$ for each pair of ions (upper value) and the values of ΔE (lower value) are given in Table 24. The charge transfer reaction between the heavy elements can be essential in the interstellar medium, in H I regions of nebulae and in the atmospheres of cool stars.

In the conditions of a low-density astrophysical plasma, especially in gaseous nebulae, the charge transfer reactions (e.g. $O^+ + H^0 \leftrightarrow O^0 + H^+$) often determine the atom ionization states of the atoms. This fact was first demonstrated by Chamberlain (1956), who found that $O^+/\,O^0 \simeq H^+/\,H^0$ in most gaseous nebulae. This relation holds due to high rates of the corresponding charge transfer reaction. The rates of this reaction have been computed by Field and Steigman (1971). Steigman *et al.* (1971) have given the rates of reaction $N^+ + H^0 \leftrightarrow N^0 + H^+$. More exact values of charge transfer rates have been found by Fehsenfeld and Ferguson (1972) for reaction $O^+ + H^0 \leftrightarrow O^0 + H^+ + 0.22$ eV, and by Butler and Dalgarno (1979) for reaction $N^+ + H^0 \leftrightarrow N^0 + H^+ + 0.95$ eV (see Table 21).

Table 22. Parameters for recombination and ionization charge transfer with H and He (Arnaud and Rothenflug, 1985)

Ion	*Interval of* T_e (10^4 *K*)	*A* (10^{-9} cm^3 s^{-1})	*B*	*C*	*D*
Recombination with H^0					
He^{1+}	~ 1	1.9–06	0.0	0.0	0.0
He^{2+}	~ 1	1.6–04	0.0	0.0	0.0
C^{1+}	1	1.4–08	0.0	0.0	0.0
C^{2+}	0.5–5	1.6–04	2.8	350.0	–4.2
C^{3+}	0.5–5	3.65	0.25	0.0	0.0
C^{4+}	0.1–1	0.76	1.4	0.0	0.0
N^{1+}	0.01–10	1.0–03	–0.27	–0.9	–8.8
N^{2+}	0.5–5	0.86	0.15	0.0	0.0
N^{3+}	0.5–5	2.93	0.85	0.0	0.0
N^{4+}	0.1–3	0.15	1.5	440.0	–35.6
O^{1+}	0.01–3	1.0	0.0	–0.66	–9.3
O^{2+}	0.5–5	0.8	0.43	0.0	0.0
O^{3+}	0.5–5	0.85	0.44	0.0	0.0
O^{4+}	0.1–3	0.31	0.44	0.0	0.0
Ne^{2+}	1	< 1.0–05	0.0	0.0	0.0
Ne^{3+}	0.5–5	5.7	0.51	0.0	0.0
Ne^{4+}	0.1–3	6.6	0.52	3.3	–5.3
Mg^{2+}	0.1–3	9.0–05	0.0	0.0	0.0
Mg^{3+}	0.1–3	6.6	0.52	2.7	–8.0
Mg^{4+}	0.1–3	6.6	0.52	3.3	–5.3
Si^{2+}	0.03–10	5.0	0.28	0.0	0.0
Si^{3+}	0.1–3	0.41	0.0	0.0	0.0
Si^{4+}	0.1–3	2.4	0.0	0.0	0.0
S^{1+}	1	< 3.0–06	0.0	0.0	0.0
S^{2+}	0.1–3	1.0–05	0.0	0.0	0.0
S^{3+}	0.1–3	2.3	0.0	1.25	–5.8
S^{4+}	0.1–3	7.0	0.0	1.25	–5.8
Ar^{2+}	0.1–3	1.0–05	0.0	0.0	0.0
Ar^{3+}	0.1–3	4.4	0.3	0.0	0.0
Ar^{4+}	0.1–3	6.5	0.83	9.4	0.0
Recombination with He^0					
C^{2+}	1	< 0.1	0.0	0.0	0.0
C^{3+}	0.1–3	4.6–02	2.0	0.0	0.0
C^{4+}	0.1–3	1.0–05	0.0	0.0	0.0
N^{2+}	0.1–3	0.33	0.29	1.3	–4.5
N^{3+}	0.1–3	0.15	0.0	0.0	0.0
N^{4+}	0.1–3	1.7	0.0	2.5	–3.7
O^{2+}	0.5–5	0.2	0.95	0.0	0.0
O^{3+}	0.1–3	1.0	0.0	1.25	–5.8
O^{4+}	0.1–3	0.64	0.0	2.0	–5.5
Ne^{2+}	0.1–3	1.0–05	0.0	0.0	0.0
Ne^{3+}	0.1–3	1.0–05	0.51	0.0	0.0
Ne^{4+}	0.1–3	1.7	0.52	3.3	–5.3

Table 22. Continued

Ion	*Interval of* T_e (10^4 *K*)	A (10^{-9} cm^3 s^{-1})	B	C	D
Mg^{3+}	0.1–3	0.75	0.0	1.25	−5.8
Mg^{4+}	0.1–3	2.2	0.33	0.88	−1.85
Si^{3+}	0.1–3	0.95	0.75	0.0	0.0
Si^{4+}	0.1–3	1.2	0.0	0.0	0.0
S^{3+}	0.1–3	1.1	0.56	0.0	0.0
S^{4+}	0.1–3	7.6–04	0.32	3.4	−5.25
Ar^{2+}	0.1–3	0.13	0.0	0.0	0.0
Ar^{3+}	0.1–3	1.0–05	0.0	0.0	0.0
Ar^{4+}	0.1–3	1.0	−0.3	0.0	0.0
Ion	*Interval of* T_e (10^4 *K*)	A (10^{-9} cm^3 s^{-1})	B	C	ΔE
Ionization with H^+					
O^0	0.01–10	0.91	0.0	10	0.0196
Mg^{1+}	1–30	7.6–05	0.0	0.0	1.44
Si^0	1	1.0–02	0.0	0.0	0.03
Si^{1+}	0.50–10	1.7	0.32	0.0	2.74
S^0	1	1.0	0.0	0.0	0.0
Ionization with He^+					
C^{1+}	0.50– 5	5.0–03	2.0	0.07	6.29
N^{1+}	1–30	3.7–03	2.1	0.063	1.44
Si^{1+}	1–30	0.15	0.24	0.0	6.91
Si^{2+}	1–30	0.15	0.44	0.0	8.88
S^{1+}	1–30	2.8–02	1.2	0.036	9.2
S^{2+}	1–30	1.4–02	1.6	0.046	10.5
Ar^{1+}	1–30	0.11	0.0	0.0	3.04

Table 23. Parameters for charge transfer with H^0 and He^+ (Suchkov and Shchekinov, 1983)*

Element	*Ion*							
	X^+		X^{2+}		X^{3+}		X^{4+}	
	k_0	α	k_0	α	k_0	α	k_0	α
	(a) $X^{i+1} + H^0 \rightarrow X^i + H^+$							
C	3.87–19	1.64	1.90–19	1.68	3.20–10	0.26	1.93–15	1.4
N	1.00–12	1.4	2.10–10	0.153	3.56–12	0.73	2.08–16	1.73
O	6.80–10	0	1.09–11	0.46	1.47–10	0.44	1.07–12	0.6
Ne	0	0	0	0	4.90–11	0.52	5.51–11	0.52
Mg	0	0	4.80–11	0.53	4.80–11	0.53	6.60–09	0
Si	0	0	5.00–09	0	2.80–10	0.041	6.40–10	0.14
S	0	0	1.00–14	0	1.64–09	0.037	2.07–09	0.124

Table 23. Continued

Element	*Ion*							
	X^+		X^{2+}		X^{3+}		X^{4+}	
	k_0	α	k_0	α	k_0	α	k_0	α
			(b) $X^{i+1} + He^0 \rightarrow X^i + He^+$					
C	0	0	0	0	1.03–17	1.67	1.00–14	0
N	0	0.9	2.30–11	0.29	1.39–12	0.48	7.35–09	–0.14
O	0	0	0	0	1.00–09	0	7.40–10	–0.013
Ne	0	0	1.00–14	0	1.00–14	0	1.39–11	0
Mg	0	0	0	0	5.40–10	0.035	1.10–10	0.33
Si	0	0	0	0	2.70–12	0.64	6.30–10	0.07
S	0	0	0	0	3.00–12	0.64	3.94–14	0.32
	k_1	α	ΔE (*eV*)					
			(c) $X^i + He^+ \rightarrow X^{i+1} + He^0$					
N II	3.00	1.79	5.03					
Mg II**	6.65–14	0.02	1.44					
Si II	1.43–11	0.26	6.91					
Si III	7.10–17	1.54	6.88					
S II	1.80–15	1.03	9.17					
S III	3.13–17	1.40	10.47					

Note. *, $k(T) = k_0 T^\alpha$ for the reactions with H^0 and He^0 and $k(T) = k_1 T^\alpha \exp(-\Delta E/kT)$ for the reaction with He^+. **, $Mg^+ + H^+ \rightarrow Mg^{2+} + H$.

Table 24. Recombination charge transfer rates (in units of 10^{-9} cm^3 s^{-1}) between atoms and ions of heavy elements (Pequignot and Aldrovandi, 1986)

Ion	*Li*	*Na*	*Mg*	*Al*	*Si*	*P*	*S*
C^+	0.0	0.0	0.0	0.3	1.0	0.1	0.0
			0.93	0.63	0.43	0.77	0.90
Li^+		3.0					
		0.25					
Na^+							
Mg^+	0.0	0.0		0.0			
Al^+	0.3	0.0					
	0.59	0.85					
Si^+	0.0	0.0	1.0	3.0			
	0.85	1.1	0.48	0.25			
P^+	0.0	0.0	0.3	0.0	1.0		3.0
			0.52	–0.14	0.01		0.13
S^+	0.0	0.0	0.0	0.0	0.0		
			–0.04		1.06		
Cl^+	0.0	0.0	0.1	0.0	0.0	0.0	0.1
			0.78				0.65

Table 24. Continued

Ion	*Li*	*Na*	*Mg*	*Al*	*Si*	*P*	*S*
Ca^+	0.1	0.0		3.0			
	0.72	0.97		0.13			
Ti^+	3.0	3.0		1.0			
				0.02,0.78			
Mn^+	0.0	3.0		0.0			
	−0.06	0.19					
Fe^+	3.0	3.0	3.0	1.0			
				0.36			
Ni^+	3.0	3.0		0.0			
				−0.03			
Ca^{++}	1.0	1.0	1.0	1.0	1.0	0.0	0.0
H^+	0.0	0.0	0.0	3.0	0.0	1.0	3.0

Ion	*Cl*	*K*	*Ca*	*Ti*	*Mn*	*Fe*	*Ni*
C^+		0.0	0.0	3.0	3.0	3.0	3.0
Li^+		0.0					
Na^+		0.1					
		0.80					
Mg^+		0.3	0.0	1.0	3.0		1.0
		0.59	−0.15	0.78,0.02	0.21		0.01
Al^+		0.0					
Si^+		0.0	3.0	3.0	0.1	3.0	3.0
			0.13		−0.06,0.7		0.33
P^+		0.0	1.0	3.0	1.0	3.0	3.0
			0.36		0.47		
S^+		0.0	0.0	3.0	3.0	3.0	3.0
			−0.04,1.1		0.18		
Cl^+		0.0	3.0	3.0	3.0	3.0	3.0
			0.28				
Ca^+		0.0					
Ti^+		3.0	0.1				
			0.66				
Mn^+		3.0	0.0	1.0			
				0.01,0.47			
Fe^+		3.0	3.0	3.0	3.0		3.0
					0.32		
Ni^+		3.0	0.0	1.0	3.0		
			1.1	0.01,0.4	0.20		
Ca^{++}		1.0	1.0	1.0	1.0	1.0	1.0
H^+	1.0	0.0	0.0	3.0	3.0	3.0	3.0
	0.47		−0.02,1.0				

Note. For each ion the value of charge transfer rate is presented in the upper line and the value of ΔE (in eV), in the lower line. No ΔE is given when several energetically favorable chanels exists.

Tarter *et al.* (1979) studied the effect of double charge transfer on the ionization state of gas medium:

$$X^{i+2} + \mathrm{He}^0 \leftrightarrow X^i + \mathrm{He}^{++},$$

finding this to be negligible.

Unfortunately, the accuracy of numerical values of charge transfer rates k for many reactions is low and the results of different authors can differ to dex due to low-quality methods of computation of charge transfer rates. Unknown are the reaction rate dependence on T_e for many reactions and the values of k for multiply ionized atoms. Probably the low precision of charge transfer rates is one of the factors involved in inexact results for calculated ionization degrees of elements in gaseous nebulae.

5 SPECTRA OF GASEOUS NEBULAE AND THEIR INTERPRETATION

The spectrum of a gaseous nebula consists of a weak continuous emission spectrum superposed by numerous emission lines. Several thousand spectral lines have been recognized but only about 200 of them can be measured with sufficient accuracy and used for analysis of physical conditions in nebulae. The spectral lines of atoms and ions of almost all chemical elements from H to Ni and heavier elements (see Pequignot and Balateau, 1994; Balateau *et al.*, 1995) have been detected. The intensity of the continuous spectrum has been measured for a comparatively small number of nebulae.

The emission lines observed in nebulae depending on the mechanism of their formation can be divided in two main types: (1) the recombinational and (2) the collisional lines. A list of the main spectral lines specified in the ultraviolet, visible and infrared spectral regions, is given in Table 25 (see, Appendix C). The values of wavelengths and transition probabilities for these lines are also presented in Table 25 (see, Appendix C).

5.1 Recombination Line Intensities

In the spectra of nebulae the spectral lines of allowed transitions between excited states of H, He, C, N and O are observed. Some lines of such types are detected for ions having lower abundances (see Table 25, Appendix C), say for Ne, Si and Mg. The main mechanism of formation of these lines is recombination: photorecombination or (and) dielectronic recombination (for He, C, N, O) of the excited states of ion X^{i+1} followed by the cascade transitions to the ground state of ion X^i. A definite contribution to the formation of some recombination lines is made also by collisional excitation processes.

Currently only the recombination spectra of H and He have been investigated in detail. The most complete data concerning the theoretical recombination line intensities of H, He I and He II are given in the papers by Brocklehurst (1971, 1972), Hummer and Storey (1987), Martin (1988), and Ilmas and Nugis (1982). The recombinational spectra of C, N and O have been less well studied. The difficulties of these calculations are caused by the complexity of the structure of their atomic energy levels and by inaccuracy of the values of transition probabilities, which determine the state populations. References on the recombination spectra of C,

N and O ions have been compiled by Nikitin *et al.* (1988), Hummer and Storey (1987) and Escalante and Victor (1990, 1992).

In most cases gaseous nebulae are transparent for the emission in the recombination lines. Thus, the energy irradiated by a nebula in a recombination line with wavelength λ_{jk} is

$$E(\lambda) = 4\pi j(\nu) = \int n_j n(X^i) A_{jk} h\nu_{jk} dV = \int n_e n(X^{i+1}) \alpha^{\text{eff}}(\lambda) h\nu_{jk} dV, \qquad (69)$$

where n_j is the population of the level j of ion X^i, the quantity A_{jk} is the corresponding spontaneous transition probability, further, $h\nu_{jk}$ is the photon energy of the transition, n_e is the electron number density, $n(X^{i+1})$ is the number density of the recombining ion and α^{eff} is the effective coefficient of recombination, which has been defined as the total recombination coefficient due to all recombination events plus the contribution from the cascade processes. The integration covers the entire volume of a nebula.

The populations of levels n_j can be found from the equation of statistical equilibrium

$$n_m \sum_{k=1}^{m-1} A_{mk} = n_e n(X^{i+1}) \alpha_m(T_e) + \sum_{k=m+1}^{k_{\max}} n_k A_{km} \quad (m = 2, 3, 4 \ldots) \qquad (70)$$

for the Menzel A case if the optical depth in the resonance line series ($\tau_{1n} \ll 1$). Here $k_{\max}$ is the index of the highest state considered. For Menzel B case ($\tau_{1n} \gg 1$) we have

$$n_m \sum_{k=2}^{m-1} A_{mk} = n_e n(X^{i+1}) \alpha_m(T_e) + \sum_{k=m+1}^{k_{\max}} n_k A_{km} \quad (m = 3, 4, 5 \ldots). \qquad (71)$$

In these equations a_m (T_e) is the total electron recombination rate to level n of ion X^{i+1}.

It must be mentioned that models A and B simplify essentially the problem of radiative transfer in recombination spectral lines. For the intermediate case if at different values of n the optical depth τ_{1n} is in the range between the Menzel A and B cases, we have to use some approximations to solve the transfer problem for the first series lines. In gaseous nebulae the optical depth in resonance line series of most abundant elements (H, He, C, N, O) is 10–10^5. Calculation of recombination spectra for H I in the case of finite optical depth in L_α for the stationary nebulae presented by the plane-parallel layers has been carried out by Grinin (1969). In the most cases one can use the standard Sobolev (1960) approximation. This approximation has been used by several authors (see, e.g. Rublev, 1969; Ilmas, 1986; Ilmas and Nugis, 1982).

The level populations of atoms and ions practically in all nebulae can be treated as the time independent quantities. Only in the case where a rapid change of ionizing radiation occurs is it inevitable to use the equations describing the time dependency of level populations.

Table 26a. Relative intensities of the Balmer lines $I(n-2)/I(4-2)$ on the scale $I(H_\beta) = 100$

	T_e (K)								
	5000			*10 000*			*20 000*		
$n \setminus n_e$ (cm^{-3})	10^2	10^4	10^6	10^2	10^4	10^6	10^2	10^4	10^6
3	303	300	291	286	285	281	274	273	272
4	100	100	100	100	100	100	100	100	100
5	45.8	46.1	46.5	46.8	47.0	47.1	47.6	47.6	47.6
6	25.2	25.2	25.8	25.9	26.0	26.2	26.4	26.4	26.6
7	15.4	15.5	15.8	15.9	15.9	16.3	16.3	16.3	16.4
8	10.2	10.2	10.9	10.5	10.5	11.0	10.7	10.7	11.0
9	7.10	7.14	7.94	7.31	7.34	7.83	7.46	7.46	7.76
10	5.16	5.20	6.11	5.30	5.33	5.88	5.40	5.40	5.74
11	3.87	3.92	4.90	3.98	4.00	4.57	4.04	4.05	4.37

Table 26b. Relative intensities of the Pashen lines $I(n-3)/I(n-2)$

	T_e (K)								
	5000			*10 000*			*20 000*		
$n \setminus n_e$ (cm^{-3})	10^2	10^4	10^6	10^2	10^4	10^6	10^2	10^4	10^6
5	0.401	0.395	0.376	0.348	0.346	0.336	0.305	0.304	0.300
10	0.379	0.376	0.345	0.347	0.346	0.326	0.318	0.317	0.304
15	0.374	0.365	0.316	0.346	0.340	0.313	0.320	0.315	0.307
20	0.372	0.346	0.308	0.346	0.328	0.308	0.320	0.310	0.307
25	0.368	0.327	0.307	0.344	0.320	0.307	0.319	0.309	0.307
30	0.362	0.315	0.307	0.339	0.313	0.307	0.315	0.309	0.307
35	0.354	0.310	0.307	0.333	0.310	0.307	0.311	0.308	0.307
40	0.343	0.308	0.307	0.327	0.308	0.307	0.309	0.307	0.307

The level population of atoms and ions having low excitation potentials can also be influenced by collisions with electrons or other particles. In this case to the right-hand part of equation (70) and equation (71) must be added the term $n_1 n_e q_{1n}$ which takes into account the excitation processes from the ground state.

From equation (70) or equation (71) we can find the quantities $n_k/[n_1(X^{i+1})n_e]$ and thereafter calculate the recombination line intensities

$I_{kj} \propto n_k A_{kj} h\nu_{jk}$.

Owing to large numbers of quantum states and of corresponding equations for nebulae the system of equations turns out to be a very bulky one (about 10 000 states for planetary nebulae). The values of A_{kj} and a_n needed are often not well known. Therefore it is reasonable to simplify the problem considering a moderate number of states (about 100) and to take the contribution of higher states into account by means of correction coefficients (e.g. Nikitin *et al.*, 1986). Using the

Table 27. Relative intensities of the He I lines (T_e in K and n_e in cm^{-3})

	T_e (K)						
	5000		*10 000*			*20 000*	
$\lambda \setminus n_e$	10^2	10^4	10^2	10^4	10^6	10^2	10^4
Triplet line intensities $I(\lambda)/I(4471)$ in the scale $I(\lambda 4471) = 100$ (*CaseA*)							
5876	302	301	276	276	273	258	258
4026	45.8	45.9	47.4	47.4	47.6	48.7	48.7
3820	25.1	25.1	26.4	26.4	26.5	27.4	27.4
4026	24.4	24.3	33.0	32.8	32.5	47.8	47.7
10830	398	396	442	442	441	502	501
3889	189	190	226	226	227	279	279
3187	74.8	74.7	91.6	91.7	92.0	116	116
Singlet line intensities $I(\lambda)/I(4471)$ in the scale $I(\lambda 4471) = 100$ (*Case B*)							
6678	86.7	86.7	79.1	79.1	78.0	73.1	73.1
4922	27.6	27.6	27.4	27.4	27.4	27.1	27.1
5016	51.2	51.2	58.8	58.8	59.0	68.9	68.9
6965	19.9	19.9	23.4	23.4	23.5	27.9	27.9

Menzel parameters b_m the level populations n_m can be expressed in the form

$$n_m = \frac{g_n h^3 n_e n(X^{i+1})}{g^+ 2(2\pi m k T_e)^{3/2}} b_m(T_e) e^{I_m/kT_e}$$
$$= 2.071 \times 10^{-16} \frac{g_n n_e n(X^{i+1})}{g^+ (T_e)^{3/2}} b_m(T_e) e^{I_m/kT_e}, \quad (72)$$

where g_n is the statistical weight for the level m, g^+ is the statistical weight for the ground state of ion X^{i+1}. The coefficients b_m, express the deviations of the level population n_m of ion X^i from its value at the local thermodynamical equilibrium, and the quantity I_m is the ionization potential for level m.

The system of statistical equilibrium equations for atoms and ions of H, He, C, N and O has been solved by numerous authors, who have taken into account the transition probabilities due to different processes populating and depopulating the levels. Here we shall refer to the results of most complete computations. For hydrogen levels the values of parameters $B_n = b_n e^{x_n} = b_n \exp(I_n/kT_e)$, which are indispensable for calculation of $E(\mathrm{H}_\beta)$ and the intensity ratios of H I, He I and He II recombination lines have been computed by Brocklehurst (1971, 1972) for different values of n_e and T_e taking into account most important processes for population and depopulation of the level. The results we reproduce in Tables 26–28. The theoretical values of the recombination line intensities of He I and He II for the Menzel B model may be taken from the paper by Hummer and Storey (1987). These line intensities have been computed taking into account the collisions with electrons for a wide range of values for n_e, T_e and for the principal quantum number

Table 28. Relative intensities of the He II lines $I(n - n')/I(3 - 4)$ for $n = 2$, 3, 4 and 5 on the scale $I(\lambda 4686) = 100$ (T_e in K and n_e in cm^{-3})

	T_e (K)					
	5000	*10 000*			*20 000*	
$\lambda \setminus n_e$	0	0	10^4	10^6	0	10^4
$n = 2$						
1640	560	625	660	681	714	745
1215	154	189	201	213	234	246
1085	66	84.1	90.4	98.1	106	113
1025	35.6	45.6	49.1	51.9	58.3	61.8
992	21.8	27.8	30.0	31.9	35.8	37.9
$n = 3$						
3204	35.5	39.8	40.3	42.5	43.8	45.2
2734	17.3	20.1	20.5	21.1	23.2	23.9
2512	10.0	12.0	12.2	12.7	14.0	14.4
2386	6.48	7.77	8.0	8.3	9.18	9.5
2307	4.46	5.38	5.6	5.8	6.39	6.6
$n = 4$						
10124	29.5	27.4	26.5	27.1	25.6	24.9
6560	13.1	13.4	13.7	13.6	13.5	13.7
5412	6.78	7.34	8.0	7.8	7.79	8.2
4859	4.52	4.69	5.1	4.9	5.06	5.3
4542	2.80	3.15	3.5	3.3	3.45	3.6
$n = 5$						
18500	10.8	9.55	9.43	8.9	8.56	8.4
11626	5.47	5.39	5.4	5.1	5.13	5.0
9345	3.20	3.31	3.4	3.2	3.27	3.2

n. The logarithms of total line intensities have been stored on microfiches in the same journal as the main paper, where the effective collision strengths γ(He II) for quantum levels $n = 1$, 2, 3 have been tabulated also. Martin (1988) calculated the H I recombination spectra in the case of extremely low temperature $T_e \leq 500$ K. Special interest in the theory of the recombination spectra presents the transitions between hihgly excited states of atoms (Rydberg states) forming the radiolines. A short review of the problem and numerous references have been presented by Gulyaev (1990).

Ferland (1980) has approximated the radiation coefficient of the H_β line (in erg cm^3 s^{-1}) with an error of less than 10% by the expression

$$4\pi j(H_\beta) = \begin{cases} 2.53 \times 10^{-22} T_e^{-0.833}, & \text{for } T_e \leq 2600 \text{ K}, \\ 1.12 \times 10^{-22} T_e^{-1.20}, & \text{for } T_e > 2600 \text{ K}. \end{cases} \quad (73)$$

Table 29 gives the relative intensities of recombination lines of some C, N and O ions, computed by Nikitin and Kholtygin (1986), Bogdanovich *et al.* (1985b) and Nikitin *et al.* (1994) for Menzel A and B cases at $T_e = 10\,000$ K and $T_e = 20\,000$ K.

Table 29. Relative intensities of the C, N, O ion recombination lines

		T_e (K)			
		10 000		20 000	
Ion	λ (Å)	*A*	*B*	*A*	*B*
C II	1760	4.1	4.2	4.4	4.4
	2748	0.4	1.7	0.4	1.8
	2838	2.5	2.5	2.7	2.7
	3921*	0.2	0.9	0.2	1.0
	4267*	1.0	1.0	1.0	1.0
	5891	0.1	0.4	0.1	0.4
	7236	0.2	1.2	0.2	1.3
C III	1256	2.11	1.12	2.02	1.13
	1532	0.29	0.07	0.24	0.06
	1620	1.23	1.54	1.04	1.44
	1923	4.00	0.93	3.20	0.80
	2010	1.73	0.81	1.64	0.86
	2163	0.62	0.14	0.50	0.12
	3609	0.09	0.12	0.08	0.11
	3884	0.26	0.06	0.22	0.05
	4056	0.11	0.02	0.09	0.02
	4070*	0.85	0.19		
	4122	0.03	0.006	0.02	0.006
	4156*	0.17	0.04	0.15	0.04
	4187*	0.33	0.07	0.25	0.06
	4516	0.12	0.04	0.12	0.06
	4650*	1.00	1.00	1.00	1.00
	5696	0.007	0.002	0.006	0.001
	8196	0.19	0.04	0.14	0.04
	8664	0.12	0.03	0.09	0.02
	9713	0.002	0.47	0.002	0.45
	11988	0.03	0.02	0.03	0.02
N III	3306	0.03	0.00	0.03	0.00
	4003	7.3	0.05	7.1	0.05
	4097*	17.2	0.40	20.0	0.44
	4379*	9.1	0.05	10.0	0.06
	4544	1.4	0.01	1.6	0.01
	4616	0.3	0.002	0.2	0.001
	4640*	1.0	1.0	1.0	1.0
	4903	0.7	0.02	1.5	0.04
	9412	1.0	0.03	2.0	0.05
N IV	1036*	3.7	1.16	3.2	1.04
	2318*	0.41	0.12	0.34	0.10
	2647*	0.72	0.22	0.60	0.17
	3078*	0.20	0.06	0.16	0.05
	3478*	1.0	1.0	1.0	1.0
	4057	0.003	0.001	0.003	0.001
	7115	0.001	0.42	0.001	0.36
O V	2787*	1.0	1.0	1.0	1.0
	3114	0.002	0.000	0.002	0.000
	5113	0.000	0.05	0.000	0.04
	5343	0.000	0.38	0.000	0.33
	7432	0.004	0.002	0.004	0.002

Note. *, This line is definitely present in the spectra of nebula; *A*, *B*, Menzel cases *A* and *B*.

Table 31. The values of total and partial effective recombination coefficients ($\alpha^R_{ki} = \alpha^{eff}_{ki} + \alpha^{di}_{ki}$) in units of 10^{-14} cm^3 s^{-1}

Ion	λ (Å)	*Case*	$T_e = 10^4 K$			$T_e = 2 \times 10^4 K$		
			α^{eff}_{ki}	α^{di}_{ki}	α^R_{ki}	α^{eff}_{ki}	α^{di}_{ki}	α^R_{ki}
C II	3921	B	21.2		21.2	13.1		13.1
	4267	A,B	23.6	0.02	23.6	14.3	1.51	15.8
	7231	B	28.3		28.3	18.7		18.7
C III	4070	A,B	20.8	6.1	26.9	10.8	18.2	29.0
	4156	A,B	4.4	1.6	6.0	2.4	1.5	3.9
	4187	A,B	8.2	2.2	10.4	4.2	6.6	10.8
	4650	A,B	28.0	63.3	91.3	18.5	36.0	54.5
C IV	4658	A,B	85.0		85.0	43.7		43.7
	7726	A,B	98.9		98.9	43.6		43.6
N II	4624	B	8.4		8.4	5.0		5.0
	4795	B	4.8		4.8	2.6		2.6
	5005	A,B	23.7	0.1	23.8	13.6	0.8	14.4
	5679	A,B	17.1	0.2	17.3	11.2	1.0	12.2
N III	4003	A,B	2.3	1.3	3.6	1.5	0.7	2.2
	4097	A,B	42.7	2.0	44.7	30.6	1.7	32.3
	4379	A,B	5.4		5.4	3.1		3.1
	4640	B	107.0	100.2	207.2	70.0	109.3	179.3
N IV	3078	A	12.5	3.6	16.1	6.5	3.8	10.3
	3478	A	70.8	47.1	117.9	46.5	33.7	80.2
	4606	A	101.5	3.3	104.8	44.6	13.4	58.0
	7703	A	66.8	0.7	67.5	27.8	5.7	33.5
O II	4075	A	18.9	0.01	18.9	9.4	0.3	9.7
	4089	A	8.4		8.4	3.8		3.8
	4119	A	9.4		9.4	4.7		4.7
	4349	A,B	20.0	0.1	20.1	10.6	0.6	11.2
	4649	A,B	36.3	0.2	36.5	19.1	1.4	20.5
O III	3133	B	13.9		13.9	7.4		7.4
	3266	A,B	63.4	35.6	99.0	33.9	30.1	64.0
	3340	B	4.4	1.9	6.3	2.5	1.4	3.9
	3430	B	8.7		8.7	4.6		4.6
	3715	B	25.5		25.5	13.7		13.7
	3760	A,B	43.2	21.6	64.8	24.1	23.0	47.1
O IV	3412	B	21.3	65.1	86.4	11.6	49.4	61.0
	4632	A,B	101.5		101.5	44.6		44.6
O V	4930	A,B	142.2	1.2	143.4	61.5	8.4	69.9
	5113	B	39.3		39.3	26.4		26.4

For many recombination lines the contribution of dielectronic recombination to the total line intensity is important. Its contribution (Nussbaumer and Storey, 1984, 1986, 1987) at low electron temperatures has been represented by

$$\alpha^{\rm di}_{ik}(T_e) = (\frac{a}{t} + b + ct + dt^2)t^{-3/2}\exp(-f/t)10^{-12}\ {\rm cm}^3\ {\rm s}^{-1}. \qquad (74)$$

The numerical values of parameters a, b, c, d and f are given in Table 30 (see, Appendix C). The value of total recombination coefficient includes the contribution

of both the photorecombination and the dielectronic recombination:

$$\alpha_{ik}^{R} = \alpha_{ik}^{\text{eff}} + \alpha_{ik}^{\text{di}}.$$

In Table 31 we have compiled the values of α_{ik}^{eff},α_{ik}^{di} and α_{ik}^{R} for main spectral lines of ions of C, N and O, which have been taken from the paper by Nikitin *et al.* (1994). Many values of α_{ik}^{eff} for recombination lines of C, N and O ions were calculated with a hydrogen-like approximation by Pequignot *et al.* (1991). Most of the values given in this paper are close to those presented in Table 31.

The observed intensities of spectral lines in nebulae are usually expressed in duly calibrated units of Balmer lines as shown above – usually of H_β, but sometimes also of H_α, H_γ or H_δ.

The effect of electron collision processes on intensities of recombination lines of H and He has been discussed by Ferland (1986a, b), Hummer and Storey (1987), Peimbert and Torres–Peimbert (1987a,b), Clegg (1987), Giovanardi *et al.* (1987), Storey and Hummer (1988). The effect of electron collisions on the recombination lines is low.

5.2 Collision-Excited Lines

In the spectra of gaseous nebulae a large number of forbidden lines of atoms and ions of C, N, O, F, Ne, Na, Mg, Al, Si, P, S, Ar, Ca, K and of some other elements have been observed. These lines are generated due to transitions from the metastable states of the corresponding ions X^i. The lines of highest intensity belong to the visible spectral region. During the last decade many forbidden spectral lines in the ultraviolet and infrared spectral regions have been detected.

The term structure and the types of forbidden transitions for configurations with the external shell p, p^2, p^3, p^4 and p^5 are shown in Figure 4. The values of wavelengths are given for ions O I–O III. The ground term of configurations p^1, p^2, p^4 and p^5 is split, the transitions between its levels give spectral lines observed in the infrared spectral region. The transitions between two higher terms of configurations p^2, p^3 and p^4 are termed auroral (A), the transitions between the middle and the lowest terms give nebular (N) lines and the transitions between the highest and the lowest terms give the transauroral (TA) spectral lines. Thus, the transitions D–P in configurations p^2 and p^4 give the nebular lines, but to transitions S–D and S–P correspond the auroral and the transauroral spectral lines, respectively. In configuration p^3 the nebular lines correspond to transitions D–S, the auroral lines to P–D transitions and the transauroral ones to P–S transitions.

The intercombination lines (I) form in dipole transitions between the levels of different multiplicity ($\Delta s \neq 0$). They are observed mainly in the ultraviolet spectral region. The list of the spectral lines, including the intercombinational ones observed in the ultraviolet, visible and infrared spectral regions is given in Table 25. The main mechanism of formation of the forbidden and intercombinational lines is collision with protons and electrons. Collisions with the neutral atoms (atoms H and others) are less effective. In most cases the contribution of recombination processes

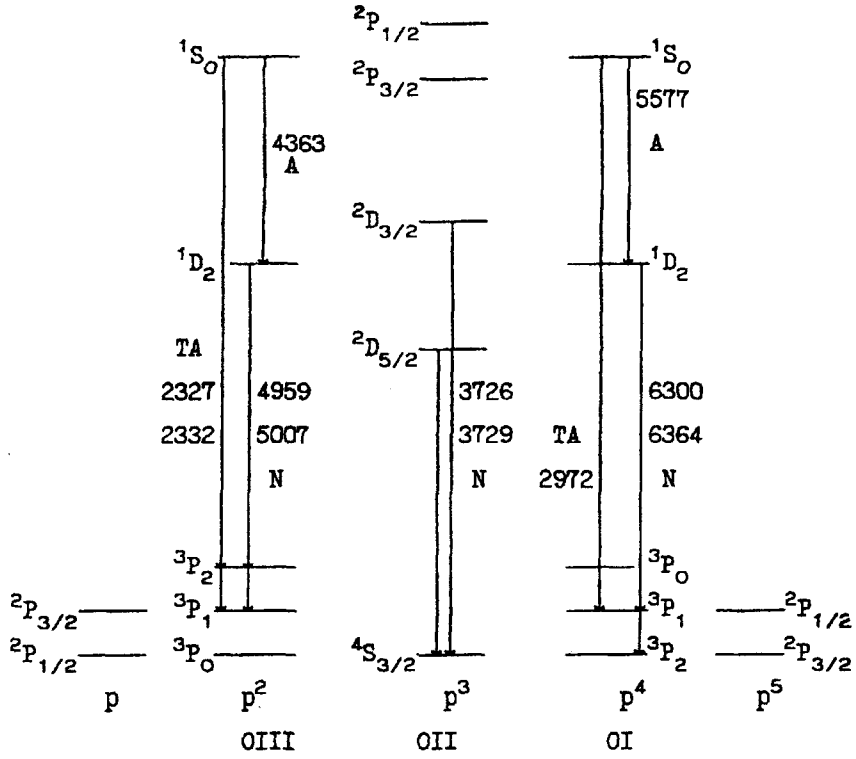

Figure 4 The term structure and the types of forbidden transitions for configurations with p, p^2, p^3, p^4 and p^5 external shells.

to the intensities of forbidden and intercombinational spectral lines of nebulae is negligible.

The energy, emitted in a forbidden or intercombinational line in nebulae is expressed by equation (69). In order to determine the level populations n_j we must solve the equations of statistical equilibrium

$$\sum_{j\neq i} n_j n_e q_{ji} + \sum_{j>i} n_j A_{ji} = \sum_{j\neq i} n_i n_e q_{ij} + \sum_{i>j} n_i A_{ij}. \tag{75}$$

where the quantities q_{ij} are the coefficients of collisional excitation if $i < j$ and of collisional deactivation if $i > j$. The quantities q_{ij} can be expressed via the effective collision strengths (see equation (43)).

To find the level populations of atoms and ions we need a large number of transition probabilities A_{ij} and effective collision strengths $\gamma_{ij}(T_e)$. These values, which are taken basically from a compilation (Mendoza, 1983), are given in Tables 16, 17 and 25.

5.3 Selective Mechanisms of the Line Excitation

Recombination and collisional excitation are the main mechanisms preceding line formation in the spectra of low-density plasma targets such as the gaseous nebulae and stellar coronae. Besides that there are the selective line excitation mechanisms which are responsible for enhancement of the intensity of the selective lines in the spectra.

The most important selective mechanisms are:

(1) photoionization;

(2) excitation as a result of Auger ionization;

(3) photoexcitation by the continuous spectrum;

(4) excitation by the light emitted in the selective lines (Bowen fluorescence);

(5) excitation in charge transfer reactions.

These excitation mechanisms have been treated in detail by Rudzikas *et al.* (1990).

The first mentioned mechanism leads mainly to the enhancement of the resonance or forbidden and intercombination line intensities in the spectra of gaseous nebulae relative to the intensities determined by electron impacts (see, for example, Ferland, 1986a, b). The photoionization mechanism appears to be effective for relatively low electron temperatures ($T_e \leq 8 \times 10^3$ K).

The Auger ionization is accompanied by the formation of the autoionization states. The radiative stabilization of such states results in generation of the excited states of the high-stripped ions and of numerous lines due to the cascade transitions from these states.

Photoexcitation by continuous radiation (non-resonant fluorescence) has been discussed by Nikitin *et al.* (1990). This kind of excitation can increase the intensity of the weak recombination lines of C, N and O ions (see, e.g. Grandi, 1976). The increase is commonly not high. On the contrary, the Bowen (resonance) fluorescence (often treated as the laser action) enhances significantly the intensity of the selective lines. The most famous example of Bowen fluorescence is the pumping of the $2p3d\,^3P_{1,2}$ of O III by the He II L_α photons (Aller, 1984; Harrington *et al.*, 1982; O'Dell and Miller, 1992; Liu and Danziger, 1994). Florescent excitation of the O I and Ne II lines has been considered by Sarazin (1986).

The charge transfer process also leads to the additional population of the excited levels. An example of such a process is the charge transfer

$$\mathrm{O\,IV} + \mathrm{H} \rightarrow \mathrm{O\,III}\ (2p3d) + \mathrm{H}^+.$$

The excited states ^1D, ^3P and ^1D of ions O III are formed as a result of this process (see, for example, Dalgarno and Sternberg, 1982).

5.4 Plasma Diagnostics for n_e and T_e

In the first approximation the emission power of the plasma depends on the mean values of electron temperature $\bar{T}_e$ and on the mean electron number density $\bar{n}_e$. The intensities of the emission lines excited by electron collisions are strongly sensitive to the values of $\bar{T}_e$ and $\bar{n}_e$. The ratio of the intensities of such lines depends on $\bar{T}_e$ and $\bar{n}_e$:

$$R_{ki;mn} = \frac{I(\lambda_{ki})}{I(\lambda_{mn})} = R(\bar{T}_e, \bar{n}_e). \tag{76}$$

If the upper levels of transitions $k \rightarrow i$ and $m \rightarrow n$ in equation (75) have a great energy difference then the ratio $R(\bar{T}_e, \bar{n}_e)$ depends mainly on $\bar{T}_e$ (see, for example, Figure 4). So, if $\bar{n}_e$ is approximately known, the mean electron temperature $\bar{T}_e$ can be found by using the function $R(\bar{T}_e, \bar{n}_e)$ and the observed line intensity ratio.

In contrast, for lines with small energy difference for the upper levels (mostly for lines of the same multiplet) the ratio of their intensities predominantly depends on the value of $\bar{n}_e$ (see Figure 4). Lines of such a type are often used for the mean electron number density determinations.

Numerous references on the recent calculations of the collision line intensities can be found in a book by Rudzikas *et al.* (1990) and in a review by Kholtygin (1990).

In the general case the line ratios depend on both $\bar{n}_e$ and $\bar{T}_e$. For determination of both the values, not less than two observed line ratios must be known. The method of line pairs (see, for detail, Aller, 1984; Pottasch, 1984) can be used.

Different pairs of lines in the spectra of a nebula give slightly different values of both $\bar{n}_e$ and $\bar{T}_e$. This difference gives evidence about the temperature and density fluctuations (or clumps) in the nebulae. A method of diagnostics of the temperature fluctuations following Peimbert (1967) has been proposed by Kholtygin and Feklistova (1992a, b). A combined study of both the temperature and the electron number density fluctuations has been carried out by Kholtygin (1996).

The recombination line intensities do not show significant dependence neither on $\bar{n}_e$ on $\bar{T}_e$ and thus they cannot be used for n_e and T_e diagnostics. Paschen lines may be an exception to this rule. The intensities of these lines depend significantly on the mean electron number density (see Table 26).

In the presence of a strong external X-ray radiation field the intensity of the collisionally excited lines can be strongly distorted by the post-Auger ionization and excitation (Aldrovandi and Gruenwald, 1985) and thus they cannot be used for n_e and T_e diagnostics.

5.5 Chemical Abundance Determination

The total flux emitted by a nebula in a spectral line can be found if we know the distance to the nebulae. The relative ion abundancies can be found from observed recombination line intensities by

$$\frac{n(X^i)}{n(\mathrm{H}^+)} = \frac{\lambda(X^i)}{\lambda(\mathrm{H}_\beta)} \frac{\alpha^{\mathrm{eff}}(\mathrm{H}_\beta)}{\alpha^{\mathrm{eff}}(\lambda)} \frac{I(\lambda)}{I(\mathrm{H}_\beta)} = X(T_e) \frac{I(\lambda)}{I(\mathrm{H}_\beta)}. \tag{77}$$

Table 32. Fit parameter values to the function $X(T_e) = \chi_0 \left(T_e/10^4\right)^{\eta}$

Ion	λ (Å)	*Case*	*Photorecom.*		*Ph. and Di.-recom.*	
			χ_0	η	χ_0	η
C II	3921	B	0.116	−0.23	0.116	−0.23
	4267	A,B	0.113	−0.19	0.113	−0.34
	7231	B	0.160	−0.32	0.160	−0.32
C III	4070	A,B	0.122	0.03	0.095	−1.03
	4156	A,B	0.591	−0.04	0.433	−0.29
	4187	A,B	0.319	0.05	0.252	−0.97
	4650	A,B	0.104	−0.32	0.032	−0.17
C IV	4658	A,B	0.034	0.04	0.034	0.04
	7726	A,B	0.049	0.26	0.049	0.26
N II	4624	B	0.344	−0.17	0.344	−0.17
	4795	B	0.624	−0.03	0.624	−0.03
	5005	A,B	0.132	−0.12	0.132	−0.19
	5679	A,B	0.208	−0.31	0.205	−0.41
N III	4003	A	1.090	−0.30	0.695	−0.21
	4097	A	0.060	−0.44	0.057	−0.45
	4379	A	0.507	−0.12	0.507	−0.12
	4640	B	0.027	−0.30	0.014	−0.71
N IV	3078	A	0.154	0.03	0.120	−0.27
	3478	A	0.031	−0.31	0.018	−0.36
	4606	A	0.028	0.27	0.028	−0.06
	7703	A	0.072	0.35	0.071	0.09
O II	4075	A	0.135	0.09	0.135	0.05
	4089	A	0.304	0.23	0.304	0.29
	4119	A	0.274	0.08	0.274	0.08
	4349	A,B	0.136	0.00	0.135	−0.07
	4649	A,B	0.080	0.01	0.080	−0.08
O III	3133	B	0.141	−0.01	0.141	−0.01
	3265	A,B	0.032	−0.01	0.021	−0.29
	3340	B	0.475	−0.10	0.332	−0.23
	3430	B	0.247	0.00	0.247	0.00
	3715	B	0.091	−0.02	0.091	−0.02
	3760	A,B	0.054	−0.08	0.036	−0.46
O IV	3412	B	0.100	−0.04	0.025	−0.41
	4632	A,B	0.028	0.27	0.029	0.27
O V	4930	A,B	0.022	0.29	0.022	0.12
	5113	B	0.081	−0.34	0.081	−0.34

This formula follows from equation (69) if we make use of averaged effective recombination coefficients.

Using the effective recombination coefficients found by Brocklehurst (1971, 1972) for He I and He II lines we can write the following formula for finding the relative ion number densities

$$\frac{n(\text{He II})}{\text{n(H II)}} = (a_i + b_i t + c_i t^2)\, \frac{I(\lambda_i \text{He I})}{I(\text{H}_\beta)} =$$

Table 33. Parameters χ, $A_{\lambda i}$ and d connecting the ultraviolet line intensities with the relative abundance of the ions

Ion	λ (Å)	*Transition*	$\chi(J, J')$	T_eK	$A_{\lambda i}$	d
C II]	2329	$2s^2 2p^2P - 2s2p^2{}^4P$	5.33	10000	2.57–7	2.69
C III]	1906	$2s^2{}^1S - 2s2p^3P^0$	6.50	10000	1.112–7	3.276
	1909					
C IV	1548	$2s^2S_{1/2} - 2p^2P_{1/2,3/2}$	8.00	13000	2.04–8	4.032
	1550					
N III]	1747	$2s^2 2p^2P - 2s2p^2{}^4P$	7.08	10000	2.99–7	3.568
	1754					
N IV]	1487	$2s^2{}^1S_0 - 2s2p^3P^0{}_1$	8.34	15000	1.064–7	4.203
N V	1239	$2s^2S - 2p^2P^0$	10.0	15000	2.17–8	5.04
	1243					
O III]	1661	$2s^2 2p^2{}^3P - 2s2p^3{}^5S_2$	7.45	10000	7.29–7	3.75
	1666					
O IV]	1403	$2s^2 2p^2P^0 - 2s2p^2{}^4P$	8.82	15000	3.88–7	4.45
	1409					
O V]	1218	$2s^2{}^1S - 2s2p^3P^0$	10.18	15000	1.056–7	5.13
O VI	1032	$2s^2S - 2p^2P^0$	11.97	15000	2.41–8	6.03
	1038					
Mg II	2800	$3s^2S - 3p^2P^0$	4.43	10000	1.98–8	2.22
Si III	1892	$3s^1S - 3s3p^3P^0$	6.55	10000	2.04–8	3.301
Si VI	1391	$3s^2S - 3p^2P^0$	8.86	15000	9.62–9	4.465

$$= \begin{cases} (3.98 + 0.33t - 0.01t^2) I(\lambda 4026\text{He I})/\text{I}(\text{H}_\beta), \\ (98.3 - 58.0t - 14.0t^2) I(\lambda 4120\text{He I})/\text{I}(\text{H}_\beta), \\ (27.6 + 2.13t - 0.068t^2) I(\lambda 4123\text{He I})/\text{I}(\text{H}_\beta), \\ (14.8 + 1.8t - 0.16t^2) I(\lambda 4388\text{He I})/\text{I}(\text{H}_\beta), \\ (274 - 153t - 36.7t^2) I(\lambda 4437\text{He I})/\text{I}(\text{H}_\beta), \\ (1.73 + 0.37t - 0.06t^2) I(\lambda 4471\text{He I})/\text{I}(\text{H}_\beta), \\ (6.36 - 1.54t - 0.23t^2) I(\lambda 4921\text{He I})/\text{I}(\text{H}_\beta), \\ (0.493 + 0.305t - 0.059t^2) I(\lambda 5876\text{He I})/\text{I}(\text{H}_\beta), \\ (5.64 + 2.13t - 0.35t^2) I(\lambda 6678\text{He I})/\text{I}(\text{H}_\beta), \\ (31.3 - 18.0t + 4.38t^2) I(\lambda 7065\text{He I})/\text{I}(\text{H}_\beta), \\ (148 - 93.4t + 23.4t^2) I(\lambda 7281\text{He I})/\text{I}(\text{H}_\beta), \end{cases}$$

and

$$\frac{n(\text{He III})}{\text{n(H II)}} = (0.076 + 0.008t) I(\lambda 4686\text{He II})/I(\text{H}_\beta),$$

where $t = T_e/10^4$ K (Osmer, 1976).

The coefficient $X(T_e)$ in equation (77) for many ion species can be expressed by

$$X(T_e) = \chi_0(t)^\eta. \tag{78}$$

The numerical values of the fitting parameters χ_0 and η for the C, N and O ion spectral lines are given in Table 32. They were derived based on the effective recombination coefficients, given in Table 31.

The relative ion abundances derived from observed intensities of the collision excited lines strongly depend on an accepted value of electron temperature of a nebulae, especially for UV lines.

In a monograph by Aller (1984) the expressions connecting the relative abundances of ions with corresponding ratios of ultraviolet line intensities are given:

$$\frac{N(X^i)}{N(\mathrm{H\ II})} = A_{\lambda i} E^0_{4,2} t^{1/2} e^{-d/t} \frac{I(\lambda)}{I(\mathrm{H}_\beta)}, \tag{79}$$

where the coefficient $E^0_{4,2}$ for line H_β has for the Menzel B case the following form

$$E^0_{4,2} = \alpha^{\mathrm{eff}}(\mathrm{H}_\beta)10^{25} = 1.387\mathrm{t}^{-0.983} \times 10^{-0.0424/\mathrm{t}}\ \mathrm{erg\ cm^3\ s^{-1}}. \tag{80}$$

The required values of $A_{\lambda i}$ and d are given in Table 33.

5.6 Continuous Spectra of Nebulae

Gaseous nebulae emit a weak continuous spectrum, which is observed in the ultraviolet, visible, infrared and radio wave regions. The continuous spectrum of a nebula has been caused by the free–free, free–bound and two-quantum transitions $2s - 1s$ of H, He atoms and of the ion He^+.

Computations of the two-quantum transitions were first carried out by Kipper (1950, 1952) and by Spitzer and Greenstein (1951). In the far-infrared spectral region the main contribution to the total continuum emission is provided by the emission of dust and by the H I free–free transitions.

The energy emitted by gas in the unit volume is

$$E_\nu d\nu = N(X^{i+1}) n_e \gamma d\nu, \tag{81}$$

where the emission coefficient

$$\gamma = \gamma(\mathrm{H\ I}) + \gamma(2q, \mathrm{H\ I}) + \gamma(\mathrm{He\ I})\frac{\mathrm{N(He\ II)}}{\mathrm{N(H\ II)}} + \gamma(\mathrm{He\ II})\frac{\mathrm{N(He\ III)}}{\mathrm{N(H\ II)}}, \tag{82}$$

In this expression $\gamma_\nu(X^i)$ is the emission coefficient due to free–free and free–bound electron transitions in H I, He I or He II, the quantity $\gamma(2q$,H I) is the two-photon emission coefficient of H atoms. The values of these coefficients are given in Table 34.

The values of $\gamma(2q$,He I) can be found in the monograph by Pottasch (1984). Two-photon transitions from singlet and triplet metastable states of He-like ions have been studied in the paper by Drake *et al.* (1969), where the corresponding values of $\gamma(2q, X^i)$ are given. Owing to relatively low helium abundance in nebulae the processes, however, can be neglected.

6 DELIVERY OF THE CATALOGUE AND ADDITIONAL INFORMATION

The electronic copy of the catalogue will be available by *anonymous* **ftp** via ftp-server **urania.aispbu.spb.su** in the directory /usr/afk/CatAda. The data included

Table 34. Coefficients of emission in continuum (in units of 10^{-40} erg cm^3 s^{-1} Hz^{-1}) (equation (82))

		$T_e = 5000$ K			
λ (Å)	$\nu \times 10^{-14}$	γ_H	γ_{2q}	$\gamma_{He\,I}$	$\gamma_{H\,II}$
1000.0	29.9790	0.000	0.000		0.000
1200.0	24.9830	0.000	0.000		0.017
1300.0	23.0610	0.000	9.122		0.106
1400.0	21.4140	0.000	13.391		0.509
1500.0	19.9860	0.001	14.974		1.988
1600.0	18.7370	0.003	15.411	0.228	6.539
1800.0	16.6550	0.023	14.951	0.925	47.489
2051.0	14.6170	0.159	13.711	3.510	329.556
2053.0	14.6030	0.161	13.700	3.549	0.340
2200.0	13.6270	0.408	12.921	6.283	0.863
2400.1	12.4910	1.199	11.892	12.104	2.548
2599.4	11.5330	2.970	10.970	19.442	6.343
2600.8	11.5270	2.987	10.964	5.048	6.379
2725.4	11.0000	4.917	10.442	12.553	10.531
2855.2	10.5000	7.884	9.912	19.675	16.937
2997.9	10.0000	12.633	9.382	26.796	27.229
3121.4	9.6044	18.334	8.956	32.430	39.633
3122.0	9.6026	18.365	8.954	27.667	39.700
3331.0	9.0000	32.354	8.301	53.754	70.282
3421.4	8.7623	40.435	8.044	64.044	88.022
3422.0	8.7607	40.496	8.042	7.223	88.155
3527.0	8.5000	51.698	7.757	9.832	112.818
3642.0	8.2315	66.459	7.460	12.519	145.422
3648.0	8.2180	0.327	7.445	12.654	5.320
3679.2	8.1483	0.349	7.368	13.352	5.685
3679.9	8.1467	0.350	7.367	0.406	5.694
4000.0	7.4948	0.649	6.646	0.759	10.576
4282.8	7.0000	1.038	6.091	1.363	16.912
4499.9	6.6622	1.429	5.710	1.775	23.292
4996.5	6.0000	2.670	4.967	4.278	43.577
5096.0	5.8829	2.982	4.838	4.721	48.673
5450.8	5.5000	4.277	4.415	6.169	69.850
5695.8	5.2634	5.342	4.153	7.063	87.285
5700.0	5.2595	5.361	4.149	7.096	14.175
5995.9	5.0000	6.839	3.862	9.411	18.124
6633.8	4.5192	10.723	3.356	13.699	28.556
6635.8	4.5178	10.736	3.355	12.413	28.594
6999.9	4.2828	13.366	3.110	15.378	35.693
7438.7	4.0302	16.901	2.846	18.565	45.284
7441.1	4.0289	16.921	2.845	18.036	45.339
7848.0	3.8200	20.532	2.627	20.926	55.182
7850.4	3.8188	20.555	2.626	14.142	55.244
8193.3	3.6590	23.821	2.463	16.043	64.187
8196.2	3.6577	23.850	2.462	8.038	64.266
8196.7	3.6575	23.854	2.462	8.040	64.278
8198.5	3.6567	23.872	2.461	5.516	64.326
8207.0	3.6529	23.956	2.457	5.534	64.556
8209.0	3.6520	3.418	2.456	5.538	21.786
8265.4	3.6271	3.499	2.433	5.655	22.305

Table 34. Continued

		$T_e = 5000\ K$			
λ (Å)	$\nu \times 10^{-14}$	γ_H	γ_{2q}	$\gamma_{He\ I}$	$\gamma_{H\ II}$
8268.1	3.6259	3.503	2.432	3.400	22.330
8499.9	3.5270	3.845	2.338	3.846	24.517
9000.1	3.3310	4.624	2.152	4.729	29.498
9500.0	3.1557	5.450	1.986	5.519	34.796
10000.1	2.9979	6.319	1.836	6.230	40.364
		$T_e = 10\,000\ K$			
λ (Å)	$\nu \times 10^{-14}$	γ_H	γ_{2q}	$\gamma_{He\ I}$	$\gamma_{H\ II}$
1000.0	29.9790	0.001	0.000	0.046	0.082
1200.0	24.9830	0.009	0.000	0.079	0.880
1300.0	23.0610	0.023	5.611	0.126	2.196
1400.0	21.4140	0.051	8.236	0.210	4.800
1500.0	19.9860	0.100	9.210	0.400	9.448
1600.0	18.7370	0.181	9.478	0.869	17.069
1800.0	16.6550	0.486	9.196	1.650	45.649
2051.0	14.6170	1.272	8.433	3.895	119.142
2053.0	14.6030	1.280	8.426	3.926	2.996
2200.0	13.6270	2.026	7.947	6.087	4.760
2400.1	12.4910	3.453	7.314	9.014	8.150
2599.4	11.5330	5.404	6.747	11.861	12.817
2600.8	11.5270	5.419	6.743	7.156	12.853
2725.4	11.0000	6.928	6.423	9.976	16.480
2855.2	10.5000	8.740	6.096	12.651	20.857
2997.9	10.0000	11.020	5.770	15.326	26.387
3121.4	9.6044	13.231	5.508	17.443	31.775
3122.0	9.6026	13.242	5.507	15.873	31.802
3331.0	9.0000	17.477	5.106	20.976	42.181
3421.4	8.7623	19.490	4.947	22.989	47.142
3422.0	8.7607	19.505	4.946	4.321	47.177
3527.0	8.5000	21.976	4.771	4.902	53.289
3642.0	8.2315	24.841	4.588	5.501	60.400
3648.0	8.2180	1.387	4.579	5.532	10.742
3679.2	8.1483	1.434	4.532	5.687	11.102
3679.9	8.1467	1.435	4.531	1.450	11.110
4000.0	7.4948	1.950	4.088	2.070	15.107
4282.8	7.0000	2.461	3.746	2.807	19.067
4499.9	6.6622	2.883	3.512	3.310	22.344
4996.5	6.0000	3.929	3.055	4.943	30.465
5096.0	5.8829	4.150	2.975	5.231	32.177
5450.8	5.5000	4.959	2.715	6.176	38.463
5695.8	5.2634	5.534	2.554	6.795	42.934
5700.0	5.2595	5.544	2.552	6.771	17.101
5995.9	5.0000	6.252	2.375	7.583	19.321
6633.8	4.5192	7.801	2.064	9.086	24.210
6635.8	4.5178	7.806	2.063	8.661	24.226
6999.9	4.2828	8.693	1.913	9.391	27.042
7438.7	4.0302	9.754	1.751	10.176	30.426
7441.1	4.0289	9.760	1.750	10.000	30.445

Table 34. Continued

		$T_e = 15\,000\ K$			
λ (Å)	$\nu \times 10^{-14}$	γ_H	γ_{2q}	$\gamma_{He\,I}$	$\gamma_{H\,II}$
7848.0	3.8200	10.729	1.616	10.607	33.555
7850.4	3.8188	10.735	1.615	8.081	33.574
8193.3	3.6590	11.537	1.515	8.497	36.161
8196.2	3.6577	11.544	1.514	5.880	36.183
8196.7	3.6575	11.545	1.514	5.880	36.186
8198.5	3.6567	11.549	1.514	5.041	36.200
8207.0	3.6529	11.569	1.511	5.048	36.263
8209.0	3.6520	4.317	1.511	5.050	21.162
8265.4	3.6271	4.368	1.496	5.098	21.411
8268.1	3.6259	4.371	1.496	4.360	21.423
8499.9	3.5270	4.578	1.438	4.596	22.443
9000.1	3.3310	5.020	1.324	5.065	24.609
9500.0	3.1557	5.449	1.221	5.483	26.718
10000.1	2.9979	5.867	1.129	5.860	28.766
		$T_e = 15\,000\ K$			
λ (Å)	$\nu \times 10^{-14}$	γ_H	γ_{2q}	$\gamma_{He\,I}$	$\gamma_{H\,II}$
1000.0	29.9790	0.016	0.000	0.212	0.546
1200.0	24.9830	0.080	0.000	0.366	2.655
1300.0	23.0610	0.147	4.212	0.488	4.869
1400.0	21.4140	0.248	6.182	0.690	8.181
1500.0	19.9860	0.389	6.913	0.990	12.817
1600.0	18.7370	0.576	7.115	1.509	18.966
1800.0	16.6550	1.107	6.903	2.375	36.369
2051.0	14.6170	2.093	6.330	4.281	68.548
2053.0	14.6030	2.102	6.325	4.304	5.382
2200.0	13.6270	2.848	5.965	5.891	7.317
2400.1	12.4910	4.049	5.490	7.702	10.454
2599.4	11.5330	5.441	5.065	9.195	14.112
2600.8	11.5270	5.451	5.062	6.608	14.139
2725.4	11.0000	6.408	4.821	8.038	16.670
2855.2	10.5000	7.467	4.576	9.395	19.484
2997.9	10.0000	8.695	4.331	10.753	22.766
3121.4	9.6044	9.804	4.135	11.826	25.743
3122.0	9.6026	9.809	4.134	10.961	25.757
3331.0	9.0000	11.766	3.833	13.048	31.045
3421.4	8.7623	12.636	3.714	13.870	33.411
3422.0	8.7607	12.642	3.713	3.645	33.428
3527.0	8.5000	13.667	3.581	3.957	36.227
3642.0	8.2315	14.805	3.444	4.279	39.350
3648.0	8.2180	2.028	3.437	4.295	12.304
3679.2	8.1483	2.073	3.402	4.376	12.575
3679.9	8.1467	2.074	3.401	2.052	12.582
4000.0	7.4948	2.544	3.068	2.620	15.430
4282.8	7.0000	2.969	2.812	3.217	18.007
4499.9	6.6622	3.298	2.636	3.625	20.005
4996.5	6.0000	4.052	2.293	4.706	24.571
5096.0	5.8829	4.202	2.233	4.898	25.478

Table 34. Continued

		$T_e = 15\,000\ K$			
λ (Å)	$\nu \times 10^{-14}$	γ_H	γ_{2q}	$\gamma_{He\,I}$	$\gamma_{H\,II}$
5450.8	5.5000	4.730	2.038	5.523	28.676
5695.8	5.2634	5.088	1.917	5.909	30.842
5700.0	5.2595	5.094	1.915	5.916	16.784
5995.9	5.0000	5.517	1.783	6.355	18.206
6633.8	4.5192	6.390	1.550	7.168	21.159
6635.8	4.5178	6.393	1.549	6.935	21.169
6999.9	4.2828	6.867	1.436	7.291	22.778
7438.7	4.0302	7.412	1.314	7.673	24.641
7441.1	4.0289	7.415	1.313	7.575	24.651
7848.0	3.8200	7.896	1.213	7.854	26.302
7850.4	3.8188	7.899	1.212	6.435	26.312
8193.3	3.6590	8.285	1.137	6.644	27.648
8196.2	3.6577	8.289	1.137	5.205	27.659
8196.7	3.6575	8.289	1.137	5.205	27.660
8198.5	3.6567	8.291	1.136	4.740	27.667
8207.0	3.6529	8.301	1.134	4.746	27.700
8209.0	3.6520	4.355	1.134	4.747	19.483
8265.4	3.6271	4.389	1.123	4.783	19.637
8268.1	3.6259	4.391	1.123	4.380	19.644
8499.9	3.5270	4.531	1.079	4.534	20.267
9000.1	3.3310	4.821	0.994	4.838	21.560
9500.0	3.1557	5.097	0.917	5.110	22.784
10000.1	2.9979	5.358	0.848	5.355	23.945
		$T_e = 20\,000\ K$			
λ (Å)	$\nu \times 10^{-14}$	γ_H	γ_{2q}	$\gamma_{He\,I}$	$\gamma_{H\,II}$
1000.0	29.9790	0.067	0.000	0.378	1.299
1200.0	24.9830	0.218	0.000	0.653	4.236
1300.0	23.0610	0.344	3.383	0.860	6.664
1400.0	21.4140	0.507	4.966	1.170	9.817
1500.0	19.9860	0.710	5.552	1.580	13.724
1600.0	18.7370	0.952	5.714	2.150	18.382
1800.0	16.6550	1.551	5.544	3.100	29.860
2051.0	14.6170	2.494	5.084	4.667	47.852
2053.0	14.6030	2.502	5.080	4.682	6.845
2200.0	13.6270	3.137	4.791	5.695	8.612
2400.1	12.4910	4.077	4.410	6.769	11.243
2599.4	11.5330	5.078	4.068	7.577	14.068
2600.8	11.5270	5.085	4.066	5.915	14.087
2725.4	11.0000	5.734	3.872	6.760	15.931
2855.2	10.5000	6.424	3.675	7.562	17.898
2997.9	10.0000	7.192	3.479	8.363	20.102
3121.4	9.6044	7.861	3.321	8.998	22.032
3122.0	9.6026	7.864	3.320	8.441	22.041
3331.0	9.0000	8.997	3.078	9.529	25.334
3421.4	8.7623	9.484	2.983	9.958	26.760
3422.0	8.7607	9.487	2.982	3.370	26.769
3527.0	8.5000	10.050	2.876	3.583	28.423

Table 34. Continued

		$T_e = 20\,000\ K$			
λ (Å)	$\nu \times 10^{-14}$	γ_H	γ_{2q}	$\gamma_{He\,I}$	$\gamma_{H\,II}$
3642.0	8.2315	10.661	2.766	3.801	30.229
3648.0	8.2180	2.359	2.761	3.812	12.658
3679.2	8.1483	2.398	2.732	3.869	12.867
3679.9	8.1467	2.399	2.732	2.370	12.871
4000.0	7.4948	2.797	2.464	2.350	14.998
4282.8	7.0000	3.141	2.258	3.331	16.838
4499.9	6.6622	3.400	2.117	3.660	18.219
4996.5	6.0000	3.969	1.842	4.436	21.253
5096.0	5.8829	4.079	1.794	4.573	21.838
5450.8	5.5000	4.459	1.637	5.022	23.861
5695.8	5.2634	4.711	1.540	5.300	25.200
5700.0	5.2595	4.715	1.538	5.304	16.070
5995.9	5.0000	5.007	1.432	5.586	17.086
6633.8	4.5192	5.594	1.245	6.109	19.137
6635.8	4.5178	5.596	1.244	5.960	19.144
6999.9	4.2828	5.906	1.153	6.176	20.233
7438.7	4.0302	6.257	1.055	6.409	21.471
7441.1	4.0289	6.258	1.055	6.350	21.477
7848.0	3.8200	6.563	0.974	6.519	22.557
7850.4	3.8188	6.565	0.974	5.590	22.563
8193.3	3.6590	6.807	0.913	5.729	23.425
8196.2	3.6577	6.809	0.913	4.810	23.432
8196.7	3.6575	6.809	0.913	4.810	23.433
8198.5	3.6567	6.810	0.913	4.500	23.437
8207.0	3.6529	6.816	0.911	4.505	23.458
8209.0	3.6520	4.254	0.911	4.506	18.123
8265.4	3.6271	4.280	0.902	4.539	18.231
8268.1	3.6259	4.281	0.902	4.270	18.237
8499.9	3.5270	4.385	0.867	4.382	18.675
9000.1	3.3310	4.599	0.798	4.604	19.576
9500.0	3.1557	4.800	0.736	4.802	20.418
10000.1	2.9979	4.988	0.681	4.980	21.209

in the Catalogue will be updated and completed at least twice a year. Any user is invited to contact A. F. Kholtygin to get additional information or with any other problems via e-mail **afk@aispbu.spb.su**. We greatly appreciate any comments and information about recent review papers, catalogues or atomic data bases not referred to in the catalogue.

References

Abramowitz, M., Stegun, I. A. (eds.) (1964) *Handbook of Mathematical Functions*, NBS Appl. Math. Ser. 55.

Akhiezer, A. I. and Berestetsky, V. B. (1969) *Quantum Electrodynamics*, Moscow, Nauka.

Alam, B. and Ansari, S. M. R. (1985) *Sol. Phys.* **96**, 219.

Aldrovandi, S. M. V. and Pequignot, D. (1973) *Astron. Astrophys.* **25**, 137.

Aldrovandi, S. M. V. and Pequignot, D. (1976) *Astron. Astrophys.* **47**, 321.
Aldrovandi, S. M. V. and Gruenwald, R. B. (1985) *Astron. Astrophys.* **147**, 331.
Allen, C. W. (1973) *Astrophysical Quantities*, London Univ., The Athlone Press.
Aller, L. H. (1984) *Physics of Thermal Gaseous Nebulae*, New York, Reidel.
Allison, D. and Dalgarno, A. (1965) *Proc. Phys. Soc. A.* **85**, 845.
Arnaud, M. and Rothenflug, R. (1985) *Astron. Astrophys. Suppl. Ser.* **60**, 425.
Arthurs, A. and Hyslop, J. (1957) *Proc. Phys. Soc. A.* **70**, 849.
Badnell, N. R. (1988) *J. Phys. B.* **21**, 749.
Balateau, J.-, Zavagno, A., Morisset, C., and Pequignot, D. (1995) *Astron. Astrophys.* **303**, 175.
Bates, D. and Moiseiwitsch, B. (1954) *Proc. Phys. Soc. A.* **67**, 805.
Beigman, I. L. and Chichkov, B. W. (1980) *J. Phys. B.* **13**, 565.
Bergeron, J. and Collin-Souffrin, S. (1974) *Astron. Astrophys.* **36**, 27.
Blint, R., Watson, W., and Christensen, R. (1976) *Astrophys. J.* **205**, 534.
Bogdanovich, O., Lukoshyavichus, R. A., Nikitin, A. A., Rudzikas, Z. B., and Kholtygin, A. F. (1985a) *Astrofizika* **22**, 555.
Bogdanovich, O., Nikitin, A. A., Rudzikas, Z. B., and Kholtygin, A. F. (1985b) *Astrofizika* **23**, 427.
Brocklehurst, M. (1971) *Mon. Not. R. Astron. Soc.* **153**, 471.
Brocklehurst, M. (1972) *Mon. Not. R. Astron. Soc.* **157**, 211.
Brown, R. (1972) *Astrophys. J.* **174**, 511.
Burgess, A. (1965) *Astrophys. J.* **141**, 1588.
Burgess, A. and Chidichimo, M. C. (1983) *Mon. Not. R. Astron. Soc.* **203**, 1269.
Burgess, A. and Summer, H. (1976) *Mon. Not. R. Astron. Soc.* **174**, 345.
Burgess, A. and Tworkowski, A. S. (1976) *Astrophys. J.* **205**, L105.
Butler, S. E., (1992) *IAU Symp. 155*, 73.
Butler, S. E., Bender, C., and Dalgarno, A. (1979) *Astrophys. J.* **230**, L59.
Butler, S. E., Guberman, S., and Dalgarno, A. (1977) *Phys. Rev. A.* **16**, 500.
Butler, S. E. and Dalgarno, A. (1979) *Astrophys. J.* **234**, 765.
Butler, S. E. and Dalgarno, A. (1980) *Astron. Astrophys.* **85**, 144.
Butler, S. E. and Dalgarno, A. (1980a) *Astrophys. J.* **241**, 838.
Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
Chamberlain, J. W. (1956) *Astrophys. J.* **124**, 390.
Chapman, R. D. and Henry, R. J. W. (1971) *Astrophys. J.* **168**, 169.
Chapman, R. D. and Henry, R. J. W. (1972) *Astrophys. J.* **173**, 243.
Christensen, R. B., Watson, W. D., and Blint, R. J. (1977) *Astrophys. J.* **213**, 712.
Clark, R. E. H., Magee, Jr N. H., Mann, J. B., and Nerts, A. L. (1982) *Astrophys. J.* **254**, 412.
Clegg, R. E. S. (1987) *Mon. Not. R. Astron. Soc.* **229**, 31.
Crandal, D. H. (1981) *Phys. Scr.* **23**, 153.
Cunto, W. and Mendoza, C. (1992) *Rev. Mex. Astron. Astrofis.* **23**, 107.
Dalgarno, A. (1954) *Proc. Phys. Soc. A.* **67**, 1010.
Dalgarno, A. (1984) *in Atoms in Astrophysics*, London, New York, Plenum Press.
Dalgarno, A. and Butler, S. E. (1978) *Commun At. Mol. Phys.* **7**, 129.
Dalgarno, A., Butler, S. E., and Heil, T. (1980) *Astron. Astrophys.* **89**, 379.
Dalgarno, A. and McCray, A. (1972) *Ann. Rev. Astron. Astrophys.* **10**, 375.
Dalgarno, A. and Sternberg, A. (1982) *Mon. Not. R. Astron. Soc.* **200**, 77 .
Daltabuit, E. and Cox, D. (1972) *Astrophys. J.* **177**, 855.
Davidson, K. and Netzer, N. (1979) *Rev. Mod. Phys.* **51**, 715.
Ditchburn, R. and Marr, G. (1953) *Proc. Phys. Soc. A.* **66**, 655.
Drake, G. W. F., Victor, G. A., and Dalgarno, A. (1969) *Phys. Rev.* **180**, 25.
Egikyan, A. G. (1984) *Astrofizika* **20**, 341.
Elwert, G. (1952) *Z. Naturforsch.* **7A**, 432.
Escalante, V. and Victor, G. A. (1990) *Astrophys. J. Suppl. Ser.* **73**, 513.
Escalante, V. and Victor, G. A. (1992) *At. Dat. Nucl. Data Tables.* **51**, 1.
Ferland, G. J. (1980) *PAS* **92**, 596.
Ferland, G. J. (1986) *Astrophys. J.* **310**, L67.
Ferland, G. J. (1986) *PAS* **98**, 549.

Fehsenfeld, F. and Ferguson, E. (1972) *J. Chem. Phys.* **56**, 3066.
Field, G. and Steigman, G. (1971) *Astrophys. J.* **166**, 59.
Flower, D. R. (1967) *Planetary Nebulae, IAU Symp. No. 34*, 77.
Gargaud, M., McCarrol, R., and Valiron, P. (1982) *Astron. Astrophys.* **106**, 197.
Garstang, R. H. (1968) *Planetary Nebulae, IAU Symp. No. 34*, 143.
Giovanardi, C., Natta, A., and Palla F. (1987) *Astron. Astrophys. Suppl. Ser.* **70**, 269.
Goldwire, Jr H. C., (1968) *Astrophys. J. Suppl. Ser.* **17**, 445.
Golovatyj, V. V., Sapar, A. A., Feklistova, T. Kh., and Kholtygin, A. F. (1991) *Atomic Data for Spectroscopy of Rarefied Astrophysical Plasma. Gaseous Nebulae*, Estonian Academy of Sciences, Tallinn.
Grandi, S. A. (1976) *Astrophys. J.* **206**, 658.
Grinin, V. (1969a) *Astrofizika* **5**, 213, 371.
Grinin, V. (1969b) *Astrofizika* **5**, 213, 371.
Gruzdev, F. (1990) *Transition Probabilities and Mean Lives of Atomic and Ion Levels*, Moscow, Energoatomizdat Publ. House.
Gulyaev, S. A. (1990) In *Radio Recombination Lines: 25 Years of Investigation*, Gordon M. A. and Sorochenko R. L. (eds.), Netherlands, Kluwer Publ.
Hanson, W. B., Patterson, T. N., and Deaonkar, S. S. (1963) *J. Geophys. Res.* **68**, 6203.
Harrington, J., Seaton, M. J., Adams, S., and Lutz, J. H. (1982) *Mon. Not. R. Astron. Soc.* **199**, 517.
Henry, R. J. M. (1970) *Astrophys. J.* **161**, 1153.
Hidalgo, M. B. (1968) *Astrophys. J.* **152**, 981.
Hidalgo, M. B. (1969) *Astrophys. J.* **157**, 479.
Hudson, R. D. and Kieffer, L. J. (1971) *Atomic Data* **2**, 205.
Hummer, D. G. (1983) *J. Quant. Spectrosc. Radiat. Transfer.* **30**, 281.
Hummer, D. G. and Storey, J. (1987) *Mon. Not. R. Astron. Soc.* **224**, 801.
Ilmas, M. (1986) *Publ. Tartu Astrophys. Obs.* **51**, 76.
Ilmas, M. and Nugis, T. (1982) *Tartu Astrofüüs. Obs. Teated. No. 67*, 3.
Jacobs, V. L., Davis, J., Kepple, C., and Blaha, M. (1977a) *Astrophys. J.* **211**, 605.
Jacobs, V. L., Davis, J., Kepple, C., and Blaha, M. (1977b) *Astrophys. J.* **215**, 690.
Jacobs, V. L., Davis, J., Rogerson, J. E., and Blaha, M. (1978) *J. Quant. Spectrosc. Radiat. Transfer.* **19**, 591.
Jacobs, V. L., Davis, J., Rogerson, J. E., and Blaha, M. (1979) *Astrophys. J.* **230**, 627.
Jacobs, V. L., Davis, J., Rogerson, J. E., Blaha, M., Cain, J., and Davis, M. (1980) *Astrophys. J.* **239**, 1119.
Jain, N. K. and Narain, U. (1976) *Sol. Phys.* **50**, 361.
Johnson, L. C. (1972) *Astrophys. J.* **174**, 227.
Johnson, C. T., Burke, P. G., and Kingston, A. E. (1987) *J. Phys. B.* **20**, 2553.
Johnson, R. and Biondi, M. (1978) *Phys. Rev. A.* **18**, 996.
Jura, M. and Dalgarno, A. (1971) *Astron. Astrophys.* **14**, 243.
Kafatos, M. and Lynch, J. (1980) *Astrophys. J. Suppl. Ser.* **42**, 611.
Kaler, J. B. (1976) *Astrophys. J. Suppl. Ser.* **31**, 517.
Karzas, W. J. and Latter, R. (1961) *Mon. Not. R. Astron. Soc.* **6**, 167.
Kholtygin, A. F. (1981) *Thesis*, Leningrad.
Kholtygin, A. F. (1988) *WR Stars and Related Objects, Tartu Astrofüüs. Obs. Teated No. 89*, 111 .
Kholtygin, A. F. (1990) *H II Regions, Itogi Nauki i Techniki*, Moscow **40**, 85.
Kholtygin, A. F. (1996) *Astronomy and Astrophys.* (in preparation).
Kholtygin, A. F., and Feklistova, T. Kh. (1992a) *Astron. Zh.* **62**, 936.
Kholtygin, A. F. and Feklistova, T. Kh. (1992b) *Baltic Astronomy*, **1**, 514.
King, G. C., Zubek, M., Rutter, M., Read, F. H., McDowell, A. A., West, J. B., and Holland, D. M. (1988) *J. Phys. B.* **21**, L403.
Kipper, A. J. (1950) In *O Razvitii Sovetskoj Nauki v Estonskoj SSR (1940–1950)*, Tallinn, 316–327.
Kipper, A. J. (1952) *Publ. Tartu Astrophys. Obs.* **32**, 63.
Kurucz, R. L. (1992) *Rev. Mex. Astron. Astrofis.* **23**, 45.

Kurucz, R. L. (1995) *SAO, Preprint Ser. No. 4080.*
Landidi, M. and Monsignori, F. B. C. (1971) *Sol. Phys.* **20**, 322.
Lang, K. R. (1974) *Astrophysical Formulae*, Berlin, Springer–Verlag, New York, Heidelberg.
Leibowitz, E. M. (1972) *J. Quant. Spectrosc. Radiat. Transfer.* **12**, 299.
Levinson, I. B. and Nikitin, A. A. (1962) *Rukovodstvo po Teoreticheskomu Vychisleniju Intensivnostej Linij v Atomnyh Spektrah*, Leningrad, LGU.
Liu, X.-W. and Danziger, I. J. (1993) *Messenger.* **71**, 25.
Liu, X.-W. and Danziger, I. J., Murdin (1993) *Mon. Not. R. Astron. Soc.* **262**, 699.
Liu, X.-W., Storey, J., Barlow, M. J., and Clegg, R. E. S. (1995) *Mon. Not. R. Astron. Soc.* **272**, 369.
Lotz, W. (1967a) *Z. Phys.* **206**, 205.
Lotz, W. (1967b) *Astrophys. J.* **14**, 207.
Lotz, W. (1968) *Z. Phys.* **216**, 241.
MacAlpine, G. M. (1974) *Astrophys. J.* **193**, 37.
Martin, G. (1988) *Astrophys. J. Suppl. Ser.* **66**, 125.
McCarroll, R. and Valiron, P. (1976) *Astron. Astrophys.* **53**, 83.
McCarroll, R. and Valiron, P. (1979) *Astron. Astrophys.* **78**, 177.
Melius, C. F. (1973) *Abstracts of papers VIII*, ICPEAC.
Mendoza, C. (1983) *Planetary Nebulae, IAU Symp. No. 103*, 143.
Menzel, D. H. and Pekeris, C. L. (1935) *Mon. Not. R. Astron. Soc.* **96**, 77.
Moore, C. E. (1949) *Atomic Energy Levels, NSRDS-NBS Cir No. 467.*
Morton, D. C. (1991) *Astrophys. J. Suppl. Ser.* **77**, 119.
Nikitin, A. A. and Kholtygin, A. F. (1986) *Izv. Akad. Nauk SSSR, Ser. Fiz.* **50**, 417.
Nikitin, A. A., Kholtygin, A. F., Sapar, A. A., and Feklistova, T. (1994) *Baltic Astronomy* **3**, 112.
Nikitin, A. A., Rudzikas, Z. B., Sapar, A. A., Feklistova, T. Kh., and Kholtygin, A. F. (1988) *Spectra of the Planetary Nebulae*, Tallinn, Valgus Publ. House.
Nikitin, A. A. and Rudzikas, Z. B. (1983) *Principles of Theory of Atomic and Ions Spectra*, Moscow, Nauka Publ. House.
Nikitin, A. A., Feklistova, T. Kh., and Kholtygin, A. F. (1986) *Publ. Tartu Astrophys. Obs.* **51**, 42.
Nikitin, A. A., Feklistova, T. Kh., and Kholtygin, A. F. (1990) *Publ. Tartu Astrophys. Obs.* **53**, 62.
Nussbaumer, H. and Schild, H. (1981) *Astron. Astrophys.* **101**, 118.
Nussbaumer, H. and Storey, J. (1983) *Astron. Astrophys.* **126**, 75.
Nussbaumer, H. and Storey, J. (1984) *Astron. Astrophys. Suppl. Ser.* **56**, 293.
Nussbaumer, H. and Storey, J. (1986) *Astron. Astrophys. Suppl. Ser.* **64**, 545.
Nussbaumer, H. and Storey, J. (1987) *Astron. Astrophys. Suppl. Ser.* **69**, 123.
Nussbaumer, H. and Storey, J. (1988) *Astron. Astrophys.* **193**, 327.
O'Dell, C. R. and Miller, C. O. (1992) *Astrophys. J.* **390**, 219.
Omidvar, K. (1983) *At. Dat. Nucl. Data Tables* **23**.
Opradolce, L., McCarroll, R., and Valiron, P. (1985) *Astron. Astrophys.* **148**, 299.
Oskinova, L. M. and Kholtygin, A. F. (1996) *Vestnik*, Sankt-Peterburskogo Universiteta (in press).
Osmer, P. M. (1976) *Astrophys. J.* **203**, 352.
Osterbrock, D. E. (1974) *Astrophysics of Gaseous Nebulae*, San Francisco, Freeman, 251.
Peimbert, M. (1967) *Astrophys. J.* **150**, 825.
Peimbert, M. and Torres–Peimbert S. (1987a) *Rev. Mex. Astron. Astrofis.* **14**, 540.
Peimbert, M. and Torres–Peimbert S. (1987b) *Rev. Mex. Astron. Astrofis.* **15**, 117.
Pengelly, R. M. and Seaton, M. J. (1964) *Mon. Not. R. Astron. Soc.* **127**, 165.
Pequignot, D. and Aldrovandi, S. M. V. (1986) *Astron. Astrophys.* **161**, 169.
Pequignot, D., Aldrovandi, S. M. V., and Stasinska, G. (1978) *Astron. Astrophys.* **63**, 313.
Pequignot, D. and Balateau, J.- (1994) *Astron. Astrophys.* **283**, 593.
Pequignot, D., Petitjean, and Boisson, C. (1991) *Astron. Astrophys.* **251**, 680.
Pottasch, S. R. (1984) *Planetary nebulae*, Dordrecht, Reidel.
Radtsig, A. A. and Smirnov, B. M. (1986) *Parameters of Atoms and Atomic Ions*, Moscow, Energoatomizdat (in Russian).
Rapp, D. (1963) *J. Geophys. Res.* **68**, 1773.

Reader, J., Corliss, C. H., Wiese, W. L., and Martin, G. A. (1980) *Wavelengths and Transition Probabilities for Atomic Ions*, NSRDS-NBS 68.
Reilman, R. F. and Manson, S. T. (1979) *Astron. Astrophys. Suppl. Ser.* **40**, 815.
Romanik, C. J. (1988) *Astrophys. J.* **330**, 1022.
Roueff, E. and Le Bourlot, J. (1990) *Astron. Astrophys.* **236**, 515.
Rublev, S. V. (1969) *Izv. SAO* **2**, 63.
Rudzikas, Z. B., Nikitin, A. A., and Kholtygin, A. F. (1990) *Theoretical Atomic Spectroscopy*, Leningrad, Izd. Lgu. (in Russian).
Sakhibullin, N. A. and Willis, A. (1978) *Astron. Astrophys. Suppl. Ser.* **31**, 11.
Sapar, A. and Kuusik, I. (1974) *Publ. Tartu Astrophys. Obs.* **42**, 272.
Sarazin, C. L. (1986) *Rev. Mod. Phys.* **58**.
Seaton, M. J. (1955) *Proc. Phys. Soc.* **68A**, 457.
Seaton, M. J. (1958) *Rev. Mod. Phys.* **30**, 979.
Seaton, M. J. (1959) *Mon. Not. R. Astron. Soc.* **119**, 81.
Seaton, M. J. (1964) *Planet. Space Sci.* **12**, 55.
Seaton, M. J. *et al.* (1992) *Rev. Mex. Astron. Astrofis.* **23**, 19.
Shevelko, V., Urnov, A. M., Vainahtein, L. A., and Müller, A. (1983) *Mon. Not. R. Astron. Soc.* **203**, 45.
Shull, M. J. and Van Steenberg, M. (1982) *Astrophys. J. Suppl. Ser.* **48**, 95.
Silk, J. and Brown, R. (1971) *Astrophys. J.* **163**, 495.
Sobelman, I. I. (1977) *Introduction in the Theory of Atomic Spectra*, Moscow, Nauka Publ. House.
Sobolev, V. V. (1960) *Moving Envelopes of Stars*, Cambridge, Harvard Univ. Press.
Sobolev, V. V. (1985) *Kurs Theoreticheskoi Astrofiziki*, Moscow, Nauka Publ. House (in Russian).
Spitzer, L. and Greenstein, J. L. (1951) *Astrophys. J.* **114**, 407.
Stasinska, G. (1984) *Astron. Astrophys. Suppl. Ser.* **55**, 15.
Steigman, G., Werner, H., and Geldon, F. (1971) *Astrophys. J.* **168** 373.
Steigman, G. (1975) *Astrophys. J.* **199**, 642.
Steigman, G. (1975a) *Astrophys. J.* **195**, L39.
Storey, J. (1981) *Mon. Not. R. Astron. Soc.* **195**, 27.
Storey, J. (1994) *Astron. Astrophys.* **282**, 999.
Storey, J. and Hummer, D. G. (1988) *Mon. Not. R. Astron. Soc.* **231**, 1139.
Suchkov, A. A. and Shchekinov, Y. A. (1983) *Astrofizika* **19**, 569.
Summers, H. (1974) *Appletion Laboratory*, AL-R-S..
Tarter, C. B. (1971) *Astrophys. J.* **168**, 713.
Tarter, C. B., Weisheit, J. C., and Dalgarno, A. (1979) *Astron. Astrophys.* **71**, 366.
Theodosiou, C. E. (1987) *At. Dat. Nucl. Data Tables* **36**, 97.
Verner, D. A., Yakovlev, D. G., Band, I. M., and Trzhaskovskaya, M. B. (1993) *At. Dat. Nucl. Data. Tables* **55**, 233.
Verner, D. A., Barthel, D., and Tytler, D. (1994) *Astron. Astrophys. Suppl. Ser.* **108**, 287.
Watson, W. D. (1978) *Ann. Rev. Astron. Astrophys.* **16**, 585.
Weisheit, J. C. (1974) *Astrophys. J.* **190**, 735.
Weisheit, J. C. and Collins, L. (1976) *Astrophys. J.* **210**, 299.
Williams, R. (1967) *Astrophys. J.* **147**, 556.
Woods, D. I., Shull, M. J., and Sarazin, C. L. (1981) *Astrophys. J.* **249**, 399.

Appendix A ATOMIC DATA REFERENCES

This appendix contains the bibliographic reference list arranged for atomic processes and the elements. It is a greatly extended and updated version of the bibliographic list presented by K. Butler (1993). We have paid special attention to review papers and recent catalogues. References to papers issued since 1991 are presented in more detail. The limited space in the catalogue does not allow for the presentation of data for all elements of the periodic system and their ions, so we have restricted our consideration mostly to the elements found in gaseous nebulae plasma conditions; these are the elements up to Fe and their ions up to the Xth ionization stage. We also exclude from consideration the processes with keV and MeV energies. Even this extreme limitation of the atoms and ions considered did not allow us to review all atomic data papers in the field. The authors beg the reader's pardon for omitting some important references which may have been excluded arbitrary.

In future we plan to place this list (extended and updated) on our Home Pages to be accessible via the WWW.

A.1 Energy Levels and Wavelengths

Review Wiese, W. L. (1991) *J. de Phys.* **1** (Coll. 1 Suppl. JP II, 3), 287.
Review Martin, W. C. (1992) In *Lecture Notes in Physics*, Zeippen C. J. and Le Dourneuf M. (eds.).
Forb. lines, ns^2np^k Be–Mo ions Kaufman, V. and Sugar, J., (1986) *J. Phys. Chem. Ref. Data* **15**, 321.
Li seq ($8 \leq Z \leq 92$) Zhang, H. L., Sampson, D. H., and Fontes, C. J. (1990) *At. Dat. Nucl. Data Tables* **44**, 31.
C I–IV Jannitti, E., Nikolosi, P., and Tondello, G. (1990) *Phys. Scr.* **41**, 458.
C I Yamamoto, S. and Saito, S. (1991, *Astrophys. J.* **370**, L103.
N I–IV Rieger, G., Bukow, H. H., and Vilkas, M. (1994) *J. Phys. B.* **27**, 2123.
N IV Laughlin, C. (1990) *Phys. Scr.* **42**, 551.
N V Laughlin, C. (1990) *Z. Phys. D* **16**, 9.
O II Pettersson, S. G. and Wenaker, I. (1990) *Phys. Scr.* **42**, 187.
O II Wenaker, I. (1990) *Phys. Scr.* **42**, 667.
O II Martin, W. C., Kaufman, V., and Musgrove, A. (1993) *J. Phys. Chem. Ref. Data* **22**, 1179.
Na ions Martin, W. C. and Zalubas, R. (1981) *J. Phys. Chem. Ref. Data* **10**, 153.
Na seq ($Z = 22, 92$) Sampson, D. H., Zhang, H. L., and Fontes, C. J. (1990) *At. Dat. Nucl. Data Tables* **44**, 209.
Na seq (Cl VII, Ar VIII) Kuplyauskene, A. V. and Zhukauskas, G., (1991) *Opt. i Spectr.* **67**, 15.
Mg ions Martin, W. C. and Zalubas, R. (1980) *J. Phys. Chem. Ref. Data* **9**, 1.
Ng seq Levashov, V. E. (1991) *Opt. i Spectr.* **71**, 732.
Mg ions Kaufman, V. and Martin, W. C. (1991) *J. Phys. Chem. Ref. Data* **20**, 83.
Mg I Clark, R. E. H., Czanak, G., and Abdallah, Jr., J. (1991) *Phys. Rev. A* **44**, 2874.
Al ions Martin, W. C. and Zalubas, R. (1979) *J. Phys. Chem. Ref. Data* **8**, 817.
Al ions Chang, E.S. (1990) *J. Phys. Chem. Ref. Data* **19**, 118.
Al I Buurman, E. P., Koning, O. J., and Donszelmann, A. (1990) *J. Phys. B.* **23**, 2673.
Al seq ($Z = 14, 19$) Hjorth–Jensen, M. and Aashamar, K. (1990) *Phys. Scr.* **42**, 309.
Al ions Kaufman, V. and Martin, W. C. (1991) *J. Phys. Chem. Ref. Data* **20**, 775.
Si ions Martin, W. C. and Zalubas, R. (1983) *J. Phys. Chem. Ref. Data* **12**, 323.
Si I Dembczynski, J. and Stachowska, E. (1991) *Phys. Scr.* **43**, 248 .
P ions Martin, W. C., Zalubas, R., and Musgrove, A. (1985) *J. Phys. Chem. Ref. Data* **14**, 751.

S ions Martin, W. C., Zalubas, R., and Musgrove, A. (1990) *J. Phys. Chem. Ref. Data* **19**, 821.
S ions Martin, W. C., Zalubas, R., and Musgrove, A. (1991) *J. Phys. Chem. Ref. Data* **20**, 205.
S I–S XVI Kaufman, V. and Martin, W. C. (1993) *J. Phys. Chem. Ref. Data* **22**, 279.
Cl III–VI Raaseen, A. J. J., Snoek, L. C., Volten, H., Uylings, P. H. M., Meijer, F. G., and Joshi, Y. N. (1992) *Astron. Astrophys. Suppl. Ser.* **95**, 223.
Ar III–V Raaseen, A. J. J., Snoek, L. C., Volten, H., Uylings, P. H. M., Meijer, F. G., and Joshi, Y. N. (1992) *Astron. Astrophys. Suppl. Ser.* **95**, 223.
K–Ni Sugar, J. and Corliss, C. (1985) *J. Phys. Chem. Ref. Data* **14** (Suppl. 2).
V VI–V XXIII Shirai, T., Nakagaki, T., Sugar, J., and Wiese, W. L. (1992) *J. Phys. Chem. Ref. Data* **21**, 273.
Cr V–Cr XXIV Shirai, T., Nakai, Y., Nakagaki, T., Sugar, J., and Wiese, W. L. (1993) *J. Phys. Chem. Ref. Data* **22**, 1279.
Fe I–Fe XXVI Corliss, C. and Sugar, J. (1982) *J. Phys. Chem. Ref. Data* **11**, 135.
Fe I–Fe VI Huang, K. N. (1990) *Rep. Inst. At. Mol. Sci., Acad. Sinica*, Dept. of Phys., Taiwan.
Fe I O'Brian, T. R., Wickliffe, M. E., Lawler, J. E., Whaling, W., and Brault, J. W. (1991) *J. Opt. Soc. Am. B* **8**, 2028.
Fe VII–Fe XXVI Shirai, T., Funatake, Y., Mori, K., Sugar, J., and Wiese, W.L. (1990) *J. Phys. Chem. Ref. Data* **19**, 127.
Co VIII–Co XXVII Shirai, T., Mengoni, A., Nakai, Y., Sugar, J., Wiese, W.L., Mori, K., and Sakai, H. (1992) *J. Phys. Chem. Ref. Data* **21**, 23.
Cu I–Cu XXIX Sugar, J. and Musgrove, A. (1990) *J. Phys. Chem. Ref. Data* **19**, 527.
Cu X–Cu XXIX Shirai, T., Nakagaki, T., Nakai, Y., Sugar, J., Ishii, K., and Mori, K. (1991) *J. Phys. Chem. Ref. Data* **20**, 1.
Ge I–Ge XXXII Sugar, J. and Musgrove, A. (1993) *J. Phys. Chem. Ref. Data* **22**, 1213.
Kr I–Kr XXXVI Sugar, J. and Musgrove, A. (1991) *J. Phys. Chem. Ref. Data* **20**, 859.
Mo I–Mo XLII Sugar, J. and Musgrove, A. (1988) *J. Phys. Chem. Ref. Data* **17**, 135.
Mo VI–Mo XLII Shirai, T., Nakai, Y., Ozano, K., Ishii, K., Sugar, J., and Mori, K. (1987) *J. Phys. Chem. Ref. Data* **16**, 327.
$\lambda \leq$ 2000Å, H–Kr Kelly, R. L. (1987) *J. Phys. Chem. Ref. Data* **16** (Suppl 1).
$\lambda \geq$ 912Å, All Elements Morton, D. C. (1991) *Astrophys. J. Suppl. Ser.* **77**, 119.
$\lambda >$ 228Å, All Elements Verner, D. A., Barthel, P. D., Tytler, D. (1994) *Astrophys. J. Suppl. Ser.* **108**, 287.

A.2 Transition Probabilities

Bibliography Biémont, E. and Zeippen, C. L. (1991) In *J. de Phys.* Zeippen, C. J. and Le Dourneuf, M.(eds.) **1** (Coll. 1 Suppl. JP II, 3), 209.
Review Wiese, W. L. (1991) In *J. de Phys.* Zeippen, C. J. and Le Dourneuf, M.(eds.) **1** (Coll. 1 Suppl. JP II, 3), 287.
Review Wiese, W. L. (1991, In *Reports on Astron. Tras. IAU*, McNally, D. (ed.), Holland, Dordrecht, Kluwer **Rep. 21A**, 111.
Review Martin, W. C. (1992) In *Lecture Notes in Physics.*
M1–Tables Kaufman, V. and Sugar, J. (1986) *J. Phys. Chem. Ref. Data* **20**, 321.
Critical evaluation Mendoza, C. (1983) In *IAU Symp. No. 103*, Flower, D. R. (ed.), p. 143 .
Critical evaluation Martin, W. C., Fuhr, J. R., and Wiese, W. L. (1988) *J. Phys. Chem. Ref. Data* **16** (Suppl. 3).
Critical evaluation Fuhr, J. R., Martin, W. C., and Wiese, W. L. (1988) *J. Phys. Chem. Ref. Data* **17** (Suppl. 4).
Critical evaluation Fuhr, J. R. and Wiese, W. L. (1990) In *CRC Handbook of Chemistry and Physics, 71st edn*, Lide D. R. (ed.).
Critical evaluation Morton, D. C. (1991) *Astrophys. J. Suppl. Ser.* **77**, 119.
Compilation: H–Bi Verner, D. A., Barthel, P. D., and Tytler, D. (1994) *Astron. Astrophys. Suppl. Ser.* **108**, 287 .
Forbidden lines Biémont, E., Hansen, J. E., Quinet, P., and Zeippen, C. J. (1995) *Astron. Astrophys. Suppl. Ser.* **111**, 333.

H ions Storey, P. J. and Hummer, D. G. (1991) *Comput. Phys. Commun.* **66**, 129.
H Omidvar, K. and Guimaraes, T. P. (1990) *Astrophys. J. Suppl. Ser.* **73**, 555.
H Malik, G. P., Malik, U., and Varma, V. S. (1991) *Astrophys. J.* **371**, 418.
He I Kono A. and Hottori S.) *Phys. Rev. A* **29**, 2981.
He I Theodosiou C. E. (1987) *At. Dat. Nucl. Data Tables* **36**, 97.
Li seq ($\leq$ **8***Z*$\leq$ **92**) Zhang, H. L., Sampson, D. H., and Fontes, C. J. (1990) *At. Dat. Nucl. Data Tables* **44**, 31.
Be seq Trabert, E. (1990) *Phys. Scr.* **41**, 675.
Be seq Tully, J. A., Seaton, M. J., and Berrington, K. A. (1990) *J. Phys. B.* **23**, 3811.
Be seq Eissner, W. B. and Tully, J. (1992) *Astron. Astrophys.* **253**, 625.
Be seq (***Z***= **4, 16**) Chou, H.-S., Chi, H.-C., and Huang, K.-N. (1994) *Chin. J. Phys.* **32**, 261.
Be seq (***Z***= **11, 14**) Granzow, J., Heckmann, P. H., and Traebert, E. (1994) *Phys. Scr.* **49**, 148.
Be seq (***Z***= **7, 36**) Fritzsche, S., and Grant, I. P. (1994) *Phys. Scr.* **50**, 473.
B seq (***Z***= **14, 64**) Zhang, H. L. and Sampson D. H. (1994) *At. Dat. Nucl. Data Tables* **58**, 255.
B seq (***Z***= **8, 26**) Merkelis, G., Vilkas, M. J., Gaigalas, G., and Kisielius, R. (1995) *Phys. Scr.* bf 51, 233.
Be I Chang, T. N. (1990) *Phys. Rev. A* **41**, 4922.
Be I Chang, T. N. and Tang, X. (1990) *J. Quant. Spectrosc. Radiat. Transfer* **43**, 45.
C seq Luo, D. and Pradhan, A.K. (1989) *J. Phys. B.* **22**, 3377.
C seq (***Z***= **8, 20**) Gupta, A. and Baluja, K. L. (1993) *Indian J. Pure Appl. Phys.* **31**, 297.
C seq (***Z***= **10, 22**) Ray, D. and Mukherjee, P. K. (1995) *Phys. Scr.* bf 51, 81.
C I Goldbach, C., Martin, M., and Nollez, G. (1989) *Astron. Astrophys.* **221**, 115.
C I Haar, R. R., Curtis, L. J., and Kvale, T. J. *et al.* (1991) *Astron. Astrophys.* **241**, 321.
C II–C III Fischer, C. F. (1994) *Phys. Scr.* **49**, 316.
C III–C VI Baudinet–Robinet, Y., Dumont, P. D., Garnir, H. P., and Himdy, A. E. (1989) *Phys. Rev. A* bf 40, 6361.
C III Allard, N., Artru, M.-C., Lanz, T., and Le Dourneuf, M. (1990) *Astron. Astrophys. Suppl. Ser.* **84**, 563.
C III Allard, N., Artru, M.-C., Lanz, T., and Le Dourneuf, M. (1991) *Astron. Astrophys. Suppl. Ser.* **91**, 399.
C III Fleming, J., Hibbert, A., and Stafford, R. P. (1994) *Phys. Scr.* **49**, 316.
C VI Tayal, S. S. and Henry, R. J. W. (1990) *Phys. Rev. A* **42**, 1831.
N seq Becker, S. R., Butler, K., and Zeippen, C. J. (1989) *Astron. Astrophys.* **221**, 375.
N seq Curtis, L. J., Rudzikas, Z. B., and Ellis, D. G. (1991) *Phys. Rev. A* **44**, 776.
N I Zhu, Q., Bridges, J. M., Hahn, T., and Wiese, W. L. (1989) *Phys. Rev. A* **40**, 3721.
N I Hibbert, A., Biémont, E., Godefroid, M., and Vaeck, N. (1990) *Astron. Astrophys. Suppl. Ser.* **88**, 505.
N I Dumont, P.-D., Garnir, H.-P., and Baudinet–Robinet, Y. (1991) *Z. Phys. D* **21**, 209.
N I Vaeck, N. and Hansen, J. E. (1991) *J. Phys. B* **24**, L469 .
N I Bell, K. L. and Berrington, K. A. (1991) *J. Phys. B* **24**, 933 .
N I–IV Rieger, G., Bukow, H. H., and Vilkas, M. (1994) *J. Phys. B* **27**, 2123.
N II Baudinet–Robinet, Y., Garnir, H.-P., Dumont, P.-D., and Resimont, J. (1990) *Phys. Rev. A*, **42**, 1080.
N II Tripp, T. M., Shemansky, D. E., James, G. K., and Ajello, J. M. (1991) *Astrophys. J.* **368**, 641.
N II Bell, K. L., Ramsbottom, C. A., and Hibbert, A. (1992) *J. Phys. B* **25**, 1735.
N II Bastin, T., Baudinet–Robinet, Y., Dumont, P.-D., and Garnir, H.-P. (1993) *J. Phys. (Orsay)* **3**, 1479.
N II Kay, L. and Sadler, D. A. (1994) *J. Phys. B* **27**, 2877.
N IV Allard, N., Artru, M.-C., Lanz, T., and Le Dourneuf, M. (1990) *Astron. Astrophys. Suppl. Ser.* **84**, 563.
N IV Chang, T. N. and Mu Yi (1990) *J. Quant. Spectrosc. Radiat. Transfer* **44**, 413.
N IV Laughlin, C. (1990) *Phys. Scr.* **42**, 551.
N IV Allard, N., Artru, M.-C., Lanz, T., and Le Dourneuf, M. (1991) *Astron. Astrophys. Suppl. Ser.* **91**, 399.
N V Laughlin, C. (1990) *Z. Phys. D* **16**, 9.

N VI Ramsbottom, C. A., Berrington, K. A., Hibbert, A., and Bell, K. L. (1994) *Phys. Scr.* **50**, 246.
O seq Chen, M. H. (1989) *Phys. Rev. A* **40**, 4330.
O seq (Z= **8, 36**) Gupta, A. and Baluja, K. L. (1993) *Indian J. Pure Appl. Phys.* **31**, 297.
O seq (Z= **20, 26**) Gaigalas, G., Kaniauskas, J., Kisielius, R., Merkelis, G., and Vilkas, M. J. (1994) *Phys. Scr.* **49**, 135.
O seq (Z= **10, 26**) Vilkas, M. J., Merkelis, G., Kisielius, R., Gaigalas, G., Bernozas, A., and Rudzikas, Z. B (1994) *Phys. Scr.* **49**, 592.
O I Tayal, S.S. and Henry, R.J.W. (1989) *Phys. Rev. A* **39**, 4531.
O I Bell, K. L. and Hibbert, A. (1990) *J. Phys. B* **23**, 2673.
O I Butler, K. and Zeippen, C.J. (1991) *J. Phys. (Paris) Colloq.* **1**, 141.
O I Bell, K. L., Hibbert, A., McLaughlin, B. M., and Higgins, K. (1991) *J. Phys. B* **24**, 2665.
O I Hibbert, A., Biémont, E., Godefroid, M., and Vaeck, N. (1991) *J. Phys. B* **24**, 3943.
O I Biémont, E., Hibbert, A., Godefroid, M., Vaeck, N., and Fawcett, B. C. (1991) *Astrophys. J.* **375**, 818.
O II Bell, K. L., Hibbert, A., McLaughlin, B. M., and Higgins, K. (1991) *J. Phys. B* **24**, 2665.
O II Bell, K. L., Hibbert, A., Stafford R. P., and McLaughlin, B. M. (1994) *Phys. Scr.* **50**, 343.
O III Kotze, T. C. and van der Westhuizen, P. (1990) *Spectrochim. Acta B* **45**, 421.
O III Baudinet–Robinet, Y., Dumont, P.-D., and Garnir, H.-P. (1991) *Phys. Rev. A* bf 43, 4022.
O III Aggarwal, K. M. and Hibbert, A. (1991) *J. Phys. B* **24**, 3445.
O III Aggarwal, K. M. and Hibbert, A. (1991) *J. Phys. B* **24**, 4685.
O III Marketos, P. (1994) *Z. Phys. D* **29**, 247.
O III Thong, X., Zou, Y., Li, J., and Liu, X. (1994) *Chin. Phys. Lett.* **11**, 69.
O V Allard, N., Artru, M.-C., Lanz, T., and Le Dourneuf, M. (1990) *Astron. Astrophys. Suppl. Ser.* **84**, 563.
O V Allard, N., Artru, M.-C., Lanz, T., and Le Dourneuf, M. (1991) *Astron. Astrophys. Suppl. Ser.* **91**, 399.
O V Hart van der, H. W. and Hansen, J. E. (1993) *J. Phys. B* **26**, 3297.
F seq (**10** $\leq z \leq$ **33**) Blackford, H. M. S. and Hibbert, A. (1994, *At. Dat. Nucl. Data Tables* **58**, 101.
Ne seq (Z= **26, 47**) Cornille, M., Dubau, J., and Jacquemot S. (1994) *At. Dat. Nucl. Data Tables* **58**, 1.
Ne seq (Z= **10, 14**) Hibbert, A. and Scott, M. P. (1994) *J. Phys. B* **27**, 1315.
Ne II Burshtein, M. L. and Vujnović, V. (1991) *Astron. Astrophys.* **247**, 252.
Na seq (Z= **11, 29**) Guet, C, Blundell, S. A., and Johnson, W. R. (1990) *Phys. Lett. A* **143**, 384.
Na seq (Z= **22, 92**) Sampson, D. H., Zhang, H. L., and Fontes, C. J. (1990) *At. Dat. Nucl. Data Tables* **44**, 209.
Mg seq Trabert, E. (1990) *Phys. Scr.* **41**, 675.
Mg seq Butler, K., Mendoza, C., and Zeippen, C. J. (1991) *J. Phys. (Paris) Colloq.* **1**, 135.
Mg seq Chang, T. N. and Rong-Qi Wang (1991) *Phys. Rev. A.* **44**, **80.**
Mg I Beck, D.R. and Ziyong Cai (1989) *Phys. Lett. A.* **142**, 378.
Mg I Chang, T. N. and Tang, X. (1990) *J. Quant. Spectrosc. Radiat. Transfer* **43**, 45.
Mg I Chang, T. N. (1990) *Phys. Rev. A.* **41**, 4922.
Mg IV Mohan, M. and Baluja, K. L. (1989) *Z. Phys. D: At. Mol. Clusters* **14**, 135.
Mg IV Mohan, M. and Hibbert, A. (1991) *Phys. Scr.* **44**, 158.
Al seq (Z= **14, 19**) Hjorth–Jensen, M. and Aashamar, K. (1990) *Phys. Scr.* **42**, 309.
Al ions Oddershede, J. and Sabin, J. R. (1990) *Nucl. Instrum. Methods Phys. Res. B.* **48**, 34.
Al I Davidson, M. D., Volten, H., and Dönszelmann, A. (1990) *Astron. Astrophys.* **238**, 452.
Al II Hibbert, A. (1989) *Phys. Scr.* **39**, 574.
Al II Serrâo, J.M.P. (1990) *J. Quant. Spectrosc. Radiat. Transfer* **45**, 121.
Al V–Al VII Biémont, E. (1991) *At. Dat. Nucl. Data Tables* **48**, 1.
Si III Hibbert, A. (1989) *Phys. Scr.* **39**, 574.
Si III Serrâo, J.M.P. (1990) *J. Quant. Spectrosc. Radiat. Transfer* **45**, 349.
Si VI Mohan, M. and Le Dourneuf, M. (1990) *Phys. Rev. A.* **41**, 2862.
P seq Curtis, L. J., Rudzikas, Z. B., and Ellis, D.G. (1991) *Phys. Rev. A* **44**, 776.

S seq (Z= **26, 29**) Traebert, E., Brandt, M., Doerfert, J. *et al.* (1993) *Phys. Scr.* **48**, 580.
S I Doering, J. P. (1990) *J. Geophys. Res.* **95**, 213.
S I Delalic, Z., Erman, P., and Kallne, E. (1990) *Phys. Scr.* **42**, 540.
S VII Hibbert, A., Mohan, M., and Le Dourneuf, M. (1992) *J. Phys. B* **25**, 1107.
S VIII Mohan, M. and Hibbert, A. (1991) *Phys. Scr.* **44**,158.
Cl seq (Z= **26, 29**) Traebert, E., Brandt, M., Doerfert, J. *et al.* (1993) *Phys. Scr.* **48**, 580.
Cl I Delalic, Z., Erman, P., Kallne, E., and Zastrow, K.-D. (1990) *J. Phys. B* **23**, 2727.
Cl I Ojha, P. C. and Hibbert, A. (1990) *Phys. Scr.* **42**, 424.
Cl I Biémont E., Gebarowski R., Zeippen C. J. (1994) *Astron. Astroph.* **287**, 290.
Cl VIII Hibbert, A., Mohan, M., and Le Dourneuf, M. (1992) *J. Phys. B* **25**, 1107.
Ar seq (Z= **18, 25**) Ghosh, T. K., Das, A. K., Castro, M., Canuto, S. and Mukherjee, P. K. (1993) *Phys. Rev. A* **48**, 2686.
Ar II Lüdtke, T. and Helbig, V. (1990) *J. Quant. Spectrosc. Radiat. Transfer* **44**, 261.
Ar II Das, M. B. and Bhattacharya, R. (1991) *J. Phys. B* **24**, 423.
Ar II Vujnović, V. and Wiese, W. L. (1992) *J. Phys. Chem. Ref. Data* **21**.
Ar IX Hibbert, A., Mohan, M., and Le Dourneuf, M. (1992) *J. Phys. B* **25**, 1107.
K seq Zilitis, V. A. (1989) *Opt. Spectrosc.* **67**, 595.
K seq Zeippen, C. J. (1990) *Astron. Astrophys.* **229**, 248.
Ca I Vaeck, N., Godefroid, M., and Hansen, J. E. (1991) *J. Phys. B* **24**, 361.
Ca II Guet, C. and Johnson, W. R. (1991) *Phys. Rev. A* **44**, 1531.
Ti I Salih, S. and Lawler, J. E. (1990) *Astron. Astrophys.* **239**, 407.
Ti I Lawler, J. E. (1991) *Astron. Astrophys.* **252**, 853.
Ti II Savanov, I. S., Huovelin, J., and Tuominen, I. (1990) *Astron. Astrophys. Suppl. Ser.* **86**, 531.
Iron group Kurucz, R. L. (1992) In *Rev. Mex. Astron. Astrofis.*, Lynas-Gray, A. E., Mendoza, C., and Zeippen, J. (eds.) **23**.
Fe I Bard, A., Kock, A., and Kock, M. (1991) *Astron. Astrophys.* **248**, 315.
Fe I O'Brian, T. R., Wickliffe, M. E., Lawler, J. E., Whaling, W., and Brault, J. W. (1991) *J. Opt. Soc. Am. B* **8**, 1165.
Fe I Johanson S., Nave G., Geller M. *et al.* (1994) *Astrophys. J* **429**, 419.
Fe I–Fe II Sigut, T. A. A. and Landstreet, J. D. (1990) *Mon. Not. R. Astr. Soc.* **247**, 611.
Fe I–Fe IV Sawey, P. M. J. and Berrington, K. A. (1992) *J. Phys. B* **25**, 1451.
Fe II Fawcett, B. C. (1987) *At. Dat. Nucl. Data Tables* **37**, 333.
Fe II Pauls, U., Grevesse, N., and Huber, M. C. E. (1990) *Astron. Astrophys.* **231**, 536.
Fe II Heise, C. and Kock, M. (1990) *Astron. Astrophys.* **230**, 244.
Fe II Bergeson, S. D., Mullman, K. L., and Lawler J. E. (1994) *Astrophys. J.* **435**, L157.
Fe II Nahar, S. N. (1995) *Astron. Astrophys.* **293**, 967.
Fe VII Saraph, H. E. (1991) *J. Phys. (Paris) Colloq.* **1**, 157.
Fe IX Fawcett, B. C. and Mason, H. (1991) *At. Dat. Nucl. Data Tables* **47**, 17.
Fe XVII Hummer, D. G., Berrington, K. A., Eissner, W., Pradhan, A. K., Saraph, H. E., and Tully, J. A. (1993) *Astron. Astrophys.* **279**, 298.
Ni seq (Z= **29, 42**) Loginov, A. V. (1993) *Phys. Scr.* **47**, 38.
Lanthanide atoms and first ions Blagoev K. A., Komarovskii V. A. (1994) *At. Dat. Nucl. Data Tables* **56**, 1.

A.3 Radiative and Dielectronic Recombination

Review Pindzola, M. S., Badnell, N. R., and Griffin, D. C. (1990) *AIP Conf.Proc.* **215**, 659.
Scaling McLaughlin, D. J. and Hahn, Y. (1991) *Phys. Rev. A* **43**, 1313.
H seq Andersen, L. H. (1994) *Comments At. Mol. Phys.* **27**, 25.
H seq with dust Hummer, D. G. and Storey, P. J. (1992) *Mon. Not. R. Astron. Soc.* **254**, 277.
He seq Andersen, L. H. (1994) *Comments At. Mol. Phys.* **27**, 25.
Li seq Dittner, P. F., Dutz, S., Miller, P. D., and Pepmiller, P. L. (1987) *Phys. Rev. A* **35**, 3668.
Li seq Andersen, L. H. (1994) *Comments At. Mol. Phys.* **27**, 25.

Be seq McLaughlin, D. J., LaGattuta, K. J., and Hahn, Y. (1987) *J. Quant. Spectrosc. Radiat. Transfer* **37**, 47.
Be seq Badnell, N. R. (1987) *J. Phys. B* **20**, 2081.
B seq Andersen, L. H. (1994) *Comments At. Mol. Phys.* **27**, 25.
B III Pradhan, A. K. (1984) *Phys. Rev. A* **30**, 2141.
B III Griffin, D. C., Pindzola, M. S., and Bottcher, C. (1985) *Phys. Rev. A* **31**, 568.
B III Geltman, S. (1985) *J. Phys. B* **18**, 1425.
C and O ions Griffin, D.C. (1989) *Phys. Scr.* **T28**, 17.
C and O ions Hahn, Y. (1989) *Phys. Scr.* **T28**, 25.
C and O ions Badnell, N. R. (1989) *Phys. Scr.* **T28**, 33.
C IV Pradhan, A. K. (1984) *Phys. Rev. A* **30**, 2141.
C IV Griffin, D. C., Pindzola, M. S., and Bottcher, C. (1985) *Phys. Rev. A* **31**, 568.
C IV Geltman, S. (1985) *J. Phys. B* **18**, 1425.
C V Hahn, Y. and Bellantone, R. (1989) *Phys. Rev. A* **40**, 6117.
C V Bellantone, R. and Hahn, Y. 1989) *Phys. Rev. A* **40**, 6913.
C V Bellantone, R. and Hahn, Y. 1990) *Phys. Scr.* **42**, 650.
C V Badnell, N. R., Pindzola, M. S., and Griffin, D. C. (1990) *Phys. Rev. A* **41**, 2422.
C V Andersen, L. H. (1994) *Comments At. Mol. Phys.* **27**, 25.
C VI Bellantone, R. and Hahn, Y. 1989) *Phys. Rev. A* **40**, 6913.
N III Nasser, I. and Hahn, Y. 1989) *Phys. Rev. A* **39**, 401.
N V Andersen, L. H., Pan, G.-Y., Schmidt, H. T., Pindzola, M. S., and Badnell, N. R. (1992) *Phys. Rev. A* **45**, 6332.
O I Chung Sunggi and Lin, C. C. (1991) *Phys. Rev. A* **43**, 3433.
O II Terao, M., Bell, K. L., Burke, P. G., and Hibbert, A. (1991) *J. Phys. B* **24**, L321.
O IV Nasser, I. and Hahn, Y. 1989) *Phys. Rev. A* **39**, 401.
O IV Janjusevic, M. and Hahn, Y. 1989) *Phys. Rev. A* **40**, 5641.
O VI Pradhan, A. K. (1984) *Phys. Rev. A* **30**, 2141.
O VI Griffin, D. C., Pindzola, M. S., and Bottcher, C. (1985) *Phys. Rev. A* **31**, 568.
O VI Roszman, L. J. (1989) *Phys. Scr.* **T28**, 36.
O VII Hahn, Y. and Bellantone, R. (1989) *Phys. Rev. A* **40**, 6117.
O VII Bellantone, R. and Hahn, Y. 1989) *Phys. Rev. A* **40**, 6913.
O VII Bellantone, R. and Hahn, Y. 1990) *Phys. Scr.* **42**, 650.
O VII Badnell, N. R., Pindzola, M. S., and Griffin, D. C. (1990) *Phys. Rev. A* **41**, 2422.
O VIII Bellantone, R. and Hahn, Y. 1989) *Phys. Rev. A* **40**, 6913.
F ions Ballantone, R., Hahn, Y., and McLaughlin, D.J. (1991) *Phys. Scr.* **43**, 379.
F V Nasser, I. and Hahn, Y. 1989) *Phys. Rev. A* **39**, 401.
F V Andersen, L. H. (1994) *Comments At. Mol. Phys.* **27**, 25.
F VII Andersen, L. H., Pan, G.-Y., Schmidt, H. T., Pindzola, M. S., and Badnell, N. R., 1992) *Phys. Rev. A* **45**, 6332.
Ne seq Dalhed, S., Nilsen, J., and Hagelstein, P. (1986) *Phys. Rev. A* **33**, 264.
Ne seq Chen, M. H. (1986) *Phys. Rev. A* **34**, 1073.
Mg seq Dube, M. P., Rasoanaivo, R., and Hahn, Y. (1985) *J. Quant. Spectrosc. Radiat. Transfer* **33**, 13.
Mg seq Dube, M. P. and LaGattuta, K. J. (1987) *J. Quant. Spectrosc. Radiat. Transfer* **38**, 311.
Mg II Pradhan, A. K. (1984) *Phys. Rev. A* **30**, 2141.
Mg II Geltman, S. (1985) *J. Phys. B* **18**, 1425.
Cl VII Pradhan, A. K. (1984) *Phys. Rev. A* **30**, 2141.
Ar ions Moussa, A. H. and Hahn, Y. (1990) *J. Quant. Spectrosc. Radiat. Transfer* **43**, 45.
Ca II Geltman, S. (1985) *J. Phys. B* **18**, 1425.

A.4 Radiative Recombination

H ions Pequignot, D., Petitjean, D., and Boisson, C. (1991) *Astron. Astrophys.* **251**, 680.
H II McLaughlin, D. J. and Hahn, Y. (1990) *Phys. Rev. A* **43**, 1313.

C I Escalante, V. and Victor, C.A. (1990) *Astrophys. J. Suppl. Ser.* **73**, 513.
C III–C V McLaughlin, D. J. and Hahn, Y. (1990) *Phys. Rev. A* **43**, 1313.
C VII Andersen, L. H., Bolko, J., and Kvistgaard, P. (1990) *Phys. Rev. Lett.* **64**, 729.
N II Escalante, V. and Victor, C. A. (1990) *Astrophys. J. Suppl. Ser.* **73**, 513.
O II Chung, S., Lin, C. C., and Lee, E. T. P. (1990) *Phys. Rev. A* **43**, 3433.
O VII McLaughlin, D.J. and Hahn, Y. (1990) *Phys. Rev. A* **43**, 1313.

A.5 Dielectronic Recombination

H seq Pindzola, M. S., Badnell, N. R., and Griffin, D. C. (1990) *Phys. Rev. A* **42**, 282.
He seq Andersen, L. H., Bolko, J., and Kvistgaard, P. (1990) *Phys. Rev. A* **41**, 1293.
He seq Romanik, C. J. (1988) *Astrophys. J.* **330**, 1022.
He seq Teng, H., Xu, Z., Sheng, B., and Zhang, W. (1994) *Phys. Scr.* **49**, 696.
He II Tanis, J. A., Bernstein, E. M., Chantrenne, S. *et al.* (1994) *Nucl. Instrum. Methods Phys. Res. B* **56–57**, 337.
Li seq Andersen, L. H., Bolko, J., and Kvistgaard, P. (1990) *Phys. Rev. A* **41**, 1293.
Li seq Chen, M. H. (1991) *Phys. Rev. A* **44**, 4215.
Li seq Romanik, C. J. (1988) *Astrophys. J.* **330**, 1022.
Li seq Teng, H., Sheng, B., Zhang, W., and Xu, Z. (1994) *Phys. Scr.* **49**, 463.
Be seq Badnell, N. R., Pindzola, M. S., Andersen, L. H., Bolko, J., and Schmidt, H. T. (1991) *J. Phys. B* **24**, 4441.
Be seq Romanik, C. J. (1988) *Astrophys. J.* **330**, 1022.
B seq Badnell, N. R., Pindzola, M. S., Andersen, L. H., Bolko, J., and Schmidt, H. T. (1991) *J. Phys. B* **24**, 4441.
O II Terao, M., Bell, K. L., Burke, P. G., and Hibbert, A. (1991) *J. Phys. B* **24**, L327.
O VII Badnell, N. R., Pindzola, M. S., and Griffin, D. C. (1990) *Phys. Rev. A* **41**, 2422.
Ne seq Teng, H., Sheng, B., Zhang, W., and Xu, Z. (1994) *Phys. Scr.* **49**, 468.
Ne Seq Romanik, C. J. (1988) *Astrophys. J.* **330**, 1022.
Ne ions Nussbaumer, H. and Storey, P. J. (1987) *Astron. Astrophys. Suppl. Ser.* **69**, 123.
Mg ions Nussbaumer, H. and Storey, P. J. (1986) *Astron. Astrophys. Suppl. Ser.* **64**, 545.
Al ions Nussbaumer, H. and Storey, P. J. (1986) *Astron. Astrophys. Suppl. Ser.* **64**, 545.
Si ions Nussbaumer, H. and Storey, P. J. (1986) *Astron. Astrophys. Suppl. Ser.* **64**, 545.
Fe seq Teng, H., Xu, Z., Zhang, W., and Sheng, B. (1994) *Phys. Scr.* **50**, 55.

A.6 Photoionization

Bibliography Le Dourneuf, M. (1991) In ZMLD, 227.
Critical evaluation Verner, D. A. and Yakovlev, D. G. (1995) *Astron. Astrophys. Suppl. Ser.* **109**, 125.
H^- Quick, Jr, C. R., Donahue, J. B., Cohen, S. *et al.* (1991) *Nucl. Instrum. Methods Phys. Res. B* **56–57**, 205.
H Norwood, K., Ng, C. Y., and Vary, J. P. (1990) *J. Chem. Phys.* **93**, 1480.
H Karule, E. (1990) *J. Opt. Soc. Am. B* **7**, 631.
H Shafer, N. and Bersohn, R. (1991) *Phys. Rev. A* **44**, 7855.
H ions Storey, P. J. and Hummer, D. G. (1991) *Comput. Phys. Commun.* **66**, 129.
Heavy systems Kelly, H. P. (1990) *AIP Conf. Proc.* **215**, 292.
Positive ions Manson, S. T. (1990) *AIP Conf. Proc.* **215**, 189.
Li I Hollauer, E. and Nascimento, M. A. C. (1990) *Phys. Rev. A* **42**, 6608.
Li II Hollauer, E. and Nascimento, M. A. C. (1990) *Phys. Rev. A* **42**, 6608.
H Shafer, N. and Bersohn, R. (1990) *Phys. Rev. A* **42**, 1313.
He–Fe Band, I. M., Trzhaskovskaya, M. B., Verner, D. A., and Yakovlev, D. G. (1990) *Astron. Astrophys.* **237**, 267.
He–Zn Verner, D. A., Yakovlev, D. G., Band, I. M., and Trzhaskovskaya, M. B. (1993) *At. Dat. Nucl. Data Tables* **55**, 233.

He Rahal, H., Gombert, M. M., and Valance, A. (1993) *Phys. Lett. A* **176**, 443.
He Andersson, L. R. and Burgdorfer, J. (1993) *Phys. Rev. Lett.* **71**, 50.
He Decleva, P., Lisini, A., and Venuti, M. (1994) *J. Phys. B* **27**, 4867.
He Samson, J. A. E., He, Z. X., Yin, L., and Haddad, G. N. (1994) *J. Phys. B* **27**, 887.
He Hino, K.-I., Bergstrom, Jr, P. M., and Macek, J.H. (1994) *Phys. Rev. Lett.* **72**, 1620.
C seq Luo, D. and Pradhan, A. K. (1989) *J. Phys. B* **22**, 3377.
C seq Nahar, S. N. and Pradhan, A. K. (1991) *Phys. Rev. A* **44**, 2935.
C I Escalante V. and Victor G. A. (1992 *At. Dat. Nucl. Data Tables* **51**, 1.
N I Samson, J. A. R. and Angel, G. C. (1990) *Phys. Rev. A* **42**, 1307.
N I Bell, K. L. and Berrington, K. A. (1991) *J. Phys. B* **24**, 933.
N I Bell, K. L., Berrington, K. A., and Ramsbottom, C. A. (1991) *J. Phys. B* **24**, 1209.
N I Bell, K. L. and Berrington, K. A. (1991) *J. Phys. B* **24**, 933.
N Andersen, J. O. and Veseth, L. (1994) *Phys. Scr.* **50**, 13.
N II Escalante, V. and Victor, G. A. (1992 *At. Dat. Nucl. Data Tables* **51**, 1.
O I Bell, K. L., Berrington, K. A., Burke, P. G., Hibbert, A., and Kingston, A. E. (1990, *J. Phys. B* **23**, 2259.
O I Butler, K. and Zeippen, C. J. (1990) *Astron. Astrophys.* **234**, 569.
Na Msezane, A. Z., Armstrong–Menzah, W., and Niles, J. (1990) *Phys. Rev. A* **42**, 1286.
Na Liu, J. C. and Liu, Z. W. (1994) *J. Phys. B* **27**, 4531.
Na D'yachkov, L. G. and Pankratov, P. M. (1994) *J. Phys. B* **27**, 461.
Mg II Ivanov, V. K., West, J. B., Gribakin, G. F., and Gribakina, A. A. (1994) *Z. Phys. D* **29**, 109.
Al VII Baliyan, K. S. and Kingston, A. E. (1991) *J. Phys. B* **24**, 4743.
S II–S VI Badnell, N. R. (1991) *Astrophys. J.* **379**, 356.
S VII Mohan, M., Kumar, A., and Baliyan, K. S. (1993) *Phys. Scr.* **47**, 674.
Ar Cvejanovic, S., Bagley, G. W., and Reddish, T. J. (1994) *J. Phys. B* **27**, 5661.
Ar, Kr Sukhorukov, V. L., Lagutin, B. M., Ktorov, I. D. *et al.* (1994) *J. Electron. Spectrosc. Relat. Phenom.* **68**, 255.
K Kupliauskiene, A. (1994) *J. Phys. B* **27**, 5647.
Ca II Miecznik, G., Berrington, K. A., Burke, P. G., and Hibbert, A. (1990) *J. Phys. B* **23**, 3305.
Fe II Nahar, S. N. and Pradhan, A. K. (1994) *J. Phys. B* **27**, 429.
Kr Ehresmann, B. M., Vollweiler, F., Schmoranzer, H. *et al.* (1994) *J. Phys. B* **27**, 1489.

A.7 Collisional Ionization

Critical evaluation Itikawa, Y. (1992) *At. Dat. Nucl. Data Tables* **49**, 209.
Critical evaluation Bell, K. L., Gilbody, H. B., Hughes, J. G., Kingston, A. E., and Smith, F. J. (1983) *J. Phys. Chem. Ref. Data* **12**, 891.
Critical evaluation Lennon, M. A., Bell, K. L., Gilbody, H. B., Hughes, J. G., Kingston, A. E., Murray, M. J., and Smith, F. J. (1986) UKAEA Report CLM-R, 270.
Semi-empir. formulas Dertsch, H., Margreiter D., and Mark, T. D. (1994) *Z. Phys. D* **29**, 31.
General Arnaud, M. and Rothenflug, R. (1990) *Astron. Astrophys. Suppl. Ser.* **60**, 425.
General Freund, R. S., Wetzel, R. C., Shul, R. J., and Hayes, T. R. (1990) *Phys. Rev. A* **41**, 3575.
Excited states Golden, L. B. and Sampson, D. H. (1980) *J. Phys. B* **13**, 2645.
Neutral atoms Padma, R. and Deshmukh, P. C. (1994) *J. Phys. B* **27**, 943.
H seq Muller, A. 1991) *Comments At. Mol. Phys.* **27**, 1.
H–He Mayol, R. and Salvat, F. (1990) *J. Phys. B* **23**, 217.
H Lebedev, V. S. (1991) *J. Phys. B* **24** (1977.
H Scholz, T. T. and Walters, H. R. J. (1991) *Astrophys. J.* **380**, 302.
H Clark, R. E. H., Abdallah, Jr, J., and Mann, J. B. (1991) *Astrophys. J.* **381**, 597.
H Jones, S., Madison, D. H., and Srvastava, M. K. (1991) *J. Phys. B* **24**, 1899.
H Bray L. and Stelbovicz, A. T. (1993) *Phys. Rev. Lett.* **70**, 746.
He seq Muller, A. 1991) *Comments At. Mol. Phys.* **27**, 1.
He Pan, C. and Kelly, H. P. (1990) *Phys. Rev. A* **41**, 3624.

He Jones, S., Madison, D. H., and Srvastava, M. K. (1991) *J. Phys. B* **24**, 1899.
He I Raeker, A., Burtschat, K., and Reid, R. H. G. (1994) *J. Phys. B* **27**, 3129.
C VI Tayal, S. S. and Henry, R. J. W. (1990) *Phys. Rev. A* **42**, 1831.
N V–Ne VIII Defrance, P., Chantrenne, S., Rachafi, S. *et al.* (1990) *J. Phys. B* **23**, 2333.
N V Muller, A. (1991) *Comments At. Mol. Phys.* **27**, 1.
F II, Ne II, Cl II, Ar II Yamada, I., Danjo, A., Hirayama, T. *et al.* (1989) *J. Phys. Soc. Jpn.* **58**, 3151.
Na Bray I. (1994) *Phys. Rev. Lett.* **73**, 1088.
Al II Hayton, S. J. T. and Peart, B. (1994) *J. Phys. B* **27**, 5331.
Ar VIII Rachafi, S., Belic, D. S., Duponchelle, M. *et al.* (1991) *J. Phys. B* **24**, 1037.
Ca II Badnell, N. R., Griffin, D. C., and Pindzola, M. S. (1991) *J. Phys. B* **24**, L275.
Fe Baluja, K. L. and Gupta, A. (1994) *Z. Phys. D* **31**, 5.

A.8 Collisional Excitation

Bibliography McDaniel E. W., Flannery M. R., Thomas E. W., Manson S. T. (1985) *At. Dat. Nucl. Data Tables* **49**, 1.
Theory Eichler, J. (1990) *Phys. Rep.* **193**, 165.
Review Henry, R. J. W. (1993) *Rep. Prog. Phys.* **56**, 3271.
Critical evaluation Itikawa, Y. (1992) *At. Dat. Nucl. Data Tables* **49**, 209.
Critical evaluation Pradhan, A. K. and Gallagher, J. W. (1992) *At. Dat. Nucl. Data Tables* **52**, 227.
Critical evaluation Gallagher, J. W. and Pradhan, A. K. (1985) *JILA Rep. No. 30.*
Critical evaluation Mendoza, C. (1983) In *IAU Symp. No. 103*, Flower, D. R. (ed.), p. 143.
General Percival, I. C. and Richards, D. (1977) *J. Phys. B* **8**, 1497.
General van Regemorter H, Sampson, D. H. and Zhang, H. L. (1992) *Phys. Rev. A* **45**, 1556.
Semiempir. formulae (H I, O VII, Ne I, Ca II) Shevelko, V. P. (1991) Phys. Scr. **43**, 266.
H seq Clark, R. E. H. (1990) *Astrophys. J.* **354**, 382.
H seq Collaway, J. (1994) *At. Dat. Nucl. Data Tables* **57**, 9.
H I King, G. C., Trajmar, S., and McConkey, J. W. (1989) *Comments At. Mol. Phys.* **23**, 229.
H I Scholz, T. T., Walters, H. R. J., and Burke, P. G. (1990) *J. Phys. B* **23**, L467.
H I Chang, E. S., Avrett, E. H., and Loeser, R. (1991) *Astron. Astrophys.* **247**, 580.
H I Aggarwal, K. M., Berrington, K. A., Burke, P. G., Kingston, A. E., and Pathak, A. (1991) *J. Phys. B* **24**, 1411.
H I Aggarwal, K. M., Berrington, K. A., Burke, P. G., Kingston, A. E., and Pathak, A. (1991) *J. Phys. B* **24**, 1385.
H I Fon, W. C., Aggarwal, K. M., and Ratnavelu, K. (1992) *J. Phys. B* **25**, 2625.
H I Odgers, B. R., Scott, M. P., and Burke, P. G. (1994) *J. Phys. B* **27**, 2577.
He seq Duban, J. (1994) *At. Dat. Nucl. Data Tables* **57**, 21.
He I Sawey, P. M. J., Berrington, K. A., Burke, P. G., and Kingston, A. E. (1990) *J. Phys. B* **23**, 4321.
He I Scholz, T. T., Walters, H. R. J., Burke, P. G., and Scott, M. P. (1990) *Mon. Not. R. Astr. Soc.* **242**, 692.
He I Nakazaki, S., Berrington, K. A., Sakimoto, K., and Itikawa, Y. (1991) *J. Phys. B* **24**, L27.
He I McCarthy, I. E., Ratnavelu, K., and Zhou, Y. (1991) *J. Phys. B* **24**, 4431.
He I Fon, W. C., Berrington, K. A., and Kingston, A. E. (1991) *J. Phys. B* **24**, 2161.
He I Cartwright, D. C., Csanak, G., Trajmar, S., and Register, D. F. (1992) *Phys. Rev. A* **45**, 1602.
He I Gerasimov, G. N. (1992) *Opt. Spectr.* **72**, 735.
He I Matyureva, A. A. and Smirnov, V. V. (1993) *Opt. Spectr.* **74**, 2.
He I Sawey, P. M. J. and Berrington, K. A. (1993) *At. Data Nucl. Data Tables* **55**, 81.
He I Bruch, R. *et al.* (1993) *Nucl. Instrum. Methods Phys. Res. B* **79**, 120.
He I Raeker, A., Burtschat, K., and Reid, R. H. G. (1994) *J. Phys. B* **27**, 3129.
He I Franca, A. and da Paixao, F. J (1994) *J. Phys. B* **27**, 1577.
He II Wen–Jia, Q., Yun–Bo, D., Rong–Long, W., and Narumi, H. (1991) *J. Phys. B* **24**, L443.

He II Aggarwal, K. M., Berrington, K. A., Kingston, A. E., Pathak, A. (1991) *J. Phys. B* **24**, 1757.
He II Aggarwal, K. M., Callaway, J., Kingston, A. E., and Unnikrishnan, K. (1992) *Astrophys. J. Suppl. Ser* **80**, 473.
Li seq Zhang, H. L., Sampson, D. H., and Fontes, C. J. (1990) *At. Dat. Nucl. Data Tables* **44**, 31.
Li seq ($z \leq$ **28**) McWhirter, R. W. P. (1994) *At. Dat. Nucl. Data Tables* **57**, 39.
Li I Tayal, S. S. and Tripath, A. N. (1984) *Can. J. Phys.* **62**, 198.
rf**Li I** Gien, T. T. (1987) *J. Phys. B* **20**, 1337.
Li II Berrington, K. A. and Nakazaki, S. (1991) *J. Phys. B* **24**, 1411.
Be seq (Be I–Ni XXV) Berrington, K. A. (1994) *At. Dat. Nucl. Data Tables* **57**, 71 .
Be I Fon, W. C., Berrington, K. A., Burke, P. G., Burke, V. M., and Hibbert, A. (1992) *J. Phys. B* **25**, 507.
Be II Lengyel, V. I., Navrotsky, V. T., and Sabad, E. P. (1990) *J. Phys. B* **23**, 2847.
B seq (z= **5–28) Sampson, D. H., Zhang, H. L., and Fontes, C. J. (1994)** *At. Dat. Nucl.Data Tables* **57, 97.**
B seq (Ne VI–Fe XXII) Zhang, H. L., Graziani, M., and Pradhan, A. K. (1994) *Astron. Astrophys.* **283**, 319.
B I Nakazaki, S. and Berrington, K. A. (1991) *J. Phys. B* **24**, 4263.
C seq (O III–Fe XXI) Monsignori Fossi, B. L. and Landini, M. (1994) *At. Dat. Nucl. Data Tables* **57**, 125.
C I Johnson, C. T., Burke, P. G., and Kingston, A. E. (1987) *J. Phys. B* **20**, 2553.
C I Doering, J. P. and Dagdigian, P. J. (1989) *Chem. Phys. Lett.* **154**, 234.
C II Luo, D. and Pradhan, A. K. (1990) *Phys. Rev. A* **41**, 165.
C II Blum, R. D. and Pradhan, A. K. (1991) *Phys. Rev. A* **44**, 6123.
C II Blum, R. D. and Pradhan, A. K. (1992) *Astrophys. J. Suppl. Ser.* **80**, 425.
C IV Petrini, D. and Tully, J. A. (1991) *Astron. Astrophys.* **241**, 327.
C IV Burke, V. M. (1992) *J. Phys. B* **25**, 4917.
C VI Aggarwal, K. M. and Kingston, A. E. (1991) *J. Phys. B* **24**, 4583.
N seq (N I–Fe XX) Kato, T. (1994) *At. Dat. Nucl. Data Tables* **57**, 181.
N I Doering, J. P. and Goembel, L. (1991) *J. Geophys. Res.* **96**, 16021.
N II Tripp, T. M., Shemansky, D. E., James, G. K., and Ajello, J. M. (1991) *Astrophys. J.* **368**, 641.
N III Luo, D. and Pradhan, A. K. (1990) *Phys. Rev. A* **41**, 165.
N III Blum, R. D. and Pradhan, A. K. (1992) *Astrophys. J. Supp. Ser.* **80**, 425.
O I–Review Itikawa, Y. and Ichimura, A. (1990) *J. Phys. Chem. Ref. Data* **19**, 637.
O seq Butler, K. and Zeipen, C. J. (1994) *Astron. Astrophys. Suppl. Ser.* **108**, 1.
O Seq (F II–Kr XXIX) Lang, J. and Summers, H. P. (1994) *At. Dat. Nucl. Data Tables* **57**, 215 .
O I Jain, R., Baluja, K. L., Setty, C. S. G. K. (1983) *Indian J. Radio and Space Phys.* **12**, 177.
O I Zipf, E. C. and Erdman, P. W. (1985) *J. Geophys. Res.* **90**, 11087.
O I Gulcicek, E. E. and Doering, J. P. (1987) *J. Geophys. Res.* **92**, 3445.
O I Vaughn, S. O. and Doering, J. P. (1988) *J. Geophys. Res.* **93**, 289.
O I Berrington, K. A. (1988) *J. Phys. B* **21**, 1083.
O I Gulcicek, E. E. and Doering, J. P. (1988) *J. Geophys. Res.* **93**, 5879.
O I Gulcicek, E. E., Doering, J. P., and Vaughn, S. O. (1988) *J. Geophys. Res.* **93**, 5885.
O I Germany, G. A., Anderson, R. J., and Salamo, G. J. (1988) *J. Chem. Phys.* **88**, 1999.
O I Tayal, S. S. and Henry, R. J. W. (1988) *Phys. Rev. A* **38**, 5945.
O I Williams, J. F. and Allen, L. J. (1989) *J. Phys. B* **22**, 3529.
O I Tayal, S. S. and Henry, R. J. W. (1989) *Phys. Rev. A* **39**, 4531.
O I Doering, J. P. and Gulcicek, E. E. (1989) *J. Geophys. Res.* **94**, 2733.
O I Laher, R. R. and Gilmore, F. R. (1990) *J. Phys. Chem. Ref. Data* **19**, 227.
O I Mantas, G. P. and Carlson, H. C. (1991) *Geophys. Res. Lett.* **18**, 159.
O I Tayal, S. S. (1992) *J. Phys. B* **25**, 2639.
O II Zuo, M., Smith, S. J., Chutjian, A. *et al.* (1995) *Astrophys. J.* **440**, 421.
O III Aggarwal, K. M. and Hibbert, A. (1991) *J. Phys. B* **24**, 3445.

O IV Luo, D. and Pradhan, A. K. (1990) *Phys. Rev. A* **41**, 165.
O IV Blum, R. D. and Pradhan, A. K. (1992) *Astrophys. J. Suppl. Ser.* **80**, 425.
O V Kato, T., Lang, J., and Berrington, K. A. (1990) *At. Dat. Nucl. Data Tables* **44**, 133.
O VI Petrini, D. and Tully, J. A.. (1991) *Astron. Astrophys.* **241**, 327.
O VIII Cornille, M., Dubau, J., Faucher, P. *et al.* (1994) *Astron. Astrophys. Suppl. Ser.* **105**, 77.
F seq Saraph, H. E. and Tully, J. A. (1994) *Astron. Astrophys. Suppl. Ser.* **107**, 29.
F seq (Ne II–Ni XX) Bhatia, A. K. (1994) *At. Dat. Nucl. Data Tables* **57**, 253.
F IV Conlon, E. S., Keenan, F. P., and Aggarwal, K. M. (1992) *Phys. Scr.* **45**, 309.
Ne seq Chen, M. H. and Reed, K. J. (1989) *Phys. Rev. A* **40**, 2292.
Ne I Taylor, K. T., Clark, C. W., and Fon, W.C. (1985) *J. Phys. B* **18**, 2967.
Ne I Pilsof, N. and Blagoev, A. (1988) *J. Phys. B* **21**, 639.
Ne I Bubelev, V. E. and Grum-Grzhimailo, A. N. (1990) *Opt. Spectrosc.* **69**, 178.
Ne V Keenan, F. P., Burke, V. M., and Aggarwal, K. M. (1991) *Astrophys. J.* **371**, 636.
Ne V Lennon, D. J. and Burke, V. M. (1991) *Mon. Not. R. Astron. Soc.* **251**, 628.
Ne VI Hayes, M. A. (1992) *J. Phys. B* **25**, 2649.
Na I Ganas, P. S. (1985) *J. Appl. Phys.* **57**, 154.
Na I Msezane, A. Z. (1988) *Phys. Rev. A* **37**, 1787.
Na I Msezane, A. Z., Handy, C. R., Mantica, G., and Lee, J. (1988) *Phys. Rev. A* **38**, 1604.
Na I Bielschowsky, C. E., Lucas, C. A., de Souza, G. G. B., and Noqueria, J. C. (1991) *Phys. Rev. A* **43**, 5975.
Na I Fleck, L., Grosser, J., Schnecke, A., Steen, W., Voigt, H. (1991) *J. Phys. B* **24**, 4017.
Na I Stacewicz, T. (1993) *Z. Phys. D* **27**, 149.
Na VI Conlon, E. S., Keenan, F. P., and Aggarwal, K. M. (1992) *Phys. Scr.* **45**, 309.
Mg I Brunger, M. J., Riley, J. L., Scholten, R. E., and Teubner, P. J. O. (1988) *J. Phys. B* **21**, 1639.
Mg I Brunger, M. J., Riley, J. L., Scholten, R. E., and Teubner, P. J. O. (1989) *J. Phys. B* **22**, 1431.
Mg I McCarthy, I. E., Ratnavelu, K., and Zhou, Y. (1989) *J. Phys. B* **22**, 2597.
Mg I Meneses, G. D., Pagan, C. B., and Machado, L. E. (1990) *Phys. Rev. A* **41**, 4759.
Mg I Meneses, G. D., Pagan, C. B., and Machado, L. E. (1990) *Phys. Rev. A* **41**, 4740.
Mg I Clark, R. E. H., Csanak, G., and Abdallah, Jr, J. (1991) *Phys. Rev. A* **44**, 2874.
Mg I Melnikov, V. V., Petrov, E. V., and Shapockin, M. B. (1992) *Opt. Spectrosc.* **72**, 731.
Mg I Houghton, R. K., Brunger, M. J., Shen, G., and Teubner, P. J. O. (1994) *J. Phys. B* **27**, 3573.
Mg I Shafran'osh, I. I., Shegurskaya, T. A., and Aleksakhin I. S. (1994) *Opt. Spectrosc.* **76**, 20.
Mg II Lengyel, V. I., Navrotsky, V. T., and Sabad, E. P. (1990) *J. Phys. B* **23**, 2847.
Mg IV Mohan, M. and Baluja, K. L. (1989) *Z. Phys. D: At. Mol. Clusters* **14**, 135.
Mg VII Burgess, A., Mason, H. E., and Tully, J. A. (1991) *Astrophys. J.* **376**, 803.
Al II Aggarwal, K. M. and Keenan, F. P. (1994) *J. Phys. B* **27**, 2309, 5327.
Al VIII Conlon, E. S., Keenan, F. P., and Aggarwal, K. M. (1992) *Phys. Scr.* **45**, 309.
Si seq Galavis, M. E., Mendoza, C., and Zeippen, C. J. (1995) *Astron. Astrophys. Suppl. Ser.* **111**, 347.
Si II Dufton, P. and Kingston, A. E. (1990) *Mon. Not. R. Astron. Soc.*, **248**, 827.
Si II–Si IV, S II–S IV Duffon, P. L. and Kingston, A. F. (1994) *At. Dat. Nucl. Data Tables* **57**, 273.
Si III Dufton, P. and Kingston, A. E. (1989) *Mon. Not. R. Astron. Soc.* **241**, 209.
Si IV Whalin, E. K., Thompson, J. S., Dunn, G. H., Phaneuf, R. A., Gregory, D. C., and Smith, A. C. H. (1991) *Phys. Rev. Lett.* **66**, 157.
Si VI Mohan, M. and Le Dourneuf, M. (1990) *Phys. Rev. A.* **41**, 2862.
Si VI Mohan, M. and Le Dourneuf, M. (1990) *Astron. Astrophys.* **227**, 285.
S seq Galavis, M. E., Mendoza, C., and Zeippen, C. J. (1995) *Astron. Astrophys. Suppl. Ser.* **111**, 347.
S I Ganas, P. S. (1990) *J. Chem. Phys.* **92**, 2374.
S II Ho, Y. K. and Henry, R. J. W. (1990) *Astrophys. J.* **351**, 701 .
S VII Mohan, M., Hibbert, A., Berrington, K. A., and Burke, P. G. (1990) *J. Phys. B* **23**, 989.

Cl I Ganas, P. S. (1988) *J. Appl. Phys.* **63**, 277.
Ar I Subramanian, K. P. and Kumar, V. (1987) *J. Phys. B* **20**, 5505.
Ar I Bielschowsky, C. E., de Souza, G. G. B., Lucas, C. A., Boechat–Roberty, H. M. (1988) *Phys. Rev. A.* **38**, 3405.
Ar I Bubelev, V. E. and Grum–Grzhimailo, A. N. (1990) *Opt. Spectrosc.* **69**, 178.
Ar I Bubelev, V. E. and Grum–Grzhimailo, A. N. (1991) *J. Phys. B* **24**, 2183.
Ar I Mityureva, A. A. and Smirnov, V. V. (1994) *J. Phys. B* **27**, 1869.
Ar II–Ni XII Pelan, J. and Berrington, K. A. (1995) *Astron. Astrophys. Suppl. Ser.* **110**, 209.
Ar III Johnson, C. T. and Kingston, A. E. (1990) *J. Phys. B* **23**, 3393.
Ca II Zatsarinny, O. I., Lendel, V. I., and Masalovich, E. A. (1989) *Opt. Spectrosc.* **67**, 10.
Ti seq Berrington, K. A. (1995) *Astron. Astrophys. Suppl. Ser.* **109**, 193.
Mn III–Ni VI Berrington, K. A. and Pelan, J. C. (1995) *Astron. Astrophys. Suppl. Ser.* **114**, 367.
Fe Baluja, K. L. and Gupta, A. (1994) *Z. Phys. D* **31**, 5.
Fe I–Fe VIII Pradhan, A. K. (1994) *At. Dat. Nucl. Data Tables* **57**, 297 .
Fe II Zhang, H. L. and Pradhan, A. K. (1995) *Astron. Astrophys.* **293**, 953.
Fe III Berrington, K. A., Zeippen, C. J., Le Dourneuf, M., Eissner, W. B., and Burke, P. G. (1990) *J. Phys. B* **24**, 3467.
Fe III Burke, P. G.,Burke, V. M., and Dunseath, K. M. (1994) *J. Phys. B* **27**, 5341.
Fe VII Keenan, F. P. and Norrington, P. H. (1991) *Astrophys. J.* **368**, 486.
Fe IX–Fe XIV Mason, H. E. (1994) *At. Dat. Nucl. Data Tables* **57**, 305.
Fe XV–Fe XVIII Badnell, N. R. and Moaes, P. L. (1994) *At. Dat. Nucl. Data Tables* **57**, 329.
Kr VII Banister, M. E., Guo, X., Q., Kojima, T. M., and Dunn, G. H. (1994) *Phys. Rev. Lett.* **72**, 3336.
Ba Petrov, E. V. and Shapockin, M. B. (1993) *Phys. Scr.* **48**, 440.

A.9 Heavy Particle Collisions

p + H I Rodriguez, V. D. and Miraglia, J. E. (1990) *J. Phys. B* **23**, 3629.
p + H I Chen, Z., Esry, B. D., Lin, C. D., and Piasentini, R. D. (1994) *J. Phys. B* **27**, 2511.
p + He I Amusia, M. Y., Rauscher, E. A., Bruch, R., and Fulling, S. (1993) *Nucl. Instrum. Methods Phys. Res. B* **79**, 117.
p + He I Bruch, R., Rauscher, E. A., Fulling, S. *et al.* (1993) *Nucl. Instrum. Methods Phys. Res. B* **79**, 20.
p + C I Roueff, E. and Le Bourlot, J. (1990) *Astron. Astrophys.* **236**, 515.
C + He Lavendy, H., Robbe, J. M., and Roueff, E. (1991) *Astron. Astrophys.* **241**, 317.
H + Si II Roueff, E. (1990) *Astron. Astrophys.* **234**, 567.

A.10 Charge Exchange

Review Dalgarno, A. (1985) *Nucl. Instrum. Methods Phys. Res. B* **B9**, 662.
General Butler, S. E. and Dalgarno, A. (1980) *Astrophys. J.* **241**, 838.
Program LZRATE Bienstock, S. (1983) *Comput. Phys. Commun.* **29**, 333.
H I Barrachina, R. O. (1990) *J. Phys. B* **23**, 2321.
H I Jouin, H. and Harel, C. (1991) *J. Phys. B* **24**, 3219.
H I Hoekstra, H. R., de Heer, F. J., and Morgenstern, R. (1991) *J. Phys. B* **24**, 4025.
H I Jackson, D., Slim, H. A., Bransden, B. H., and Flower, D. R. (1992) *J. Phys. B* **25**, L127.
H I Errea, L. F., López, A., Méndez, L., and Riera, S. (1992) *J. Phys. B* **25**, 811.
He I Valiron, P., Gayet, R., McCarroll, R., Masnou–Seeuws, F., and Philippe, M. (1979) *J. Phys. B* **12**, 53.
He I Kovach, A. P., Lazur, V. Y., and Mashika, Y. Y. (1988) *Sov. Phys.-Tech. Phys.* **33**, 1159.
He I Barrachina, R. O. (1990) *J. Phys. B* **23**, 2321.
He I Slim, H. A., Heck, E. L., Bransden, B. H., and Flower, D. R. (1991) *J. Phys. B* **24**, 1683.
He II Errea, L. F., Méndez, L., and Riera, A. (1991) *Phys. Rev. A* **43**, 3578.

He II Jackson, D., Slim, H. A., Bransden, B. H., and Flower, D. R. (1992) *J. Phys. B* **25**, L127.
He III Jouin, H. and Harel, C. (1991 *J. Phys. B* **24**, 3219.
C II Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
C III Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
C IV Watson, W. D. and Christensen, R. B. (1979) *Astrophys. J.* **231**, 627.
C IV Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
C IV Gargaud, M., Hanssen, J., McCarroll, R., and Valiron, P. (1981) *J. Phys. B* **14**, 2259.
C IV Opradolce, L., Benmeuraiem, L., McCarroll, R., and Piacentini, R. D. (1988) *J. Phys. B* **21**, 503.
C IV Errea, L. F., Herrero, B., Méndez, L., Mó. O. and Riera, S. (1991) *J. Phys. B* **24**, 4049.
C IV Errea, L. F., Herrero, B., Méndez, L., and Riera, A. (1991) *J. Phys. B* **24**, 4061.
C V Gargaud, M. and McCarroll, R. (1985) *J. Phys. B* **18**, 463.
C V Gargaud, M., McCarroll, R. and Valiron, P. (1987) *J. Phys. B* **20**, 1555.
C V Barat, M., Roncin, P., Guillemot, L., Gaboriaud, M. N., and Laurent, H. (1990) *J. Phys. B* **23**, 2811.
C VI Suraud, M. G., Hoekstra, R., de Heer, F. J., Bonnet, J. J., and Morgenstern, R. (1991) *J. Phys. B* **24**, 2543.
C VII Harel, C., Jouin, H., and Pons, B. (1991) *J. Phys. B* **24**, L425.
C VII Janev, R. K., Phaneuf, R. A., Tawara, H., and Shirai, T. (1993) *At. Dat. Nucl. Data Tables* **55**, 201.
N III Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
N IV Watson, W. D. and Christensen, R. B. (1979) *Astrophys. J.* **231**, 627.
N IV McCarroll, R. and Valiron, P. (1979) *Astron. Astrophys.* **78**, 177 .
N IV Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
N IV Gargaud, M., Hanssen, J., McCarroll, R., and Valiron, P. (1981) *J. Phys. B* **14**, 2259.
N IV Gargaud, M. and McCarroll, R. (1985) *J. Phys. B* **18**, 463.
N VI Gargaud, M. and McCarroll, R. (1985) *J. Phys. B* **18**, 463.
N VII Suraud, M. G., Hoekstra, R., de Heer, F. J., Bonnet, J. J., and Morgenstern, R. (1991) *J. Phys. B* **24**, 2543.
O III Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
O III Gargaud, M., McCarroll, R., and Opradolce, L. (1989) *Astron. Astrophys.* **208**, 251.
O III Bacchus–Montabonel, M. C., Courbin, C., and McCarroll, R. (1991) *J. Phys. B* **24**, 4409.
O III Gargaud, M., Bacchus–Montabonel, M. C., and McCarroll, R. (1993) *J. Chem. Phys.* **99**, 4495.
O III Kwang, V. H. S. and Fang, Z. (1993) *Phys. Rev. Lett.* **71**, 4127.
O III Honvault, P., Bacchus–Montabonel, M. C., and McCarroll, R. (1994) *J. Phys. B* **27**, 3115.
O III Honvault, P., Gargaud, M., Bacchus–Montabonel, M. C., and McCarroll, R. (1995) *Astron. Astrophys.* **302**, 931.
O IV Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
O VI Andersson, L. R., Gargaud, M., and McCarroll, R. (1991) *J. Phys. B* **24**, 2073.
O VII Zhukov, S. P., Korukhov, V. V., Nikulin, N. G., Troshin, B. I., and Chernenko, A. A. (1988) *Sov. J. Quantum Electron* **18**, 399.
Ne III Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
Ne III Forster, H. C., Cooper, I. L., Dickinson, A. S., Flower, D. R., and Méndez, L. (1991) *J. Phys. B* **24**, 3433.
Ne IV Butler, S. E., Heil, T. G., and Dalgarno, A. (1980) *Astrophys. J.* **241**, 442.
Na I Mo, O. and Riera, A. (1990) *J. Phys. B* **23**, L373.
Na I Tiwari, Y. N. and Roy, D. N. (1990) *Indian J. Pure Appl. Phys.* **28**, 721.
Al III Gargaud, M. *et al.* (1990) *J. Phys. B* **23**, 505.
Si II Gargaud, M., McCarroll, R., and Valiron, P. (1982) *Astron. Astrophys.* **106**, 197.
Si III McCarroll, R. and Valiron, P. (1976) *Astron. Astrophys.* **53**, 83.
Si V Opradolce, L., McCarroll, R., and Valiron, P. (1985) *Astron. Astrophys.* **148**, 229.
Ar I Phelps, A. V. (1992) *J. Phys. Chem. Ref. Data* **21**, 883.
Ar VII Opradolce, L., Valiron, P., and McCarroll, R. (1983) *J. Phys. B* **16**, 2017.
Ar VII Andersson, L. R., Cederquist, H., Barany, A. *et al.* (1991) *Phys. Rev. A* **43**, 4075.

A.11 Line Broadening

Critical evaluation Konjević, N., Dimitrijević, M. S., and Wiese, W. L. (1984) *J. Phys. Chem. Ref. Data* **13**, 619.
Critical evaluation Konjević, N., Dimitrijević, M. S., and Wiese, W. L. (1984) *J. Phys. Chem. Ref. Data* **13**, 649.
Review Dimitrijević, M. S. and Sahal-Bréchot, S. (1991) In *J. de Phys.* Zeippen C. J. and Le Dourneuf M. (eds.) **1** (Coll. 1, Suppl. JP II, 3), 209.
General Seaton, M. J. (1987) *J. Phys. B* **20**, 6431.
General Seaton, M. J. (1988) *J. Phys. B* **21**, 3033.
General Dimitrijević, M. S. and Konjević, N. (1987) *Astron. Astrophys.* **172**, 345.
Simple formyla (collisions with HI) Irwin A. W. (1979) *Mon. Not. R. Astron. Soc.* **188**, 707.
Neutrals Seaton, M. J. (1989) *J. Phys. B* **22**, 3603.
Shifts Wiese, W. L. and Konjević, N. (1992) *J. Quant. Spectrosc. Radiat. Transfer* **47**, 185.
H Seaton, M. J. (1990) *J. Phys. B* **23**, 3255.
H I Unnikrishnan, K. and Callaway, J. (1991) *Phys. Rev. A* **43**, 3619.
H II Schöning, T. (1994) *J. Phys. B* **27**, 4501.
He I Dimitrijević, M. S. and Sahal-Bréchot, S. (1990) *Astron. Astrophys. Suppl. Ser.* **82**, 519.
He II Unnikrishnan, K., Callaway, J., and Oza, D. H. (1990) *Phys. Rev. A* **42**, 6602.
Li seq (C IV–O V) Glenzer, S. *et al.* (1994) *J. Phys. B* **27**, 5507.
Li I Dimitrijević, M. S. and Sahal-Bréchot, S. (1991) *J. Quant. Spectrosc. Radiat. Transfer* **46**, 41.
Be seq Dimitrijević, M. S. (1984) *Astron. Astrophys.* **131**, 327.
C IV Dimitrijević, M. S., Sahal -Bréchot, S., and Bommier, V. (1991) *Astron. Astrophys. Suppl. Ser.* **89**, 581.
C IV Schöning, T. (1993) *Astron. Astrophys.* **267**, 300.
C IV Schöning, T. (1992) *J. Phys. B* **25**.
C IV Dimitrijević, M. S. and Sahal-Bréchot, S. (1992) *Astron. Astrophys. Suppl. Ser.* **96**, 613.
C IV Burke, V. M. (1992) *J. Phys. B* **25**.
N II Djeniže, Srećković A., and Labat J. (1992) *Astron. Astrophys.* **253**, 632.
N V Dimitrijević, M. S. and Sahal-Bréchot, S. (1992) *Astron. Astrophys. Suppl. Ser.* **95**, 109.
N V Schöning, T. (1995) *Astron. Astrophys. Suppl. Ser.* **113**, 579.
OIV–OV Dimitrijević, M. S. and Sahal-Bréchot, S. (1995) *Astron. Astrophys. Suppl. Ser.* **109**, 551.
O VI Dimitrijević, M. S. and Sahal-Bréchot, S. (1992) *Astron. Astrophys. Suppl. Ser.* **93**, 359.
Ne VIII Dimitrijević, M. S. and Sahal-Bréchot, S. (1994) *Astron. Astrophys. Suppl. Ser.* **107**, 349.
Na I Dimitrijević, M. S. and Sahal-Bréchot, S. (1990) *J. Quant. Spectrosc. Radiat. Transfer* **44**, 421.
Na IX Dimitrijević, M. S. and Sahal-Bréchot, S. (1994) *Astron. Astrophys. Suppl. Ser.* **107**, 349.
Mg I Djeniže, S., Srećković, A., Platiša, M., Labat, J., Konjević, R., and Purić, J. (1990) *J. Quant. Spectrosc. Radiat. Transfer* **44**, 405.
Mg II Djeniže, S., Srećković, A., Platiša, M., Labat, J., Konjević, R., and Purić, J. (1990) *J. Quant. Spectrosc. Radiat. Transfer* **44**, 405.
SiII–III Dimitrijević, M. S. (1983) *Astron. Astrophys.* **127**, 568.
Si III Bakshi, V. (1990) *Aip Conf. Proc.* **216**, 71.
Si III Djeniže, S., Srećković, A., Labat, J., Purić, J., and Platiša, M. (1992) *J. Phys. B* **25**, 785.
Si IV Dimitrijević, M. S., Sahal-Bréchot, S., and Bommier, V. (1991) *Astron. Astrophys. Suppl. Ser.* **89**, 591.
Si IV Djeniže, S., Srećković, A., Labat, J., Purić, J., and Platiša, M. (1992) *J. Phys. B* **25**, 785.
Ca I Spielfiedel, A., Feautrier, N., Chambaud, G., and Lévy, B. (1991) *J. Phys. B* **24**, 4711.
Fe II Dimitrijević, M. S. (1995) *Astron. Astrophys. Suppl. Ser.* **111**, 565.
Ni II Dimitrijević, M. S. (1995) *Astron. Astrophys. Suppl. Ser.* **114**, 171.

A.12 Opacities and Atomic Data for Opacity Calculations

Workshop Lynas-Gray, A. E., Mendoza, C., and Zeippen, C. J. (eds.) (1992) *Rev. Mex. Astron. Astrofis.* **23**, special issue, 254 pp.
Tables Rogers, F. J. and Iglesias, C. A. (1992) *Astron. Astrophys. Suppl. Ser.* **79**, 507.
Summary Seaton, M. J. (1987) *J. Phys. B* **20**, 6363.
Programs Berrington, K. A. *et al.* (1987) *J. Phys. B* **20**, 6379.
Lines Seaton, M. J. (1987) *J. Phys. B* **20**, 6431.
Lines Seaton, M. J. (1988) *J. Phys. B* **21**, 3033.
Lines Seaton, M. J. (1989) *J. Phys. B* **22**, 3603.
Lines Burke, V. M. (1992) *J. Phys. B* **25**, 4917.
Rosseland opacities Alexander D. R. (1992) *Astroph. J.* **437**, 879.
H lines Seaton, M. J. (1990) *J. Phys. B* **23**, 3255.
He target Thornbury, J. F. and Hibbert, A. (1987) *J. Phys. B* **20**, 6447.
He II seq Fernley, J. A., Taylor, K. T., and Seaton, M. J. (1987) *J. Phys. B* **20**, 6457.
Li seq Peach, G., Saraph, H. E., and Seaton, M. J. (1988) *J. Phys. B* **21**, 3669.
Be seq Tully, J. A., Seaton, M. J., and Berrington, K. A. (1990) *J. Phys. B* **23**, 3811.
C seq Luo, D. and Pradhan, A. K. (1989) *J. Phys. B* **22**, 3377.
C II f-values Yu Yan, Taylor, K. T. and Seaton, M. J. (1987) *J. Phys. B* **20**, 6399.
C II photo Yu Yan and Seaton, M. J. (1987) *J. Phys. B* **20**, 6409.
O III Luo, D., Pradhan, A. K., Saraph, H. E., Storey, P. J., and Yu Yan, (1989) *J. Phys. B* **22**, 389.
Fe I–IV Sawey, P. M. J. and Berrington, K. A. (1992) *J. Phys. B* **25**, 1451.

Appendix B ATOMIC CATALOGUE AND DATA BASES

Many of the atomic data required can be extracted from data bases and catalogues of atomic data. The best known of these are reviewed in this appendix. Special attention is drawn to the AMDIS atomic data base and VALD atomic data base. Moreover, there are many collections of atomic data, not included in the regular journals. These include laboratory and agency reports, workshop proceedings, newsletters, etc. which can be referred to as miscellaneous atomic data sources. They are also refered to by Smith (1992) as a grey literature. Such sources are also shortly reviewed.

B.1 Catalogues of Atomic Data and Bibliographical Sources

For half a century, the main source for atomic data was the USA National Institute of Standards and Technology (NIST) formerly named the National Bureau of Standards (NBS). The best known editions of NIST (NBS) are the Charlotte Moore level and multiplet tables cited by Johansson and Cowley (1988), Martin (1992) and Wiese (1992a, b).

Current NIST atomic data are collected at two data centers. The first is the Atomic Energy Levels Center directed by W. C. Martin. They prepare atomic data bibliographical files including critically evaluated and compiled data on atomic energy levels and wavelengths, ionization potentials and related values. The NIST data centers on Atomic Transition Probabilities and Line Shapes headed by W. L. Wiese compile and critically evaluate data on transition probabilities and radiative lifetimes and the shape parameters of their lines. Access to the NIST atomic data base where these files can be found is described in the next section.

Some recent contributions from the NIST data centers are published in *J. Phys. Chem. Ref. Data* reviewed by Martin(1992) and Wiese (1992a, b).

Commission 14 (Atomic and Molecular Data) of the International Astronomical Union (IAU) compile the triénnial reports including references to spectroscopic data in the following fields: Atomic Spectra and Wavelength Standard, Transition Probabilities, Collision Processes, Line Broadening, Molecular structure and Spectra (see, e.g. Sahal-Brechot, 1991).

May of calculations of atomic data have been performed in *Vilnius*, most of which are cited in Rudzikas *et al.* (1990) (see, also, review by Rudzikas and Bogdanovich, 1994).

B.2 Atomic Data Bases

Until recently, and even now, most of the atomic data used by astronomers, physicists and astrophysicists have been taken from printed sources. Now, some of the atomic data used by astronomers and physicists have become available electronically. There are a large number of atomic data bases which can be extracted using FTP (file transfer protocol) or which can be reached with URL (uniform resource

Table B1. Atomic data bases

Name	*Location*	*Country*	*Type of Data*
ADA: Atomic Data for Astrophysics	University of Kentucky	USA	MSCD
ADRAL: Atomic Data for Resonance Absorption lines	Herzberg Institute of Astrophysics	Canada	WL, TP, OS, damping constants
ATOM PHTI: Atomic Photoionization Data base	St.Petersburg Phys. Tech. Institute	Russia	PHI
ATOM VNIFTRI: Atomic Data Data base	Inst. Phys. Tech. Radio Measurements, Mendeleevo	Russia	MSCD
BIBL: Spectral Bibliography Data base	Institute of Spectroscopy, Troitsk	Russia	Bibl: MSCD
CCP7: CCP7 Data Library	University of St.Andrews	UK	EL, WL
CDS	Centre de Données Astronomiques de Strasbourg	France	MSCD
CfAD: Harvard–Smithsonian Center for Astrophysics Data bases	Harvard	USA	EL, OS, TP, WL
DASGAL: Bibliography Data base on Atomic Line Shapes and Shifts	Observatory of Paris–Meudon	France	Bibl: LS, SH
GAPHYOR: GAPHYOR Data Centre	Centre de Données, Orsay	France	Bibl: MSCD
IAEA AMDIS: IAEA Atomic and Molecular Data Information System	Int. Atomic Energy Agency, Vienna	Austria	ElEx, ElIon, CT, HP, Bibl
LLNL EPAS: Elastic-Photon-ATOM Scattering Data base	Lawrence Livermore National Laboratory	USA	SF
NIFS: Data base	National Institute for Fusion Science	Japan	ElEx, ElIon, CT, HP
NIST ASD: Atomic Spectroscopy Data base	NASA Astrophys. Data System	USA	EL, OS, TP, WL
NIST ATPBD: Atomic Transition Probability Bibliographic Data base	NASA Astrophys. Data System	USA	Bibl: OS, TP
TOPbase: Opacity Project Data base	Centre de Données Astronomiques de Strasbourg	France	EL, OS, TP, PHI, WL
CFADC: ORNL Controlled Fusion Atomic Data Center Data bases	Oak Ridge National Laboratory	USA	Bibl: MSCD
SAM: Systematic, Accurate, Multiconf. Calculations Project Data	NASA	USA	EL,OS,TP,HfS
UUD: Uppsala University Data bases	Uppsala University	Sweden	OS, SF, WL
VALD: Vienna Atomic Line Data base	Institute für Astronomie, Vienna	Austria	EL, OS, TP

Note. Bibl: *AAA*, bibliography for data marked *AAA*; CT, Charge transfer; EL, energy levels; ElEx, electron impact excitation; ElIon, electron impact ionization; HP, heavy particles interaction; Hfs , hyperfine structure parameters; LSSH, line shapes and line shifts; MSCD, miscellaneous spectroscopic and collision data; OS, Oscillator strengths; PHI, photoionization cross sections; SF, scattering factors; TP, transition probabilities; WL, wavelengths.

locator). Others, for example, TOPBASE, the atomic data base of the Opacity project, require registration and/or use of a specialized data base management system.

Table B2. Access to atomic data bases

Name	*Contact*	*Access*	
ADA	D. Verner	**www:**	*http://www.pa.uky.edu/verner/atom.html*
ADRAL	D. C. Morton	**www:**	*http://www.dao.nrc.ca/dcm/atomic_data.html*
ATOM VNIFTRI	A. Faenov	**e-mail:**	faenov@glas.apc.org
BIBL	A. N. Ryabtsev	**www:**	*http://plasma-gate.weizmann.ac.il/bibl.html*
CCP7	C. S. Jeffery	**ftp:**	*ftp://ccp7.st-and.ac.uk/ccp7/*
CDS	–	**www:**	*http://cdsweb.u-strasbg.fr/cats/VI.html*
		www:	*http://cdsweb.u-strasbg.fr/cats/J.html*
DASGAL	A. Lesage	**www:**	*http://www.obspm.fr/department/dasgal/lesage/*
CfAD	P. L. Smith	**www:**	*http://cfa-www.harvard.edu/amp/data/amdata.html*
		e-mail:	plsmith@cfa.harvard.edu
GAPHYOR	J. L. Delcroix	**www:**	*http://gaphyor.lpgp.u-psud.fr/*
		e-mail:	gaphyor@lpgp.u-psud.fr
IAEA AMDIS	R. K. Janev	**telnet:**	*aladdin@.ripcrs01.iaea.or.at*
		e-mail:	psm@.ripcrs01.iaea.or.at
LLNL EPAS	L. Kyssel	**www:**	*http://www-phys.llnl.gov/V_Div/scattering/elastic.html*
NIFS	H. Tawara	**telnet:**	*msp.nifs.ac.jp**
		e-mail:	tawara@dptawara.nifs.ac.jp
NIST ASD	D. Kelleher	**www:**	*http://aeldata.phy.nist.gov/nist_atomic_spectra.html*
	A. Musgrove	**e-mail:**	ael@enh.nist.gov
NIST ATPBD	P. J. Mohr	**www:**	*http://physics.nist.gov/PhysRefData/fvalbib/reffrm0.html*
	J. Fuhr	**e-mail:**	fuhr@tiber.nist.gov
TOPbase:	C. Mendoza	**www:**	*http://cdsarc.u-strasbg.fr/OP.html*
		telnet:	*cdsarc.u-strasb.fr*
		(userid:	*topbase*, password *Seaton+*)
CFADC	D. R. Schultz	**www:**	*http://www-cfadc.phy.ornl.gov/*
SAM	T. Brage	**www:**	*http://aniara.gsfc.nasa.gov/sam/sam.html*
UUD	–	**www:**	*http://xray.uu.se/*
		ftp:	*grace.lbl.gov/pub/sf/ xray1.physics.sunysb.edu/pub/henke/*
VALD	F. Kupka	**e-mail:**	vald@galileo.ast.univie.ac.ut

Note. *, There is no *anonymous* access to the NIFS data base so to have an userid with a password one should send a request to the *Research Information Center*, NIFS, Nagoya 464-01, Japan.

To aid readers, most of the existing data bases are listed in Table B1. This table is compiled mainly from papers by Ralchenko (1996), Smith *et. al.* (1996) and a compilation by Nave (1994). A permanently updated hypertext list of atomic data and data bases on the Internet can be found at the URL *http://plasma-gate.weizmann.ac.il/DBfAPP.html*. Table B2 describes how the above-mention data bases can be accessed. Below we also present detail descriptions of some of the atomic data bases mentioned.

B.2.1 VALD: The Vienna atomic line data base

The Vienna Atomic Line Data Base (VALD) consists of a set of critically evaluated lists of astrophysically important atomic transition parameters and supporting extraction software. Lines of neutral atoms and selected first ions of elements from H to U are included in the data base. VALD contains about 600 000 entries and is one of the largest collections of accurate and homogeneous data. It also includes specific tools for extracting data for spectrum synthesis and model atmosphere calculations. The data base is presently restricted to spectral lines which are relevant for stars for which the LTE approximation is sufficient and molecular lines do not have to be taken into account. The structure of VALD, the available data sets and specific retrieval tools are described in a paper by Piskunov *et al.* (1995). The e-mail interface (VALD-EMS) allows remote access to VALD by external users.

The *first step* is to register on the list of VALD clients, which contains internet e-mail addresses from where VALD-EMS requests will be accepted. To do so, send an e-mail message to the VALD manager at the following address: *VALDADM@GALILEO.AST.UNIVE.AC.AT* with your full name and your e-mail address. The detail descriptions of the typical VALD-EMS requests can also be found in a paper Piskunov *et al.* (1995)

B.2.2 Atomic and molecular data information system

AMDIS, the Atomic and Molecular Data Information System, which currently contains atomic and molecular collision and particle–surface interaction data is located at the International Atomic Energy Agency (IAEA), Vienna, Austria. The AMDIS consists of the following data bases:

ALADDIN (format and interface program) – recommended and evaluated data;

AMBDS – Atomic and Molecular Bibliographical Data Retrieval System containing over 35 000 references on atomic, molecular and plasma–material interaction data of interest to fusion;

AMBB – Electronic Bulletin Board with Atomic and Molecular related news.

ALADDIN, **A** **L**abelled **A**tomic **D**ata **In**terface, is the system adopted by the IAEA for exchange of data since 1988 (Hulse, 1990). The system is available online on the INTERNET. The IP address is: ripcrs01.iaea.or.at (161.5.74.1). To access it, telnet to this address and login using: user id: *aladdin* , password: *aladdin*. Non-registered users may work with userid *guest* but may not save the search results into a file. In order to become a registered user one can send an e-mail to *psm@ripcrs01.iaea.or.at*. ALLADIN is also available as a set of FORTRAN77 codes and data files which can be downloaded from *anonymous* FTP-site at *ftp://ripcrs01.iaea.or.at*. Any comments and/or suggestions are very welcome.

B.3 Miscellaneous Atomic Data Sources

This part of the work is based mainly on the review of Smith (1992). Much useful information can also be extracted from the review by Mendoza (1986).

B.3.1 Laboratory, agency and society reports

The international Atomic Energy Agency (IAEA) in Vienna publish the *International Bulletin on Atomic and Molecular Data for Fusion.* The bulletin presents a comprehensive compilation of references to papers on atomic (*and molecular*) structure, spectra and collisions (many of these references are included in Appendix A). There were quarterly issues of the Bulletin until 1988, semi-annual ones until No. 41 in 1990, and a hiatus ended with the publication of Nos. 42–45. The most recent issue that the authors have seen is No. 49 (June 1995). The editor of the Bulletin is J. Botero, who can be reached by e-mail *RNDS@IAEA1.BITNET.*

Japan institute for Plasma Physics (it is now the National Institute for Fusion Science) produced more then a hundred compilations of atomic data for fusion research in the IPPJ-AM series (1977–1988) and the issue has been continued with the NIFS-DATA series. The current editor of these series is Hiro Tawara, who can be contacted via e-mail *TAWARA@NIFS.AC.JP.* Some of the IPPJ and NIFS reports have also been published in *J. Phys. Chem. Ref. Data.* Atomic data compilations produced by the Japan Atomic Energy Institute (JAERI) mostly are published in *J. Phys. Chem. Ref. Data* too. The current editor is T. Shirai contactable via e-mail *J3323@JPNJAERI.*

The GAYPHOR (Gas–PHYsics–ORsay) data base at the Centre de Données, Orsay, France maintains bibliographical data which include references to properties of neutral and ionized atoms (and molecules) and to parameters for electron and proton collision processes. The quests for experts reports can also be sent by e-mail to *gaphyor@lpgp.u-psud.fr* but this service is not free of charge.

B.3.2 Newsletters and proceedings from symposia and workshops

Collaborative Computational Project No. 7 (CCP7) supported by the Science and Engineering Research Council (SERC) of the UK produces the *Newsletter on Analysis of Astronomical Spectra*, which includes data or other information useful in modelling stellar spectra. Issue No. 17 contains a review of plasma diagnostic methods using line intensity ratios, a useful summary of the most reliable atomic data, a bibliography of the Opacity Project and a review of Stark broadening data. The current editor is C. S. Jeffery, who can be contacted by e-mail *CJS@ST-AND.AC.UK.*

Collaborative Computational Project No. 2 (CCP2) on the Continuum States of Atoms and Molecules and on Applications to Solar Physics and Astrophysics publishes the *Information Quarterly for Atomic Processses and Applications.* Current editors are W. Eissner from Queen's University in Belfast (e-mail *AMG0400@VAX1.APP-MATHS.QUEENS-BELFAST.AC.UK* (capital letters are mandatory) and C. J. Noble from Daresbury Laboratory , e-mail *CJN@CXA.DL.AC.UK.*

CCP2 and other agencies have sponsored international workshops on atomic data for fusion and astrophysics. They are partly described in a report on recommended data (Aggarwal *et al.*, 1985) and have been stored in the Queen's University/Daresbury Laboratory Atomic Data Bank directed by K. A. Berrington (e-mail *AMG0016@VAX1.APP-MATHS.QUEENS-BELFAST.AC.UK*

A lot of useful information can be extracted from the proceedings of meetings on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory plasmas; the last and fifth in a series was held in Meudon, France, August 28–31, 1995 (Tchang–Brillet *et al.*, 1996).

References

Aggarwal, K., Berrington, K., Eisner, W., and Kingston, A. (1985) *Recomended Data from the Daresbury Atomic Data Workshop* Daresbury, SERC Daresbury Laboratory.

Canto, W., Mendoza, C., Oshenbein, F., and Zieppen, C. J. (1993) *Astron. Astrophys.* **275**, L5.

Hulse, R. A. (1990) In *Atomic Processes in Plasmas*, AIP Conf. Proc., **206**, 63.

Johansson, S. and Cowley, C. R. (1988) *J. Opt. Soc. Am. B* **5**, 2264.

Martin, W. C. 1992, in *Atomic and Molecular Data for Space Astronomy: Needs, Analysis and Availability*, P. L. Smith and W. L. Wiese (eds.), Berlin, Springer-Verlag, p. 121.

Mendoza, C. (1986) *Publ. Astron. Soc. Pacif.* **96**, 999.

Nave, G. (1994) *Data Bases and Compilations of Atomic Data of Relevance to Astrophysics* at the URL *http: //cfa-www.harvard.edu/amp/data/g_nave.html.*

Piskunov, N. E., Kupka, F., Ryabchikova, T. A., Weiss, W. W., and Jeffery, C. S. (1995) *Astron. Astroph. Suppl. Ser.* **275**, 525.

Ralchenko, Y. V. (1996) *Preprint WIS-96/4/Jan-PH.*

Rudzikas, Z. and Bogdanovich, P. (1994) *Baltic Astron.* **3**, 131.

Rudzikas, Z. B., Nikitin, A. A., and Kholtygin, A. F. (1990) *Theoretical Atomic Spectroscopy, Leningrad, Leningrad University Publisher (in Russian).*

Sahal–Brechot, S. (1991) In *Rep. Astron.* **XXA**, 105

Smith, P. L. (1992) In *Proc. of the First Symp. Nuclear Physics in the Universe, Oak Ridge, TN, September 1992*, 387.

Smith, P. L., Esmond, J. R., Heise, C., and Kurucz, R. L. (1996) In *Proc. of the 5th Int. Colloq. on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas*, Meudon, France, August 28–31.

Tchang–Brillet, W.-U. L., Wyart, J.-F., and Zeippen, C. J. (eds.) (1996) In *Proc. of Colloq. on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory plasmas*, Meudon, France, August 28–31, Publications de l'Observatoire de Paris (in press).

Wiese, W. L. (1992a) Spectroscopic data for fusion edge plasmas, In *Atomic and Plasma-Material Interaction Data for Fusion*, Supplement to Nuclear Fusion, R. K. Janev (ed.), Vienna, IAEA, p. 7.

Wiese, W. L. (1992b) Spectroscopic reference data, In *Inductively Coupled Plasmas in Analytical Atomic Spectroscopy*, 2nd edn, A. Montaser and D. W. Colighty (eds.), New York, p. 451.

Appendix C

Table 25. The list of lines observed in the spectra of gaseous nebulae

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
919.78	Ar II	$3p^5\,^2P_{3/2} - 3p^6\,^2S_{1/2}$	1.398+8	C	M91
932.05	Ar II	$3p^5\,^2P_{1/2} - 3p^6\,^2S_{1/2}$	6.719+7	C	M91
933.38	S VI	$3s\,^2S_{1/2} - 3p\,^2P_{3/2}$	1.690+9	C	M91
972.11	He II	2–8	3.550+6	R	R80
972.54	HI–L_γ	$1s\,^2S_{1/2} - 4p\,^2P_{3/2}$	6.818+7	R	M91
977.03	C III	$2s^2\,^1S_0 - 2p\,^1P_1$	1.775+9	C,Au	M91
989.79	N III	$2p\,^2P_{1/2} - 2p^2\,^2D_{3/2}$	3.630+8	C	M91
991.51	N III	$2p\,^2P_{3/2} - 2p^2\,^2D_{5/2}$	4.332+8	C	M91
992.36	He II	2–7	7.030+6	R	R80
998.43	Ar VI	$3p\,^2P_{1/2} - 3p^2\,^4P_{3/2}$		C	
1000.16	Ar VI	$3p\,^2P_{1/2} - 3p^2\,^4P_{1/2}$		C	
1012.67	Ar VI	$3p\,^2P_{3/2} - 3p^2\,^4P_{3/2}$		C	
1020	Ne VI	$2p\,^2P_{3/2} - 2p^2\,^4P_{1/2}$		C	
1022.6	Ar VI	$3p\,^2P_{3/2} - 3p^2\,^4P_{1/2}$		C	
1025.27	He II	2–6	1.560+7	R	R80
1025.72	HI–L_β	$1s\,^2S_{1/2} - 3p\,^2P_{1/2}$	1.672+8	R	M91
1031.91	O VI	$2s\,^2S_{1/2} - 2p\,^2P_{3/2}$	4.163+8	C,Au	M91
1037.02	C II	$2p\,^2P_{3/2} - 2p^2\,^2S_{1/2}$	1.526+9	C	M91
1037.61	O VI	$2s\,^2S_{1/2} - 2p\,^2P_{1/2}$	4.095+8	C,Au	M91
1072.99	S IV	$3p\,^2P_{3/2} - 3p^2\,^2D_{5/2}$	1.377+8	C	M91
1084.58	N II	$2p^2\,^3P_1 - 2p^3\,^3D_2$	2.629+8	C	M91
1084.94	He II	2–5	4.050+7	R	R80
1085.70	N II	$2p^2\,^3P_2 - 2p^3\,^3D_3$	3.494+8	C	M91
1175.71	C III	$2p\,^3P_2 - 2p^2\,^3P_2$		C,D	
1176.37	C III	$2p\,^3P_2 - 2p^2\,^3P_1$		C,D,Au	
1194.50	Si II	$3p\,^2P_{3/2} - 3p^2\,^2P_{3/2}$	2.914+9	C	M91
1198.6	S V	$3s^2\,^1S_0 - 3p\,^3P_1$	1.640+5	C	M91
1201.97	S III	$3p^2\,^3P_2 - 3p^3\,^3D_3$	6.098+7	C	M91
1206.51	Si III	$3s^2\,^1S_0 - 3p\,^1P_1$	2.550+9	C	M91
1215.09	He II	2–4	1.350+8	R	R80
1215.17	He II	2–4	1.350+8	R	R80
1215.67	HI–L_α	$1s\,^2S_{1/2} - 2p\,^2P_{3/2}$	6.265+8	R	M91
1218.34	O V]	$2s^2\,^1S_0 - 2p\,^3P_1$	2.210+3	C,Au	M91
1238.82	N V	$2s\,^2S_{1/2} - 2p\,^2P_{3/2}$	3.411+8	C,Au	M91
1242.80	N V	$2s\,^2S_{1/2} - 2p\,^2P_{1/2}$	3.378+8	C,Au	M91
1247.38	C III	$2p\,^1P_1 - 2p^2\,^1S_0$	1.860+9	C,D	R80
1256.52	C III	$3s\,^3S_1 - 4p\,^3P_2$	1.040+8	C,D	NS84
1259.52	S II	$3p^3\,^4S_{3/2} - 3p^4\,^4P_{5/2}$	4.553+7	C	M91
1264.74	SiII	$3p\,^2P_{3/2} - 3d\,^2D_{5/2}$	2.512+9	C	M91
1302.17	OI	$2p^4\,^3P_2 - 3s\,^3S_1$	3.204+8	C	M91
1304.37	SiII	$3p\,^2P_{1/2} - 3p^2\,^2S_{1/2}$	5.776+8	C	M91
1304.86	OI	$2p^4\,^3P_1 - 3s\,^3S_1$	1.911+8	C	M91
1306.03	OI	$2p^4\,^3P_0 - 3s\,^3S_1$	6.352+7	C	M91
1309.28	SiII	$3p\,^2P_{3/2} - 3p^2\,^2S_{1/2}$	1.142+9	C	M91
1335.71	CII	$2p\,^2P_{3/2} - 2p^2\,^2D_{5/2}$	2.864+8	C,D	M91
1343.51	OIV	$2p^2\,^2P_{3/2} - 2p^3\,^2D_{5/2}$	2.640+8	C	R80
1371.29	OV	$2p\,^1P_1 - 2p^2\,^1D_2$	3.480+8	C,D	Kh81
1393.78	SiIV	$3s\,^2S_{1/2} - 3p\,^2P_{3/2}$	8.825+8	C	M91
1397.20	OIV]	$2p\,^2P_{1/2} - 2p^2\,^4P_{3/2}$	5.815+1	C	M91
1399.77	OIV]	$2p\,^2P_{1/2} - 2p^2\,^4P_{1/2}$	2.075+3	C	M91
1401.16	OIV]	$2p\,^2P_{3/2} - 2p^2\,^4P_{5/2}$	1.466+3	C	M91

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
1402.77	Si IV	$3s\ ^2S_{1/2} - 3p\ ^2P_{1/2}$	8.656+8	C	M91
1404.81	O IV]	$2p\ ^2P_{3/2} - 2p^2\ ^4P_{3/2}$	4.414+2	C	M91
1407.39	O IV]	$2p\ ^2P_{3/2} - 2p^2\ ^4P_{1/2}$	2.120+3	C	M91
1483.3	N IV]	$2s^2\ ^1S_0 - 2p\ ^3P_2$	1.150−2	C	M83
1486.50	N IV]	$2s^2\ ^1S_0 - 2p\ ^3P_1$	5.773+2	C	M91
1503.7	[Na IV]	$2p^4\ ^3P_2 - 2p^4\ ^1S_0$	1.050−2	C	M83
1529.1	[Na IV]	$2p^4\ ^3P_1 - 2p^4\ ^1S_0$	0.710+1	C	M83
1548.20	C IV	$2s\ ^2S_{1/2} - 2p\ ^2P_{3/2}$	2.654+8	C	M91
1550.77	C IV	$2s\ ^2S_{1/2} - 2p\ ^2P_{1/2}$	2.641+8	C	M91
1574.9	[Ne V]	$2p^2\ ^3P_1 - 2p^2\ ^1S_0$	0.421+1	C	M83
1592.7	[Ne V]	$2p^2\ ^3P_2 - 2p^2\ ^1S_0$	6.690−3	C	M83
1608.8	[Ne IV]	$2p^3\ ^4S_{3/2} - 2p^3\ ^2P_{3/2}$	0.127+1	C	M83
1609.0	[Ne IV]	$2p^3\ ^4S_{3/2} - 2p^3\ ^2P_{1/2}$	5.210−1	C	M83
1620.05	C III	$3p\ ^3P_1 - 4d\ ^3D_2$	8.520+8	R,D	NS84
1640.33	He II	2–3	7.060+8	R	R80
1640.47	He II	2–3	7.060+8	R	R80
1640.49	He II	2–3	7.060+8	R	R80
1641.3	O I]	$2p^4\ ^1D_2 - 3s\ ^3S_1$		C	
1661.17	O III]	$2p^2\ ^3P_1 - 2p^3\ ^5S_2$	2.369+2	C,Au	M91
1666.52	O III]	$2p^2\ ^3P_2 - 2p^3\ ^5S_2$	5.845+2	C,Au	M91
1711.30	Si II	$3p^2\ ^2D_{5/2} - 5f\ ^2F_{7/2}$		R	
1718.55	N IV	$2p\ ^1P_1 - 2p^2\ ^1D_2$	2.540+8	C,D	Kh81
1746.82	N III]	$2p\ ^2P_{1/2} - 2p^2\ ^4P_{3/2}$	8.950+0	C	M91
1748.61	N III]	$2p\ ^2P_{1/2} - 2p^2\ ^4P_{1/2}$	3.390+2	C	M91
1749.67	N III]	$2p\ ^2P_{3/2} - 2p^2\ ^4P_{5/2}$	2.510+2	C	M91
1751.22	N III]	$2p\ ^2P_{3/2} - 2p^2\ ^4P_{3/2}$	5.900+1	C	M91
1753.99	N III]	$2p\ ^2P_{3/2} - 2p^2\ ^4P_{1/2}$	3.640+2	C	M91
1760.40	C II	$2p^2\ ^2D_{5/2} - 3p\ ^2P_{3/2}$	3.500+7	R	B85
1793.8	[Ne III]	$2p^4\ ^3P_2 - 2p^4\ ^1S_0$	3.940−3	C	M83
1808.01	Si II	$3p\ ^2P_{1/2} - 3p^2\ ^2D_{3/2}$	5.639+6	C	M91
1814.7	[Ne III]	$2p^4\ ^3P_1 - 2p^4\ ^1S_0$	2.000+0	C	M83
1816.93	Si II	$3p\ ^2P_{3/2} - 3p^2\ ^2D_{5/2}$	6.668+6	C	M91
1817.45	Si II	$3p\ ^2P_{3/2} - 3p^2\ ^2D_{3/2}$	1.110+6	C	M91
1854.72	Al III	$3s\ ^2S_{1/2} - 3p\ ^2P_{3/2}$	5.432+8	C	M91
1862.79	Al III	$3s\ ^2S_{1/2} - 3p\ ^2P_{1/2}$	5.361+8	C	M91
1867.4	[F IV]	$2p^2\ ^3P_0 - 2p^2\ ^1S_0$		C	
1875.5	[F IV]	$2p^2\ ^3P_1 - 2p^2\ ^1S_0$	1.100+0	C	G68
1883	Si III]	$3s^2\ ^1S_0 - 3p\ ^3P_2$	1.200−2	C	M83
1889.3	[F IV]	$2p^2\ ^3P_2 - 2p^2\ ^1S_0$	2.300−3	C	G68
1892.03	Si III]	$3s^2\ ^1S_0 - 3p\ ^3P_1$	1.670+4	C	M91
1906.68	C III]	$2s^2\ ^1S_0 - 2p\ ^3P_2$	5.190−3	C,Au,Ph	M83
1908.73	C III]	$2s^2\ ^1S_0 - 2p\ ^3P_1$	7.520+1	C,Au,Ph	M91
1922.93	C III	$3p\ ^3D_3 - 4f\ ^3F_4$	7.720+8	R,D	NS84
1939.6	[F III]	$2p^3\ ^4S_{3/2} - 2p^3\ ^4P_{3/2}$	0.260+0	C	G68
1939.6	[F III]	$2p^3\ ^4S_{3/2} - 2p^3\ ^4P_{1/2}$	0.100+0	C	G68
2009.57	C III	$3p\ ^3P_1 - 4s\ ^3S_1$	6.860+8	R	NS84
2010.09	C III	$3p\ ^3P_2 - 4s\ ^3S_1$	6.860+8	R	NS84
2112.0	[Ca VII]	$3p^2\ ^3P_1 - 3p^2\ ^1S_0$	3.400+1	C	G68
2139.01	N II]	$2p^2\ ^3P_1 - 2p^3\ ^5S_2$	5.700+1	C	M91
2225.61	[F II]	$2p^4\ ^3P_2 - 2p^4\ ^1S_0$	1.600−3	C	G68
2226.0	[Ca VII]	$3p^2\ ^3P_2 - 3p^2\ ^1S_0$	0.250+0	C	G68

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
2242.61	[F II]	$2p^4\,{}^3P_1 - 2p^4\,{}^1S_0$	0.490+0	C	G68
2252.69	He II–P_ζ	3–10	8.250+5	R	R80
2280.0	[Ca V]	$3p^4\,{}^3P_2 - 3p^4\,{}^1S_0$	0.145+0	C	M83
2296.87	C III	$2p\,{}^1P_1 - 2p^2\,{}^1D_2$	1.490+8	C,D	Kh81
2306.19	HeII–P_ϵ	3–9	1.430+6	R	R80
2321.08	[O III]	$2p^2\,{}^3P_1 - 2p^2\,{}^1S_0$	0.223+0	C	M83
2325.40	C II]	$2p\,{}^2P_{3/2} - 2p^2\,{}^4P_{5/2}$	4.320+1	C	M91
2328.12	C II]	$2p\,{}^2P_{3/2} - 2p^2\,{}^4P_{1/2}$	6.550+1	C	M91
2331.55	[O III]	$2p^2\,{}^3P_2 - 2p^2\,{}^1S_0$	7.850−4	C	M83
2334.40	Si II]	$3p\,{}^2P_{1/2} - 3p^2\,{}^4P_{1/2}$	4.550+3	C	M91
2334.61	Si II]	$3p\,{}^2P_{3/2} - 3p^2\,{}^4P_{5/2}$	2.400+3	C	M91
2350.17	Si II]	$3p\,{}^2P_{3/2} - 3p^2\,{}^4P_{1/2}$	3.000+3	C	M91
2366.8	[K VI]	$3p^2\,{}^3P_1 - 3p^2\,{}^1S_0$	1.600+1	C	G68
2385.40	He II–P_δ	3–8	2.640+6	R	R80
2399.2	Fe II	$4s^6D_{5/2} - z^6F_{5/2}$	1.366+8	C	M91
2412.4	[Ca V]	$3p^4\,{}^3P_1 - 3p^4\,{}^1S_0$	2.310+1	C	M83
2416.5	[Mg V]	$2p^4\,{}^1D_2 - 2p^4\,{}^1S_0$	4.230+0	C	M83
2421.8	[Ne IV]	$2p^3\,{}^4S_{3/2} - 2p^3\,{}^2D_{3/2}$	5.540−3	C,Au	M83
2436.2	Fe II	$a^4G_{11/2} - y^4H_{11/2}$		C	
2438.6	[Ne IV]	$2p^3\,{}^4S_{3/2} - 2p^3\,{}^2D_{5/2}$	4.840−4	C	M83
2441.6	[Mg VII]	$2p^2\,{}^1D_2 - 2p^2\,{}^3P_0$	1.600−4	C	KL80
2444.5	Fe II	$b^4P_{5/2} - y^4D_{7/2}$		C	
2458.8	Fe II	$a^4G_{9/2} - y^4H_{11/2}$		C	
2465.2	Fe II	$b^4P_{1/2} - y^4D_{3/2}$		C	
2470.32	[O II]	$2p^3\,{}^4S_{3/2} - 2p^3\,{}^2P_{1/2}$	0.232−1	C	M83
2470.41	[O II]	$2p^3\,{}^4S_{3/2} - 2p^3\,{}^2P_{3/2}$	0.564−1	C	M83
2471.7	[K VI]	$3p^2\,{}^3P_2 - 3p^2\,{}^1S_0$	0.140+0	C	G68
2479.2	Fe II	$c^2D_{5/2} - w^2D_{3/2}$		C	
2481.0	Fe II	$b^2H_{11/2} - y^4H_{11/2}$		C	
2482.3	Fe II	$c^2D_{3/2} - w^2D_{3/2}$		C	
2484.2	Fe II	$b^2H_{11/2} - y^4H_{13/2}$		C	
2492.3	Fe II	$b^2H_{9/2} - y^4H_{11/2}$		C	
2494.5	[K V]	$3p^3\,{}^4S_{3/2} - 3p^3\,{}^2P_{3/2}$	5.190+0	C	M83
2506.4	Fe II	$c^4F_{9/2} - z^4G_{9/2}$		C	
2506.8	Fe II	$c^4F_{7/2} - y^6F_{9/2}$		C	
2508.3	Fe II	$c^4F_{7/2} - w^4G_{9/2}$		C	
2511.20	He II–P_γ	3–7	5.370+6	R	R80
2512.0	[Mg VII]	$2p^2\,{}^3P_1 - 2p^2\,{}^1D_2$	1.050+0	C	KL80
2514.5	[K V]	$3p^3\,{}^4S_{3/2} - 3p^3\,{}^2P_{1/2}$	2.140+0	C	M83
2519.4	Fe II	$b^2P_{1/2} - x^4P_{3/2}$		C	
2548.2	Fe II	$b^4F_{5/2} - y^6P_{7/2}$		C	
2562.5	Fe II	$a^4D_{7/2} - x^4P_{5/2}$		C	
2582.6	Fe II	$a^4D_{3/2} - x^4P_{3/2}$		C	
2585.9	Fe II	$a^6D_{9/2} - x^6D_{7/2}$	8.046+7	C	M91
2591.5	Fe II	$a^4D_{5/2} - x^4P_{5/2}$		C	
2593.5	[K IV]	$3p^4\,{}^3P_2 - 3p^4\,{}^1S_0$	0.817−1	C	M83
2593.60	Ne III	$3s\,{}^5S_2 - 3p\,{}^5P_2$		R	
2595.68	Ne III	$3s\,{}^5S_2 - 3p\,{}^5P_1$		R	
2598.4	Fe II	$a^6D_{7/2} - z^6D_{5/2}$	1.307+8	C	M91
2599.4	Fe II	$a^6D_{9/2} - a^6D_{7/2}$		C	

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
2604.0	Fe II	$c^2F_{7/2} - v^2G_{7/2}$		C	
2605.0	Fe II	$c^2F_{5/2} - v^2G_{7/2}$		C	
2606.5	Fe II	$b^2D_{5/2} - x^2D_{5/2}$		C	
2607.1	Fe II	$a^6D_{5/2} - z^6D_{3/2}$	1.658+8	C	M91
2611.9	Fe II	$a^6D_{7/2} - z^6D_{7/2}$	1.089+8	C	M91
2613.8	Fe II	$a^6D_{3/2} - z^6D_{1/2}$	1.988+8	C	M91
2617.6	Fe II	$a^6D_{5/2} - z^6D_{5/2}$	4.364+7	C	M91
2620.4	Fe II	$a^6D_{3/2} - z^6D_{3/2}$	3.590+6	C	M91
2625.6	Fe II	$a^6D_{7/2} - z^6D_{9/2}$	3.353+7	C	M91
2628.3	Fe II	$a^6D_{1/2} - z^6D_{3/2}$	8.560+7	C	M91
2631.0	Fe II	$a^6D_{3/2} - z^6D_{5/2}$	7.682+7	C	M91
2631.3	Fe II	$a^6D_{5/2} - z^6D_{7/2}$	6.032+7	C	M91
2663.27	He I	$2s\ ^3S_1 - 11p\ ^3P_{0-2}$	3.190+5	R	T87
2669.16	Al II	$3s^2\ ^1S_0 - 3p\ ^3P_1$	3.330+3	C	M91
2690.82	[Ar V]	$3p^2\ ^3P_1 - 3p^2\ ^1S_0$	6.550+0	C	KL80
2696.12	He I	$2s\ ^3S_1 - 9p\ ^3P_{0-2}$	5.790+5	R	T87
2709.4	Fe II	$a^4D_{5/2} - z^4F_{3/2}$		C	
2711.2	[K IV]	$3p^4\ ^3P_1 - 3p^4\ ^1S_0$	1.000+1	C	M83
2711.8	Fe II	$a^4G_{11/2} - z^2I_{13/2}$		C	
2712.4	Fe II	$a^4G_{9/2} - z^2I_{11/2}$		C	
2714.4	Fe II	$a^4D_{7/2} - z^4D_{5/2}$		C	
2716.7	Fe II	$a^4D_{7/2} - z^4F_{7/2}$		C	
2723.19	He I	$2s\ ^3S_1 - 8p\ ^3P_{0-2}$	8.170+5	R	T87
2724.9	Fe II	$a^4D_{5/2} - z^4F_{5/2}$		C	
2727.5	Fe II	$a^4D_{5/2} - z^4D_{3/2}$		C	
2730.7	Fe II	$a^4D_{3/2} - z^4F_{3/2}$		C	
2732.4	Fe II	$a^4F_{9/2} - z^6D_{9/2}$		C	
2733.30	He II-P$_\beta$	3–6	1.250+7	R	R80
2739.5	Fe II	$a^4D_{7/2} - z^4D_{7/2}$		C	
2741.7	Fe II	$z^2F_{5/2} - e^2F_{5/2}$		C	
2743.2	Fe II	$a^4D_{1/2} - z^4F_{3/2}$		C	
2746.5	Fe II	$a^4D_{3/2} - z^4F_{5/2}$		C	
2747.0	Fe II	$a^4D_{5/2} - z^4D_{5/2}$		C	
2749.2	Fe II	$a^4D_{3/2} - z^4D_{3/2}$		C	
2749.3	Fe II	$a^4D_{5/2} - z^4F_{7/2}$		C	
2749.5	Fe II	$a^4D_{1/2} - z^4D_{1/2}$		C	
2754.9	Fe II	$z^6F_{7/2} - e^6D_{5/2}$		C	
2755.1	Fe II	$z^6F_{7/2} - e^6D_{3/2}$		C	
2755.7	Fe II	$a^4D_{7/2} - z^4F_{9/2}$		C	
2763.80	He I	$2s\ ^3S_1 - 7p\ ^3P_{0-2}$	1.200+6	R	T87
2767.5	Fe II	$b^2H_{11/2} - z^2I_{13/2}$		C	
2767.5	Fe II	$z^6F_{9/2} - e^6D_{7/2}$		C	
2768.9	Fe II	$a^4D_{3/2} - z^4D_{5/2}$		C	
2771.2	Fe II	$b^2G_{9/2} - y^4H_{11/2}$		C	
2776.9	Fe II	$z^6F_{7/2} - e^6D_{7/2}$		C	
2783.2	[Mg V]	$2p^4\ ^3P_2 - 2p^4\ ^1D_2$	1.850+0	C	M83
2785.2	Fe II	$z^6F_{11/2} - e^6D_{9/2}$		C	
2785.76	[Ar V]	$3p^2\ ^3P_2 - 3p^2\ ^1S_0$	0.569−1	C	KL80
2790.6	Fe II	$b^2G_{7/2} - y^4H_{9/2}$		C	
2790.78	Mg II	$3p\ ^2P_{1/2} - 3d\ ^2D_{3/2}$		C,R	

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
2795.53	Mg II	$3s\ ^2S_{1/2} - 3p\ ^2P_{3/2}$	2.612+8	C	M91
2797.99	Mg II	$3p\ ^2P_{3/2} - 3d\ ^2D_{5/2}$		C,R	
2802.70	Mg II	$3s\ ^2S_{1/2} - 3p\ ^2P_{1/2}$	2.592+8	C	M91
2803.3	[Na IV]	$2p^4\ ^1D_2 - 2p^4\ ^1S_0$	3.460+0	C	M83
2818.68	O III	$3p\ ^3D_2 - 3d\ ^3P_2$	6.980+5	B,R	E84
2829.08	He I	$2s\ ^3S_1 - 6p\ ^3P_{0-2}$	1.860+6	R	T87
2836.34	O III	$3p\ ^3D_3 - 3d\ ^3P_2$	8.710+6	B,R	E84
2839.5	Fe II	$z^4F_{9/2} - e^4D_{7/2}$		C	
2845.5	Fe II	$z^4D_{3/2} - e^4D_{3/2}$		C	
2848.1	Fe II	$z^4D_{5/2} - e^4D_{5/2}$		C	
2848.3	Fe II	$z^4F_{5/2} - e^4D_{3/2}$		C	
2851.7	Fe II	$z^4F_{3/2} - e^4D_{1/2}$		C	
2853.68	[Ar IV]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2P_{3/2}$	2.110+0	C	M83
2856.4	Fe II	$z^6P_{5/2} - e^6D_{7/2}$		C	
2856.9	Fe II	$z^4D_{7/2} - e^4D_{7/2}$		C	
2865.5	Fe II	$z^4F_{3/2} - e^4D_{3/2}$		C	
2868.18	[Ar IV]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2P_{1/2}$	0.862+0	C	M83
2886.2	Fe II	$b^2H_{11/2} - z^4G_{9/2}$		C	
2888.1	Fe II	$b^2P_{3/2} - y^4P_{5/2}$		C	
2916.2	Fe II	$a^4D_{7/2} - z^6F_{7/2}$		C	
2922.0	Fe II	$b^4D_{7/2} - x^4G_{9/2}$		C	
2926.6	Fe II	$a^4D_{7/2} - z^6F_{9/2}$		C	
2928.7	[Mg V]	$2p^4\ ^3P_1 - 2p^4\ ^1D_2$	0.541+0	C	M83
2930.0	[F III]	$2p^3\ ^4S_{3/2} - 2p^3\ ^2D_{3/2}$	1.300−3	C	G68
2933.1	[F III]	$2p^3\ ^4S_{3/2} - 2p^3\ ^2D_{5/2}$	1.300−4	C	G68
2944.1	Fe II	$a^4P_{3/2} - z^4P_{1/2}$		C	
2945.11	He I	$2s\ ^3S_1 - 5p\ ^3P_{0-2}$	3.080+6	R	T87
2945.3	Fe II	$a^4D_{5/2} - z^6F_{5/2}$		C	
2953.8	Fe II	$a^4D_{5/2} - z^6F_{7/2}$		C	
2958.36	[O I]	$2p^4\ ^3P_2 - 2p^4\ ^1S_0$	2.880−4	C	M83
2964.6	Fe II	$a^4P_{1/2} - z^4P_{1/2}$		C	
2965.0	Fe II	$a^4P_{3/2} - z^4P_{3/2}$		C	
2970.5	Fe II	$a^4D_{3/2} - z^6F_{5/2}$		C	
2972.29	[O I]	$2p^4\ ^3P_1 - 2p^4\ ^1S_0$	0.732−1	C	M83
2972.56	N III	$3p'\ ^2P_{1/2} - 3d'\ ^2P_{1/2}$	6.310+7	R,D	NS84
2973.4	[Ne V]	$2p^2\ ^1D_2 - 2p^2\ ^1S_0$	2.850+0	C	M83
2978.83	N III	$3p'\ ^2P_{1/2} - 3d'\ ^2P_{3/2}$	3.600+7	R,D	NS84
2979.1	Fe II	$b^2F_{7/2} - z^2H_{9/2}$		C	
2979.3	Fe II	$a^4D_{1/2} - z^6F_{3/2}$		C	
2984.8	Fe II	$a^4P_{5/2} - z^4P_{5/2}$		C	
3002.7	Fe II	$a^4P_{3/2} - z^4P_{5/2}$		C	
3005.22	[Ar III]	$3p^4\ ^3P_2 - 3p^4\ ^1S_0$	0.417−1	C	M83
3023.45	O III	$3s\ ^3P_1 - 3p\ ^3P_2$	5.100+7	B,R	E84
3024.57	O III	$3s\ ^3P_0 - 3p\ ^3P_1$	6.560+7	B,R	E84
3047.13	O III	$3s\ ^3P_2 - 3p\ ^3P_2$	1.610+8	B,R	E84
3059.30	O III	$3s\ ^3P_2 - 3p\ ^3P_1$	9.650+7	B,R	E84
3062.83	[N II]	$2p^2\ ^3P_1 - 2p^2\ ^1S_0$	0.338−1	C	M83
3070.55	[N II]	$2p^2\ ^3P_2 - 2p^2\ ^1S_0$	1.510−4	C	M83
3109.16	[Ar III]	$3p^4\ ^3P_1 - 3p^4\ ^1S_0$	3.910+0	C	M83
3118.61	[Cl IV]	$3p^2\ ^3P_1 - 3p^2\ ^1S_0$	2.470+0	C	KL80

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
3121.71	O III	$3p\ ^3S_1 - 3d\ ^3P_1$	1.240+8	B,R	E84
3132.86	O III	$3p\ ^3S_1 - 3d\ ^3P_2$	1.360+8	B,R	E84
3183.1	Fe II	$a^4P_{3/2} - z^4P_{5/2}$		C	
3187.74	He I	$2s\ ^3S_1 - 4p\ ^3P_{0-2}$	5.420+6	R	T87
3196.1	Fe II	$a^4P_{5/2} - z^4F_{7/2}$		C	
3203.10	HeII-P$_\alpha$	3–5	3.520+7	R	R80
3203.60	[Cl IV]	$3p^2\ ^3P_2 - 3p^2\ ^1S_0$	0.262−1	C	KL80
3241.67	[Na IV]	$2p^4\ ^3P_2 - 2p^4\ ^1D_2$	0.610+0	C	M83
3260.98	O III	$3p\ ^3D_2 - 3d\ ^3F_3$	2.040+8	R,D	E84
3265.43	O III	$3p\ ^3D_3 - 3d\ ^3F_4$	2.240+8	R,D	E84
3299.36	O III	$3s\ ^3P_0 - 3p\ ^3S_1$	2.090+7	B,R	E84
3300.0	[Ne V]	$2p^2\ ^3P_0 - 2p^2\ ^1D_2$	2.370−5	C	M83
3306.63	N III	$4p\ ^2P_{3/2} - 5d\ ^2D_{5/2}$	7.980+7	R	NS84
3312.30	O III	$3s\ ^3P_1 - 3p\ ^3S_1$	5.780+7	B,R,D,Ch	E84
3319.00	[Fe III]	$a\ ^5D_2 - a\ ^3D_3$		C	
3334.84	[Fe III]	$a\ ^5D_2 - a\ ^3D_2$		C	
3334.84	Ne II	$3s^4P_{5/2} - 3p^4D_{7/2}$		R	
3340.74	O III	$3s\ ^3P_2 - 3p\ ^3S_1$	7.970+7	B,R,D,Ch	E84
3340.81	[Fe III]	$a\ ^5D_1 - a\ ^3D_3$		C	
3342.55	[Ne III]	$2p^4\ ^1D_2 - 2p^4\ ^1S_0$	2.710+0	C	M83
3342.85	[Cl III]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2P_{3/2}$	0.754+0	C	M83
3345.86	[Ne V]	$2p^2\ ^3P_1 - 2p^2\ ^1D_2$	0.131+0	C	M83
3349.12	O IV	$3s\ ^2P_{3/2} - 3p\ ^2D_{5/2}$	1.330+8	R	NS84
3350.68	O III	$3s'\ ^5P_2 - 3p'\ ^5P_1$		R,D	
3350.99	O III	$3s'\ ^5P_3 - 3p'\ ^5P_3$		R,D	
3353.21	[Cl III]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2P_{1/2}$	0.305+0	C	M83
3355.05	Ne II	$3s^4P_{3/2} - 3p^4D_{5/2}$	1.300+8	R	R80
3355.05	[Fe III]	$a\ ^5D_1 - a\ ^3D_1$		C	
3362.20	[Na IV]	$2p^4\ ^3P_1 - 2p^4\ ^1D_2$	0.186+0	C	M83
3381.24	O IV	$3s^4P_{3/2} - 3p^4P_{5/2}$		R	
3382.69	O III	$3p'\ ^5P_2 - 3d'\ ^5D_3$		R,D	
3385.50	O IV	$3s^4P_{5/2} - 3p^4D_{7/2}$		R	
3396.67	O IV	$3s^4P_{3/2} - 3p^4D_{3/2}$		R	
3403.54	O IV	$3p\ ^2P_{1/2} - 3d\ ^2D_{3/2}$	8.060+7	R	NS84
3404.82	Ne II	$3p^2D_{3/2} - 3d^2D_{5/2}$	1.900+8	R	R80
3405.74	O III	$3p\ ^3P_0 - 3d\ ^3P_1$	2.070+7	B,R	E84
3407.38	O II	$3p^2D_{5/2} - 4s^2D_{5/2}$	4.080+7	R	NS84
3407.38	O II	$3p^2D_{5/2} - 4s^2D_{3/2}$	4.080+7	R	NS84
3407.96	O III	$3p\ ^3P_1 - 3d\ ^3P_0$	8.200+7	R	E84
3409.60	O IV	$3s^4P_{5/2} - 3p^4D_{5/2}$		R	
3411.69	O IV	$3p^2P_{3/2} - 3d^2D_{5/2}$	1.030+8	R	NS84
3415.18	O III	$3p\ ^3P_1 - 3d\ ^3P_1$	2.560+7	B,R	E84
3416.2	[Na IV]	$2p^4\ ^3P_0 - 2p^4\ ^1D_2$	2.240−5	C	M83
3425.97	[Ne V]	$2p^2\ ^3P_2 - 2p^2\ ^1D_2$	0.365+0	C	M83
3428.67	O III	$3p\ ^3P_1 - 3d\ ^3P_2$	9.840+6	B,R	E84
3430.60	O III	$3p\ ^3P_2 - 3d\ ^3P_1$	3.120+7	B,R	E84
3433.9	O VI	$6fgFG - 7ghGH$	5.910+8	R	Kh93
3444.10	O III	$3p\ ^3P_2 - 3d\ ^3P_2$	5.820+7	B,R	E84
3447.59	He I	$2s\ ^1S_0 - 6p\ ^1P_1$	2.230+6	R	T87
3450.40	O III	$3p'\ ^5D_1 - 3d'\ ^5F_1$		R,D	
3455.20	O III	$3p'\ ^5D_2 - 3d'\ ^5F_2$		R,D	

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
3466.50	[N I]	$2p^3\,^4S_{3/2} - 2p^3\,^2P_{3/2}$	6.580−3	C	M83
3466.54	[N I]	$2p^3\,^4S_{3/2} - 2p^3\,^2P_{1/2}$	2.710−3	C	M83
3471.81	He I	$2p\,^3P - 16d\,^3D$	3.140+5	R	T87
3478.71	N IV	$3s\,^3S_1 - 3p\,^3P_2$	1.100+8	R,D	R80
3478.96	He I	$2p\,^3P - 15d\,^3D$	3.820+5	R	T87
3485.5	[Mg VI]	$2p^3\,^2D_{5/2} - 2p^3\,^2P_{3/2}$	2.400+0	C	G68
3487.72	He I	$2p\,^3P - 14d\,^3D$	4.710+5	R	T87
3488.1	[Mg VI]	$2p^3\,^2D_{3/2} - 2p^3\,^2P_{3/2}$	3.800+0	C	G68
3498.64	He I	$2p\,^3P - 13d\,^3D$	5.900+5	R	T87
3500.4	[Mg VI]	$2p^3\,^2D_{5/2} - 2p^3\,^2P_{1/2}$	0.150+0	C	G68
3503.0	[Mg VI]	$2p^3\,^2D_{3/2} - 2p^3\,^2P_{1/2}$	2.500+0	C	G68
3512.51	He I	$2p\,^3P - 12d\,^3D$	7.520+5	R	T87
3530.49	He I	$2p\,^3P - 11d\,^3D$	9.810+5	R	T87
3532.2	[F IV]	$2p^2\,^1D_2 - 2p^2\,^1S_0$	2.100+0	C	G68
3554.34	Ne II	$3p\,^2D_{5/2} - 3d\,^4D_{7/2}$		R	
3554.41	He I	$2p\,^3P - 10d\,^3D$	1.310+6	R	T87
3568.53	Ne II	$3s\,^2D_{5/2} - 3p\,^2F_{7/2}$	1.400+8	R	R80
3583.0	[C III]	$3p^4\,^3P_2 - 3p^4\,^1S_0$	0.197−1	C	M83
3586.0	[Fe VII]	$3d^2(a^3F_3 - a^1G_4)$		C	
3587.27	He I	$2p\,^3P - 9d\,^3D$	1.810+6	R	T87
3609.62	C III	$4p\,^3P_2 - 5d\,^3D_3$	9.090+7	R	NS84
3613.64	He I	$2s\,^1S_0 - 5p\,^1P_1$	3.740+6	R	T87
3634.23	He I	$2p\,^3P_{1,2} - 8d\,^3D_{1-3}$	2.320+6	R	T87
3634.37	He I	$2p\,^3P_0 - 8d\,^3D_1$	1.450+8	R	T87
3657.68	H_{35}	2–35	1.320+2	R	Kh93
3658.56	H_{34}	2–34	1.520+2	R	Kh93
3659.46	H_{33}	2–33	1.770+2	R	Kh93
3660.34	H_{32}	2–32	2.060+2	R	Kh93
3661.28	H_{31}	2–31	2.420+2	R	Kh93
3662.25	H_{30}	2–30	2.850+2	R	Kh93
3662.50	[Fe VI]	$3d^3(a^4F_{7/2} - a^2D_{5/2})$		C	
3663.35	H_{29}	2–29	3.380+2	R	Kh93
3664.67	H_{28}	2–28	4.020+2	R	Kh93
3666.15	H_{27}	2–27	4.830+2	R	Kh93
3667.66	H_{26}	2–26	5.830+2	R	Kh93
3669.46	H_{25}	2–25	7.100+2	R	Kh93
3671.48	H_{24}	2–24	8.710+2	R	Kh93
3673.76	H_{23}	2–23	1.080+3	R	Kh93
3675.0	[C III]	$3p^4\,^3P_1 - 3p^4\,^1S_0$	1.310+0	C	M83
3676.36	H_{22}	2–22	1.350+3	R	Kh93
3679.35	H_{21}	2–21	1.700+3	R	Kh93
3682.81	H_{20}	2–20	2.170+3	R	Kh93
3686.83	H_{19}	2–19	2.810+3	R	Kh93
3688.0	[Ca VII]	$3p^2\,^1D_2 - 3p^2\,^1S_0$	4.300+0	C	G68
3690.07	He II	4–36	9.660+2	R	Kh93
3691.55	H_{18}	2–18	3.690+3	R	Kh93
3694.21	Ne II	$3s\,^4P_{5/2} - 3p\,^4P_{5/2}$	1.000+8	R	R80
3697.15	H_{17}	2–17	4.910+3	R	Kh93
3698.07	Ne II	$3d\,^4P_{3/2} - 5p\,^4D_{1/2}$		R	
3698.72	He II	4–33	1.500+3	R	Kh93
3701.77	Ne II	$3p\,^2P_{3/2} - 3d\,^4P_{5/2}$	2.700+7	R	R80
3703.85	H_{16}	2–16	6.660+3	R	Kh93

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
3705.00	He I	$2p\ ^3P_{1,2} - 7d\ ^3D_{1-3}$	3.520+6	R	T87
3705.15	He I	$2p\ ^3P_0 - 7d\ ^3D_1$	2.200+6	R	T87
3707.24	O III	$3p\ ^3P_1 - 3d\ ^3D_2$	7.740+7	R	E84
3709.52	O III	$3s'\ ^5P_1 - 3p'\ ^5D_0$		R,D	
3709.52	Ne II	$3s\ ^4P_{3/2} - 3p\ ^4P_{1/2}$	1.100+8	R	R80
3711.97	H_{22}	2–15	9.210+3	R	Kh93
3715.08	O III	$3p\ ^3P_2 - 3d\ ^3D_3$	9.810+7	B,R	E84
3715.15	He II	4–29	2.870+3	R	R80
3715.46	Ne II	$4p\ ^2D_{5/2} - 7s\ ^2P_{3/2}$		R	
3720.72	Ne II	$3d\ ^2F_{5/2} - 5p\ ^2D_{5/2}$		R	
3721.88	[S III]	$3p^2\ ^3P_1 - 3p^2\ ^1S_0$	0.796+0	C	KL80
3721.94	H_{14}	2–14	1.300+4	R	Gr90
3726.19	[O II]	$2p^3\ ^4S_{3/2} - 2p^3\ ^2D_{3/2}$	1.650−4	C,Ph	M83
3729.11	[O II]	$2p^3\ ^4S_{3/2} - 2p^3\ ^2D_{5/2}$	3.820−5	C,Ph	M83
3731.60	O III	$3p\ ^3P_2 - 3d\ ^3D_1$	2.150+6	B,R	E84
3732.34	Ne II	$3p\ ^2P_{3/2} - 3d\ ^4F_{3/2}$		R	
3732.82	He II	4–26	4.980+3	R	R80
3732.86	He I	$2p\ ^3P_{1,2} - 7s\ ^3S_1$	1.290+6	R	T87
3733.01	He I	$2p\ ^3P_0 - 7s\ ^3S_1$	1.610+5	R	T87
3734.37	H_{13}	$2p\ ^2P - 13d\ ^2D$	1.880+4	R	Gr90
3736.85	O IV	$3p'\ ^4D_{7/2} - 3d'\ ^4F_{9/2}$		R,D	
3740.22	He II	4–25	6.060+3	R	R80
3740.30	[Fe VI]	$3d\ ^4F_{9/2} - 3d\ ^2H_{9/2}$		C	
3745.91	N III	$3s'\ ^4P_{1/2} - 3p'\ ^4S_{3/2}$		R,D	
3747.86	Ne II	$3d\ ^2P_{1/2} - 5p\ ^2S_{1/2}$		R	
3748.60	He II	4–24	7.450+3	R	R80
3750.15	H_{12}	$2p\ ^2P - 12d\ ^2D$	2.820+4	R	Gr90
3754.67	O III	$3s\ ^3P_1 - 3p\ ^3D_2$	8.270+7	B,R,Ch	E84
3757.21	O III	$3s\ ^3P_0 - 3p\ ^3D_1$	6.120+7	B,R,Ch	E84
3758.14	He II	4–23	9.240+3	R	R80
3759.0	[Fe VII]	$3d^2(a^3F_4 - a^1G_4)$		C	
3759.87	O III	$3s\ ^3P_2 - 3p\ ^3D_3$	1.080+8	B,R,Ch	E84
3768.07	He II	4–22	1.160+4	R	R80
3768.78	He I	$2p\ ^1P_1 - 13d\ ^1D_2$	4.320+5	R	T87
3770.63	H_{11}	$2p\ ^2P - 11d\ ^2D$	4.370+4	R	Gr90
3773.98	[Fe VI]	$3d\ ^4F_{3/2} - 3d\ ^2P_{1/2}$		C	
3774.00	O III	$3s\ ^3P_1 - 3p\ ^3D_1$	4.290+7	B,R,Ch	E84
3777.07	[Fe V]	$3d\ ^5D_0 - 3d\ ^3P_2$		C	
3777.07	Ne II	$3s\ ^4P_{1/2} - 3p\ ^4P_{3/2}$		R	
3781.62	F II	$3s'\ ^3D_2 - 3p'\ ^1F_3$		R,D	
3781.68	He II	4–21	1.460+4	R	R80
3783.47	[Fe V]	$3d\ ^5D_2 - 3d\ ^3F_3$		C	
3784.86	He I	$2d\ ^1P_1 - 12d\ ^1D_2$	5.550+5	R	T87
3791.26	O III	$3s\ ^3P_2 - 3p\ ^3D_2$	2.490+7	B,R,Ch	E84
3795.23	[Fe V]	$3d\ ^5D_2 - 3d\ ^3F_2$		C	
3796.3	Si III	$4p\ ^3P_1 - 4d\ ^3D_2$		R	
3796.33	He II	4–20	1.880+4	R	R80
3796.7	[S III]	$3p^2\ ^3P_2 - 3p^2\ ^1S_0$	0.105−1	C	KL80
3797.90	H_{10}	$2p\ ^2P - 10d\ ^2D$	7.080+4	R	Gr90
3805.74	He I	$2p\ ^1P_1 - 11d\ ^1D_2$	7.240+5	R	T87
3810.80	O III	$3s\ ^3P_2 - 3p\ ^3D_1$		B,R,Ch	

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
3813.49	He II	4–19	2.440+4	R	R80
3814.56	F II	$3p'\,^3P_1 - 3d'\,^3S_1$		R,D	
3819.61	He I	$2p\,^3P_{1,2} - 6d\,^3D_{1-3}$	5.720+6	R	T87
3819.76	He I	$2p\,^3P_0 - 6d\,^3D_1$	3.580+6	R	T87
3829.75	Ne II	$3p\,^2P_{3/2} - 3d\,^2D_{5/2}$	8.400+7	R	R80
3829.79	N II	$3p\,^3P_1 - 4s\,^3P_2$	1.500+7	R	R80
3833.55	He I	$2p\,^1P_1 - 10d\,^1D_2$	9.720+5	R	T87
3833.78	He II	2–10	2.850+5	R	Kh93
3833.80	He II	4–18	3.210+4	R	R80
3835.38	H_9	$2p\,^2P - 9d\,^2D$	1.210+5	R	Gr90
3839.27	[Fe V]	$3d^4(a^5D_3 - a^3F_3)$		C	
3842.82	O II	$3p\,^4D_{1/2} - 3d\,^4D_{3/2}$	1.460+7	R	NS84
3851.20	[Fe V]	$3d^5D_3 - 3d^3F_2$		C	
3853.66	Si II	$3p^2\,^2D_{3/2} - 4p\,^2P_{3/2}$		R	
3856.02	Si II	$3p^2\,^2D_{5/2} - 4p\,^2P_{3/2}$		R	
3857.81	Ne II	$3p'\,^2P_{1/2} - 4d\,^2D_{3/2}$		R,D	
3858.07	He II	4–17	4.300+4	R	R80
3862.59	Si II	$3p^2\,^2D_{3/2} - 4p\,^2P_{1/2}$		R	
3867.48	He I	$2p\,^3P_{2,1} - 6s\,^3S_1$	2.120+6	R	T87
3867.63	He I	$2p\,^3P_0 - 6s\,^3S_1$	2.640+5	R	T87
3868.76	[Ne III]	$2p^4\,^3P_2 - 2p^4\,^1D_2$	0.171+0	C	M83
3871.79	He I	$2p\,^1P_1 - 9d\,^1D_2$	1.350+6	R	T87
3875.50	O II]	$3p\,^4D_{7/2} - 3d\,^2F_{5/2}$		R	
3883.82	C III	$4d\,^3D_1 - 5f\,^3F_2$	9.030+7	R,D	NS84
3885.94	C III	$4d\,^3D_2 - 5f\,^3F_3$	9.560+7	R	NS84
3887.44	He II	4–16	5.860+4	R	R80
3887.57	N I	$3s\,^2P_{1/2} - 5p\,^2D_{3/2}$	6.410+6	R	NS84
3888.65	He I	$2s\,^3S_1 - 3p\,^3P_{0-2}$	9.120+6	R	T87
3889.05	H_8	2–8	2.210+5	R	S77
3891.28	[Fe V]	$^5D_4 - {}^3F_4$		C	
3895.22	[Fe V]	$^5D_3 - {}^3P_2$		C	
3918.98	C II	$3p\,^2P_{1/2} - 4s\,^2S_{1/2}$	1.810+8	R,NF	B85
3920.69	C II	$3p\,^2P_{3/2} - 4s\,^2S_{1/2}$	1.810+8	R,NF	B85
3923.48	He II	4–15	8.160+4	R	R80
3924.47	Si III	$4f\,^1F_3 - 5g\,^1G_4$		R	
3926.53	He I	$2p\,^1P_1 - 8d\,^1D_2$	1.950+6	R	T87
3954.37	O II	$3s\,^2P_{1/2} - 3p\,^2P_{1/2}$	4.320+7	R	NS84
3956.74	O IV	$3s'\,^4P_{3/2} - 3d'\,^4P_{3/2}$		R,D	
3960.7	[F IV]	$2p^2\,^3P_0 - 2p^2\,^1D_2$	6.400−6	C	G68
3961.59	O III	$3p\,^1D_2 - 3d\,^1F_3$	1.500+8	R	E84
3964.73	He I	$2s\,^1S_0 - 4p\,^1P_1$	6.830+6	R	T87
3967.47	[Ne III]	$2p^4\,^3P_1 - 2p^4\,^1D_2$	0.542−1	C	M83
3968.43	He II	4–14	1.160+5	R	R80
3970.07	H_7	$2p\,^2P - 7d\,^2D$	4.390+5	R	S77
3996.3	[Ca V]	$3p^4\,^1D_2 - 3p^4\,^1S_0$	3.730+0	C	M83
3997.4	[F IV]	$2p^2\,^3P_1 - 2p^2\,^1D_2$	0.340−1	C	G68
4003.58	N III	$4d\,^2D_{5/2} - 5f\,^2F_{7/2}$	1.820+8	R,D	NS84
4007.91	[Fe III]	$a^5D_4 - a^3G_4$		C	
4009.27	He I	$2p\,^1P_1 - 7d\,^1D_2$	2.980+6	R	T87
4011.60	[Na V]	$2p^3\,^2D_{5/2} - 2p^3\,^2P_{3/2}$		C	
4012.7	[Ne III]	$2p^4\,^3P_0 - 2p^4\,^1D_2$	8.510−6	C	M83

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
4025.60	He II	4–13	1.710+5	R	R80
4026.13	He I	$2p\ ^3P_{1,2} - 5d\ ^3D_{1-3}$	1.030+7	R	T87
4026.36	He I	$2p^3P_0 - 5d^3D_1$	6.440+6	R	T87
4033.18	O II	$3d\ ^4F_{3/2} - 4f\ ^4F_{3/2}$	2.300+7	R	NS84
4035.09	O II	$3d\ ^4F_{5/2} - 4f\ ^2F_{5/2}$		R	
4046.5	[Fe III]	$3d^6(a^5D_3 - a^3G_3)$		C	
4047.80	O II	$3d\ ^4F_{7/2} - 4f\ ^4F_{7/2}$	2.200+7	R	NS84
4056.06	C III	$4d\ ^1D_2 - 5f\ ^1F_3$	2.520+8	R,D	Kh81
4057.76	N IV	$3p\ ^1P_1 - 3d\ ^1D_2$	7.080+7	R	Kh81
4060.2	[F IV]	$2p^2\ ^3P_2 - 2p^2\ ^1D_2$	0.098+0	C	G68
4068.7	[S II]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2P_{3/2}$	0.225+0	C	M83
4068.91	C III	$4f\ ^3F_3 - 5g\ ^3G_4$	3.070+8	R,D	NS84
4069.64	O II	$3p\ ^4D_{1/2} - 3d\ ^4F_{3/2}$	1.420+8	R	NS84
4069.90	O II	$3p\ ^4D_{3/2} - 3d\ ^4F_{3/2}$	1.520+8	R	NS84
4070.26	C III	$4f\ ^3F_4 - 5g\ ^3G_5$	3.270+8	R	NS84
4071.3	[Fe V]	$^5D_2 - ^3P_1$		C	
4072.16	O II	$3p\ ^4D_{5/2} - 3d\ ^4F_{7/2}$	1.740+8	R	NS84
4073.90	O III	$3s'\ ^3P_1 - 3p'\ ^3D_2$	3.110+7	R,D	NS84
4076.20	[S II]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2P_{1/2}$	0.906−1	C	M83
4077.78	C II	$3d'\ ^4D_{7/2} - 4f'\ ^2F_{7/2}$		R	
4078.86	O II	$3p\ ^4D_{3/2} - 3d\ ^4F_{3/2}$	5.680+7	R	NS84
4081.10	O III	$3s'\ ^3P_2 - 3p'\ ^3D_3$	4.140+7	R	NS84
4085.12	O II	$3p\ ^4D_{5/2} - 3d\ ^4F_{5/2}$	4.950+7	R	NS84
4087.16	O II	$3d\ ^4F_{3/2} - 4f\ ^4G_{5/2}$	2.240+8	R	R80
4089.29	O II	$3d\ ^4F_{9/2} - 4f\ ^4G_{11/2}$	2.620+8	R	R80
4092.80	O II	$3p\ ^4D_{7/2} - 3d\ ^4F_{7/2}$	2.900+7	R	NS84
4097.0	[K VI]	$3p^2\ ^1D_2 - 3p^2\ ^1S_0$	4.100+0	C	G68
4097.33	N III	$3s\ ^2S_{1/2} - 3p\ ^2P_{3/2}$	1.190+8	R	B85
4100.04	He II	4–12	2.590+5	R	R80
4101.74	H_δ	$2p\ ^2P - 6d\ ^2D$	9.730+5	R	S77
4102.94	Si I]	$3p^2\ ^1S_0 - 4s\ ^3P_1$		C	
4103.43	N III	$3s\ ^2S_{1/2} - 3p\ ^2P_{1/2}$	1.190+8	R	B85
4107.07	O II	$3d\ ^4F_{5/2} - 4f\ ^4D_{7/2}$	3.790+3	R	NS84
4115.83	Si IV	$4s\ ^2S_{1/2} - 4p\ ^2P_{1/2}$		R	
4119.22	O II	$3p\ ^4P_{5/2} - 3d\ ^4D_{7/2}$	1.480+8	R	R80
4120.82	He I	$2p\ ^3P_{1,2} - 5s\ ^3S_1$	3.860+6	R	T87
4120.55	O II	$3p\ ^4P_{5/2} - 3d\ ^4D_{3/2}$	7.600+6	R	NS84
4120.99	He I	$2p\ ^3P_{2-0} - 5s\ ^3S_1$	4.820+5	R	T87
4121.84	C III	$4p\ ^1P_1 - 5d\ ^1D_2$	1.090+8	R	NS84
4122.46	[K V]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2D_{5/2}$	4.590−3	C	M83
4128.75	[Fe III]	$3d^6(a^5D_1 - a^3G_3)$		C	
4143.76	He I	$2p\ ^1P_1 - 6d\ ^1D_2$	4.910+6	R	T87
4146.06	O II	$3p\ ^6P_{7/2} - 3d\ ^6D_{7/2}$		R	
4152.51	C III	$3p'\ ^3D_1 - 5f\ ^3F_2$	1.090+8	R,D	Kh81
4156.45	O II	$3p\ ^4P_{5/2} - 3d\ ^4P_{3/2}$	4.350+7	R	NS84
4156.49	C III	$3p'\ ^3D_2 - 5f\ ^3F_3$	1.150+8	R,D	Kh81
4157.5	[F II]	$2p^4\ ^1D_2 - 2p^4\ ^1S_0$	2.100+0	C	G68
4162.86	C III	$3p'\ ^3D_3 - 5f\ ^3F_4$	1.300+8	R,D	Kh81
4163.05	[K V]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2D_{3/2}$		C	
4163.30	[K V]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2D_{3/2}$	0.884−1	C	M83
4168.97	He I	$2p\ ^1P_1 - 6s\ ^1S_0$	1.100+6	R	T87

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
4180.59	[Fe V]	$^5D_1 - {}^3P_0$		C	
4185.46	O II	$3p'\,^2F_{5/2} - 3d'\,^2G_{7/2}$		R	
4186.90	C III	$4f\,^1F_3 - 5g\,^1G_4$	4.310+8	R,D	Kh81
4189.79	O II	$3p'\,^2F_{7/2} - 3d'\,^2G_{9/2}$	1.980+8	R,D	NS84
4195.76	N III	$3s'\,^2P_{1/2} - 3p'\,^2D_{3/2}$		R,D	
4199.83	He II	4–11	4.090+5	R	R80
4227.19	[Fe V]	$a^5D_4 - a^3H_4$		C	
4229.27	[Fe V]	$a^5D_2 - a^3P_0$		C	
4244.0	[Fe II]	$a^4F_{9/2} - a^4G_{11/2}$		C	
4247.31	C III	$3p'\,^1P_1 - 5p\,^1P_1$	1.060+7	R	NS84
4253.74	O II	$3d'\,^2G_{9/2} - 4f'\,^2H_{9,11/2}$		R,D	
4253.98	O II	$3d'\,^2G_{7/2} - 4f'\,^2H_{9/2}$		R,D	
4267.00	C II	$3d\,^2D_{3/2} - 4f\,^2F_{5/2}$	2.220+8	R	B85
4267.26	C II	$3d\,^2D_{5/2} - 4f\,^2F_{7/2}$	2.380+8	R	B85
4275.52	O II	$3d\,^4D_{7/2} - 4f\,^4F_{9/2}$		R	
4276.71	O II	$3d\,^4P_{3/2} - 4f\,^4D_{1/2}$		R	
4276.71	O II	$3d\,^4D_{5/2} - 4f\,^4F_{7/2}$	1.820+8	R	R80
4276.71	O II]	$3d\,^4D_{5/2} - 4f\,^2F_{5/2}$		R	
4287.0	[Fe II]	$a^6D_{9/2} - a^6S_{5/2}$		C	
4295.24	O II	$3d\,^4P_{3/2} - 4f\,^4D_{5/2}$		R	
4303.83	O II	$3d\,^4P_{5/2} - 4f\,^4D_{7/2}$		R	
4325.56	C III	$3s'\,^1P_1 - 3p'\,^1D_2$	8.070+7	R,D	NS84
4338.67	He II	4–10	6.760+5	R	R80
4340.47	H_γ	$2p\,^2P - 5d\,^2D$	2.530+6	R	S77
4349.43	O II	$3s\,^4P_{5/2} - 3p\,^4P_{5/2}$	7.400+7	R	R80
4359.0	[Fe II]	$a^6D_{7/2} - a^6S_{5/2}$		C	
4363.21	[O III]	$2p^2\,^1D_2 - 2p^2\,^1S_0$	1.780+0	C	M83
4366.84	O II	$3s\,^4P_{5/2} - 3p\,^4P_{3/2}$		R	
4368.25	O I	$3s\,^3S_1 - 4p\,^3P_{2-0}$		R	
4379.11	N III	$4f\,^2F - 5g\,^2G$	3.560+8	R	NS84
4387.93	He I	$2p\,^1P_1 - 5d\,^1D_2$	9.100+6	R	T87
4414.91	O II	$3s\,^2P_{3/2} - 3p\,^2D_{5/2}$	1.150+8	R	R80
4416.98	O II	$3s\,^2P_{1/2} - 3p\,^2D_{3/2}$	9.500+7	R	R80
4437.55	He I	$2p\,^1P_1 - 5s\,^1S_0$	3.210+6	R	T87
4447.99	O II	$3p\,^2F_{7/2} - 3d\,^2F_{7/2}$		R	
4452.73	O II	$3s\,^2P_{3/2} - 3p\,^2D_{3/2}$		R	
4471.48	He I	$2p\,^3P_{1,2} - 4d\,^3D_{1-3}$	2.190+7	R	T87
4471.68	He I	$2p\,^3P_0 - 4d\,^3D_1$	1.370+7	R	T87
4481.13	Mg II	$3d\,^2D_{5/2} - 4f\,^2F_{7/2}$		R	
4491.25	O II	$3d\,^2P_{3/2} - 4f\,^2D_{5/2}$	1.100+8	R	NS84
4506.9	[S I]	$3p^4\,^3P_2 - 3p^4\,^1S_0$	8.230−3	C	M83
4510.94	[K IV]	$3p^4\,^1D_2 - 3p^4\,^1S_0$	3.180+0	C	M83
4514.86	N III	$3s'\,^4P_{5/2} - 3p'\,^4D_{7/2}$		R,D	
4516.77	C III	$4p\,^3P_2 - 5s\,^3S_1$	1.660+8	R	NS84
4518.15	N III	$3s'\,^4P_{1/2} - 3p'\,^4D_{1/2}$		R,D	
4523.58	N III	$3s'\,^4P_{3/2} - 3p'\,^4D_{3/2}$		R,D	
4534.58	N III	$3s'\,^4P_{5/2} - 3p'\,^4D_{5/2}$		R,D	
4541.59	He II	4–9	1.210+6	R	R80
4544.85	N III	$4p\,^2P_{3/2} - 5s\,^2S_{1/2}$	8.290+7	R	NS84
4552.00	Si III	$4s\,^3S_1 - 4p\,^3P_2$		R	

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
4562.60	Mg I]	$3s^2\,{}^1S_0 - 3p\,{}^3P_2$	4.130−4	C	M83
4568.50	O IV	$5f\,{}^2F - 6d\,{}^2D$		R	
4571.10	Mg I]	$3s^2\,{}^1S_0 - 3p\,{}^3P_1$	1.800+2	C	M83
4571.0	[Ca VII]	$3p^2\,{}^3P_0 - 3p^2\,{}^1D_2$	2.100−4	C	G68
4589.0	[S I]	$3p^4\,{}^3P_1 - 3p^4\,{}^1S_0$	0.350+0	C	M83
4590.97	O II	$3s'\,{}^2D_{5/2} - 3p'\,{}^2F_{7/2}$	8.510+7	R	NS84
4596.17	O II	$3s'\,{}^2D_{3/2} - 3p'\,{}^2F_{5/2}$	7.940+7	R	NS84
4603.73	N V	$3s\,{}^2S_{1/2} - 3p\,{}^2P_{3/2}$	4.120+7	R	R80
4606.6	[Fe III]	$a^5D_4 - a^3F_3$		C	
4618.40	C II	$3d'\,{}^2F_{5/2} - 4f'\,{}^2G_{7/2}$	2.550+8	R	NS84
4619.98	N V	$3s\,{}^2S_{1/2} - 3p\,{}^2P_{1/2}$	4.080+7	R	R80
4620.10	C II	$3d'\,{}^2F - 4f'\,{}^2G$		R	
4621.39	N II	$3s\,{}^3P_1 - 3p\,{}^3P_0$	9.000+7	R	R80
4621.57	[C I]	$2p^2\,{}^3P_1 - 2p^2\,{}^1S_0$	2.710−3	C	M83
4624.93	[Ar V]	$3p^2\,{}^1D_2 - 3p^2\,{}^1S_0$	3.290+0	C	KL80
4627.35	[C I]	$2p^2\,{}^3P_2 - 2p^2\,{}^1S_0$	2.000−5	C	M83
4631.89	O IV	$5g\,{}^2G - 6h\,{}^2H$		R	
4634.14	N III	$3p\,{}^2P_{1/2} - 3d\,{}^2D_{3/2}$	5.660+7	R,D	B85
4640.64	N III	$3p\,{}^2P_{3/2} - 3d\,{}^2D_{5/2}$	6.790+7	R,D	B85
4641.85	N III	$3p\,{}^2P_{3/2} - 3d\,{}^2D_{3/2}$	1.130+7	R,D	B85
4647.42	C III	$3s\,{}^3S_1 - 3p\,{}^3P_2$	7.180+7	R,D	NS84
4649.14	O II	$3s\,{}^4P_{5/2} - 3p\,{}^4D_{7/2}$	8.570+7	R	NS84
4650.25	C III	$3s\,{}^3S_1 - 3p\,{}^3P_1$	7.180+7	R,D	NS84
4651.47	C III	$3s\,{}^3S_1 - 3p\,{}^3P_0$	7.180+7	R,D	NS84
4658.0	[Fe III]	$a^5D - a^3F$		C	
4658.30	C IV	$5g\,{}^2G - 6h\,{}^2H$		R	
4661.63	O II	$3s\,{}^4P_{3/2} - 3p\,{}^4D_{3/2}$	5.200+7	R	R80
4663.64	C III	$3s'\,{}^3P_1 - 3p'\,{}^3P_0$		R,D	
4665.61	C IV	$5f\,{}^2F - 6d\,{}^2D$		R	
4665.86	C III	$3s'\,{}^3P_2 - 3p'\,{}^3P_2$		R,D	
4669.20	[P II]	$3p^2\,{}^3P_1 - 3p^2\,{}^1S_0$		C	
4673.75	O II	$3s\,{}^4P_{3/2} - 3p\,{}^4D_{1/2}$		R	
4676.23	O II	$3s\,{}^4P_{5/2} - 3p\,{}^4D_{5/2}$		R	
4678.14	N II	$3d\,{}^1P_1 - 4f\,{}^1D_2$		R	
4685.71	He II	3–4	1.430+8	R	R80
4701.3	[Fe III]	$a^5D_3 - a^3F_3$		C	
4711.15	[Ar IV]	$3p^3\,{}^4S_{3/2} - 3p^3\,{}^2D_{5/2}$	1.770−3	C	M83
4713.14	He I	$2p\,{}^3P_{1,2} - 4s\,{}^3S_1$	8.270+6	R	T87
4713.38	He I	$2p\,{}^3P_0 - 4s\,{}^3S_1$	1.030+6	R	T87
4714.3	[Ne IV]	$2p^3\,{}^2D_{5/2} - 2p^3\,{}^2P_{3/2}$	0.400+0	C,Au	M83
4715.7	[Ne IV]	$2p^3\,{}^2D_{5/2} - 2p^3\,{}^2P_{1/2}$	0.115+0	C,Au	M83
4724.3	[Ne IV]	$2p^3\,{}^2D_{3/2} - 2p^3\,{}^2P_{3/2}$	0.437+0	C,Au	M83
4725.7	[Ne IV]	$2p^3\,{}^2D_{3/2} - 2p^3\,{}^2P_{1/2}$	0.393+0	C,Au	M83
4733.0	[Fe III]	$a^5D_2 - a^3F_2$		C	
4736.6	[P II]	$3p^2\,{}^3P_2 - 3p^2\,{}^1S_0$		C	
4740.18	[Ar IV]	$3p^3\,{}^4S_{3/2} - 3p^3\,{}^2D_{3/2}$	0.223−1	C	M83
4754.90	[Fe III]	${}^5D_3 - {}^3F_4$		C	
4789.45	[F II]	$2p^4\,{}^3P_2 - 2p^4\,{}^1D_2$	0.038+0	C	G68
4859.32	He II	4–8	2.280+6	R	R80
4861.29	H_β	$2p\,{}^2P - 4d\,{}^2D$	8.420+6	R	S77
4868.99	[F II]	$2p^4\,{}^3P_1 - 2p^4\,{}^1D_2$	0.012+0	C	G68

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
4893.42	[Fe VII]	$^3F_2 - {}^3P_1$		C	
4904.80	N III	$4d\ ^2D_{5/2} - 5p\ ^2P_{3/2}$		R	
4904.56	[F II]	$2p^4\ ^3P_0 - 2p^4\ ^1D_2$	4.100−6	C	G68
4906.60	O II	$3p^4S_{3/2} - 3d^4P_{3/2}$		R	
4921.93	He I	$2p\ ^1P_1 - 4d\ ^1D_2$	1.990+7	R	T87
4930.27	O V	$6h\ ^{3,1}H - 7i\ ^{3,1}I$		R	
4931.78	[O III]	$2p^2\ ^3P_0 - 2p^2\ ^1D_2$	2.740−6	C	M83
4938.6	[Ca VII]	$3p^2\ ^3P_1 - 3p^2\ ^1D_2$	1.200+0	C	G68
4944.6	[Fe VII]	$^3F_3 - {}^3P_2$		C	
4959.52	[O III]	$2p^2\ ^3P_1 - 2p^2\ ^1D_2$	6.740−3	C,Au	M83
4972.47	[Fe VI]	$^4F_{5/2} - {}^2G_{7/2}$		C	
4988.8	[Fe VII]	$a^3F_2 - a^3P_0$		C	
5007.57	[O III]	$2p^2\ ^3P_2 - 2p^2\ ^1D_2$	0.196−1	C,Au	M83
5015.67	He I	$2s\ ^1S_0 - 3p\ ^1P_1$	1.310+7	R	T87
5032.07	C II	$2p^3\ ^2P_{3/2} - 3p'\ ^2D_{5/2}$		R,D	
5041.0	[Fe IV]	$3d^5\ ^4G - 3d^5\ ^4F$		C	
5041.03	Si II	$4p\ ^2P_{1/2} - 4d\ ^2D_{3/2}$	9.800+7	R	R80
5047.74	He I	$2p\ ^1P_1 - 4s\ ^1S_0$	6.670+6	R	T87
5055.98	Si II	$4p\ ^2P_{3/2} - 4d\ ^2D_{5/2}$	1.200+8	R	R80
5114.07	O V	$3s\ ^1S_0 - 3p\ ^1P_1$	1.700+7	R	R80
5145.75	[Fe VI]	$^4F_{7/2} - {}^2G_{7/2}$		C	
5151.0	[Fe III]	$a^5D_4 - a^3P_2$		C	
5158.9	[Fe VII]	$^3F_3 - {}^3P_1$		C	
5176.04	[Fe VI]	$^4F_{9/2} - {}^2G_{9/2}$		C	
5191.8	[Ar III]	$3p^4\ ^1D_2 - 3p^4\ ^1S_0$	2.590+0	C	M83
5197.90	[N I]	$2p^3\ ^4S_{3/2} - 2p^3\ ^2D_{3/2}$	2.020−5	C	M83
5200.26	[N I]	$2p^3\ ^4S_{3/2} - 2p^3\ ^2D_{5/2}$	7.270−6	C	M83
5269.2	[K VI]	$3p^2\ ^3P_0 - 3p^2\ ^1D_2$	1.100−4	C	G68
5270.3	[Fe III]	$a^5D_3 - a^3P_2$		C	
5277.8	[Fe VII]	$^3F_4 - {}^3P_2$		C	
5309.2	[Ca V]	$3p^4\ ^3D_2 - 3p^4\ ^1D_2$	1.900+0	C	M83
5323.3	[C IIV]	$3p^2\ ^1D_2 - 3p^2\ ^1S_0$	2.800+0	C	KL80
5335.18	[Fe VI]	$^4F_{3/2} - {}^4P_{1/2}$		C	
5411.52	He II	4–7	4.860+6	R	R80
5424.22	[Fe VI]	$^4F_{5/2} - {}^4P_{3/2}$		C	
5426.64	[Fe VI]	$^4F_{7/2} - {}^4P_{5/2}$		C	
5484.84	[Fe VI]	$^4F_{5/2} - {}^4P_{1/2}$		C	
5517.72	[Cl III]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2D_{5/2}$	7.040−4	C	M83
5537.89	[Cl III]	$3p^3\ ^4S_{3/2} - 3p^3\ ^2D_{3/2}$	4.830−3	C	M83
5577.34	[O I]	$2p^4\ ^1D_2 - 2p^4\ ^1S_0$	1.220+0	C	M83
5592.37	O III	$3s\ ^1P_1 - 3p\ ^1P_1$	4.120+7	C,Ch	E84
5603.2	[K VI]	$3p^2\ ^3P_1 - 3p^2\ ^1D_2$	0.530+0	C	G68
5614.7	[Ca VII]	$3p^2\ ^3P_2 - 3p^2\ ^1D_2$	2.500+0	C	G68
5631.07	[Fe VI]	$^4F_{7/2} - {}^4P_{3/2}$		C	
5666.63	N II	$3s\ ^3P_1 - 3p\ ^3D_2$	4.230+7	R	R80
5676.95	[Fe VI]	$^4F_{9/2} - {}^4P_{5/2}$		C	
5679.56	N II	$3s\ ^3P_2 - 3p\ ^3D_3$	5.600+7	R	R80
5695.92	C III	$3p\ ^1P_1 - 3d\ ^1D_2$	4.980+7	R	Kh81
5696.4	[Fe I]	$4s^2\ ^5D_4 - 4s\ ^5P_3$		C	
5721.1	[Fe VII]	$^3F_2 - {}^1D_2$		C	

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
5721.2	[F III]	$2p^3\,^2D_{5/2} - 2p^3\,^2P_{1/2}$	0.088+0	C	G68
5733.0	[F III]	$2p^3\,^2D_{3/2} - 2p^3\,^2P_{1/2}$	0.160+0	C	G68
5733.0	[F III]	$2p^3\,^2D_{3/2} - 2p^3\,^2P_{3/2}$	0.114+0	C	G68
5754.59	[N II]	$2p^2\,^1D_2 - 2p^2\,^1S_0$	1.120+0	C	M83
5776.4	[Mn VI]	$3d^2\,^3F_3 - 3d^2\,^3P_1$		C	
5784.94	He II	5–40	4.630+2	R	R80
5789.72	He II	5–39	5.260+2	R	R80
5794.88	He II	5–38	6.000+2	R	R80
5800.48	He II	5–37	6.860+2	R	R80
5801.33	C IV	$3s^2S_{1/2} - 3p^2P_{3/2}$	3.190+7	NF,R,Ch	R80
5806.56	He II	5–36	7.870+2	R	R80
5811.98	C IV	$3s^2S_{1/2} - 3p^2P_{1/2}$	3.160+7	NF,R,Ch	R80
5813.19	He II	5–35	9.080+2	R	R80
5820.43	He II	5–34	1.050+3	R	R80
5828.36	He II	5–33	1.220+3	R	R80
5837.06	He II	5–32	1.430+3	R	R80
5846.65	He II	5–31	1.670+3	R	R80
5857.26	He II	5–30	1.980+3	R	R80
5863.0	[Mn V]	$3d^3\,^4F_{7/2} - 3d^3\,^2G_{7/2}$		C	
5867.82	Si II	$4s\,^4P_{5/2} - 4p\,^4P_{5/2}$		R	
5869.02	He II	5–29	2.350+3	R	R80
5875.62	He I	$2p\,^3P_{1,2} - 3d\,^3D_{1-3}$	6.280+7	R	T87
5875.97	He I	$2p\,^3P_0 - 3d\,^3D_1$	3.930+7	R	T87
5882.12	He II	5–28	2.800+3	R	R80
5889.77	C II	$3d\,^2D_{5/2} - 4p\,^2P_{3/2}$		R	
5891.0	[Mn V]	$3d^3\,^4F_{9/2} - 3d^3\,^2G_{9/2}$		C	
5894.0	[Mn VI]	$3d^2\,^3F - 3d^2\,^3P$		C	
5896.78	He II	5–27	3.370+3	R	R80
5913.24	He II	5–26	4.080+3	R	R80
5931.83	He II	5–25	4.980+3	R	R80
5952.93	He II	5–24	6.130+3	R	R80
5977.02	He II	5–23	7.610+3	R	R80
6004.72	He II	5–22	9.550+3	R	R80
6036.78	He II	5–21	1.210+4	R	R80
6074.19	He II	5–20	1.550+4	R	R80
6086.9	[Ca V]	$3p^4\,^3P_1 - 3p^4\,^1D_2$	0.426+0	C	M83
6086.9	[Fe VII]	$^3F_3 - {}^1D_2$		C	
6101.8	[K IV]	$3p^4\,^3P_2 - 3p^4\,^1D_2$	0.814+0	C	M83
6118.26	He II	5–19	2.020+4	R	R80
6133.42	[Ar V]	$3p^2\,^3P_0 - 3p^2\,^1D_2$	3.500−5	C	KL80
6152.9	[C III]	$3p^4\,^1D_2 - 3p^4\,^1S_0$	2.060+0	C	M83
6166.2	[Mn V]	$3d^3\,^4F_{7/2} - 3d^3\,^4P_{5/2}$		C	
6170.69	He II	5–18	2.670+4	R	R80
6218.6	[Mn V]	$3d^3\,^4F_{5/2} - 3d^3\,^4P_{3/2}$		C	
6221.0	[Mn V]	$3d^3\,^4F_{5/2} - 3d^3\,^4P_{1/2}$		C	
6223.0	[K V]	$3p^3\,^2D_{3/2} - 3p^3\,^2P_{3/2}$	1.860+0	C	M83
6228.4	[K VI]	$3p^2\,^3P_2 - 3p^2\,^1D_2$	1.100+0	C	G68
6233.82	He II	5–17	3.590+4	R	R80
6300.30	[O I]	$2p^4\,^3P_2 - 2p^4\,^1D_2$	6.340−3	C	M83
6310.85	He II	5–16	4.920+4	R	R80
6312.1	[S III]	$3p^2\,^1D_2 - 3p^2\,^1S_0$	2.220+0	C,Ch	KL80

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
6317.0	[K V]	$3p^3\,^2D_{5/2} - 3p^3\,^2P_{3/2}$	1.210+0	C	M83
6347.10	Si II	$4s\,^2S_{1/2} - 4p\,^2P_{3/2}$	7.000+7	R,D	R80
6349.0	[K V]	$3p^3\,^2D_{3/2} - 3p^3\,^2P_{1/2}$	1.250+0	C	M83
6363.77	[O I]	$2p^4\,^3P_1 - 2p^4\,^1D_2$	2.110−3	C	M83
6371.36	Si II	$4s\,^2S_{1/2} - 4p\,^2P_{1/2}$	6.900+7	R,D	R80
6391.74	[O I]	$2p^4\,^3P_0 - 2p^4\,^1D_2$	7.230−7	C	M83
6393.62	[Mn V]	$3d^3\,^4F_{9/2} - 3d^3\,^4P_{5/2}$		C	
6406.38	He II	5–15	6.880+4	R	R80
6428.2	[Ca V]	$3p^4\,^3P_0 - 3p^4\,^1D_2$	8.420−5	C	M83
6434.72	[Ar V]	$3p^2\,^3P_1 - 3p^2\,^1D_2$	0.204+0	C	KL80
6447.0	[K V]	$3p^3\,^2D_{5/2} - 3p^3\,^2P_{1/2}$	0.141+0	C	M83
6518.3	[Mn VI]	$3d^2\,^3F - 3d^2\,^1D$		C	
6527.10	He II	5–14	9.880+4	R	R80
6527.23	[N II]	$2p^2\,^3P_0 - 2p^2\,^1D_2$	5.350−7	C	M83
6548.05	[N II]	$2p^2\,^3P_1 - 2p^2\,^1D_2$	1.010−3	C	M83
6560.10	He II	4–6	1.230+7	R	R80
6562.85	H_α	$2p\,^2P - 3d\,^2D$	4.410+7	R	S77
6583.45	[N II]	$2p^2\,^3P_2 - 2p^2\,^1D_2$	2.990−3	C	M83
6598.76	[Fe VII]	$3d^2(^3F_4 - {}^1D_2)$		C	
6678.15	He I	$2p\,^1P_1 - 3d\,^1D_2$	6.370+7	R	T87
6683.90	He II	5–13	1.460+5	R	R80
6716.4	[S II]	$3p^3\,^4S_{3/2} - 3p^3\,^2D_{5/2}$	2.600−4	C	M83
6730.8	[S II]	$3p^3\,^4S_{3/2} - 3p^3\,^2D_{3/2}$	8.820−4	C	M83
6795.8	[K IV]	$3p^4\,^3P_1 - 3p^4\,^1D_2$	0.198+0	C	M83
6890.90	He II	5–12	2.240+5	R	R80
7005.58	[Ar V]	$3p^2\,^3P_2 - 3p^2\,^1D_2$	0.476+0	C	KL80
7065.19	He I	$2p\,^3P_{1,2} - 3s\,^3S_1$	2.430+7	R	T87
7065.71	He I	$2p\,^3P_0 - 3s\,^3S_1$	3.030+6	R	T87
7110.4	[K IV]	$3p^4\,^3P_0 - 3p^4\,^1D_2$	4.540−5	C	M83
7136.15	[Ar III]	$3p^4\,^3P_2 - 3p^4\,^1D_2$	0.314+0	C	M83
7170.70	[Ar IV]	$3p^3\,^2D_{3/2} - 3p^3\,^2P_{3/2}$	0.789+0	C	M83
7177.52	He II	5–11	3.590+5	R	R80
7231.32	C II	$3p\,^2P_{1/2} - 3d\,^2D_{3/2}$	3.600+7	R	R80
7236.42	C II	$3p\,^2P_{3/2} - 3d\,^2D_{5/2}$	4.400+7	R	R80
7238.14	[Ar IV]	$3p^3\,^2D_{5/2} - 3p^3\,^2P_{3/2}$	0.598+0	C	M83
7261.43	[Cl IV]	$3p^2\,^3P_0 - 3p^2\,^1D_2$	1.560−5	C	KL80
7262.96	[Ar IV]	$3p^3\,^2D_{3/2} - 3p^3\,^2P_{1/2}$	0.603+0	C	M83
7281.35	He I	$2p\,^1P_1 - 3s\,^1S_0$	1.810+7	R	T87
7318.63	[O II]	$2p^3\,^2D_{5/2} - 2p^3\,^2P_{1/2}$	0.615−1	C	M83
7319.43	[O II]	$2p^3\,^2D_{5/2} - 2p^3\,^2P_{3/2}$	0.117+0	C	M83
7329.90	[O II]	$2p^3\,^2D_{3/2} - 2p^3\,^2P_{1/2}$	0.102+0	C	M83
7330.70	[O II]	$2p^3\,^2D_{3/2} - 2p^3\,^2P_{3/2}$	0.614−1	C	M83
7332.15	[Ar IV]	$3p^3\,^2D_{5/2} - 3p^3\,^2P_{1/2}$	0.119+0	C	M83
7530.83	[Cl IV]	$3p^2\,^3P_1 - 3p^2\,^1D_2$	0.723−1	C	KL80
7592.75	He II	5–10	6.080+5	R	R80
7724.7	[S I]	$3p^4\,^1D_2 - 3p^4\,^1S_0$	1.530+0	C	M83
7751.43	[Ar III]	$3p^4\,^3P_1 - 3p^4\,^1D_2$	0.823−1	C	M83
7876.00	[P II]	$3p^2\,^1D_2 - 3p^2\,^1S_0$		C	
8036.76	[Ar III]	$3p^4\,^3P_0 - 3p^4\,^1D_2$	2.210−5	C	M83
8046.27	[Cl IV]	$3p^2\,^3P_2 - 3p^2\,^1D_2$	0.179+0	C	KL80
8196.48	C III	$5g\,^{1,3}G - 6h\,^{1,3}H$	1.380+8	R	Kh81

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
8236.78	He II	5–9	1.100+6	R	R80
8347.6	[Fe I]	$4s^2\,^5D_4 - 4s\,^3F_4$		C	
8433.94	[Cl III]	$3p^3\,^2D_{3/2} - 3p^3\,^2P_{3/2}$	0.323+0	C	M83
8481.16	[Cl III]	$3p^3\,^2D_{5/2} - 3p^3\,^2P_{3/2}$	0.316+0	C	M83
8500.20	[Cl III]	$3p^3\,^2D_{3/2} - 3p^3\,^2P_{1/2}$	0.303+0	C	M83
8502.48	H I(P_{16})	$3d\,^2D - 16f\,^2F$	4.650+3	R	Gr90
8545.38	H I(P_{22})	$3d\,^2D - 15f\,^2F$	6.450+3	R	Gr90
8548.17	[Cl III]	$3p^3\,^2D_{5/2} - 3p^3\,^2P_{1/2}$	0.100+0	C	M83
8579.5	[C III]	$3p^4\,^3P_2 - 3p^4\,^1D_2$	0.104+0	C	M83
8598.39	H I(P_{14})	$3d\,^2D - 14f\,^2F$	9.160+3	R	Gr90
8663.65	C III	$5f\,^3F_3 - 6g\,^3G_4$		R	
8665.02	H I(P_{13})	$3d\,^2D - 13f\,^2F$	1.340+4	R	Gr90
8727.13	[C I]	$2p^2\,^1D_2 - 2p^2\,^1S_0$	0.528+0	C	M83
8750.47	H I(P_{12})	$3d\,^2D - 12f\,^2F$	2.010+4	R	Gr90
8831.5	[S III]	$3p^2\,^3P_0 - 3p^2\,^1D_2$	5.820−6	C	M83
8862.78	H I(P_{11})	$3d\,^2D - 11f\,^2F$	3.140+4	R	Gr90
9014.91	H I(P_{10})	$3d\,^2D - 10f\,^2F$	5.130+4	R	Gr90
9069.4	[S III]	$3p^2\,^3P_1 - 3p^2\,^1D_2$	0.221−1	C,Ch	KL80
9125.8	[C III]	$3p^4\,^3P_1 - 3p^4\,^1D_2$	0.292−1	C	M83
9229.02	H I(P_9)	$3d\,^2D - 9f\,^2F$	8.850+4	R	Gr90
9344.94	He II	5–8	2.210+6	R	R80
9381.8	[C III]	$3p^4\,^3P_0 - 3p^4\,^1D_2$	9.820−6	C	M83
9412.0	N III	$4s\,^2S_{1/2} - 4p\,^2P_{3/2}$		R	
9532.1	[S III]	$3p^2\,^3P_2 - 3p^2\,^1D_2$	0.576−1	C	KL80
9545.97	H I(P_8)	$3d\,^2D - 8f\,^2F$	1.640+5	R	Gr90
9715.11	C III	$3p\,^3P - 3d\,^3D$		R	
9808.32	[C I]	$2p^2\,^3P_0 - 2p^2\,^1D_2$	7.770−8	C	M83
9824.13	[C I]	$2p^2\,^3P_1 - 2p^2\,^1D_2$	8.210−5	C	M83
9850.26	[C I]	$2p^2\,^3P_2 - 2p^2\,^1D_2$	2.440−4	C	M83
10049.37	HI–P_δ	$3d^2D - 7f\,^2F$	3.360+5	R	S77
10123.61	He II	4–5	4.320+7	R	R80
10287.1	[S II]	$3p^3\,^2D_{3/2} - 3p^3\,^2P_{3/2}$	0.133+0	C	M83
10320.6	[S II]	$3p^3\,^2D_{5/2} - 3p^3\,^2P_{3/2}$	0.179+0	C	M83
10338.8	[S II]	$3p^3\,^2D_{3/2} - 3p^3\,^2P_{1/2}$	0.163+0	C	M83
10371.27	Si I	$4s\,^3P_1 - 4p\,^3S_1$		R	
10372.6	[S II]	$3p^3\,^2D_{5/2} - 3p^3\,^2P_{1/2}$	0.779−1	C	M83
10397.74	[N I]	$2p^3\,^2D_{5/2} - 2p^3\,^2P_{3/2}$	0.614−1	C	M83
10398.16	[N I]	$2p^3\,^2D_{5/2} - 2p^3\,^2P_{1/2}$	0.345−1	C	M83
10407.17	[N I]	$2p^3\,^2D_{3/2} - 2p^3\,^2P_{3/2}$	0.276−1	C	M83
10407.59	[N I]	$2p^3\,^2D_{3/2} - 2p^3\,^2P_{1/2}$	0.529−1	C	M83
10603.43	Si I	$4s\,^3P_1 - 4p\,^3P_2$		R	
10627.65	Si I	$4p\,^1P_1 - 4d\,^3P_2$		R	
10689.72	Si I	$4p\,^3D_1 - 4d\,^3F_2$		R	
10691.25	C I	$3s\,^3P_2 - 3p\,^3D_3$		R	
10819.8	[S I]	$3p^4\,^3P_2 - 3p^4\,^1D_2$	0.278−1	C	M83
10829.09	He I	$2s\,^3S_1 - 2p\,^3P_0$	1.020+7	R	T87
10830.25	He I	$2s\,^3S_1 - 2p\,^3P_1$	1.020+7	R	T87
10830.34	He I	$2s\,^3S_1 - 2p\,^3P_2$	1.020+7	R	T87
10938.10	HI–P_γ	$3d^2D - 6f\,^2F$	7.780+5	R	S77
10994.0	[Si I]	$3p^2\,^1D_2 - 3p^2\,^1S_0$	1.140+0	C	M83
11305.8	[S I]	$3p^4\,^3P_1 - 3p^4\,^1D_2$	8.160−3	C	M83
11540.1	[S I]	$3p^4\,^3P_0 - 3p^4\,^1D_2$	3.840−6	C	M83

Table 25. Continued

λ (Å)	*Ion*	*Transition*	A (s^{-1})	*Ex.M.*	*Ref*
11626.42	He II	5–7	5.180+6	R	R80
12818.08	HI–P_β	$3d\,^2D - 5f\,^2F$	2.200+6	R	S77
18636.78	He II	5–6	1.630+7	R	R80
18751.02	HI–P_α	$3d\,^2D - 4f\,^2F$	8.990+6	R	S77
20581.30	He I	$2s\,^1S_0 - 2p\,^1P_1$	1.970+6	R	T87
4.49μm	[Mg IV]	$2p^5\,^2P_{3/2} - 2p^5\,^2P_{1/2}$	0.199+0	C	M83
5.34	[Fe II]	$^6D_{9/2} - {}^4F_{9/2}$	4.170−5	C	NS88
5.61	[Mg V]	$2p^4\,^3P_2 - 2p^4\,^3P_1$	0.127+0	C	M83
6.62	[Ni II]	$^2P_{1/2} - {}^2P_{3/2}$		C	
6.98	[Ar II]	$3p^5\,^2P_{1/2} - 3p^5\,^2P_{3/2}$	5.270−2	C	M83
7.90	[Ar V]	$3p^2\,^3P_2 - 3p^2\,^3P_1$	0.272−1	C	KL80
8.99	[Ar III]	$3p^4\,^3P_1 - 3p^4\,^3P_2$	0.308−1	C	M83
10.52	[S IV]	$3p\,^2P_{3/2} - 3p\,^2P_{1/2}$	7.730−3	C	M83
11.76	[Cl IV]	$3p^2\,^3P_1 - 3p^2\,^3P_2$	8.250−3	C	KL80
12.8	[Ne II]	$2p^5\,^2P_{1/2} - 2p^5\,^2P_{3/2}$	8.550−3	C	M83
13.10	[Ar V]	$3p^2\,^3P_1 - 3p^2\,^3P_0$	7.990−3	C	KL80
13.5	[Mg V]	$2p^4\,^3P_1 - 2p^4\,^3P_0$	0.217−1	C	M83
14.3	[Ne V]	$2p^2\,^3P_2 - 2p^2\,^3P_1$	4.590−3	C	M83
15.6	[Ne III]	$2p^4\,^3P_1 - 2p^4\,^3P_2$	5.970−3	C	M83
18.7	[S III]	$3p^2\,^3P_2 - 3p^2\,^3P_1$	2.070−3	C	KL80
20.30	[Cl IV]	$3p^2\,^3P_0 - 3p^2\,^3P_1$	2.160−3	C	KL80
21.83	[Ar III]	$3p^4\,^3P_0 - 3p^4\,^3P_1$	5.170−3	C	M83
22.9	[Fe III]	$^5D_3 - {}^5D_4$		C	
24.3	[Ne V]	$2p^2\,^3P_1 - 2p^2\,^3P_0$	1.280−3	C	M83
25.91	[O IV]	$2p\,^2P_{3/2} - 2p\,^2P_{1/2}$	5.200−4	C	M83
25.98	[Fe II]	$4s(^6D_{7/2} - {}^6D_{9/2})$	2.130−3	C	NS88
32.59	[O III]	$2p^2\,^3P_0 - 2p^2\,^3P_2$	3.020−11	C	M83
33.0	[Fe III]	$a^5D_3 - a^5D_2$		C	
33.5	[S III]	$3p^2\,^3P_1 - 3p^2\,^3P_0$	4.720−4	C	KL80
34.81	[Si II]	$3p\,^2P_{1/2} - 3p\,^2P_{3/2}$	2.170−4	C	M83
35.3	[Fe II]	$3d^64s(^6D_{5/2} - {}^6D_{7/2})$		C	
36.1	[Ne III]	$2p^4\,^3P_0 - 2p^4\,^3P_1$	1.150−3	C	M83
36.33	[Fe V]	$a^5D_1 - a^5D_2$		C	
51.69	[O III]	$2p^2\,^3P_2 - 2p^2\,^3P_1$	9.760−5	C	M83
57.3	[N III]	$2p\,^3P_{3/2} - 2p\,^3P_{1/2}$	4.770−5	C	M83
63.17	[O I]	$2p^4\,^3P_1 - 2p^4\,^3P_2$	8.920−5	C	M83
70.35	[Fe V]	$a^5D_0 - a^5D_1$		C	
88.16	[O III]	$2p^2\,^3P_1 - 2p^2\,^3P_0$	2.620−5	C	M83
121.8	[N II]	$2p^2\,^3P_1 - 2p^2\,^3P_2$	7.460−6	C	M83
145.48	[O I]	$2p^4\,^3P_0 - 2p^4\,^3P_1$	1.740−5	C	M83
157.6	[C II]	$2p\,^2P_{3/2} - 2p\,^2P_{1/2}$	2.290−6	C	M83
205.3	[N II]	$2p^2\,^3P_0 - 2p^2\,^3P_1$	2.080−6	C	M83
370.3	[C I]	$2p^2\,^3P_1 - 2p^2\,^3P_2$	2.650−7	C	M83
609.6	[C I]	$2p^2\,^3P_0 - 2p^2\,^3P_1$	7.930−8	C	M83

Note. We used the following abbreviations for the line generation mechanisms: R, radiative recombination; D, dielectronic recombination; B, bowen mechanism; C, collision excitation; Ch, charge transfer excitation; Au, auger excitation; NF, nonresonance fluorescence; Ph, photoionization mechanism. *References*: B85, Bogdanovich *et al.* (1985) G68, Garstang (1968) KL80, Kafatos and Lynch (1980); Kh81, Kh93, Kholtygin (1981, 1993); M83, Mendoza (1983) NS84, NS88, Nussbaumer and Storey (1984, 1988); R80, Reader *et al.* (1980) T87, Theodosiou (1987); E84, Egikyan (1984); Gr90, Gruzdev (1990); M91, Morton (1991); S77, Sobelman (1977).

Table 30. Parameters of the analytical approximation equation (74) of the effective dielectronic recombination coefficients for lines of the ions of C, N, O, Ne, Mg, Al and Si

	λ (Å)	$L-L'$	A	a	b	c	d	f	t_l	Y
					C I					
*	1140.1	D – D	*	0.0000	0.4616	0.0000	0.0000	1.0136	0.10	0.168
					C II					
	8797.3	D – F	*	0.0000	0.0859	0.0000	0.0000	0.4749	0.10	0.053
	6579.3	S – P		0.0619	–0.1724	0.1524	–0.0055	1.6026	0.30	0.007
	5113.4	P – D	*	0.0000	0.3787	0.0000	0.0000	3.6080	0.15	0.010
	4961.1	P – P	*	0.0000	0.0273	0.0000	0.0000	0.7948	0.10	0.012
	4619.1	F – G	*	–0.0004	0.9778	0.0002	0.0000	3.5887	0.15	0.027
	4267.2	D – F		0.8583	–1.9394	1.1805	–0.0323	5.6506	0.60	0.000
*	4142.4	D – P	*	0.0000	0.1297	0.0000	0.0000	2.3123	0.10	0.013
	3165.7	F – G	*	0.0001	0.3373	0.0000	0.0000	5.0189	0.20	0.002
	1335.3	P – D		1.5568	3.9044	2.6807	–0.0123	0.5834	0.10	4.536
	1167.5	S – P	*	0.0000	0.2038	0.0000	0.0000	0.7948	0.10	0.092
	1092.5	P – P	*	0.0000	0.7724	0.0001	0.0000	0.7948	0.10	0.349
	1036.8	P – S		0.4879	0.1712	1.3281	–0.0308	0.9202	0.10	0.780
*	971.1	D – F	*	–0.0003	6.4693	0.0006	–0.0001	7.4627	0.25	0.004
*	952.5	P – D	*	–0.0003	3.3894	0.0003	0.0000	5.7634	0.20	0.011
	946.1	S – P	*	0.0001	1.4276	0.0001	0.0000	0.7949	0.10	0.645
	799.8	D – F	*	–0.0001	6.8606	0.0002	0.0000	0.4749	0.10	4.267
					C III					
*	14382.5	H – I		0.0291	–0.1855	0.3267	–0.0338	4.6059	0.20	0.001
	13986.1	F – G		0.0263	–0.0947	0.1296	–0.0109	3.7460	0.30	0.001
*	13717.4	H – I		0.0859	–0.5480	0.9649	–0.0997	4.6058	0.20	0.004
*	13579.6	G – H		0.1094	–0.2675	0.1883	–0.0090	2.0379	0.40	0.003
	9700.4	D – F		0.0002	0.0060	0.0004	0.0000	0.3000	0.10	0.005
	8664.6	F – G		0.0886	–0.2722	0.2362	–0.0138	2.0358	0.35	0.005
	8340.8	D – F		0.0116	0.1716	0.0132	–0.0005	0.3184	0.10	0.001
*	8315.1	F – G	*	0.0000	0.3579	0.0001	0.0000	5.3545	0.20	0.002
*	8226.2	G – H	*	0.0001	0.3041	0.0000	0.0000	5.3518	0.20	0.001
	8196.5	G – H		0.3807	–1.1942	1.0595	–0.0718	2.3905	0.40	0.016
	8196.5	G – H		0.1278	–0.4040	0.3619	–0.0250	2.4353	0.40	0.005
*	8189.1	H – I	*	0.0005	0.5632	0.0001	0.0000	5.3503	0.20	0.003
	7597.8	F – G		0.0287	–0.1106	0.1235	–0.0069	1.7323	0.30	0.006
	6740.3	P – D		0.0207	–0.0509	0.0782	–0.0023	0.5355	0.10	0.027
	5826.2	D – F		0.0018	0.0078	0.0026	0.0000	0.4390	0.10	0.008
	5305.3	F – G		0.0298	–0.1075	0.1472	–0.0124	3.7460	0.30	0.001
	5263.1	P – S		0.0008	0.0046	0.0017	–0.0001	0.4000	0.10	0.005
*	5133.4	G – H		0.1048	–0.2563	0.1805	–0.0086	2.0382	0.40	0.003
*	4717.9	D – F	*	0.0000	0.2144	0.0000	0.0000	3.6259	0.15	0.006
	4662.4	P – P		0.0019	0.0063	0.0042	–0.0002	0.4188	0.10	0.008
	4648.8	S – P		0.1151	–0.1057	0.3451	–0.0113	0.4817	0.10	0.212
*	4593.2	D – F	*	0.0005	0.6813	0.0001	0.0000	3.6254	0.15	0.018
*	4542.7	F – G	*	0.0000	0.0064	0.0000	0.0000	0.2711	0.10	0.005
*	4429.2	G – H	*	0.0000	0.4335	0.0001	0.0000	3.5947	0.15	0.012
	4395.3	D – F	*	0.0000	0.0074	0.0000	0.0000	0.3643	0.10	0.005
*	4371.1	F – G	*	0.0000	0.3019	0.0000	0.0000	3.6551	0.15	0.008
*	4330.0	G – H	*	0.0005	1.3291	0.0000	0.0000	3.5934	0.15	0.037
	4325.5	P – D		0.0013	0.0060	0.0021	–0.0001	0.4500	0.10	0.006
*	4300.8	P – D	*	0.0000	0.2610	0.0000	0.0000	3.6685	0.15	0.007

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_l	Y
	4187.0	F – G		0.1051	–0.4050	0.4552	–0.0261	1.7717	0.30	0.022
	4158.7	D – F		0.0116	–0.0223	0.0367	–0.0009	0.4847	0.10	0.015
	4069.4	F – G		0.2862	–1.1021	1.2297	–0.0691	1.7324	0.30	0.061
*	3927.4	F – G	*	0.0003	0.5449	0.0000	0.0000	3.6034	0.15	0.015
	3887.1	D – F		0.0177	–0.0341	0.0559	–0.0013	0.4847	0.10	0.024
*	3602.6	D – F	*	0.0000	0.2012	0.0000	0.0000	3.3809	0.15	0.007
*	3414.9	F – G	*	0.0000	0.0060	0.0000	0.0000	0.2711	0.10	0.005
*	3385.2	F – G	*	0.0000	0.0554	0.0000	0.0000	0.3472	0.10	0.039
*	2512.2	F – G	*	0.0000	0.5505	0.0000	0.0000	0.3472	0.10	0.389
*	2440.0	F – G	*	0.0000	0.1694	0.0000	0.0000	0.2711	0.10	0.129
	2296.9	P – D		0.8743	3.8841	1.4779	–0.0483	0.4521	0.10	3.937
*	2296.1	P – D	*	0.0000	0.4000	0.0000	0.0000	0.5770	0.10	0.225
*	2200.4	P – D	*	0.0000	0.5229	0.0000	0.0000	0.4931	0.10	0.319
	2162.9	D – F		0.0396	–0.0138	0.1125	0.0029	0.5586	0.10	0.081
*	2114.3	F – G	*	0.0000	0.3575	0.0000	0.0000	0.3472	0.10	0.253
*	2017.4	P – D	*	0.0000	0.8108	0.0000	0.0000	0.4931	0.10	0.495
*	1923.3	D – D	*	0.0000	0.3165	0.0000	0.0000	0.4931	0.10	0.193
	1923.1	D – F		0.2666	–0.3774	0.7627	0.0310	0.6278	0.10	0.365
*	1828.0	F – G	*	–0.0001	3.8078	–0.0002	0.0000	0.2711	0.10	2.903
	1796.8	D – F	*	0.0000	0.2882	0.0000	0.0000	0.3643	0.10	0.200
*	1777.9	F – D	*	0.0000	0.1239	0.0000	0.0000	0.4931	0.10	0.076
*	1701.6	P – P	*	0.0000	0.1853	0.0000	0.0000	0.3240	0.10	0.134
*	1633.6	S – P	*	0.0000	0.2130	0.0000	0.0000	0.3240	0.10	0.154
	1620.3	P – D		0.0243	0.0381	0.0513	–0.0017	0.4200	0.10	0.074
	1577.1	D – F		0.2336	3.4440	0.2656	–0.0109	0.3185	0.10	2.860
	1548.9	D – F	*	0.0000	0.2776	0.0000	0.0000	0.3643	0.10	0.193
*	1516.3	F – G	*	0.0000	0.1069	0.0000	0.0000	0.3472	0.10	0.076
*	1491.2	D – P	*	0.0000	0.3415	0.0000	0.0000	0.3240	0.10	0.247
*	1480.4	F – D	*	0.0000	0.1479	0.0000	0.0000	0.5770	0.10	0.083
*	1478.1	F – D	*	0.0000	0.4007	0.0000	0.0000	0.4931	0.10	0.245
	1381.7	D – F		0.0128	0.0598	0.0227	–0.0012	0.4327	0.10	0.061
	1296.3	D – F		0.1194	–0.2296	0.3770	–0.0090	0.4847	0.10	0.159
	1247.4	P – S		–0.0001	0.8535	0.5001	–0.0341	0.6671	0.10	0.677
	1175.7	P – P		0.3864	3.1446	1.1348	–0.0611	0.4130	0.10	3.047
	977.0	S – P		0.8323	5.1970	2.5875	–0.0812	0.4437	0.10	5.477
	574.3	P – D		0.0980	0.1127	0.2229	0.0007	0.4990	0.10	0.264
	538.2	P – S		0.1342	–0.1435	0.4201	–0.0134	0.4903	0.10	0.243
	511.5	D – F		0.0589	0.2539	0.0849	–0.0015	0.4390	0.10	0.255
	493.5	P – P		0.1009	0.5483	0.2102	–0.0138	0.5706	0.10	0.478
	492.6	D – F		0.0728	0.3386	0.1285	–0.0069	0.4327	0.10	0.346
	483.7	P – P		0.0718	0.3649	0.1455	–0.0090	0.5733	0.10	0.323
*	476.0	S – P	*	0.0000	1.1418	0.0000	0.0000	0.9157	0.10	0.457
	459.6	P – D		0.9723	2.2972	1.8844	–0.0286	0.3893	0.10	3.473
	450.7	P – D		0.0000	0.2904	0.0481	–0.0036	0.3764	0.10	0.230
	433.3	P – D		0.0453	0.1992	0.0720	–0.0020	0.4534	0.10	0.200
	411.7	D – F	*	0.0001	4.3059	0.0000	0.0000	0.3643	0.10	2.991
*	398.4	P – P	*	0.0001	2.6254	0.0002	0.0000	0.3240	0.10	1.899
	371.7	P – D		0.1225	0.1922	0.2586	–0.0088	0.4200	0.10	0.371
					N I					
	10594.8	F – G	*	0.0000	0.0135	0.0000	0.0000	0.4078	0.10	0.009
	9048.1	D – F		0.0000	0.0190	0.0024	–0.0003	0.3710	0.10	0.015

Table 30. Continued

	λ (Å)	$L-L'$	A	a	b	c	d	f	t_l	Y
	8180.4	D – D		0.0000	0.0064	0.0003	0.0000	0.3500	0.10	0.005
	1000.2	D – D	*	0.0000	0.0395	0.0000	0.0000	0.2727	0.10	0.030
*	994.2	D – F	*	0.0000	0.0721	0.0000	0.0000	0.3594	0.10	0.050
*	980.7	D – D	*	0.0000	0.4728	0.0000	0.0000	0.5591	0.10	0.270
					N II					
	5679.6	P – D		0.0234	–0.0852	0.0927	–0.0056	2.3686	0.30	0.002
*	5495.1	D – F	*	0.0000	0.0781	0.0000	0.0000	1.1623	0.10	0.024
	5004.4	D – F		0.0704	–0.1990	0.1603	–0.0099	3.3831	0.40	0.001
*	4724.1	S – P	*	0.0000	0.0186	0.0000	0.0000	0.7718	0.10	0.009
	1085.1	P – D		0.0005	0.8561	2.3770	–0.1017	0.8595	0.10	1.326
	916.3	P – P		0.0143	–0.2447	1.1821	0.0132	0.8461	0.10	0.414
*	646.4	D – F	*	0.0009	2.2631	0.0000	0.0000	1.1627	0.10	0.708
					N III					
	6938.2	D – F	*	0.0000	0.2206	0.0000	0.0000	0.7295	0.10	0.106
	5334.7	S – P	*	0.0000	0.1260	0.0000	0.0000	0.9211	0.10	0.050
*	4507.5	D – F	*	0.0005	0.8446	0.0000	0.0000	4.0119	0.15	0.015
*	4477.8	G – H	*	0.0004	1.0155	0.0001	0.0000	4.0085	0.15	0.018
	4373.6	F – G	*	0.0000	0.9660	0.0001	0.0000	4.0183	0.15	0.017
	4199.6	P – D		0.0149	0.0226	0.0304	–0.0002	0.8516	0.10	0.029
	4099.4	S – P		0.0000	0.0194	0.0280	–0.0010	0.8274	0.10	0.020
	4001.8	D – F		0.0023	0.0256	0.0027	0.0000	0.8500	0.10	0.013
*	3429.0	D – P	*	0.0000	0.1420	0.0000	0.0000	2.8512	0.10	0.008
	2197.8	F – G	*	0.0000	0.2454	0.0001	0.0000	0.7958	0.10	0.111
	2188.1	P – D	*	–0.0001	1.7355	–0.0001	0.0000	0.8199	0.10	0.764
	2064.3	F – G	*	0.0001	4.2360	0.0014	–0.0001	0.7958	0.10	1.912
	1885.1	D – F		0.4468	–0.8007	0.3715	0.0369	3.0634	0.45	0.003
	1857.2	D – D	*	0.0000	0.3940	0.0000	0.0000	0.8200	0.10	0.174
	1498.3	D – F	*	0.0000	0.9684	0.0000	0.0000	0.7295	0.10	0.467
	991.0	P – D		2.8315	12.9695	16.8995	–0.5167	0.8162	0.10	14.229
	979.9	D – D		0.1764	–0.4582	0.6309	0.0215	1.0251	0.10	0.133
	782.9	D – F	*	0.0014	6.8449	0.0000	0.0000	1.7651	0.10	1.172
	764.0	P – S		1.1769	3.6750	3.8084	–0.1470	0.9780	0.10	3.202
	685.7	P – P		0.5940	–0.4426	4.3937	–0.3217	0.9795	0.10	1.586
	472.3	S – P		–0.0545	1.1395	0.1343	–0.0013	0.7456	0.10	0.578
	418.8	D – F		0.4465	3.5875	0.5445	–0.0132	0.8626	0.10	1.927
	411.3	P – P	*	0.0000	1.3202	–0.0001	0.0000	0.9211	0.10	0.526
	391.3	P – P	*	0.0022	9.8112	0.0001	0.0000	2.7078	0.10	0.654
	387.4	S – P	*	–0.0002	5.2820	–0.0002	0.0000	0.9211	0.10	2.103
	374.4	P – D		0.0961	–1.1219	4.6102	–0.4746	0.8564	0.10	1.321
	348.7	D – F	*	–0.0004	15.4012	–0.0006	0.0001	0.7295	0.10	7.425
	340.2	D – F	*	0.0045	18.4734	–0.0004	0.0001	1.7651	0.10	3.163
	323.3	D – F	*	0.0341	32.2696	–0.0123	0.0018	3.9830	0.15	0.602
	311.6	P – D		0.2238	0.3397	0.4567	–0.0033	0.8515	0.10	0.434
					N IV					
	9203.0	D – F		0.0111	–0.1354	0.4831	–0.0482	0.5315	0.10	0.183
*	7850.8	F – G		0.0097	0.0216	0.0354	0.0009	1.5444	0.10	0.014
*	7760.0	G – H	*	0.0000	0.5947	–0.0001	0.0000	6.4512	0.25	0.001
*	7742.0	H – I	*	–0.0001	0.5524	0.0000	0.0000	6.4494	0.25	0.001
*	7740.8	I – J	*	–0.0002	0.8844	–0.0004	0.0000	6.4485	0.25	0.001
	7703.2	H – I		0.0783	–0.2678	0.2577	–0.0190	3.3144	0.35	0.002

Table 30. Continued

	λ (Å)	$L-L'$	A	a	b	c	d	f	t_l	Y
	7703.2	H – I		0.2348	–0.8031	0.7726	–0.0569	3.3133	0.35	0.005
	7582.3	G – H		0.1075	–0.3417	0.3133	–0.0219	3.0892	0.35	0.003
	7581.7	G – H		0.0404	–0.1053	0.0858	–0.0048	2.5490	0.30	0.001
	5209.1	P – D		0.0000	0.0043	0.0195	–0.0018	0.4783	0.20	0.014
	4803.6	F – G		0.0202	–0.0542	0.0678	–0.0040	1.8505	0.15	0.005
*	4757.2	G – H	*	0.0000	0.3191	0.0000	0.0000	4.5945	0.15	0.003
*	4745.2	D – F	*	0.0003	0.5548	0.0000	0.0000	4.6121	0.15	0.006
*	4708.1	F – G	*	0.0000	0.3688	0.0000	0.0000	4.5974	0.15	0.004
	4707.4	F – G		0.0814	–0.2208	0.2735	–0.0166	1.8703	0.15	0.018
*	4705.7	F – G	*	0.0025	1.1065	0.0002	0.0000	4.5996	0.15	0.011
*	4680.1	H – I	*	0.0000	0.5669	–0.0001	0.0000	4.5904	0.15	0.006
*	4676.2	H – I	*	–0.0001	1.7011	0.0004	–0.0001	4.5902	0.15	0.017
*	4640.1	G – H	*	0.0010	0.9578	–0.0001	0.0000	4.5926	0.15	0.010
	4606.4	G – H		0.2266	–1.0525	1.4037	–0.1084	2.6627	0.25	0.033
	4606.2	G – H		0.0951	–0.3764	0.4486	–0.0331	2.4572	0.25	0.011
	4512.8	P – S		0.0002	0.0054	0.0129	–0.0011	0.5497	0.20	0.010
*	4289.9	D – F		0.0154	–0.0448	0.0594	–0.0039	1.6851	0.20	0.005
*	4124.4	F – G	*	0.0000	0.3355	0.0000	0.0000	4.6276	0.15	0.003
*	4073.5	F – G	*	0.0004	0.5100	–0.0001	0.0000	4.5780	0.15	0.005
	3480.9	S – P		0.0045	–0.0291	0.6366	–0.0515	0.1742	0.10	0.471
	3459.1	P – P		–0.0001	0.0048	0.0060	–0.0004	0.2000	0.10	0.008
	3200.9	S – P	*	0.0000	0.0110	0.0000	0.0000	0.2391	0.10	0.009
	3078.3	F – G		0.0405	0.0627	0.0874	–0.0040	1.6451	0.10	0.036
	3004.1	P – S		–0.0005	0.0186	0.0007	0.0000	0.2062	0.10	0.015
	2664.4	P – P	*	0.0000	0.1852	0.0000	0.0000	0.2391	0.10	0.146
	2646.4	F – G		0.3066	0.6885	0.7846	–0.0310	1.6158	0.10	0.348
*	2630.2	D – F	*	0.0001	0.6841	0.0000	0.0000	1.5424	0.10	0.146
*	2602.6	G – H	*	0.0002	1.1617	–0.0001	0.0000	1.5171	0.10	0.255
*	2574.6	D – F	*	0.0001	2.1507	0.0003	0.0000	1.5406	0.10	0.461
*	2550.6	G – H	*	–0.0001	3.5429	0.0002	0.0000	1.5142	0.10	0.779
	2457.1	D – P	*	0.0000	0.1785	0.0000	0.0000	0.2391	0.10	0.141
	2430.8	P – S		–0.0019	0.0709	0.0026	–0.0001	0.2062	0.10	0.058
*	2418.8	P – D	*	0.0002	0.8460	0.0001	0.0000	1.5806	0.10	0.174
	2318.1	D – F		0.0054	–0.0820	0.3300	–0.0360	0.6469	0.10	0.114
*	2234.7	F – G	*	0.0001	1.1331	0.0000	0.0000	1.5707	0.10	0.236
*	2190.2	F – G	*	0.0002	1.8069	–0.0001	0.0000	1.4918	0.10	0.407
*	2159.5	D – F	*	0.0000	0.5740	0.0000	0.0000	1.0459	0.10	0.202
	2080.3	F – G		0.1309	0.2038	0.2829	–0.0129	1.6449	0.10	0.117
	1718.6	P – D		0.0751	–1.3414	6.4456	–0.6185	0.3433	0.10	3.236
	1699.8	F – G		0.1002	0.2187	0.2544	–0.0103	1.6169	0.10	0.112
	1325.3	D – F		0.0667	–0.8159	2.9104	–0.2907	0.5315	0.10	1.099
*	1279.7	D – F		0.0025	–0.0455	0.2315	–0.0235	0.5303	0.10	0.097
	1271.6	P – D		0.0036	–0.0444	0.2866	–0.0275	0.1932	0.10	0.180
*	1260.3	D – F	*	0.0000	0.8144	0.0000	0.0000	1.0459	0.10	0.286
*	1255.8	F – G		–0.0014	1.1562	0.3338	–0.0313	1.4122	0.10	0.355
*	1239.8	F – G	*	0.0002	1.2463	0.0000	0.0000	1.4918	0.10	0.280
*	1233.8	G – H	*	0.0000	1.0352	0.0001	0.0000	1.5142	0.10	0.228
*	1231.0	G – F	*	0.0001	0.8813	0.0001	0.0000	1.5406	0.10	0.189
*	1230.4	F – D	*	0.0002	0.6921	0.0000	0.0000	1.5806	0.10	0.143
*	1228.4	P – D	*	0.0000	0.6558	0.0001	0.0000	0.7942	0.10	0.296
	1225.5	P – S		0.0016	–0.0276	0.1766	–0.0156	0.1317	0.10	0.118
	1223.8	S – P	*	0.0000	0.3810	0.0000	0.0000	0.2391	0.10	0.300

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_l	Y
	1222.3	S – P	*	0.0000	0.1345	0.0000	0.0000	0.5296	0.10	0.079
*	1221.3	D – P	*	0.0000	0.4580	0.0000	0.0000	1.4106	0.10	0.112
*	1173.6	P – D		–0.0128	0.9919	0.1844	–0.0155	1.4480	0.20	0.270
*	1102.4	F – G		–0.0032	0.4261	0.0453	–0.0024	1.1909	0.10	0.105
	1036.2	D – F		0.0466	–0.6226	2.3090	–0.1996	0.6230	0.10	0.822
*	993.2	F – G		–0.0013	1.3770	0.3981	–0.0374	1.4124	0.10	0.423
	955.3	P – S		0.0349	–0.2307	1.5474	–0.1407	0.5544	0.10	0.696
*	952.9	D – F		0.0081	–0.1496	0.7610	–0.0774	0.5303	0.10	0.319
	923.2	P – P		0.1057	–0.3719	4.7527	–0.4378	0.2552	0.10	3.137
	765.1	S – P		0.1051	–1.9051	10.2062	–0.9291	0.3490	0.10	5.274
	756.6	P – P	*	0.0000	0.2633	0.0000	0.0000	0.2391	0.10	0.207
*	715.7	F – G	*	0.0009	3.2627	–0.0002	0.0000	1.4919	0.10	0.734
	704.8	D – P	*	0.0000	0.2364	0.0000	0.0000	0.2391	0.10	0.186
*	678.0	D – F	*	0.0001	1.9513	0.0001	0.0000	1.0459	0.10	0.686
	322.6	P – S		0.0063	–0.1200	0.9206	–0.0779	0.0798	0.10	0.673
	297.7	P – P		0.0427	–0.4023	1.3341	–0.1392	0.4279	0.10	0.545
	283.5	P – D		0.1599	–1.8302	6.3083	–0.5637	0.5187	0.10	2.425
	239.6	P – D		0.0238	–0.2925	1.8886	–0.1810	0.1931	0.10	1.186
	234.2	P – P		–0.0031	0.1646	0.2047	–0.0151	0.1978	0.10	0.288
*	225.3	D – F	*	–0.0001	7.3142	–0.0009	0.0001	1.1402	0.10	2.338
	221.8	P – P	*	0.0000	0.7356	0.0000	0.0000	0.2391	0.10	0.579
*	217.9	P – P	*	0.0004	3.5092	–0.0003	0.0001	1.4107	0.10	0.856
	209.4	P – S		–0.0049	0.1832	0.0068	–0.0002	0.2062	0.10	0.150
	177.6	P – D	*	0.0000	1.5341	0.0001	0.0000	0.7942	0.10	0.693
					O I					
	27639.7	S – P		0.1953	–0.7805	0.8492	–0.0759	13.2470	0.50	0.000
	18022.8	D – F		0.0971	–0.8743	1.6447	–0.1593	14.3535	0.50	0.000
	11298.9	P – S		0.2147	–0.9024	1.0281	–0.0820	12.9529	0.50	0.000
	9263.6	P – D		1.3752	–0.0677	3.8878	–0.4719	15.3842	0.50	0.000
	7949.5	D – F	*	0.0000	0.0400	0.0000	0.0000	0.5587	0.10	0.023
	7773.3	S – P		1.0991	–1.9677	5.9828	–0.6378	14.1284	0.45	0.000
*	6318.6	D – P	*	0.0000	0.0280	0.0000	0.0000	1.0257	0.10	0.010
					O II					
*	25393.1	F – G	*	0.0000	0.0040	0.0000	0.0000	0.2971	0.10	0.003
*	11945.6	F – G		–0.0001	0.0072	0.0015	–0.0002	0.3500	0.10	0.006
*	9377.4	P – D	*	0.0000	0.0063	0.0000	0.0000	0.3616	0.10	0.004
*	8883.3	D – F	*	0.0000	0.0056	0.0000	0.0000	0.3475	0.10	0.004
*	8771.8	F – G	*	0.0000	0.0161	0.0000	0.0000	0.3456	0.10	0.011
	4651.4	P – D		0.1037	–0.2657	0.2045	–0.0029	3.0303	0.35	0.002
	4593.2	D – F		0.0000	0.0080	0.0059	–0.0006	0.3499	0.10	0.009
	4349.8	D – D		0.0000	0.0048	0.0075	–0.0005	0.3000	0.10	0.009
	4341.1	P – P		0.0376	–0.0999	0.0783	–0.0003	2.8346	0.30	0.001
	4188.0	F – G		–0.0001	0.0154	0.0079	–0.0008	0.3498	0.10	0.016
	4074.8	D – F		0.0923	–0.1817	0.1002	–0.0007	4.2197	0.50	0.000
*	3800.2	D – F	*	0.0000	0.1009	0.0000	0.0000	2.2340	0.10	0.011
*	3077.8	P – D	*	0.0000	0.0099	0.0000	0.0000	0.3616	0.10	0.007
*	3017.9	D – F	*	0.0000	0.0082	0.0000	0.0000	0.3475	0.10	0.006
*	3009.0	D – D	*	0.0000	0.0076	0.0000	0.0000	0.3616	0.10	0.005
*	386.3	D – F	*	0.0000	0.4461	0.0000	0.0000	0.2804	0.10	0.337
*	385.7	D – D	*	0.0000	0.3115	0.0000	0.0000	0.3318	0.10	0.224

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_l	Y
					O III					
*	4587.1	F – G	*	0.0000	0.2800	0.0000	0.0000	4.6381	0.15	0.003
*	3881.6	D – F	*	0.0000	0.1304	0.0000	0.0000	0.9941	0.10	0.048
*	3763.1	P – D	*	0.0000	0.0746	0.0000	0.0000	1.6189	0.10	0.015
	3762.3	P – D		0.0053	–0.0983	0.4693	0.0054	0.5684	0.10	0.216
	3326.6	P – S		0.0090	0.0107	0.0226	–0.0004	0.7877	0.10	0.019
	3265.9	D – F		0.0001	0.9493	0.1777	0.0623	1.2049	0.10	0.356
*	3191.9	F – G	*	0.0000	0.0723	0.0000	0.0000	1.8883	0.10	0.011
*	3176.1	F – G	*	0.0000	0.2069	0.0000	0.0000	1.3144	0.10	0.056
	3041.6	P – P		0.0139	–0.0463	0.0950	–0.0013	1.1799	0.10	0.019
*	2092.0	D – F	*	0.0001	0.7959	0.0000	0.0000	1.5025	0.10	0.177
*	1947.2	F – G	*	0.0000	1.1393	0.0002	0.0000	1.3915	0.10	0.283
*	1924.2	P – D	*	0.0000	0.5098	0.0001	0.0000	1.3217	0.10	0.136
	834.5	P – D		–0.0092	16.2803	6.0953	–0.3399	1.2980	0.15	6.015
	703.4	P – P		0.0646	–1.0379	5.4702	–0.3506	0.6221	0.10	2.226
	599.6	D – D		0.0002	1.4709	1.2954	–0.0807	1.5493	0.10	0.570
*	541.6	P – P	*	0.0002	2.4329	0.0001	0.0000	1.2893	0.10	0.670
	374.1	P – P		–0.0005	1.8930	1.0691	–0.0524	1.1337	0.15	0.936
	320.7	P – D	*	–0.0001	3.8598	0.0000	0.0000	1.5798	0.10	0.795
	300.5	D – F	*	0.0003	13.1930	0.0015	–0.0002	1.3900	0.10	3.286
	299.3	D – D	*	–0.0001	6.0914	0.0000	0.0000	1.5798	0.10	1.255
					O IV					
	9225.1	P – D		0.0001	0.0009	0.0005	0.0000	0.1500	0.10	0.001
*	8723.6	P – D	*	0.0000	0.0335	0.0000	0.0000	0.9214	0.10	0.013
*	6099.6	D – F	*	0.0000	0.0283	0.0000	0.0000	1.0719	0.10	0.010
*	4541.3	F – G	*	0.0011	0.6456	0.0000	0.0000	4.8635	0.20	0.005
*	4491.5	D – F	*	0.0003	0.6584	0.0000	0.0000	4.8271	0.15	0.005
	4034.0	D – F	*	0.0000	0.0702	0.0000	0.0000	0.0719	0.10	0.065
*	3799.3	P – P	*	0.0000	0.0189	0.0000	0.0000	0.3721	0.10	0.013
*	3794.0	D – F	*	0.0000	0.1226	0.0000	0.0000	2.5050	0.10	0.010
*	3720.8	D – P	*	0.0000	0.1250	0.0000	0.0000	0.3721	0.10	0.086
*	3553.8	G – F	*	0.0000	0.0045	0.0000	0.0000	0.0719	0.10	0.004
	3549.1	D – F	*	0.0000	0.0012	0.0000	0.0000	0.0719	0.10	0.001
	3490.9	P – D		0.0033	0.0082	0.0069	0.0003	0.1785	0.10	0.016
	3409.1	P – D		0.0004	0.0001	0.0016	0.0002	0.2052	0.10	0.002
	3350.7	P – D		0.0012	–0.0001	0.0091	–0.0002	0.1795	0.10	0.008
	3066.1	S – P		0.0230	0.0016	0.0859	0.0015	0.2149	0.10	0.090
*	3037.9	G – F	*	0.0000	1.5217	0.0000	0.0000	0.7085	0.10	0.749
	3027.9	P – D	*	0.0000	0.0918	0.0000	0.0000	0.9214	0.10	0.037
	3024.3	P – D		0.0002	0.0005	0.0005	0.0000	0.2000	0.15	0.001
*	3003.0	F – G	*	0.0007	0.5561	0.0000	0.0000	4.8630	0.10	0.004
	2907.1	F – D	*	0.0000	0.2918	0.0000	0.0000	0.9214	0.10	0.116
	2772.5	D – F	*	0.0000	0.6734	–0.0001	0.0000	1.6944	0.10	0.124
*	2637.7	P – D	*	0.0000	1.1338	–0.0002	0.0000	1.6242	0.10	0.223
*	2620.0	D – F	*	0.0000	1.0784	0.0000	0.0000	1.0719	0.10	0.369
*	2511.2	D – F	*	0.0002	2.8067	–0.0001	0.0000	1.7471	0.10	0.489
	2486.3	D – F	*	0.0000	0.3204	0.0000	0.0000	0.0719	0.10	0.298
*	2363.6	D – P	*	0.0000	0.2168	0.0000	0.0000	0.3721	0.10	0.149
*	1936.1	P – P	*	0.0000	0.1495	0.0000	0.0000	0.3721	0.10	0.103
*	1785.9	D – F	*	0.0000	0.5212	0.0000	0.0000	1.0719	0.10	0.178
	1515.5	P – D		0.0008	0.0086	0.0048	0.0000	0.1501	0.10	0.012

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_l	Y
	1355.1	F – D		0.0016	0.0209	0.0111	0.0001	0.1392	0.10	0.029
	1341.8	P – D		0.0734	–0.7096	2.5557	–0.1364	0.3106	0.10	1.307
*	1296.4	P – P	*	0.0000	0.2047	0.0000	0.0000	0.3721	0.10	0.141
	1289.4	D – F	*	0.0000	1.1066	0.0001	0.0000	0.0719	0.10	1.030
	1212.9	P – D		0.0309	–0.3064	0.8385	–0.0813	0.5422	0.10	0.280
*	1102.0	P – D	*	0.0018	5.6429	8.0008	–0.0001	6.9210	0.25	0.006
	1079.9	P – D		0.0027	–0.0002	0.0195	–0.0005	0.1795	0.10	0.018
	1067.8	D – F		0.0935	–0.1253	0.2148	0.0392	0.8956	0.15	0.091
	1060.0	P – D		0.0103	0.0256	0.0214	0.0011	0.1784	0.10	0.049
	1046.0	P – S		0.0404	–0.2108	0.3873	–0.0250	0.6667	0.10	0.099
*	1006.7	F – G	*	0.0161	12.4488	0.0002	0.0000	7.5667	0.25	0.006
	922.7	P – P		0.7799	–3.0453	4.4113	–0.2320	1.0333	0.20	0.681
*	844.4	F – G	*	–0.0001	3.3684	0.0001	0.0000	0.7085	0.10	1.659
	789.4	P – D		4.7096	–7.7314	39.5926	–1.4842	0.2109	0.10	28.415
	779.9	D – D		0.4003	–3.8675	13.9290	–0.7433	0.3108	0.10	7.124
*	745.8	S – P	*	0.0000	0.5476	0.0000	0.0000	0.3721	0.10	0.377
*	713.0	D – F	*	0.0041	6.5679	–0.0013	0.0002	2.5057	0.10	0.536
	703.9	D – F	*	0.0000	0.5760	0.0000	0.0000	0.0719	0.10	0.536
	636.5	P – D		0.1084	0.2681	0.2245	0.0112	0.1785	0.10	0.512
	617.0	D – P		1.7032	–6.6508	9.6338	–0.5066	1.0333	0.20	1.487
	609.4	P – S		0.4193	–1.9258	5.0398	–0.0611	0.4046	0.10	2.317
	554.4	P – P		0.9392	–0.7450	8.8543	–0.2444	0.4542	0.10	5.590
	487.0	D – F	*	0.0000	0.3641	0.0000	0.0000	0.0719	0.10	0.339
	442.8	S – P		0.0228	0.0016	0.0852	0.0015	0.2149	0.10	0.090
	379.8	D – P		0.1502	0.0108	0.5603	0.0096	0.2149	0.10	0.590
	342.3	D – D		0.0096	0.0238	0.0199	0.0010	0.1785	0.10	0.045
	306.7	D – P		0.0046	–0.0187	0.3118	–0.0071	0.0888	0.10	0.266
	303.5	D – D		0.0043	0.0573	0.0305	0.0003	0.1392	0.10	0.080
	289.9	D – D		0.0113	0.0019	0.2579	–0.0234	0.1676	0.10	0.209
*	288.5	P – D	*	0.0000	3.7916	–0.0007	0.0001	1.6242	0.10	0.747
	285.8	S – P		0.0521	–0.4336	1.0532	0.0448	0.5153	0.10	0.428
	279.8	P – S		0.0999	–0.2634	0.4500	0.0242	0.3298	0.10	0.223
*	276.1	P – D	*	0.0124	18.7191	0.0017	–0.0002	3.8567	0.15	0.396
*	273.5	P – D	*	–0.0018	25.0077	0.0020	–0.0002	4.3545	0.15	0.321
	267.0	D – D		0.1622	–1.1147	2.2783	–0.1975	0.7623	0.15	0.526
*	265.5	D – F	*	–0.0001	16.4077	0.0006	–0.0001	1.0719	0.10	5.617
	260.5	D – F		0.0005	2.2010	2.6463	–0.1639	0.6095	0.15	2.546
*	258.6	D – F	*	0.0060	6.1638	–0.0005	0.0001	2.5060	0.10	0.503
*	252.5	D – D	*	0.0128	20.5521	0.0011	–0.0001	3.8567	0.15	0.435
*	250.3	D – D	*	–0.0023	31.5306	0.0025	–0.0003	4.3545	0.15	0.405
	238.5	P – D		0.2115	0.0327	0.5626	0.0832	0.2035	0.10	0.653
*	224.1	P – P	*	0.0000	3.2339	0.0001	0.0000	0.3721	0.10	2.222
*	216.2	S – P	*	0.0000	0.5602	0.0000	0.0000	0.3721	0.10	0.386
	213.0	D – F		–0.0657	1.4583	0.2876	0.0223	0.6524	0.10	0.887
*	211.3	S – P	*	0.0022	5.2042	0.0232	–0.0015	1.9159	0.10	0.770
	207.2	P – D		0.1477	–0.0102	1.0783	–0.0272	0.1795	0.10	0.993
	203.0	P – S		0.0846	0.2543	0.3268	–0.0198	0.4614	0.10	0.407
	200.8	D – F	*	0.0001	10.4614	0.0006	–0.0001	0.0719	0.10	0.736
	196.4	D – F	*	0.0031	19.1580	–0.0023	0.0004	1.6946	0.10	3.519
*	188.2	D – F	*	–0.0032	32.3813	–0.0036	0.0005	4.8979	0.15	0.242
*	184.2	D – F	*	–0.0017	29.1270	0.0040	–0.0006	6.5238	0.20	0.043
	182.8	P – D		0.1135	0.2808	0.2350	0.0117	0.1785	0.10	0.536

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_l	Y
	171.1	P – D		0.0174	0.2317	0.1234	0.0014	0.1392	0.10	0.325
	158.6	P – D	*	0.0012	7.8984	0.0004	0.0000	0.9216	0.10	3.143
					O V					
	6487.5	D – F		−0.0765	4.1680	1.2966	−0.1261	2.8234	0.15	0.313
	5875.5	G – H		0.0274	−0.0918	0.1266	−0.0106	3.3189	0.15	0.002
*	5023.2	G – H	*	−0.0001	0.5197	0.0000	0.0000	5.8621	0.20	0.001
*	5006.9	D – F	*	0.0000	0.4687	0.0000	0.0000	5.8758	0.20	0.001
*	4982.4	F – G	*	0.0008	0.8823	0.0001	0.0000	5.8662	0.20	0.003
	4981.4	F – G		0.0221	−0.0957	0.1292	−0.0117	3.5562	0.20	0.001
*	4961.4	G – H	*	0.0012	1.4623	0.0001	0.0000	5.8616	0.20	0.004
*	4961.4	G – H	*	0.0009	0.5036	−0.0002	0.0000	5.8627	0.20	0.001
*	4958.7	H – I	*	0.0000	0.4494	0.0000	0.0000	5.8588	0.20	0.001
*	4953.3	H – I	*	0.0011	1.3491	−0.0006	0.0001	5.8599	0.20	0.004
*	4952.5	I – J	*	0.0000	2.1583	−0.0001	0.0000	5.8576	0.20	0.006
*	4952.5	I – J	*	0.0004	0.7195	0.0001	0.0000	5.8581	0.20	0.002
*	4944.7	I – H	*	0.0000	0.3643	0.0000	0.0000	5.8621	0.20	0.001
	4930.3	H – I		0.0407	−0.2476	0.4153	−0.0419	3.9910	0.20	0.003
	4930.3	H – I		0.1223	−0.7431	1.2467	−0.1257	3.9913	0.20	0.009
*	4924.2	G – H	*	0.0007	0.7699	0.0001	0.0000	5.8606	0.20	0.002
	4498.2	G – H		0.0226	−0.0754	0.1040	−0.0087	3.3188	0.15	0.002
*	4493.9	F – G	*	0.0005	0.4192	−0.0001	0.0000	5.8498	0.20	0.001
	4462.6	G – H		0.0457	−0.1671	0.2516	−0.0184	3.2313	0.10	0.004
*	3236.6	P – P	*	0.0000	0.1399	0.0000	0.0000	1.9093	0.10	0.021
	3164.3	F – G		0.0160	0.1955	0.0529	−0.0039	2.9938	0.10	0.013
*	3129.6	P – D	*	0.0000	0.1965	0.0000	0.0000	3.0685	0.10	0.009
*	3083.8	D – F	*	0.0001	0.4411	0.0000	0.0000	2.9807	0.10	0.022
*	3077.9	D – P	*	0.0000	0.1517	0.0000	0.0000	1.9094	0.10	0.022
*	3031.3	G – H	*	0.0002	0.7817	0.0000	0.0000	2.9583	0.10	0.041
*	3023.6	D – F	*	0.0009	1.3603	0.0001	0.0000	2.9790	0.10	0.069
*	3016.6	F – G	*	0.0000	0.5112	0.0000	0.0000	2.9986	0.10	0.025
*	3005.2	F – G	*	0.0002	0.9032	0.0002	0.0000	2.9618	0.10	0.047
*	3003.8	F – G	*	0.0009	2.7109	0.0000	0.0001	2.9619	0.10	0.140
*	2993.3	H – I	*	0.0007	1.3851	−0.0001	0.0000	2.9537	0.10	0.072
*	2991.3	H – I	*	0.0035	4.1590	0.0002	−0.0001	2.9540	0.10	0.217
*	2974.6	G – H	*	0.0000	2.3453	−0.0001	0.0000	2.9549	0.10	0.122
	2941.4	G – H		0.3768	2.0972	0.8634	−0.0657	3.0325	0.10	0.158
	2941.4	G – H		0.1258	0.6993	0.2887	−0.0220	3.0326	0.10	0.053
	2784.0	S – P		0.0075	−0.1040	0.5878	−0.0604	1.8618	0.10	0.067
*	2696.3	F – G	*	0.0009	1.2340	−0.0001	0.0000	2.9394	0.10	0.065
*	1660.8	G – H		0.1433	2.3447	0.1964	−0.0148	2.9947	0.10	0.134
	1643.7	F – G		0.4277	2.2318	1.0820	−0.0818	3.0315	0.10	0.177
*	1629.2	D – F		0.1100	1.9840	0.1615	−0.0121	2.9944	0.10	0.112
*	1524.4	G – H		0.0751	1.2396	0.1036	−0.0078	2.9944	0.10	0.071
	1371.3	P – D		0.1526	−2.1819	12.1631	−1.1983	2.0811	0.10	1.115
	1085.8	D – F		−0.0859	5.0151	1.5551	−0.1513	2.8250	0.15	0.376
*	1071.6	G – H	*	0.0003	1.3349	0.0000	0.0000	2.9583	0.10	0.069
*	1067.9	G – H	*	0.0000	4.0933	−0.0001	0.0000	2.9549	0.10	0.213
*	1055.1	D – F	*	0.0012	1.7375	0.0001	0.0000	2.9791	0.10	0.088
	1040.6	F – G		0.1517	0.8702	0.3453	−0.0262	3.0318	0.10	0.065
*	1037.4	F – G	*	0.0004	2.3306	−0.0002	0.0000	2.9389	0.10	0.123
*	1032.5	H – I	*	0.0011	1.5181	−0.0002	0.0000	2.9540	0.10	0.079

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_t	Y
*	1031.9	H – G	*	0.0012	1.3021	–0.0001	0.0000	2.9625	0.10	0.067
	1020.0	F – G		0.0011	1.9488	0.1513	–0.0122	2.9376	0.10	0.111
*	943.7	D – F	*	0.0001	1.1447	0.0000	0.0000	2.6478	0.10	0.081
	774.5	P – S		0.0308	–0.3144	2.7102	–0.2657	2.0844	0.10	0.269
	760.4	P – P		0.0565	–1.0006	9.1628	–0.9287	1.7646	0.10	1.248
	681.3	D – F		0.5482	4.2072	1.6253	–0.1233	3.0007	0.15	0.311
	629.7	S – P		0.2120	–3.1260	19.1353	–1.8583	2.0594	0.10	1.832
	202.3	P – P		0.0577	–0.7299	3.0596	–0.3423	1.9926	0.10	0.279
	192.9	P – D		0.1384	–2.1966	9.3514	–1.0249	2.1022	0.10	0.766
	168.0	P – D		0.0839	–1.2048	5.8036	–0.6387	1.8941	0.10	0.608
*	141.3	D – F	*	–0.0005	11.8982	–0.0002	0.0000	3.0188	0.10	0.581
					Ne III					
*	13625.8	F – G	*	0.0000	0.0145	0.0000	0.0000	0.0711	0.10	0.014
*	13577.7	F – F	*	0.0000	0.0112	0.0000	0.0000	0.0424	0.10	0.011
*	13430.0	F – G	*	0.0001	0.0215	0.0033	–0.0003	0.0541	0.10	0.023
*	13083.7	D – F	*	0.0000	0.0250	0.0000	0.0000	0.0424	0.10	0.024
*	12546.8	D – D	*	0.0000	0.0172	0.0000	0.0000	0.0895	0.10	0.016
*	12211.1	P – D	*	0.0000	0.0085	0.0000	0.0000	0.0895	0.10	0.008
*	6454.4	F – F		0.0000	0.0477	0.0169	–0.0015	0.2234	0.10	0.050
*	6441.1	F – G		0.0000	0.0753	0.0253	–0.0023	0.2323	0.10	0.078
*	6329.0	F – G		0.0000	0.0728	0.0325	–0.0032	0.2049	0.10	0.083
*	6253.4	G – F		–0.0001	0.0086	0.0052	–0.0006	0.0499	0.10	0.012
*	6191.8	D – F		0.0000	0.1072	0.0380	–0.0034	0.2233	0.10	0.113
*	4797.4	I – G	*	0.0000	0.0054	0.0008	–0.0001	0.0541	0.10	0.006
*	4797.4	G – F	*	0.0000	0.0078	0.0000	0.0000	0.0424	0.10	0.007
*	4687.6	D – F	*	0.0000	0.0440	0.0000	0.0000	0.2475	0.10	0.034
*	4535.1	F – G	*	0.0000	0.0820	0.0000	0.0000	0.2565	0.10	0.063
*	4416.9	D – F	*	0.0000	0.0523	0.0000	0.0000	0.2532	0.10	0.041
*	4349.6	P – P	*	0.0000	0.0419	0.0000	0.0000	0.2502	0.10	0.033
*	4348.9	P – D	*	0.0000	0.0899	0.0000	0.0000	0.2508	0.10	0.070
*	4332.9	S – P	*	0.0000	0.0396	0.0000	0.0000	0.2502	0.10	0.031
*	4063.9	G – I	*	0.0000	0.1139	0.0000	0.0000	0.2551	0.10	0.088
*	4032.1	G – G	*	0.0000	0.0462	0.0000	0.0000	0.2502	0.10	0.036
*	4027.1	G – I	*	0.0000	0.0776	0.0007	–0.0001	0.2547	0.10	0.061
*	4013.6	D – F	*	0.0000	0.0548	0.0000	0.0000	0.2475	0.10	0.043
*	3985.8	F – F	*	0.0000	0.0489	0.0000	0.0000	0.2475	0.10	0.038
*	3982.8	F – G	*	0.0000	0.2303	0.0000	0.0000	0.2502	0.10	0.179
	2823.9	P – D		0.0726	0.6307	0.1468	–0.0036	0.1612	0.10	0.720
	2782.2	D – D		0.0000	0.5976	0.1945	0.0033	0.1727	0.10	0.669
	2612.4	D – F		0.0000	0.7904	0.2577	0.0154	0.1695	0.10	0.898
*	2538.9	D – F		0.0000	0.3747	0.1072	0.0013	0.2012	0.10	0.395
*	2270.7	F – G		0.0000	0.3024	0.0715	–0.0024	0.2377	0.10	0.293
	2264.5	F – F		0.0000	0.2206	0.0685	–0.0024	0.2020	0.10	0.234
	2214.2	F – G		0.0000	0.3833	0.0970	0.0039	0.2225	0.10	0.388
	2150.7	D – F		0.0000	0.5284	0.1641	–0.0058	0.2019	0.10	0.561
*	2127.7	P – D	*	0.0000	0.2288	0.0000	0.0000	0.0960	0.10	0.208
*	1994.3	F – G	*	0.0000	0.5395	0.0001	0.0000	0.1046	0.10	0.486
*	1937.9	D – D	*	0.0000	0.1217	0.0000	0.0000	0.0895	0.10	0.111
*	1920.6	D – F	*	0.0000	0.3395	0.0000	0.0000	0.1027	0.10	0.306
*	1916.8	D – F		0.1519	1.4169	0.2218	–0.0067	0.1600	0.10	1.520
*	1901.2	P – D	*	0.0000	0.7709	–0.0001	0.0000	0.0895	0.10	0.705

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_l	Y
*	1881.9	F – G	*	0.0000	1.6523	0.0000	0.0000	0.0992	0.10	1.496
*	1240.3	F – G	*	0.0000	0.6013	0.0000	0.0000	0.2501	0.10	0.468
	489.6	P – P		0.0001	1.1526	–0.0645	0.3080	0.1153	0.10	1.244
	487.2	P – D		0.0795	0.6903	0.1608	–0.0040	0.1612	0.10	0.789
	283.4	P – D		0.0001	1.5517	0.6174	0.0542	0.1567	0.10	1.901
	267.3	P – P		–0.0342	0.6163	0.2502	0.0007	0.0017	0.10	0.832
*	227.7	D – F		0.0528	0.4933	0.0716	–0.0017	0.1652	0.10	0.522
*	217.5	S – P	*	0.0002	2.6149	0.0004	–0.0001	0.1590	0.10	2.231
*	216.4	P – P		0.0632	0.5891	0.0828	–0.0028	0.1510	0.10	0.630
*	204.2	D – P	*	0.0000	1.0020	–0.0001	0.0000	0.1675	0.10	0.847
*	203.9	D – D	*	–0.0001	2.6427	0.0000	0.0000	0.2568	0.10	2.044
*	203.8	D – F	*	–0.0003	4.1059	–0.0002	0.0000	0.2828	0.10	3.094
*	194.3	P – D	*	–0.0001	2.9725	–0.0002	0.0000	0.0895	0.10	2.718
*	194.1	P – P	*	–0.0006	3.7682	–0.0004	0.0001	0.1620	0.10	3.204
					Ne IV					
*	14740.9	G – F	*	0.0000	0.0059	0.0000	0.0000	0.0377	0.10	0.006
*	4927.9	G – F	*	0.0000	0.0057	0.0000	0.0000	0.0377	0.10	0.005
*	2341.5	P – D		0.0504	2.1346	0.1934	0.0854	0.1963	0.10	2.025
	2197.3	P – P		0.0168	0.4174	0.0209	0.0084	0.2123	0.10	0.375
*	1955.7	D – F	*	0.0000	0.1915	0.0000	0.0000	0.1632	0.10	0.163
*	1924.5	D – F		0.0001	1.6034	0.1353	0.0327	0.1776	0.10	1.483
*	1884.8	P – D		0.0004	1.4190	0.0310	0.0142	0.1805	0.10	1.223
*	1790.2	D – D		–0.0001	0.5402	0.0118	0.0054	0.1801	0.10	0.465
	542.8	S – P		1.0096	1.7831	5.9186	0.0374	0.3308	0.10	6.285
*	482.7	D – F	*	0.0000	1.3626	0.0000	0.0000	0.1632	0.10	1.157
*	473.8	F – F	*	0.0000	1.4170	0.0000	0.0000	0.1632	0.10	1.204
	293.6	P – P		0.0442	1.0990	0.0551	0.0222	0.2123	0.10	0.987
	208.6	S – P		0.0653	2.5781	0.2454	0.1076	0.1984	0.10	2.457
*	166.3	P – P	*	–0.0003	2.2490	–0.0001	0.0000	0.2306	0.10	1.786
					Ne V					
*	2141.8	P – D		0.0185	–0.3307	1.6479	–0.1446	–0.0837	0.10	1.295
*	1970.9	D – F		0.0009	7.1793	2.0464	–0.1008	0.7266	0.15	4.413
*	666.0	F – G	*	–0.0025	6.9245	0.0009	–0.0001	0.5398	0.10	4.035
	571.0	P – D		0.0684	15.0815	11.7144	–0.3123	0.1580	0.10	22.671
	482.2	P – P		–0.0089	9.1893	8.2286	–0.2473	0.1961	0.10	14.106
*	416.2	D – D		–0.0887	15.6785	3.1163	–0.0989	0.4225	0.10	12.195
*	143.2	D – F		0.0709	8.0229	0.0576	0.0235	0.5439	0.10	4.745
*	133.0	D – F	*	–0.0012	8.4732	–0.0006	0.0001	0.3684	0.10	5.861
*	122.9	P – D	*	0.0000	5.0572	–0.0006	0.0001	0.1384	0.10	4.403
*	122.6	P – S	*	0.0001	4.5451	–0.0004	0.0001	0.4137	0.10	3.005
*	118.3	D – F	*	0.0001	1.9793	0.0000	0.0000	0.0758	0.10	1.835
*	118.2	D – D	*	0.0002	10.0646	–0.0005	0.0001	0.1384	0.10	8.764
					Ne VI					
*	26845.5	P – D	*	0.0000	0.0089	0.0000	0.0000	0.0291	0.10	0.009
*	22830.0	S – P	*	0.0000	0.0071	0.0000	0.0000	0.0765	0.10	0.007
*	20832.0	D – D	*	0.0000	0.0062	0.0000	0.0000	0.0291	0.10	0.006
*	15502.0	P – D	*	0.0000	0.0212	0.0000	0.0000	0.1137	0.10	0.019
*	9261.0	P – P		0.0020	0.0141	0.0024	0.0001	0.1093	0.10	0.017
*	5416.8	P – D		0.0087	–0.0132	0.0343	–0.0021	0.2037	0.10	0.023
*	5247.9	P – S		0.0034	0.0073	0.0088	–0.0005	0.1856	0.10	0.016

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_t	Y
*	3111.1	D – F		0.0102	–0.0274	0.0446	–0.0013	0.2547	0.10	0.020
*	2556.3	D – F		0.7076	–1.9884	3.0536	–0.0101	0.2791	0.10	1.333
*	2273.4	P – D		1.1576	1.2542	5.2039	–0.0659	0.1593	0.10	6.438
*	2195.6	D – D	*	0.0000	0.0447	0.0000	0.0000	0.0291	0.10	0.043
*	2179.8	D – P	*	0.0000	0.2197	0.0000	0.0000	0.0765	0.10	0.204
*	2136.5	F – D	*	0.0000	0.2989	0.0000	0.0000	0.0291	0.10	0.290
*	2135.3	D – F	*	0.0004	3.0805	0.0035	0.0001	0.3453	0.10	2.184
*	2133.2	F – D	*	0.0000	0.1390	0.0000	0.0000	0.1137	0.10	0.124
*	2104.4	P – D	*	0.0000	1.5887	0.0001	0.0000	0.4227	0.10	1.041
*	2081.7	G – I	*	0.0439	1.2607	0.0233	–0.0008	0.3949	0.10	0.894
*	2073.8	I – J	*	0.0001	1.2209	0.0004	0.0000	0.3609	0.10	0.851
*	2072.1	F – G	*	0.1830	1.2443	0.2218	–0.0068	0.4368	0.10	1.061
*	2071.5	F – G	*	–0.0003	3.0796	0.0012	0.0000	0.3839	0.10	2.098
*	1949.6	D – F	*	0.0000	2.2160	0.0001	0.0000	0.2711	0.10	1.690
*	1933.6	P – D	*	–0.0001	2.9390	–0.0002	0.0000	0.3693	0.10	2.031
*	1911.8	D – D	*	0.0000	0.5504	0.0000	0.0000	0.3693	0.10	0.380
*	1909.2	P – S		0.0636	4.1603	0.7689	–0.0185	0.0993	0.10	4.504
*	1815.8	D – D	*	0.0000	0.2206	0.0000	0.0000	0.1137	0.10	0.197
*	1777.6	P – D	*	–0.0002	1.3931	0.0000	0.0000	0.0289	0.10	1.353
*	1767.2	P – P	*	0.0000	0.4055	0.0000	0.0000	0.0765	0.10	0.376
*	1751.3	D – F	*	0.0000	0.9615	–0.0001	0.0000	0.4055	0.10	0.641
*	1739.5	S – P	*	0.0000	0.5624	0.0000	0.0000	0.0765	0.10	0.521
*	1712.1	D – D	*	0.0000	0.3994	0.0000	0.0000	0.0290	0.10	0.388
*	1686.6	P – D	*	0.0000	0.5327	–0.0001	0.0000	0.1137	0.10	0.475
*	1623.7	P – P		–0.3295	10.5177	2.1247	–0.0311	0.0006	0.10	12.274
*	1188.0	P – S		–0.0049	0.1045	0.0095	0.0017	0.0044	0.10	0.110
*	1157.3	D – P		0.0294	0.2077	0.0357	0.0016	0.1093	0.10	0.246
*	1149.8	G – I		0.0425	0.6826	0.0338	–0.0011	0.4050	0.10	0.505
*	1141.2	F – D		0.0045	0.0520	0.0028	0.0052	0.0849	0.10	0.059
*	1141.1	P – D		–0.0205	0.5738	0.0466	0.0000	0.2866	0.10	0.450
*	1043.8	P – D		–0.0026	0.0549	0.0062	0.0000	–0.0070	0.10	0.059
*	1043.1	D – F		–0.0031	0.0700	0.0068	–0.0002	–0.0380	0.10	0.076
*	1022.8	G – I		0.0321	0.5155	0.0255	–0.0008	0.4050	0.10	0.382
*	831.0	P – P		0.0359	0.2534	0.0436	0.0020	0.1093	0.10	0.300
*	745.4	F – D	*	0.0000	0.2572	0.0000	0.0000	0.0291	0.10	0.250
*	734.8	F – G	*	–0.0006	5.5159	0.0021	0.0000	0.3839	0.10	3.758
*	702.1	D – F	*	0.0000	3.7977	0.0001	0.0000	0.2711	0.10	2.896
*	695.9	P – D	*	–0.0002	5.6743	–0.0003	0.0001	0.3693	0.10	3.922
*	654.5	P – D	*	–0.0002	2.5295	0.0000	0.0000	0.0290	0.10	2.457
*	653.1	P – P	*	0.0000	0.7390	0.0000	0.0000	0.0765	0.10	0.685
*	639.8	P – D	*	–0.0001	1.4214	–0.0002	0.0000	0.1137	0.10	1.268
*	633.4	S – P	*	0.0000	1.4323	0.0000	0.0000	0.0765	0.10	1.327
*	632.4	D – D	*	–0.0002	1.0291	0.0000	0.0000	0.0289	0.10	1.000
*	622.0	P – D	*	–0.0002	1.0101	0.0000	0.0000	0.0289	0.10	0.981
*	580.0	D – D	*	0.0000	0.2658	0.0000	0.0000	0.0291	0.10	0.258
	561.4	P – D		–0.2533	97.6182	29.2031	7.5539	0.2735	0.10	102.028
*	554.4	P – P	*	0.0000	5.4871	–0.0003	0.0000	0.5727	0.10	3.095
	553.8	D – D		0.9183	1.0476	2.6567	3.9920	0.3542	0.10	6.045
*	544.4	F – D		0.7035	–2.1526	2.6324	–0.0832	0.4318	0.15	0.714
*	543.0	P – S		0.1356	0.2891	0.3468	–0.0209	0.1856	0.10	0.623
*	474.4	P – P	*	0.0000	6.6601	–0.0003	0.0001	0.5727	0.10	3.756
*	464.5	D – P	*	–0.0024	8.1686	–0.0004	0.0001	0.5724	0.10	4.607

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_l	Y
*	445.1	P – S		2.2651	0.4577	17.0656	2.0497	0.1979	0.10	17.917
	440.5	D – P		0.6570	–0.1444	3.5553	0.9494	0.3583	0.10	3.506
	434.8	P – S		1.0266	6.6458	2.6769	0.4527	0.4353	0.10	6.990
	401.7	P – P		6.5154	4.6515	19.1526	2.2099	0.2697	0.10	24.840
*	355.8	P – D		0.5696	–0.8623	2.2383	–0.1390	0.2037	0.10	1.474
*	355.1	P – S		0.1960	0.4182	0.5015	–0.0302	0.1856	0.10	0.902
*	312.8	P – D	*	–0.0002	4.1359	0.0003	0.0000	0.4227	0.10	2.710
*	306.6	F – G	*	0.0001	9.1484	0.0035	0.0000	0.3840	0.10	6.234
*	290.6	P – D	*	–0.0004	13.3780	–0.0007	0.0001	0.3693	0.10	9.246
*	289.6	D – F	*	0.0001	9.0101	0.0003	–0.0001	0.2711	0.10	6.871
*	286.4	D – D	*	–0.0001	2.7522	–0.0001	0.0000	0.3693	0.10	1.902
*	269.7	D – D	*	–0.0001	1.7400	–0.0002	0.0000	0.1136	0.10	1.553
*	268.3	D – F	*	–0.0001	8.2744	–0.0007	0.0001	0.4055	0.10	5.516
*	264.8	P – D	*	–0.0027	8.7713	–0.0001	0.0000	0.0288	0.10	8.520
*	264.6	P – P	*	0.0001	2.8478	–0.0001	0.0000	0.0766	0.10	2.638
*	262.6	P – D		0.0181	0.2081	0.0113	0.0209	0.0849	0.10	0.237
*	261.2	P – P		0.1090	0.7695	0.1325	0.0060	0.1093	0.10	0.912
*	258.3	S – P	*	–0.0011	3.7846	–0.0001	0.0000	0.0763	0.10	3.505
*	253.0	D – D	*	–0.0004	3.0182	0.0000	0.0000	0.0289	0.10	2.932
*	252.0	P – D	*	–0.0009	4.1133	–0.0005	0.0001	0.1135	0.10	3.671
*	176.5	S – P		–0.0246	0.8196	0.1640	–0.0022	0.0027	0.10	0.954
*	146.7	P – D		0.2299	2.2531	0.2757	0.0274	0.3368	0.10	1.989
*	137.5	S – P		0.3079	4.1347	0.5582	0.0796	0.4264	0.10	3.317
*	137.1	P – P		4.0592	14.6438	13.5656	–0.4131	0.1407	0.10	27.674
*	132.9	D – D		0.7423	7.2838	0.8907	0.0885	0.3368	0.10	6.430
*	129.5	D – F		1.6659	11.9733	1.8272	0.2808	0.4282	0.10	10.262
*	127.7	S – P		1.1055	–1.8401	2.6588	0.3543	0.2564	0.10	1.763
*	126.4	S – P		1.0652	0.8708	1.9413	0.0579	0.1750	0.10	3.303
*	121.7	P – D		–0.0085	1.8480	1.3390	0.0020	0.1185	0.10	2.825
*	120.9	P – P		–0.0024	10.8948	2.7003	–0.1399	0.2625	0.10	10.347
	113.9	P – P		0.4141	4.2564	0.7776	0.0431	0.1863	0.10	4.558
*	113.1	P – D		0.3108	1.2993	0.4324	0.0146	0.3681	0.10	1.424
*	110.6	P – D		0.0162	7.7973	2.3068	0.0739	0.2497	0.10	7.942
*	105.5	S – P	*	0.0034	15.7035	–0.0008	0.0001	0.5729	0.10	8.857
*	104.5	P – D		–0.0226	5.2957	1.1728	0.0450	0.5063	0.10	3.858
*	104.0	P – P		0.0028	3.3531	2.3489	0.0931	0.4597	0.10	3.661
*	103.9	D – F		0.8717	4.3566	1.1836	0.0133	0.4552	0.10	4.076
*	101.7	S – P	*	–0.0268	211.7048	–0.0066	0.0009	5.6164	0.15	0.770
*	100.8	P – P		–0.0002	1.7886	0.7584	–0.0617	0.3235	0.15	1.798
*	97.5	P – D	*	–0.0022	14.1459	–0.0017	0.0003	0.1135	0.10	12.625
*	97.5	P – D		0.0048	0.6658	0.6030	0.0471	0.1175	0.10	1.174
*	97.3	P – P		0.0127	3.7185	1.0611	0.0292	0.2921	0.10	3.600
*	95.2	D – F		–0.1107	2.4409	0.3237	–0.0004	0.2955	0.10	1.975
*	91.2	D – D	*	–0.0012	10.0202	–0.0012	0.0002	0.1136	0.10	8.942
*	91.0	D – F	*	–0.0032	83.0573	–0.0046	0.0010	0.4054	0.10	55.371
*	89.4	P – P		0.2071	0.4369	0.5181	–0.0163	0.2262	0.10	0.914
*	85.6	P – D	*	–0.0035	103.8713	–0.0364	0.0054	0.0291	0.10	100.859
*	85.5	P – P	*	0.0028	33.9198	–0.0009	0.0001	0.0766	0.10	31.420
					Ne VII					
*	4375.7	D – F		–0.0985	6.6857	1.0389	–0.0598	2.7506	0.15	0.483
*	3890.6	K – L	*	–0.0012	4.7193	–0.0010	0.0001	6.5103	0.20	0.007

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_l	Y
*	3883.6	J – K		0.3340	−1.8561	2.8070	−0.2700	4.4467	0.25	0.012
*	3880.4	J – K	*	0.0009	4.0951	0.0001	0.0000	6.5035	0.20	0.006
	973.3	P – D		0.3882	−6.9111	33.3715	−3.6104	1.9030	0.10	3.465
	561.6	P – P		0.6753	−11.9880	58.6325	−6.4317	1.7846	0.10	6.864
	465.2	S – P		−0.1572	38.0673	36.5808	−3.5998	2.4232	0.15	6.284
*	106.1	P – D		0.3255	50.4158	9.5826	−0.6318	2.7553	0.15	3.796
					Mg I					
*	73889.7	G – H		−0.0039	2.8850	0.0007	0.0000	4.7002	0.15	0.026
*	38584.6	F – G		0.0449	−0.3457	0.7112	−0.0722	3.0453	0.20	0.016
*	38584.6	F – G		0.0027	4.3474	0.4176	−0.0506	4.5253	0.20	0.051
	33191.5	D – F		0.0003	1.0490	0.0813	−0.0095	4.4843	0.25	0.013
*	25380.2	F – G		0.0235	−0.2232	0.5930	−0.0692	3.4488	0.15	0.010
	15026.7	S – P		0.0001	0.6847	0.1866	−0.0210	3.0106	0.10	0.042
	14879.1	D – F		0.0258	5.7319	1.0514	−0.1184	4.2611	0.25	0.094
	12084.2	D – F		0.0692	−0.5212	1.0643	−0.1129	2.8427	0.20	0.029
	10811.4	D – F		0.0004	1.3958	0.1078	−0.0126	4.4844	0.25	0.017
	8806.6	P – D		0.1259	−0.6903	1.1785	−0.0960	2.0651	0.15	0.066
	5176.7	P – S		0.0000	0.1658	0.5114	−0.0569	2.1817	0.10	0.070
	3834.4	P – D		0.1283	−1.2733	4.6334	−0.4728	2.7691	0.10	0.189
	3094.4	P – D		0.0367	−0.3357	1.2721	−0.1456	3.0682	0.10	0.038
					Al I					
	3089.1	P – D		0.0744	−0.2889	0.3467	−0.0191	2.1198	0.25	0.014
	3058.1	P – P	*	0.0000	0.7295	−0.0001	0.0000	1.9328	0.10	0.106
*	1876.9	P – D	*	0.0003	1.1728	−0.0001	0.0000	0.7304	0.10	0.565
	1766.1	P – P	*	−0.0061	1.9676	0.0003	0.0000	1.2079	0.10	0.586
					Al II					
*	30770.3	H – I		0.0025	2.3374	0.0250	−0.0030	6.4483	0.20	0.004
*	30770.3	H – I		0.0249	7.0436	0.0538	−0.0061	6.4518	0.20	0.011
*	30230.6	G – H		0.1207	−0.6941	1.1275	−0.1127	4.5391	0.20	0.005
	23623.0	D – P		0.0703	−0.2925	0.3573	−0.0257	1.9300	0.25	0.016
*	18269.9	G – H		0.3516	−2.5821	5.1388	−0.5435	4.5701	0.25	0.024
*	18269.9	G – H		0.1943	−1.0111	1.4329	−0.1330	4.0130	0.30	0.009
	17779.2	S – P		0.1187	−0.4938	0.6031	−0.0434	1.9300	0.25	0.027
	16263.7	F – G		0.1901	−0.8555	1.0693	−0.0940	3.6770	0.35	0.008
*	11471.3	G – H		0.1152	−0.6626	1.0764	−0.1076	4.5391	0.20	0.005
	10093.1	D – P		0.0679	0.1508	0.3309	−0.0113	0.9868	0.10	0.201
	9331.9	F – G		0.4271	−1.6475	1.8194	−0.1412	3.0970	0.30	0.021
	9289.4	F – G		0.9003	−4.3736	5.8042	−0.4776	3.4290	0.30	0.060
	8358.2	D – F		0.4042	−1.3235	1.2535	−0.0742	2.2203	0.30	0.028
*	7271.3	D – P	*	0.0000	0.0177	0.0000	0.0000	0.1692	0.10	0.015
	7049.2	S – P		0.1750	0.3882	0.8526	−0.0291	0.9868	0.10	0.517
	6237.4	P – D		0.1329	−0.5974	0.7937	−0.0400	1.7245	0.20	0.052
	6182.6	F – G		0.2468	−1.1106	1.3881	−0.1220	3.6770	0.35	0.010
	5859.7	D – F		0.1889	−0.6182	0.5981	−0.0324	2.2041	0.30	0.015
*	5228.1	D – P	*	0.0000	0.0143	0.0000	0.0000	0.1692	0.10	0.012
	5145.2	F – G		0.0998	−0.4961	0.6743	−0.0603	4.1118	0.30	0.004
	4663.1	D – P		0.0025	−0.0476	0.2648	−0.0201	0.0861	0.10	0.183
	3900.7	P – D		0.1931	−1.1764	3.1451	−0.1611	0.4004	0.10	1.341
	3586.9	D – F		1.5156	−5.4947	6.0201	−0.3498	2.2296	0.30	0.182
*	3539.6	D – P	*	0.0000	0.0157	0.0000	0.0000	0.1692	0.10	0.013

Table 30. Continued

	λ (Å)	$L-L'$	A	a	b	c	d	f	t_l	Y
*	3221.7	D – F	*	0.0018	1.0715	0.0001	0.0000	3.5009	0.15	0.032
	2816.2	P – S		0.0277	0.1892	0.0500	–0.0007	0.2429	0.10	0.209
	1860.3	P – S		0.2511	0.2248	1.0554	–0.0188	1.0095	0.10	0.551
*	1733.5	S – P	*	0.0000	0.2278	0.0000	0.0000	0.1692	0.10	0.192
	1723.2	P – D		2.3605	–6.2188	6.3081	–0.2098	1.4623	0.20	0.519
	1670.8	S – P		0.3800	–1.4654	3.8451	–0.1094	0.3581	0.10	1.853
*	1480.2	D – P	*	0.0000	0.1003	0.0000	0.0000	0.1692	0.10	0.085
*	1281.6	D – F	*	0.0011	4.5198	–0.0001	0.0000	1.6757	0.10	0.846
					Si I					
*	1486.2	P – P	*	0.0000	0.5032	0.0000	0.0000	0.2150	0.10	0.406
					Si II					
	13087.1	D – D	*	0.0000	0.0028	0.0000	0.0000	0.0250	0.10	0.003
	10239.9	D – P	*	0.0000	0.0333	0.0000	0.0000	0.3306	0.10	0.024
	9000.9	P – P	*	0.0000	0.0268	0.0000	0.0000	0.0897	0.10	0.025
	6685.3	P – D	*	0.0000	0.1129	0.0000	0.0000	0.0250	0.10	0.110
	6355.1	S – P		0.3053	–0.9342	0.9443	–0.0540	0.7417	0.20	0.125
	5853.9	P – P	*	0.0000	0.2133	0.0000	0.0000	0.3306	0.10	0.153
	5681.2	F – D	*	0.0000	0.1094	0.0000	0.0000	0.0250	0.10	0.107
	5601.6	P – S	*	0.0000	0.0679	0.0000	0.0000	0.4413	0.10	0.044
	5219.4	P – D	*	0.0019	0.2475	0.0001	0.0000	1.2544	0.10	0.071
	5197.9	D – F	*	0.0004	0.9363	0.0001	0.0000	2.7927	0.10	0.057
	4192.7	D – P	*	0.0000	0.0814	0.0000	0.0000	0.0894	0.10	0.074
	4075.7	D – P		0.0007	0.0018	0.0039	–0.0003	0.1784	0.10	0.005
	3995.2	F – G	*	0.0420	1.4203	0.0033	–0.0004	3.5961	0.15	0.040
	3858.1	D – P		0.2886	–0.8830	0.8925	–0.0510	0.7417	0.20	0.118
	3474.7	P – P	*	0.0000	0.0115	0.0000	0.0000	0.0891	0.10	0.011
*	3165.1	D – F	*	0.0016	2.0587	0.0000	0.0000	3.4712	0.15	0.064
*	3025.5	P – D	*	0.0002	1.2798	0.0000	0.0000	3.7123	0.15	0.031
	1944.9	P – P	*	0.0000	0.0705	0.0000	0.0000	0.0895	0.10	0.064
	1869.7	D – D		0.0724	–0.1614	0.2842	–0.0043	0.3030	0.10	0.141
	1814.0	P – D		0.7512	–2.9732	4.1373	–0.2040	0.5606	0.15	0.977
	1531.2	P – S		0.2128	–1.0704	1.8562	–0.1382	0.5235	0.15	0.510
	1350.3	P – P		0.0012	0.2908	0.0509	–0.0063	0.1302	0.10	0.296
	1263.3	P – D		1.2378	–5.0297	5.9419	–0.4477	1.4003	0.25	0.420
	1194.1	P – P		0.5954	–2.3035	3.5048	–0.1816	1.3998	0.25	0.398
					Si III					
	13644.4	H – I		0.1265	–0.8241	1.4772	–0.1537	5.6521	0.20	0.002
	13642.6	H – I		0.3800	–2.4732	4.4279	–0.4606	5.6500	0.20	0.007
	13395.8	G – H		0.4768	–1.1841	0.8376	–0.0386	3.0607	0.40	0.004
	11339.9	S – P		0.0450	–0.2170	0.3664	–0.0272	0.8267	0.15	0.073
	8266.3	P – D		0.2716	–0.8315	0.8409	–0.0463	1.0614	0.20	0.081
	8191.1	F – G		0.4698	–1.4238	1.2271	–0.0805	3.1211	0.40	0.008
	8103.5	G – H		1.6682	–5.3113	4.7586	–0.3220	3.4159	0.40	0.026
	8102.8	G – H		0.5480	–1.7034	1.4744	–0.0921	3.2546	0.40	0.009
	7464.5	D – P		0.1144	–0.5518	0.9317	–0.0691	0.8267	0.15	0.186
	5707.5	F – D		0.0900	–0.2757	0.2788	–0.0153	1.0613	0.20	0.027
	5472.8	P – D		0.0002	0.0327	0.0061	–0.0001	0.4000	0.10	0.026
	5113.9	F – G		0.2220	–0.5918	0.4389	–0.0206	3.0733	0.45	0.002
	5091.5	G – H		0.4564	–1.1333	0.8016	–0.0369	3.0606	0.40	0.004
	4822.1	F – G		0.8599	–2.9089	2.8067	–0.1346	2.3510	0.35	0.059

Table 30. Continued

	λ (Å)	$L - L'$	A	a	b	c	d	f	t_l	Y
	4560.1	S – P		–0.0025	1.2046	0.6437	–0.0162	0.4221	0.10	1.200
	4338.5	S – P		–0.0008	0.0054	0.0829	–0.0050	0.0298	0.10	0.080
*	4229.8	G – H	*	–0.0001	1.2661	–0.0003	0.0000	4.6099	0.15	0.013
*	4212.5	D – F	*	0.0000	0.0383	0.0000	0.0000	0.3889	0.10	0.026
*	4179.2	D – D	*	0.0000	0.0225	0.0000	0.0000	0.2470	0.10	0.018
	3924.5	F – G		0.4774	–1.7240	1.7647	–0.0783	2.4288	0.30	0.039
*	3883.3	P – D	*	0.0000	0.3459	0.0000	0.0000	0.5279	0.10	0.204
	3801.3	P – D		0.0627	2.5957	1.1673	–0.0418	0.4485	0.10	2.416
*	3644.1	S – P	*	0.0000	0.1912	0.0000	0.0000	0.8731	0.10	0.080
	3590.4	P – D		0.0000	0.0898	0.1304	–0.0103	0.2192	0.10	0.169
*	3583.3	D – F	*	0.0000	0.7158	0.0000	0.0000	0.3889	0.10	0.485
*	3552.3	P – P	*	0.0000	0.1779	0.0000	0.0000	0.8731	0.10	0.074
	3487.0	D – F		0.1264	–0.3660	0.3507	–0.0128	1.5101	0.25	0.022
*	3463.4	D – D	*	0.0000	0.1175	0.0000	0.0000	0.5279	0.10	0.069
*	3450.7	P – D	*	0.0000	0.1640	0.0000	0.0000	0.2470	0.10	0.128
	3253.8	F – D		0.0193	–0.0148	0.0352	0.0065	0.5862	0.10	0.026
	3237.8	P – S		0.0037	–0.0583	0.2653	–0.0269	0.4523	0.10	0.117
	3200.0	F – G		0.8311	–2.8114	2.7127	–0.1300	2.3510	0.35	0.057
	3089.8	D – P		–0.0008	2.1244	1.1338	–0.0286	0.4239	0.10	2.113
*	3071.5	D – F	*	0.0000	0.1558	0.0000	0.0000	0.3889	0.10	0.106
*	3056.1	D – F	*	0.0000	0.2353	0.0000	0.0000	1.5119	0.10	0.052
	2541.8	P – D		0.0292	–0.4171	2.6108	–0.0531	0.2087	0.10	1.761
	1842.6	D – P		–0.0022	0.0159	0.2447	–0.0149	0.0298	0.10	0.236
	1782.0	D – F		–0.0001	1.5277	2.3834	0.0558	0.6350	0.10	2.102
*	1713.2	P – F	*	–0.0002	1.7253	–0.0002	0.0000	0.8174	0.10	0.762
	1500.9	D – F		0.0701	–1.1675	5.4084	–0.4030	0.3860	0.10	2.657
*	1480.9	D – D	*	0.0000	0.5570	0.0001	0.0000	0.2470	0.10	0.435
*	1449.8	F – G	*	–0.0001	7.4809	0.0000	0.0000	1.2092	0.10	2.233
	1435.9	P – D		0.0012	0.5137	0.0959	–0.0008	0.3974	0.10	0.410
*	1403.6	D – F	*	0.0000	1.7133	–0.0001	0.0000	0.3889	0.10	1.161
*	1398.6	D – F	*	0.0001	1.3631	0.0002	0.0000	0.9197	0.10	0.544
*	1384.9	D – D	*	0.0001	1.8000	0.0000	0.0000	0.5279	0.10	1.062
*	1302.8	F – F	*	0.0004	3.4080	–0.0004	0.0001	0.8174	0.10	1.505
	1298.9	P – P		–0.0003	0.1836	2.6554	–0.0518	0.5271	0.10	1.645
	1210.5	D – F		0.2954	0.5299	0.8371	0.0426	1.0134	0.10	0.619
	1207.5	D – D		0.0129	–0.2262	1.0662	–0.0959	0.1456	0.10	0.654
	1206.5	P – D		0.0154	–0.0858	0.6481	0.1265	0.3126	0.10	0.515
	1206.5	S – P		0.1152	–0.3082	4.4734	0.0207	0.2981	0.10	3.192
	1143.1	P – P		0.3069	0.2054	1.5713	–0.0313	0.8580	0.10	0.870
	1111.6	P – D		0.0842	–1.7568	10.2865	–0.1147	0.1059	0.10	7.645
	996.1	P – S		0.1799	0.9786	1.0052	–0.0099	0.5044	0.10	1.301

Note. An asterisk in column 1 indicates that λ is uncertain. It means that it is derived entirely from calculated term energies or that the experimental data were incomplete or very uncertain for one of the two terms. An asterisk in column 4 indicates that the upper state is an autoionizing state. The value t_l in column 10 is chosen such that the maximum error in the fit is less than 10%. Y in the last column is the value $\alpha_{\text{eff}}(\lambda)$ at $T_e = 10^4$ K in units of 10^{-12} cm^3 s^{-1}.