

THE IONIZATION EQUILIBRIUM OF ELEMENTS BETWEEN CARBON AND NICKEL

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SUMMARY

The ionization equilibrium $N(\text{ion})/N(\text{Element})$, for ions of elements abundant in the Sun, has been calculated as a function of temperature between $T_e \sim 10^4$ °K and $\sim 10^8$ °K. Two sets of results are given. The first includes the processes of collisional ionization, collisional excitation followed by auto-ionization, direct radiative recombination, radiative recombination via bound levels, and di-electronic recombination, reduced by a density dependent term. As the variation of the electron density with electron temperature in the solar atmosphere enters into the calculations these results are applicable only to the solar corona and chromosphere. The second set includes collisional ionization, collisional excitation followed by auto-ionization, direct radiative recombination, and the full di-electronic recombination rate. These results are applicable to any low density plasma where the radiation field is negligible.

I. INTRODUCTION

The ionization equilibrium of an element as a function of temperature is one of the quantities necessary in the interpretation of the solar extreme ultraviolet spectrum. House (1964) calculated the ionization equilibrium of elements between hydrogen and iron, over a wide range of temperatures, including the processes of collisional ionization, radiative and collisional recombination. But since his calculations were made the importance of two other processes has been realized. These processes are di-electronic recombination (Burgess (1964) and Burgess & Seaton (1964)) and collisional excitation followed by auto-ionization (Goldberg *et al.* (1965)). Tucker & Gould (1966), performed similar calculations, but used only an approximate expression for di-electronic recombination and did not include auto-ionization. Two sets of results are given in the present paper. The first include the processes of collisional ionization from the ground term, collisional excitation followed by auto-ionization, radiative recombination from the continuum and bound levels, and di-electronic recombination reduced by a density dependent term. As the variation of the electron density with electron temperature in the solar atmosphere enters into the calculations, these results are applicable only to the solar corona and chromosphere. The second set includes collisional ionization, collisional excitation followed by auto-ionization, radiative recombination from the continuum and the full di-electronic recombination rate. These results are applicable to any low density plasma where the radiation field is negligible. Collisional recombination, direct and via bound levels, and collisional ionization via bound levels below the first ionization limit, were calculated and found to be negligible.

The calculations include all stages of ionization of C, N, O, Ne, Mg, Si and S, and cover the range of temperatures from 5000°K to 10^8 °K. For Fe and Ni, the calculations are restricted to Fe v–xxiii, Ni vii–xxv. The ions above Fe xviii were included to enable the distribution of $N(\text{Fe xviii})/N(\text{Fe})$ to be determined

accurately at high temperatures. Since the calculations were made, Fe xx–xxvi have been observed in flare spectra, (Neupert *et al.* (1967)). However it was not considered worthwhile to extend the calculations beyond Fe xxiii as they would not be applicable to the interpretation of flare spectra, which are probably formed in non-thermal conditions.

The relative population of two successive stages of ionization is found by equating the rate of ionization from, and recombination to, a given stage of ionization. Thus

$$\frac{N(X^{+(m+1)})}{N(X^{+m})} = \frac{Q(X^{+m})}{\alpha_{\text{tot}}(X^{+m})} \quad (1)$$

where $Q(X^{+m})$ is the total rate coefficient for ionization from X^{+m} to $X^{+(m+1)}$, and $\alpha_{\text{tot}}(X^{+m})$ is the total rate coefficient for recombination from $X^{+(m+1)}$ to X^{+m} .

The ionization equilibrium $N(X^{+m})/N(E)$, where $N(E)$ is the total number density of the element, is calculated from the values of $N(X^{+(m+1)})/N(X^{+m})$. The rate coefficients used in the calculations are discussed in Section 3 of this paper.

The results are presented in tabular form, giving $-\log_{10} N(X^{+m})/N(E)$ as a function of $\log_{10} T_e$, where T_e , the electron temperature is in °K. The results for O, Si and Fe are also given graphically, to illustrate the typical shapes of the ionization curves. The results of House (1964) for O, Si and Fe are also illustrated to show the effect of including di-electronic recombination and collisional excitation followed by auto-ionization.

2. DATA

The calculations require a large amount of atomic data. The ionization potentials have been taken from Allen (1963), except for iron and nickel beyond the twentieth stage of ionization, for which values have been calculated by iso-electronic extrapolation.

The energy levels needed in the calculation of the di-electronic recombination rate have been taken from Moore (1949), and from recent work by House & Sawyer (1964), Fawcett *et al.* (1964), Gabriel *et al.* (1966), Fawcett *et al.* (1967) and (1968). Where necessary, energy levels were calculated by the writer by iso-electronic extrapolation.

The oscillator strengths needed in the calculation of the di-electronic recombination rate have been taken from the following sources; the tabulations of Wiese *et al.* (1966) for some ions of C, N, O, Ne; Pfennig *et al.* (1965) for the Be I sequence; Garstang (1962) for Si x and Fe xiv; Garstang (1966) for Fe xvii; Froese (1964) for Fe xv and xvi; Stewart & Rotenberg (1965) for low ions of C, N, O; Fawcett *et al.* (1968) for Fe ix–xiv and Ni xi–xiv; Cowan & Peacock (1966) for Fe viii. Where precise calculations were not available, oscillator strengths calculated by the method of Bates & Damgaard (1949) were used. Griem (1964) and Allen (1963) tabulate some values, and the remainder were calculated by the writer.

3. RATE COEFFICIENTS

(a) Ionization

The rate coefficient used for direct collisional ionization from the ground term is that given by Seaton (1964),

$$q(X^{+m}) = 2.0 \times 10^{-8} T_e^{1/2} \sum \zeta_i(n, l) I_i^{-2}(n, l) 10^{-5.04 I_i(n, l)/T_e} \text{ cm}^3 \text{ s}^{-1} \quad (2)$$

where $\zeta_i(n, l)$ is the number of electrons with quantum numbers (n, l) and $I_i(n, l)$ is the corresponding ionization potential in electron volts. Collisional ionization from low levels other than the ground term will not be important because of the small population of such levels relative to that of the ground term.

The collisional ionization rate via bound levels has been calculated by the method proposed by Wilson (1962). This assumes that excitation to all levels above a certain level n_t , is equivalent to ionization, since the rates for further excitation and ionization from these levels are greater than those for radiative decay. The level n_t is given by

$$n_t^7 = 1.4 \times 10^{15} Z^6 T_e^{1/2} N_e^{-1}. \quad (3)$$

The similar expression given by Griem (1964), was used in the present calculations;

$$n_t \approx 1.26 \times 10^2 Z^{14/17} N_e^{-2/17} \left[\frac{kT_e}{Z^2 E_H} \right]^{1/17} \exp \left[\frac{4Z^2 E_H}{17n_t^3 kT_e} \right]. \quad (4)$$

Z is the effective charge, N_e is the electron density, E_H is the ionization energy of hydrogen. Then, assuming that the levels above n_t are hydrogenic, the hydrogenic rate for collisional ionization via bound levels derived by Wilson (1964, 1967) has been used,

$$S(X^{+m}) = 4.8 \times 10^{-5} Z^{-2} T_e^{-1/2} e^{-I_i/kT_e} n_t^{-2} e^{-\chi_i/kT_e}. \quad (5)$$

where χ_i is the excitation energy of the level n_t , and is given by

$$\chi_i^7 = 6 \times 10^{-28} \frac{I_i}{kT_e} N_e^2. \quad (6)$$

The electron density as a function of temperature is required in equations (4) and (6). This has been taken from a model of the chromosphere and corona derived by the author. The values of N_e and T_e are given in Table I. It is found that the collisional ionization rate via bound levels is negligible compared with direct collisional ionization. The values of n_t calculated from equation (4) are also used in the calculation of the radiative and collisional recombination rates via bound levels, and the effective di-electronic recombination rates.

TABLE I

The dependence of N_e on T_e in the solar chromosphere and corona, according to the author's model

$\log T_e$	$\log N_e$
3.70	11.53
3.80	11.38
3.90	11.15
4.00	10.98
4.10	10.82
4.20	10.70
	Values given by
to	$\log N_e T_e = 14.90$
5.70	9.20
5.80	9.08
5.90	8.96
6.00	8.78
6.10	8.30
≥ 6.20	8.30

Goldberg *et al.* (1965) have suggested that for certain ions, notably Fe xv and Fe xvi, auto-ionization from levels excited by collisions with inner shell electrons and which lie above the first ionization continuum, is comparable with the direct ionization rate given by equation (2). They find that inclusion of this process increases the ionization rates for Fe xv and Fe xvi by factors of two and three respectively. Bely (1967) has discussed auto-ionization in ions of Fe ix–xviii. He finds that inclusion of auto-ionization increases the ionization rate by a factor of three for Fe xv and a factor of six for Fe xvi. His factors are larger than those found by Goldberg *et al.* (1965) as he included excitation from further inner electron shells. Goldberg *et al.* calculate the auto-ionization rate by using the excitation rates to singly excited levels lying above the first ionization continuum and use the excitation rate given by Seaton (1964).

$$C_{12} = 1.7 \times 10^{-3} f_{12} W_{12}^{-1} T_e^{-1/2} P(W/kT_e) 10^{-5040 W_{12}/T_e} \text{ cm}^3 \text{ s}^{-1}, \quad (7)$$

where f_{12} is the oscillator strength, W_{12} is the excitation energy of the level, $P(W/kT_e)$ is the integrated gaunt-factor as calculated by Van Regemorter (1962). Then

$$q_{\text{auto}} = \sum_j D_{1j}, \quad (8)$$

where j includes all levels which auto-ionize rather than undergo spontaneous radiative decay. In view of the extent of the calculations involved in computing the auto-ionization rates for all levels in each ion, the present writer has used the following simplifications. The integrated gaunt-factor has been taken as constant at its asymptotic value of $P(W/kT_e) = 0.20$, as $W/kT_e > 1.0$ for the levels involved in auto-ionization. The total oscillator strength of a series is given by

$$\sum_i f_{li} = n,$$

where n is the number of electrons in the shell from which the excitations take place. It has been assumed that 0.70 of the total oscillator strength occurs in the first line of the series, 0.13 of the total in the second, and so on using hydrogenic decrements. To find whether or not any of the first three members of a series lies below the first ionization limit, the following empirical conditions, which give the correct result in all ions where the levels are known, have been used. The energy of the first level is given by $W_1 \simeq I_2 - I_1$ where I_1 and I_2 are the energies of the first and second ionization limits. If $1.8 W_1 < I_1$ the second member also lies below the first limit; if $2.4 W_1 < I_1$ the third member also lies below the first limit. The ionization rate is then calculated from the excitation rate to the first level above the ionization limit, using the values of f_{12} and W_{12} summarized as follows.

$$\text{If } W_1 > I_1; \quad f_{12} = 0.70 \Sigma n, \quad W_{12} = W_1.$$

$$\text{If } W_1 < I_1, \text{ and } 1.8 W_1 > I_1; \quad f_{12} = 0.13 \Sigma n, \quad W_{12} = I_1.$$

$$\text{If } 1.8 W_1 < I_1 \text{ and } 2.4 W_1 > I_1; \quad f_{12} = 0.049 \Sigma n, \quad W_{12} = I_1.$$

$$\text{If } 2.4 W_1 < I_1; \quad f_{12} = 0.023 \Sigma n, \quad W_{12} = I_1.$$

The auto-ionization process is most important for iso-electronic sequences where there are a large number of electrons in the first inner shell compared with the number in the outershell, e.g. the Na I, Mg I, Ca I, K I sequences and for low ions of the B I, C I sequences.

The total ionization rate $Q(X^{+m})$ is given by

$$Q(X^{+m}) = q(X^{+m}) + q_{\text{auto}}.$$

TABLE III

- $\log N(I)/N(E)$ for C ions

$\log_{10} T_e$	Ion	CI	II	III	IV	V	VI	VII
3.7	-	0.00	6.33	-	-	-	-	-
3.8	-	0.00	3.89	-	-	-	-	-
3.9	-	0.00	1.96	-	-	-	-	-
4.0	-	0.14	0.56	-	-	-	-	-
4.1	-	0.87	0.06	5.92	-	-	-	-
4.2	-	1.80	0.01	3.81	-	-	-	-
4.3	-	2.56	0.00	2.19	-	-	-	-
4.4	-	3.20	0.05	0.98	-	-	-	-
4.5	-	3.88	0.29	0.32	-	-	-	-
4.6	-	4.60	0.70	0.10	3.53	-	-	-
4.7	-	5.25	1.12	0.03	2.19	-	-	-
4.8	-	5.94	1.61	0.04	1.17	3.64	-	-
4.9	-	-	2.08	0.20	0.47	1.74	-	-
5.0	-	-	2.95	0.67	0.19	0.47	-	-
5.1	-	-	4.25	1.71	0.64	0.13	-	-
5.2	-	-	5.53	2.72	1.18	0.03	-	-
5.3	-	-	6.68	3.65	1.72	0.01	-	-
5.4	-	-	-	-	2.18	0.00	-	-
5.5	-	-	-	-	2.62	0.00	-	-
5.6	-	-	-	-	3.02	0.00	2.96	-
5.7	-	-	-	-	0.00	1.81	5.26	-
5.8	-	-	-	-	0.05	0.95	3.26	-
5.9	-	-	-	-	0.24	0.39	1.75	-
6.0	-	-	-	-	0.69	0.21	0.78	-
6.1	-	-	-	-	1.28	0.37	0.28	-
6.2	-	-	-	-	1.95	0.73	0.09	-
6.3	-	-	-	-	2.57	1.15	0.03	-
6.4	-	-	-	-	-	1.53	0.01	-
6.5	-	-	-	-	-	1.87	0.00	-
6.6	-	-	-	-	-	2.18	0.00	-
6.7	-	-	-	-	-	2.46	0.00	-
6.8	-	-	-	-	-	2.71	0.00	-
6.9	-	-	-	-	-	2.94	0.00	-
7.0	-	-	-	-	-	3.16	0.00	-

TABLE IV

- $\log N(I)/N(E)$ for N ions

$\log_{10} T_e$	Ion	NI	II	III	IV	V	VI	VII	VIII
3.7	-	0.00	9.80	-	-	-	-	-	-
3.8	-	0.00	6.70	-	-	-	-	-	-
3.9	-	0.00	4.25	-	-	-	-	-	-
4.0	-	0.00	2.28	-	-	-	-	-	-
4.1	-	0.08	0.79	-	-	-	-	-	-
4.2	-	0.64	0.11	5.63	-	-	-	-	-
4.3	-	1.45	0.02	3.52	-	-	-	-	-
4.4	-	2.34	0.00	2.04	-	-	-	-	-
4.5	-	3.01	0.05	0.95	-	-	-	-	-
4.6	-	3.68	0.27	0.33	3.41	-	-	-	-
4.7	-	4.53	0.73	0.10	2.08	-	-	-	-
4.8	-	5.33	1.23	0.06	1.16	5.30	-	-	-
4.9	-	-	1.82	0.17	0.51	3.32	-	-	-
5.0	-	-	2.50	0.48	0.19	1.90	4.45	-	-
5.1	-	-	-	0.93	0.12	0.93	2.32	-	-
5.2	-	-	-	1.63	0.35	0.40	0.86	-	-
5.3	-	-	-	2.72	1.06	0.52	0.21	-	-
5.4	-	-	-	4.06	2.05	0.95	0.05	-	-
5.5	-	-	-	-	2.99	1.50	0.01	-	-
5.6	-	-	-	-	3.78	1.93	0.00	5.54	-
5.7	-	-	-	-	2.29	0.00	3.94	-	-
5.8	-	-	-	-	2.64	0.00	2.65	-	-
5.9	-	-	-	-	-	0.01	1.60	-	-
6.0	-	-	-	-	-	0.07	0.82	2.74	-
6.1	-	-	-	-	-	0.27	0.38	1.46	-
6.2	-	-	-	-	-	0.75	0.27	0.65	-
6.3	-	-	-	-	-	1.21	0.44	0.23	-
6.4	-	-	-	-	-	1.87	0.80	0.08	-
6.5	-	-	-	-	-	2.52	1.17	0.03	-
6.6	-	-	-	-	-	3.12	1.52	0.01	-
6.7	-	-	-	-	-	3.66	1.83	0.00	-
6.8	-	-	-	-	-	4.13	2.12	0.00	-
6.9	-	-	-	-	-	4.65	2.38	0.00	-
7.0	-	-	-	-	-	5.11	2.62	0.00	-

TABLE VI

$-\log N(I)/N(E)$ for Ne ions

Ion	Ne I	II	III	IV	V	VI	VII	VIII	IX	X	XI
	0.00	6.65	-	-	-	-	-	-	-	-	-
4.0	0.00	4.27	-	-	-	-	-	-	-	-	-
4.1	0.00	2.45	-	-	-	-	-	-	-	-	-
4.2	0.06	0.85	-	-	-	-	-	-	-	-	-
4.3	0.61	0.12	4.17	-	-	-	-	-	-	-	-
4.4	1.53	0.01	2.31	-	-	-	-	-	-	-	-
4.5	2.41	0.05	0.94	5.63	-	-	-	-	-	-	-
4.6	3.46	0.41	0.22	3.29	-	-	-	-	-	-	-
4.7	4.68	1.08	0.04	1.93	6.96	-	-	-	-	-	-
4.8	5.67	1.70	0.05	1.04	4.55	-	-	-	-	-	-
4.9	6.47	2.24	0.20	0.44	2.72	6.98	-	-	-	-	-
5.0	-	3.09	0.55	0.16	1.48	4.48	-	-	-	-	-
5.1	-	3.97	1.10	0.15	0.68	2.75	6.31	-	-	-	-
5.2	-	-	1.80	0.39	0.27	1.42	3.95	-	-	-	-
5.3	-	-	2.66	0.84	0.20	0.64	2.31	5.04	-	-	-
5.4	-	-	3.67	1.51	0.39	0.28	1.23	2.97	4.71	-	-
5.5	-	-	4.91	2.42	0.82	0.24	0.61	1.57	2.66	-	-
5.6	-	-	-	3.30	1.41	0.53	0.41	0.73	1.09	-	-
5.7	-	-	-	-	2.60	1.27	0.73	0.55	0.31	-	-
5.8	-	-	-	-	-	2.38	1.45	0.84	0.08	-	-
5.9	-	-	-	-	-	3.46	2.22	1.24	0.02	-	-
6.0	-	-	-	-	-	4.48	2.94	1.63	0.01	-	-
6.1	-	-	-	-	-	5.38	3.56	1.96	0.00	2.64	-
6.2	-	-	-	-	-	-	4.10	2.23	0.01	1.69	4.31
6.3	-	-	-	-	-	-	-	2.45	0.04	1.01	2.79
6.4	-	-	-	-	-	-	-	2.71	0.17	0.53	1.58
6.5	-	-	-	-	-	-	-	3.10	0.46	0.32	0.76
6.6	-	-	-	-	-	-	-	3.67	0.90	0.38	0.33
6.7	-	-	-	-	-	-	-	-	1.48	0.62	0.14
6.8	-	-	-	-	-	-	-	-	-	2.08	0.92
6.9	-	-	-	-	-	-	-	-	-	-	1.21
7.0	-	-	-	-	-	-	-	-	-	-	2.63
7.1	-	-	-	-	-	-	-	-	-	-	1.49
7.2	-	-	-	-	-	-	-	-	-	-	1.74
7.3	-	-	-	-	-	-	-	-	-	-	1.98

TABLE V

$-\log N(I)/N(E)$ for O ions

Ion	O I	II	III	IV	V	VI	VII	VIII	IX
	0.00	-	-	-	-	-	-	-	-
3.7	0.00	6.15	-	-	-	-	-	-	-
3.8	0.00	3.68	-	-	-	-	-	-	-
3.9	0.01	1.71	-	-	-	-	-	-	-
4.0	0.20	0.44	-	-	-	-	-	-	-
4.1	1.04	0.04	-	-	-	-	-	-	-
4.2	2.01	0.00	-	-	-	-	-	-	-
4.3	2.79	0.00	3.08	-	-	-	-	-	-
4.4	3.48	0.01	1.58	-	-	-	-	-	-
4.5	-	0.14	0.55	4.30	-	-	-	-	-
4.6	-	0.59	0.13	2.55	-	-	-	-	-
4.7	-	1.15	0.04	1.43	5.33	-	-	-	-
4.8	-	1.78	0.13	0.60	3.35	-	-	-	-
4.9	-	2.47	0.38	0.25	1.90	-	-	-	-
5.0	-	3.29	0.83	0.12	1.04	4.13	-	-	-
5.1	-	4.17	1.39	0.21	0.46	2.51	-	-	-
5.2	-	-	2.11	0.52	0.19	1.27	2.56	-	-
5.3	-	-	3.12	1.11	0.21	0.66	1.03	-	-
5.4	-	-	4.34	2.01	0.79	0.60	0.25	-	-
5.5	-	-	5.89	3.26	1.66	1.01	0.05	-	-
5.6	-	-	-	4.42	2.49	1.41	0.02	-	-
5.7	-	-	-	5.56	3.32	1.85	0.00	-	-
5.8	-	-	-	-	4.03	2.23	0.00	3.22	-
5.9	-	-	-	-	4.63	2.56	0.00	2.10	5.49
6.0	-	-	-	-	-	2.78	0.03	1.21	3.61
6.1	-	-	-	-	-	0.12	0.63	2.12	-
6.2	-	-	-	-	-	0.34	0.32	1.13	-
6.3	-	-	-	-	-	0.74	0.29	0.50	-
6.4	-	-	-	-	-	1.28	0.51	0.19	-
6.5	-	-	-	-	-	1.89	0.82	0.08	-
6.6	-	-	-	-	-	2.47	1.14	0.03	-
6.7	-	-	-	-	-	3.04	1.46	0.02	-
6.8	-	-	-	-	-	3.55	1.75	0.01	-
6.9	-	-	-	-	-	4.01	2.00	0.00	-
7.0	-	-	-	-	-	-	-	-	-

TABLE VII

$\log_{10} T_e$	Ion	$-\log N(i)/N(E)$ for Mg ions												
		MgI	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
4.0		1.02	0.05	4.26	-	-	-	-	-	-	-	-	-	-
4.1		1.82	0.00	2.45	-	-	-	-	-	-	-	-	-	-
4.2		2.50	0.04	1.08	-	-	-	-	-	-	-	-	-	-
4.3		3.28	0.35	0.25	-	-	-	-	-	-	-	-	-	-
4.4		4.33	1.07	0.04	-	-	-	-	-	-	-	-	-	-
4.5		-	1.80	0.01	-	-	-	-	-	-	-	-	-	-
4.6		-	2.41	0.00	-	-	-	-	-	-	-	-	-	-
4.7		-	2.92	0.00	4.62	-	-	-	-	-	-	-	-	-
4.8		-	3.35	0.00	2.86	-	-	-	-	-	-	-	-	-
4.9		-	3.74	0.01	1.52	-	-	-	-	-	-	-	-	-
5.0		-	-	0.13	0.57	3.11	-	-	-	-	-	-	-	-
5.1		-	-	0.58	0.15	1.61	5.02	-	-	-	-	-	-	-
5.2		-	-	1.11	0.14	0.73	3.01	7.11	-	-	-	-	-	-
5.3		-	-	1.96	0.36	0.28	1.63	4.54	-	-	-	-	-	-
5.4		-	-	2.80	0.81	0.17	0.75	2.68	5.70	-	-	-	-	-
5.5		-	-	3.74	1.45	0.35	0.32	1.42	3.44	-	-	-	-	-
5.6		-	-	4.96	2.24	0.76	0.22	0.66	1.90	4.17	-	-	-	-
5.7		-	-	-	3.26	1.45	0.45	0.31	0.93	2.40	4.46	-	-	-
5.8		-	-	-	-	2.28	0.93	0.35	0.43	1.28	2.51	3.85	-	-
5.9		-	-	-	-	3.33	1.68	0.74	0.31	0.63	1.25	1.88	-	-
6.0		-	-	-	-	-	2.77	1.50	0.68	0.54	0.63	0.65	-	-
6.1		-	-	-	-	-	4.21	2.65	1.49	0.96	0.64	0.20	-	-
6.2		-	-	-	-	-	5.85	4.04	2.56	1.69	0.98	0.06	-	-
6.3		-	-	-	-	-	-	5.27	3.53	2.36	1.33	0.02	3.73	-
6.4		-	-	-	-	-	-	-	4.43	2.99	1.67	0.01	2.65	-
6.5		-	-	-	-	-	-	-	5.13	3.43	1.85	0.01	1.78	4.34
6.6		-	-	-	-	-	-	-	5.87	3.99	2.01	0.03	1.11	2.88
6.7		-	-	-	-	-	-	-	-	-	2.21	0.12	0.64	1.75
6.8		-	-	-	-	-	-	-	-	-	2.50	0.32	0.38	0.94
6.9		-	-	-	-	-	-	-	-	-	-	0.68	0.36	0.45
7.0		-	-	-	-	-	-	-	-	-	-	1.17	0.52	0.20
7.1		-	-	-	-	-	-	-	-	-	-	1.70	0.76	0.09
7.2		-	-	-	-	-	-	-	-	-	-	2.20	1.02	0.04
7.3		-	-	-	-	-	-	-	-	-	-	-	1.28	0.02
7.4		-	-	-	-	-	-	-	-	-	-	-	1.52	0.01
7.5		-	-	-	-	-	-	-	-	-	-	-	1.76	0.01

TABLE VIII

- $\log N(i)/N(E)$ for Si ions

$\log_{10} T_e$	Ion	SiI	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
3.8		0.02	1.31	-	-	-	-	-	-	-	-	-	-	-	-	-
3.9		0.37	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-
4.0		1.24	0.03	3.89	-	-	-	-	-	-	-	-	-	-	-	-
4.1		2.02	0.00	2.06	-	-	-	-	-	-	-	-	-	-	-	-
4.2		2.62	0.08	0.80	-	-	-	-	-	-	-	-	-	-	-	-
4.3		3.32	0.46	0.18	-	-	-	-	-	-	-	-	-	-	-	-
4.4		3.97	0.86	0.06	4.09	-	-	-	-	-	-	-	-	-	-	-
4.5		-	1.23	0.02	2.72	7.28	-	-	-	-	-	-	-	-	-	-
4.6		-	1.52	0.02	1.70	4.71	-	-	-	-	-	-	-	-	-	-
4.7		-	1.81	0.06	0.90	2.57	-	-	-	-	-	-	-	-	-	-
4.8		-	2.25	0.29	0.43	1.02	-	-	-	-	-	-	-	-	-	-
4.9		-	3.12	0.96	0.50	0.23	-	-	-	-	-	-	-	-	-	-
5.0		-	4.37	2.03	1.06	0.04	5.78	-	-	-	-	-	-	-	-	-
5.1		-	-	3.08	1.65	0.01	4.01	-	-	-	-	-	-	-	-	-
5.2		-	-	4.00	2.16	0.00	2.60	6.94	-	-	-	-	-	-	-	-
5.3		-	-	-	2.61	0.01	1.50	4.52	-	-	-	-	-	-	-	-
5.4		-	-	-	3.01	0.09	0.71	2.65	5.96	-	-	-	-	-	-	-
5.5		-	-	-	-	0.33	0.30	1.38	3.55	7.04	-	-	-	-	-	-
5.6		-	-	-	-	0.79	0.23	0.64	1.92	4.33	-	-	-	-	-	-
5.7		-	-	-	-	1.45	0.46	0.31	0.86	2.41	-	-	-	-	-	-
5.8		-	-	-	-	2.23	0.96	0.40	0.38	1.26	2.76	-	-	-	-	-
5.9		-	-	-	-	3.16	1.61	0.72	0.29	0.61	1.46	3.11	5.13	-	-	-
6.0		-	-	-	-	-	2.63	1.39	0.52	0.36	0.71	1.70	3.00	4.40	-	-
6.1		-	-	-	-	-	3.80	2.29	1.07	0.51	0.36	0.85	1.57	2.28	-	-
6.2		-	-	-	-	-	-	3.32	1.83	1.01	0.49	0.55	0.79	0.92	-	-
6.3		-	-	-	-	-	-	-	3.05	1.95	1.10	0.79	0.64	0.28	-	-
6.4		-	-	-	-	-	-	-	4.58	3.21	2.03	1.39	0.87	0.09	4.58	-
6.5		-	-	-	-	-	-	-	-	4.36	2.99	2.04	1.22	0.02	3.35	7.53
6.6		-	-	-	-	-	-	-	-	-	3.81	2.59	1.49	0.01	3.39	5.55
6.7		-	-	-	-	-	-	-	-	-	4.56	3.10	1.71	0.02	1.62	3.93
6.8		-	-	-	-	-	-	-	-	-	-	3.56	1.93	0.04	1.04	2.65
6.9		-	-	-	-	-	-	-	-	-	-	4.08	2.21	0.13	0.63	1.65
7.0		-	-	-	-	-	-	-	-	-	-	-	2.52	0.33	0.39	0.91
7.1		-	-	-	-	-	-	-	-	-	-	-	-	0.67	0.36	0.45
7.2		-	-	-	-	-	-	-	-	-	-	-	-	1.10	0.50	0.22
7.3		-	-	-	-	-	-	-	-	-	-	-	-	1.61	0.72	0.11
7.4		-	-	-	-	-	-	-	-	-	-	-	-	2.09	0.94	0.05
7.5		-	-	-	-	-	-	-	-	-	-	-	-	2.58	1.19	0.03
7.6		-	-	-	-	-	-	-	-	-	-	-	-	-	1.40	0.01
7.7		-	-	-	-	-	-	-	-	-	-	-	-	-	1.61	0.01
7.8		-	-	-	-	-	-	-	-	-	-	-	-	-	1.81	0.00
7.9		-	-	-	-	-	-	-	-	-	-	-	-	-	2.00	0.00

TABLE IX
 - $\log N(i)/N(e)$ for S ions

$\log_{10} T_e$	Ion	SI	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
3.9		0.02	1.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.0		0.31	0.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.1		1.18	0.03	5.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.2		2.06	0.00	3.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.3		2.75	0.01	1.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.4		3.30	0.08	0.75	4.49	-	-	-	-	-	-	-	-	-	-	-	-	-
4.5		3.87	0.37	0.24	2.73	-	-	-	-	-	-	-	-	-	-	-	-	-
4.6		-	0.81	0.09	1.59	5.20	-	-	-	-	-	-	-	-	-	-	-	-
4.7		-	1.29	0.09	0.86	3.39	-	-	-	-	-	-	-	-	-	-	-	-
4.8		-	1.84	0.22	0.42	2.16	5.67	-	-	-	-	-	-	-	-	-	-	-
4.9		-	2.46	0.51	0.19	1.23	3.61	-	-	-	-	-	-	-	-	-	-	-
5.0		-	3.21	0.96	0.19	0.64	2.01	4.12	-	-	-	-	-	-	-	-	-	-
5.1		-	-	1.62	0.42	0.33	0.91	1.97	-	-	-	-	-	-	-	-	-	-
5.2		-	-	2.53	1.05	0.51	0.44	0.61	-	-	-	-	-	-	-	-	-	-
5.3		-	-	-	2.28	1.32	0.71	0.12	5.10	-	-	-	-	-	-	-	-	-
5.4		-	-	-	3.61	2.33	1.28	0.02	3.72	-	-	-	-	-	-	-	-	-
5.5		-	-	-	4.90	3.28	1.82	0.00	2.32	5.84	-	-	-	-	-	-	-	-
5.6		-	-	-	-	4.11	2.25	0.02	1.42	3.83	7.24	-	-	-	-	-	-	-
5.7		-	-	-	-	-	2.60	0.08	0.76	2.30	4.61	-	-	-	-	-	-	-
5.8		-	-	-	-	-	2.97	0.27	0.39	1.23	2.73	5.18	-	-	-	-	-	-
5.9		-	-	-	-	-	-	0.63	0.32	0.60	1.42	3.06	5.28	-	-	-	-	-
6.0		-	-	-	-	-	-	1.23	0.53	0.37	0.69	1.67	3.15	5.36	-	-	-	-
6.1		-	-	-	-	-	-	2.00	1.06	0.51	0.37	0.80	1.68	3.17	4.92	-	-	-
6.2		-	-	-	-	-	-	3.00	1.78	0.94	0.45	0.83	1.71	2.86	3.62	-	-	-
6.3		-	-	-	-	-	-	4.29	2.72	1.61	0.87	0.49	0.46	0.92	1.57	1.76	-	-
6.4		-	-	-	-	-	-	-	4.07	2.68	1.67	0.99	0.56	0.64	0.87	0.62	-	-
6.5		-	-	-	-	-	-	-	5.82	4.15	2.88	1.92	1.23	0.95	0.78	0.19	5.17	-
6.6		-	-	-	-	-	-	-	-	-	4.32	3.09	2.11	1.55	1.08	0.05	3.86	-
6.7		-	-	-	-	-	-	-	-	-	-	4.14	2.92	2.08	1.30	0.02	2.87	6.39
6.8		-	-	-	-	-	-	-	-	-	-	5.07	3.61	2.51	1.47	0.01	2.15	4.79
6.9		-	-	-	-	-	-	-	-	-	-	-	4.21	2.87	1.58	0.02	1.56	3.48
7.0		-	-	-	-	-	-	-	-	-	-	-	4.82	3.23	1.69	0.04	1.14	2.46
7.1		-	-	-	-	-	-	-	-	-	-	-	-	-	1.85	0.09	0.83	1.64
7.2		-	-	-	-	-	-	-	-	-	-	-	-	-	2.06	0.18	0.62	0.99
7.3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.43	0.51	0.50
7.4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.70	0.60	0.26
7.5		-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.76	0.12
7.6		-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.55	0.96	0.06
7.7		-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.97	1.17	0.03
7.8		-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.39	1.38	0.02
7.9		-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.82	1.58	0.01
8.0		-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.22	1.77	0.01

TABLE X

$\log_{10} T_e$	Ion	FeV	$-\log N(i)/N(E)$ for Fe ions																		
			VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI			
5.0		0.64	0.13	1.64	4.63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.1		1.27	0.13	0.68	2.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.2		2.03	0.46	0.29	0.89	3.55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.3		2.90	1.07	0.44	0.27	2.24	6.96	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.4		3.77	1.73	0.80	0.10	1.50	5.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.5		4.60	2.39	1.20	0.07	1.03	3.84	7.29	-	-	-	-	-	-	-	-	-	-	-	-	-
5.6		5.46	3.08	1.59	0.11	0.67	2.57	5.12	-	-	-	-	-	-	-	-	-	-	-	-	-
5.7		6.16	3.65	1.98	0.21	0.44	1.74	3.57	5.83	-	-	-	-	-	-	-	-	-	-	-	-
5.8		-	4.25	2.36	0.38	0.30	1.07	2.31	3.88	5.50	-	-	-	-	-	-	-	-	-	-	-
5.9		-	4.96	2.89	0.67	0.30	0.62	1.34	2.40	3.67	5.46	-	-	-	-	-	-	-	-	-	-
6.0		-	5.88	3.61	1.18	0.57	0.42	0.67	1.20	1.98	3.18	4.82	6.36	-	-	-	-	-	-	-	-
6.1		-	-	4.60	1.99	1.12	0.64	0.51	0.63	0.94	1.66	2.80	3.66	3.90	-	-	-	-	-	-	-
6.2		-	-	6.06	3.27	2.15	1.34	0.85	0.59	0.50	0.81	1.47	1.74	1.58	5.03	-	-	-	-	-	-
6.3		-	-	-	5.19	3.82	2.71	1.90	1.32	0.85	0.77	1.02	0.79	0.42	3.08	-	-	-	-	-	-
6.4		-	-	-	-	5.95	4.57	3.47	2.69	1.84	1.43	1.33	0.70	0.15	2.18	-	-	-	-	-	-
6.5		-	-	-	-	-	-	5.14	3.97	2.90	2.18	1.76	0.79	0.11	1.62	-	-	-	-	-	-
6.6		-	-	-	-	-	-	6.68	5.26	3.90	2.91	2.18	0.88	0.09	1.20	2.48	3.96	-	-	-	-
6.7		-	-	-	-	-	-	-	6.47	4.86	3.61	2.60	1.04	0.12	0.85	1.75	2.76	3.93	-	-	-
6.8		-	-	-	-	-	-	-	-	5.77	4.25	3.00	1.25	0.21	0.63	1.17	1.81	2.57	-	-	-
6.9		-	-	-	-	-	-	-	-	-	5.08	3.59	1.57	0.42	0.53	0.76	1.08	1.52	-	-	-
7.0		-	-	-	-	-	-	-	-	-	6.05	4.31	2.14	0.85	0.67	0.60	0.63	0.75	-	-	-
7.1		-	-	-	-	-	-	-	-	-	-	5.74	3.27	1.85	1.41	1.07	0.81	0.64	-	-	-
7.2		-	-	-	-	-	-	-	-	-	-	-	4.75	3.21	2.53	1.94	1.41	0.92	-	-	-
7.3		-	-	-	-	-	-	-	-	-	-	-	-	6.15	4.46	3.55	2.72	1.94	1.27	-	-

TABLE XI

$\log_{10} T_e$	Ion	$-\log N(i)/N(E)$ for Ni ions																			
		Ni VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII			
5.3		0.17	0.50	2.01	4.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.4		0.40	0.28	1.17	2.52	6.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.5		0.75	0.26	0.67	1.28	4.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.6		1.34	0.53	0.49	0.48	2.62	5.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.7		2.11	1.05	0.65	0.19	1.77	4.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.8		2.91	1.63	0.92	0.10	1.24	2.81	5.03	-	-	-	-	-	-	-	-	-	-	-	-	-
5.9		3.76	2.24	1.24	0.10	0.84	1.89	3.52	5.49	-	-	-	-	-	-	-	-	-	-	-	-
6.0		4.56	2.89	1.63	0.20	0.57	1.16	2.24	3.62	5.26	7.06	-	-	-	-	-	-	-	-	-	-
6.1		-	3.65	2.14	0.44	0.47	0.63	1.24	2.11	3.19	4.41	5.48	-	-	-	-	-	-	-	-	-
6.2		-	-	2.84	0.88	0.60	0.50	0.69	1.12	1.72	2.43	3.10	3.90	-	-	-	-	-	-	-	-
6.3		-	-	-	1.80	1.23	0.89	0.72	0.62	0.81	0.98	1.31	1.59	1.65	-	-	-	-	-	-	-
6.4		-	-	-	3.55	2.71	1.95	1.47	1.18	1.00	0.88	0.86	0.69	0.52	3.12	-	-	-	-	-	-
6.5		-	-	-	5.92	4.83	3.79	2.99	2.39	1.86	1.40	1.13	0.57	0.22	2.35	4.66	-	-	-	-	-
6.6		-	-	-	-	6.91	5.61	4.45	3.65	2.84	2.08	1.54	0.64	0.14	1.77	3.49	5.45	-	-	-	-
6.7		-	-	-	-	-	7.36	6.12	4.86	3.75	2.70	1.93	0.75	0.12	1.31	2.64	4.13	5.72	-	-	-
6.8		-	-	-	-	-	-	-	6.00	4.63	3.33	2.33	0.88	0.13	0.91	1.82	2.94	4.11	-	-	-
6.9		-	-	-	-	-	-	-	-	5.52	3.97	2.74	1.07	0.20	0.67	1.25	1.95	2.76	-	-	-
7.0		-	-	-	-	-	-	-	-	6.53	4.73	3.28	1.38	0.37	0.55	0.82	1.18	1.69	-	-	-
7.1		-	-	-	-	-	-	-	-	-	5.65	3.48	1.91	0.77	0.67	0.67	0.72	0.83	-	-	-
7.2		-	-	-	-	-	-	-	-	-	-	5.14	2.85	1.58	1.21	0.93	0.72	0.68	-	-	-
7.3		-	-	-	-	-	-	-	-	-	-	-	-	4.10	2.69	2.08	1.55	1.10	0.80	-	-

TABLE XIII

- LOG N(I)/N(E) FOR N IONS

Ion	NI	II	III	IV	V	VI	VII	VIII
$\log_{10} T_e$								
3.7	0.00	-	-	-	-	-	-	-
3.8	0.00	6.47	-	-	-	-	-	-
3.9	0.00	4.07	-	-	-	-	-	-
4.0	0.00	2.15	-	-	-	-	-	-
4.1	0.09	0.71	-	-	-	-	-	-
4.2	0.70	0.10	5.37	-	-	-	-	-
4.3	1.40	0.02	3.44	-	-	-	-	-
4.4	1.87	0.00	2.63	-	-	-	-	-
4.5	2.14	0.01	1.69	-	-	-	-	-
4.6	2.41	0.04	0.99	4.66	-	-	-	-
4.7	2.75	0.17	0.50	3.18	-	-	-	-
4.8	3.15	0.40	0.22	2.07	-	-	-	-
4.9	3.69	0.76	0.11	1.26	4.68	-	-	-
5.0	-	1.16	0.15	0.68	3.01	5.39	-	-
5.1	-	1.69	0.31	0.32	1.75	3.01	-	-
5.2	-	2.38	0.68	0.22	0.90	1.25	-	-
5.3	-	-	1.44	0.60	0.69	0.30	-	-
5.4	-	-	2.67	1.48	1.06	0.06	-	-
5.5	-	-	3.92	2.42	1.56	0.01	-	-
5.6	-	-	4.93	3.14	1.92	0.00	-	-
5.7	-	-	-	3.79	2.26	0.00	3.92	-
5.8	-	-	-	-	2.53	0.00	2.63	-
5.9	-	-	-	-	2.64	0.01	1.58	-
6.0	-	-	-	-	2.69	0.06	0.89	2.80
6.1	-	-	-	-	2.80	0.18	0.49	1.56
6.2	-	-	-	-	3.03	0.45	0.34	0.71
6.3	-	-	-	-	3.50	0.93	0.48	0.26
6.4	-	-	-	-	-	1.53	0.81	0.09
6.5	-	-	-	-	-	2.14	1.17	0.03
6.6	-	-	-	-	-	2.76	1.52	0.01
6.7	-	-	-	-	-	3.29	1.84	0.01
6.8	-	-	-	-	-	3.79	2.12	0.00
6.9	-	-	-	-	-	4.27	2.38	0.00
7.0	-	-	-	-	-	4.72	2.62	0.00

TABLE XII

- LOG N(I)/N(E) FOR C IONS

Ion	CI	II	III	IV	V	VI	VII
$\log_{10} T_e$							
3.7	0.00	5.94	-	-	-	-	-
3.8	0.00	3.70	-	-	-	-	-
3.9	0.01	1.76	-	-	-	-	-
4.0	0.19	0.46	-	-	-	-	-
4.1	0.96	0.05	5.67	-	-	-	-
4.2	1.71	0.01	3.61	-	-	-	-
4.3	2.07	0.00	2.39	-	-	-	-
4.4	2.29	0.01	1.56	-	-	-	-
4.5	2.49	0.05	0.93	-	-	-	-
4.6	2.73	0.16	0.52	4.76	-	-	-
4.7	3.08	0.35	0.26	3.23	-	-	-
4.8	3.49	0.65	0.12	2.06	4.30	-	-
4.9	-	0.94	0.09	1.19	2.27	-	-
5.0	-	1.45	0.25	0.64	0.76	-	-
5.1	-	2.48	0.99	0.77	0.14	-	-
5.2	-	3.75	2.00	1.28	0.02	-	-
5.3	-	4.92	2.93	1.80	0.01	-	-
5.4	-	-	3.77	2.28	0.00	-	-
5.5	-	-	4.44	2.63	0.00	4.38	-
5.6	-	-	5.12	3.02	0.00	2.95	-
5.7	-	-	-	3.22	0.01	1.79	5.24
5.8	-	-	-	3.26	0.05	0.98	3.29
5.9	-	-	-	3.28	0.17	0.51	1.87
6.0	-	-	-	3.41	0.40	0.32	0.89
6.1	-	-	-	3.85	0.84	0.42	0.33
6.2	-	-	-	4.48	1.46	0.74	0.10
6.3	-	-	-	-	2.13	1.15	0.03
6.4	-	-	-	-	2.79	1.53	0.01
6.5	-	-	-	-	3.37	1.88	0.01
6.6	-	-	-	-	3.87	2.18	0.00
6.7	-	-	-	-	-	2.46	0.00
6.8	-	-	-	-	-	2.71	0.00
6.9	-	-	-	-	-	2.94	0.00
7.0	-	-	-	-	-	3.16	0.00

TABLE XIV

- $\log N(\text{I})/N(\text{E})$ for O ions

$\log_{10} T$	Ion	O I	II	III	IV	V	VI	VII	VIII	IX
3.7		0.00	-	-	-	-	-	-	-	-
3.8		0.00	5.91	-	-	-	-	-	-	-
3.9		0.00	3.50	-	-	-	-	-	-	-
4.0		0.01	1.59	-	-	-	-	-	-	-
4.1		0.28	0.33	-	-	-	-	-	-	-
4.2		1.21	0.03	-	-	-	-	-	-	-
4.3		2.06	0.00	-	-	-	-	-	-	-
4.4		2.60	0.00	3.03	-	-	-	-	-	-
4.5		2.85	0.00	1.82	-	-	-	-	-	-
4.6		3.09	0.04	0.99	5.19	-	-	-	-	-
4.7		3.40	0.18	0.47	3.52	-	-	-	-	-
4.8		3.79	0.44	0.19	2.30	-	-	-	-	-
4.9		-	0.79	0.09	1.44	4.85	-	-	-	-
5.0		-	1.22	0.11	0.80	3.26	-	-	-	-
5.1		-	1.70	0.25	0.38	2.04	5.73	-	-	-
5.2		-	2.31	0.55	0.22	1.21	3.86	5.95	-	-
5.3		-	-	0.94	0.20	0.61	2.39	3.48	-	-
5.4		-	-	1.51	0.38	0.32	1.37	1.63	-	-
5.5		-	-	2.32	0.88	0.40	0.88	0.47	-	-
5.6		-	-	3.65	1.91	1.05	1.00	0.04	-	-
5.7		-	-	-	3.02	1.93	1.45	0.02	-	-
5.8		-	-	-	4.24	2.75	1.88	0.00	4.57	-
5.9		-	-	-	-	3.46	2.26	0.00	3.20	-
6.0		-	-	-	-	3.91	2.44	0.00	2.09	5.46
6.1		-	-	-	-	-	-	0.02	1.28	3.67
6.2		-	-	-	-	-	-	0.09	0.72	2.25
6.3		-	-	-	-	-	-	0.25	0.42	1.22
6.4		-	-	-	-	-	-	0.54	0.36	0.57
6.5		-	-	-	-	-	-	1.01	0.53	0.21
6.6		-	-	-	-	-	-	1.57	0.82	0.08
6.7		-	-	-	-	-	-	2.13	1.41	0.03
6.8		-	-	-	-	-	-	2.67	1.46	0.02
6.9		-	-	-	-	-	-	3.20	1.75	0.01

TABLE XV
- $\log N(\text{I})/N(\text{E})$ for Ne ions

$\log_{10} T$	Ion	Ne I	II	III	IV	V	VI	VII	VIII	IX	X	XI
4.0		0.00	6.56	-	-	-	-	-	-	-	-	-
4.1		0.00	4.20	-	-	-	-	-	-	-	-	-
4.2		0.00	2.30	-	-	-	-	-	-	-	-	-
4.3		0.07	0.82	-	-	-	-	-	-	-	-	-
4.4		0.63	0.11	4.04	-	-	-	-	-	-	-	-
4.5		1.56	0.01	2.25	-	-	-	-	-	-	-	-
4.6		2.38	0.04	1.02	6.08	-	-	-	-	-	-	-
4.7		3.17	0.26	0.36	4.06	-	-	-	-	-	-	-
4.8		3.91	0.62	0.12	2.73	-	-	-	-	-	-	-
4.9		4.49	1.01	0.05	1.82	5.98	-	-	-	-	-	-
5.0		5.02	1.41	0.05	1.09	4.07	-	-	-	-	-	-
5.1		-	1.85	0.15	0.57	2.61	-	-	-	-	-	-
5.2		-	2.13	0.38	0.26	1.50	4.11	-	-	-	-	-
5.3		-	-	0.77	0.18	0.75	2.54	5.70	-	-	-	-
5.4		-	-	1.32	0.31	0.36	1.46	3.74	-	-	-	-
5.5		-	-	2.00	0.63	0.23	0.76	2.30	4.44	-	-	-
5.6		-	-	2.95	1.24	0.34	0.37	1.30	2.68	3.68	-	-
5.7		-	-	-	1.84	0.68	0.28	0.70	1.41	1.71	-	-
5.8		-	-	-	-	1.38	0.62	0.60	0.80	0.51	-	-
5.9		-	-	-	-	2.68	1.60	1.13	0.90	0.11	-	-
6.0		-	-	-	-	-	2.63	1.88	1.27	0.03	5.16	-
6.1		-	-	-	-	-	3.66	2.59	1.65	0.01	3.75	-
6.2		-	-	-	-	-	4.53	3.17	1.93	0.00	2.63	-
6.3		-	-	-	-	-	5.26	3.67	2.15	0.01	1.71	4.32
6.4		-	-	-	-	-	-	-	2.31	0.04	1.02	2.79
6.5		-	-	-	-	-	-	-	2.50	0.15	0.58	1.63
6.6		-	-	-	-	-	-	-	2.78	0.38	0.36	0.80
6.7		-	-	-	-	-	-	-	3.32	0.80	0.40	0.35
6.8		-	-	-	-	-	-	-	-	1.33	0.62	0.14
6.9		-	-	-	-	-	-	-	-	1.50	0.92	0.06
7.0		-	-	-	-	-	-	-	-	2.44	1.20	0.02
7.1		-	-	-	-	-	-	-	-	-	1.49	0.01
7.2		-	-	-	-	-	-	-	-	-	1.74	0.00
7.3		-	-	-	-	-	-	-	-	-	-	0.00

TABLE XVI

$\log_{10} T_e$	Ion	- Log N(1)/N(E) for Mg ions												
		MgI	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
4.0		0.34	0.26	4.00	-	-	-	-	-	-	-	-	-	-
4.1		0.64	0.18	2.26	-	-	-	-	-	-	-	-	-	-
4.2		1.20	0.10	0.84	-	-	-	-	-	-	-	-	-	-
4.3		2.01	0.50	0.16	-	-	-	-	-	-	-	-	-	-
4.4		3.13	1.24	0.02	-	-	-	-	-	-	-	-	-	-
4.5		4.14	1.94	0.00	-	-	-	-	-	-	-	-	-	-
4.6		5.05	2.53	0.00	-	-	-	-	-	-	-	-	-	-
4.7		-	3.01	0.00	4.52	-	-	-	-	-	-	-	-	-
4.8		-	3.42	0.00	2.88	-	-	-	-	-	-	-	-	-
4.9		-	3.77	0.01	1.66	-	-	-	-	-	-	-	-	-
5.0		-	-	0.07	0.76	3.81	-	-	-	-	-	-	-	-
5.1		-	-	0.29	0.31	2.33	6.25	-	-	-	-	-	-	-
5.2		-	-	0.66	0.14	1.32	4.13	-	-	-	-	-	-	-
5.3		-	-	1.11	0.15	0.67	2.56	5.95	-	-	-	-	-	-
5.4		-	-	1.67	0.35	0.31	1.43	3.82	-	-	-	-	-	-
5.5		-	-	2.29	0.69	0.21	0.72	2.32	4.83	-	-	-	-	-
5.6		-	-	3.10	1.21	0.36	0.35	1.28	2.95	5.68	-	-	-	-
5.7		-	-	-	1.88	0.70	0.26	0.64	1.68	3.60	5.97	-	-	-
5.8		-	-	-	-	1.24	0.44	0.37	0.86	2.15	3.73	5.01	-	-
5.9		-	-	-	-	1.95	0.84	0.41	0.42	1.17	2.13	2.71	-	-
6.0		-	-	-	-	-	1.54	0.77	0.38	0.66	1.09	1.09	-	-
6.1		-	-	-	-	-	2.68	1.61	0.87	0.75	0.76	0.30	-	-
6.2		-	-	-	-	-	4.23	2.90	1.85	1.38	0.99	0.07	-	-
6.3		-	-	-	-	-	-	4.17	2.83	2.05	1.33	0.02	3.73	-
6.4		-	-	-	-	-	-	-	3.67	2.61	1.60	0.01	2.65	-
6.5		-	-	-	-	-	-	-	4.48	3.15	1.87	0.01	1.78	4.34
6.6		-	-	-	-	-	-	-	5.01	3.49	1.94	0.04	1.16	2.93
6.7		-	-	-	-	-	-	-	-	2.02	0.11	0.69	1.80	-
6.8		-	-	-	-	-	-	-	-	-	2.23	0.29	0.43	0.99
6.9		-	-	-	-	-	-	-	-	-	-	0.60	0.38	0.47
7.0		-	-	-	-	-	-	-	-	-	-	1.06	0.53	0.21
7.1		-	-	-	-	-	-	-	-	-	-	1.58	0.76	0.09
7.2		-	-	-	-	-	-	-	-	-	-	2.19	1.02	0.04
7.3		-	-	-	-	-	-	-	-	-	-	-	1.28	0.02
7.4		-	-	-	-	-	-	-	-	-	-	-	1.52	0.01
7.5		-	-	-	-	-	-	-	-	-	-	-	1.76	0.01

TABLE XVII

- Log N(i)/N(E) for Si ions

$\log_{10} T_e$	Ion	SI I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
3.9		0.20	0.44	-	-	-	-	-	-	-	-	-	-	-	-	-
4.0		0.51	0.16	3.62	-	-	-	-	-	-	-	-	-	-	-	-
4.1		0.83	0.07	2.12	-	-	-	-	-	-	-	-	-	-	-	-
4.2		1.19	0.05	1.28	-	-	-	-	-	-	-	-	-	-	-	-
4.3		1.55	0.09	0.77	-	-	-	-	-	-	-	-	-	-	-	-
4.4		1.97	0.21	0.43	5.22	-	-	-	-	-	-	-	-	-	-	-
4.5		2.39	0.38	0.23	3.82	-	-	-	-	-	-	-	-	-	-	-
4.6		-	0.59	0.10	2.65	5.36	-	-	-	-	-	-	-	-	-	-
4.7		-	0.86	0.07	1.77	3.20	-	-	-	-	-	-	-	-	-	-
4.8		-	1.14	0.09	1.08	1.48	-	-	-	-	-	-	-	-	-	-
4.9		-	1.68	0.42	0.80	0.36	-	-	-	-	-	-	-	-	-	-
5.0		-	2.83	1.30	1.16	0.02	5.82	-	-	-	-	-	-	-	-	-
5.1		-	-	2.35	1.74	0.01	4.15	-	-	-	-	-	-	-	-	-
5.2		-	-	3.24	2.21	0.01	2.89	-	-	-	-	-	-	-	-	-
5.3		-	-	3.88	2.47	0.01	1.87	5.32	-	-	-	-	-	-	-	-
5.4		-	-	-	2.62	0.04	1.10	3.50	-	-	-	-	-	-	-	-
5.5		-	-	-	-	0.14	0.59	2.13	3.75	-	-	-	-	-	-	-
5.6		-	-	-	-	0.37	0.30	1.18	2.90	5.71	-	-	-	-	-	-
5.7		-	-	-	-	0.74	0.27	0.59	1.57	3.32	-	-	-	-	-	-
5.8		-	-	-	-	1.24	0.47	0.38	0.78	2.05	3.89	-	-	-	-	-
5.9		-	-	-	-	1.90	0.86	0.42	0.41	1.11	2.30	4.25	-	-	-	-
6.0		-	-	-	-	-	1.54	0.78	0.32	0.57	1.25	3.57	4.17	-	-	-
6.1		-	-	-	-	-	2.42	1.38	0.56	0.40	0.61	1.42	2.37	3.08	-	-
6.2		-	-	-	-	-	-	2.12	1.02	0.59	0.42	0.78	1.25	1.38	-	-
6.3		-	-	-	-	-	-	-	1.96	1.24	0.72	0.70	0.78	0.42	6.32	-
6.4		-	-	-	-	-	-	-	3.40	2.40	1.54	1.18	0.89	0.11	4.60	-
6.5		-	-	-	-	-	-	-	-	3.56	2.50	1.82	1.22	0.04	3.38	-
6.6		-	-	-	-	-	-	-	-	-	3.29	2.33	1.45	0.02	2.42	5.58
6.7		-	-	-	-	-	-	-	-	-	4.04	2.83	1.66	0.02	1.66	3.97
6.8		-	-	-	-	-	-	-	-	-	-	3.29	1.87	0.04	1.08	2.69
6.9		-	-	-	-	-	-	-	-	-	-	3.76	2.09	0.12	0.67	1.69
7.0		-	-	-	-	-	-	-	-	-	-	4.31	2.41	0.29	0.42	0.94
7.1		-	-	-	-	-	-	-	-	-	-	-	-	0.62	0.37	0.47
7.2		-	-	-	-	-	-	-	-	-	-	-	-	1.03	0.50	0.23
7.3		-	-	-	-	-	-	-	-	-	-	-	-	1.52	0.71	0.11
7.4		-	-	-	-	-	-	-	-	-	-	-	-	2.01	0.94	0.05
7.5		-	-	-	-	-	-	-	-	-	-	-	-	2.48	1.18	0.03
7.6		-	-	-	-	-	-	-	-	-	-	-	-	-	1.41	0.01
7.7		-	-	-	-	-	-	-	-	-	-	-	-	-	1.61	0.01
7.8		-	-	-	-	-	-	-	-	-	-	-	-	-	1.81	0.00
7.9		-	-	-	-	-	-	-	-	-	-	-	-	-	2.00	0.00

TABLE XVIII

- Log N(1)/N(E) for S ions

$\log_{10} T_e$	Ion	SI	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
3.9		0.01	1.69	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.0		0.36	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.1		1.13	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.2		1.70	0.01	3.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.3		1.94	0.00	2.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.4		2.19	0.02	1.47	5.72	-	-	-	-	-	-	-	-	-	-	-	-	-
4.5		2.35	0.06	0.89	4.11	-	-	-	-	-	-	-	-	-	-	-	-	-
4.6		-	0.18	0.47	2.79	7.01	-	-	-	-	-	-	-	-	-	-	-	-
4.7		-	0.41	0.23	1.87	5.09	-	-	-	-	-	-	-	-	-	-	-	-
4.8		-	0.71	0.13	1.18	3.59	-	-	-	-	-	-	-	-	-	-	-	-
4.9		-	1.09	0.16	0.67	2.38	5.28	-	-	-	-	-	-	-	-	-	-	-
5.0		-	1.56	0.31	0.35	1.46	3.37	5.27	-	-	-	-	-	-	-	-	-	-
5.1		-	1.96	0.64	0.26	0.84	1.99	2.76	-	-	-	-	-	-	-	-	-	-
5.2		-	2.92	1.12	0.38	0.50	0.99	1.02	-	-	-	-	-	-	-	-	-	-
5.3		-	-	2.27	1.23	0.93	0.86	0.16	-	-	-	-	-	-	-	-	-	-
5.4		-	-	-	2.61	1.93	1.38	0.03	3.80	-	-	-	-	-	-	-	-	-
5.5		-	-	-	3.76	2.75	1.78	0.01	2.66	6.53	-	-	-	-	-	-	-	-
5.6		-	-	-	-	3.44	2.08	0.01	1.77	4.53	-	-	-	-	-	-	-	-
5.7		-	-	-	-	-	2.27	0.04	1.10	3.00	5.68	-	-	-	-	-	-	-
5.8		-	-	-	-	-	2.46	0.13	0.63	1.81	3.69	6.43	-	-	-	-	-	-
5.9		-	-	-	-	-	2.71	0.30	0.39	1.03	2.23	4.15	6.62	-	-	-	-	-
6.0		-	-	-	-	-	-	0.62	0.36	0.56	1.24	2.49	4.21	-	-	-	-	-
6.1		-	-	-	-	-	-	1.08	0.57	0.41	0.65	1.35	2.46	4.19	6.13	-	-	-
6.2		-	-	-	-	-	-	1.81	1.01	0.55	0.43	0.73	1.33	2.48	3.80	4.56	-	-
6.3		-	-	-	-	-	-	2.71	1.67	0.95	0.56	0.47	0.66	1.34	2.16	2.35	-	-
6.4		-	-	-	-	-	-	3.82	2.52	1.55	1.08	0.68	0.50	0.78	1.17	0.92	-	-
6.5		-	-	-	-	-	-	-	4.22	3.00	2.06	1.37	0.92	0.84	0.86	0.27	-	-
6.6		-	-	-	-	-	-	-	-	4.69	3.51	2.54	1.79	1.40	1.08	0.07	3.88	-
6.7		-	-	-	-	-	-	-	-	-	4.80	3.57	2.56	1.88	1.26	0.03	2.93	6.45
6.8		-	-	-	-	-	-	-	-	-	5.95	4.49	3.23	2.28	1.38	0.02	2.18	4.82
6.9		-	-	-	-	-	-	-	-	-	-	5.33	3.83	2.62	1.47	0.03	1.61	3.52
7.0		-	-	-	-	-	-	-	-	-	-	-	4.44	2.99	1.57	0.04	1.20	2.52
7.1		-	-	-	-	-	-	-	-	-	-	-	-	3.38	1.73	0.09	0.87	1.68
7.2		-	-	-	-	-	-	-	-	-	-	-	-	-	1.92	0.17	0.66	1.03
7.3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.40	0.53	0.52
7.4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.66	0.61	0.27
7.5		-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.05	0.76	0.13
7.6		-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.51	0.97	0.07
7.7		-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.92	1.17	0.03
7.8		-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.35	1.38	0.02
7.9		-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.77	1.58	0.01
8.0		-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.17	1.77	0.01

TABLE XIX

$\log_{10} T_e$	Ion	<u>- Log N(i)/N(E) for Fe ions</u>																		
		FeV	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI		
5.0		0.50	0.17	1.85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.1		0.09	0.13	0.85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.2		1.37	0.28	0.43	1.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.3		1.94	0.66	0.43	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.4		2.64	1.14	0.65	0.16	2.03	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.5		3.26	1.62	0.91	0.09	1.51	4.73	-	-	-	-	-	-	-	-	-	-	-	-	
5.6		3.99	2.17	1.23	0.07	1.04	3.36	-	-	-	-	-	-	-	-	-	-	-	-	
5.7		4.64	2.68	1.51	0.10	0.76	2.45	4.62	-	-	-	-	-	-	-	-	-	-	-	
5.8		-	3.18	1.79	0.18	0.52	1.66	3.23	5.11	-	-	-	-	-	-	-	-	-	-	
5.9		-	3.77	2.18	0.33	0.37	1.05	2.09	3.41	4.96	-	-	-	-	-	-	-	-	-	
6.0		-	4.44	2.65	0.58	0.39	0.61	1.17	1.98	3.03	4.47	6.34	-	-	-	-	-	-	-	
6.1		-	-	3.36	1.10	0.62	0.48	0.65	1.04	1.61	2.56	3.92	5.01	-	-	-	-	-	-	
6.2		-	-	4.43	1.98	1.24	0.78	0.58	0.58	0.74	1.27	2.14	2.64	2.96	-	-	-	-	-	
6.3		-	-	-	3.41	2.41	1.63	1.10	0.77	0.54	0.67	1.12	1.11	1.22	4.04	-	-	-	-	
6.4		-	-	-	-	4.13	3.07	2.24	1.60	1.08	0.87	0.97	0.55	0.45	2.63	-	-	-	-	
6.5		-	-	-	-	-	-	3.80	2.86	2.01	1.48	1.26	0.48	0.25	1.92	-	-	-	-	
6.6		-	-	-	-	-	-	5.37	4.17	3.02	2.21	1.67	0.56	0.18	1.44	2.84	4.39	-	-	
6.7		-	-	-	-	-	-	-	5.35	3.94	2.86	2.03	0.69	0.16	1.03	2.05	3.17	4.56	-	
6.8		-	-	-	-	-	-	-	-	4.88	3.52	2.44	0.87	0.19	0.74	1.40	2.15	3.01	-	
6.9		-	-	-	-	-	-	-	-	-	4.33	2.94	1.16	0.33	0.56	0.90	1.32	1.82	-	
7.0		-	-	-	-	-	-	-	-	-	-	5.24	3.66	1.69	0.70	0.64	0.68	0.81	0.99	
7.1		-	-	-	-	-	-	-	-	-	-	-	-	2.70	1.46	1.14	0.91	0.75	0.65	
7.2		-	-	-	-	-	-	-	-	-	-	-	-	3.92	2.62	2.06	1.57	1.13	0.77	
7.3		-	-	-	-	-	-	-	-	-	-	-	-	5.30	3.83	3.03	2.30	1.61	1.09	

TABLE XX

$\log_{10} T_e$	Ion	<u>- Log N(i)/N(E) for Ni ions</u>																		
		Ni VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII		
5.4		0.21	0.42	1.67	3.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.5		0.37	0.31	1.12	1.94	5.08	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.6		0.67	0.33	0.70	0.96	3.44	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.7		1.14	0.54	0.57	0.43	2.34	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.8		1.81	0.98	0.69	0.18	1.64	3.75	-	-	-	-	-	-	-	-	-	-	-	-	
5.9		2.61	1.53	0.94	0.11	1.16	2.70	4.60	-	-	-	-	-	-	-	-	-	-	-	
6.0		3.33	2.10	1.24	0.12	0.79	1.82	3.15	4.57	6.44	-	-	-	-	-	-	-	-	-	
6.1		-	2.75	1.63	0.22	0.54	1.09	1.95	3.05	4.35	5.79	-	-	-	-	-	-	-	-	
6.2		-	-	2.15	0.48	0.48	0.64	1.07	1.72	2.53	3.45	4.30	5.27	-	-	-	-	-	-	
6.3		-	-	-	1.01	0.71	0.52	0.58	0.84	1.23	1.70	2.21	2.62	2.80	-	-	-	-	-	
6.4		-	-	-	2.24	1.66	1.14	0.88	0.78	0.79	0.86	1.05	0.99	0.96	-	-	-	-	-	
6.5		-	-	-	4.33	3.49	2.68	2.10	1.71	1.37	1.09	1.00	0.54	0.33	2.59	5.00	-	-	-	
6.6		-	-	-	6.68	5.59	4.51	3.65	2.94	2.33	1.74	1.37	0.56	0.19	1.91	3.73	5.78	-	-	
6.7		-	-	-	-	-	6.28	5.15	4.17	3.24	2.36	1.75	0.65	0.14	1.44	2.82	4.37	6	-	
6.8		-	-	-	-	-	-	-	5.30	4.10	2.96	2.12	0.78	0.14	1.07	2.08	3.26	4	-	
6.9		-	-	-	-	-	-	-	-	5.01	3.61	2.53	0.94	0.18	0.76	1.43	2.21	3	-	
7.0		-	-	-	-	-	-	-	-	5.97	4.32	3.01	1.20	0.29	0.57	0.93	1.38	2	-	
7.1		-	-	-	-	-	-	-	-	-	5.22	3.67	1.66	0.62	0.62	0.69	0.82	1	-	
7.2		-	-	-	-	-	-	-	-	-	-	4.67	2.47	1.30	1.03	0.83	0.69	0	-	
7.3		-	-	-	-	-	-	-	-	-	-	-	6.00	3.60	2.28	1.76	1.31	0.91	-	

(b) *Recombination*

For temperatures greater than $T_e \simeq 6 \times 10^5 \text{K}$, the radiative recombination rate given by Burgess & Seaton (1964), has been used;

$$\alpha(X^{+m}) = 1.3 \times 10^{-9} (m+1)^2 I_m^{1/2} T_e^{-1} \text{ cm}^3 \text{ s}^{-1}. \quad (9)$$

This is an approximation, for high temperatures, to the hydrogenic expression derived by Seaton (1959).

For temperatures less than $T_e \simeq 6 \times 10^5 \text{K}$, the radiative recombination rate of Elwert (1952) was used;

$$\alpha(X^{+m}) = 0.97 \times 10^{-12} I_m n_0 g T_e^{-1/2} \text{ cm}^3 \text{ s}^{-1}, \quad (10)$$

where n_0 is the ground state total quantum number; $g \simeq 4$ for iron and nickel and $g \simeq 3$ for lighter atoms.

Burgess (1965a) has developed a simplified expression for the general calculation of α_d , the coefficient of di-electronic recombination. This is,

$$\alpha_d(X^{+m}) = 3.0 \times 10^{-3} T_e^{-3/2} B(z) \sum_i f(j, i) A(x) e^{-E/kT} \text{ cm}^3 \text{ s}^{-1}, \quad (11)$$

where

$$A(x) = z^{1/2} / (1 + 0.105x + 0.015x^2) \quad \text{for} \quad x > 0.05,$$

$$B(z) = z^{1/2} (z+1)^{5/2} (z^2 + 13.4)^{-1/2} \quad \text{for} \quad z \leq 20$$

and

$$E/kT = 0.158 (z+1)^2 \epsilon_{ij} t^{-1} a^{-1},$$

with

$$a = 1 + 0.015 z^3 (z+1)^{-2}, \quad \text{for} \quad E/kT \lesssim 5.0,$$

i is the initial state of the recombining ion; z is the charge on the recombining ion; $f(j, i)$ is the $i \rightarrow j$ oscillator strength of the recombining ion.

$\epsilon_{ij} = \nu_i^{-2} - \nu_j^{-2}$ where ν_i and ν_j are the effective principle quantum numbers of the states i and j , and $x = (z+1)\epsilon_{ij}$. The summation in equation (9) is over all bound states j of the recombining ion such that $\epsilon_{ij} > 0$.

The expression is only applicable to conditions of low radiation and particle densities, and should give results to an accuracy of about 20 per cent in coronal conditions, i.e. $N_e < 10^9 \text{ cm}^{-3}$.

However, many lines in the solar EUV spectrum are formed in the region where $10^9 \text{ cm}^{-3} < N_e < 10^{11} \text{ cm}^{-3}$. Burgess has been investigating recombination processes in these regions of higher densities, but as yet no simple method of modifying equation (11) has been derived.

Burgess (1965b) points out that as the density increases, the highly excited states above the level n_t (the collision limit), become effectively part of the continuum because of the large cross-sections for collisional transitions to neighbouring states. He argues that states with $n > n_t$ should not be included in the summation in the di-electronic rate but points out that a full treatment of the problem at high densities is needed. In the case of Ca II Burgess suggests that an estimate of the reduction in the di-electronic recombination rate may be made by considering the quantity,

$$D = \sum_{n=4}^{n_t} \alpha_d(n) / \sum_{n=4}^{\infty} \alpha_d(n) \quad (12)$$

where

$$\alpha_d(n) = \sum_i \alpha_d(i, j, nl).$$

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He calculates the value of D for a range of values of n_t and his results are given in Table II. In view of the lack of accurate calculations for each ion, the writer decided to use the relation found by Burgess for Ca II for all ions, and thus obtain very approximate reduction factors to the total di-electronic rate, to give $\alpha_d(\text{eff})$, the effective di-electronic recombination rate. The dependence of D on n_t will depend on the electron configuration of the ion, especially in the case of low ions where n_t is small. However, in these cases the di-electronic rate is often less important than the radiative rate and so the results do not depend critically on the value of D where D is most uncertain.

TABLE II
The reduction in α_d caused by the exclusion of levels above the thermal limit n_t , in the case of Ca II

n_t	D
200	0.91
100	0.62
60	0.43
20	0.15
10	0.06
8	0.04
6	0.02

Radiative decay from bound levels above the thermal limit n_t to those below is equivalent to recombination. Then, assuming the levels above n_t to be hydrogenic, the expression for the radiative recombination rate via bound levels derived by Wilson (1967) is

$$\alpha_b \simeq 1.2 \times 10^{-6} Z^4 T_e^{-3/2} n_t^{-1} \exp(\chi_t/kT) \text{ cm}^3 \text{ s}^{-1} \quad (13)$$

where Z is the charge on the recombining ion, n_t and χ_t are given by equations (4) and (6). In low ions, such as C II, O II, Si II, this process is comparable with the direct radiative recombination rate.

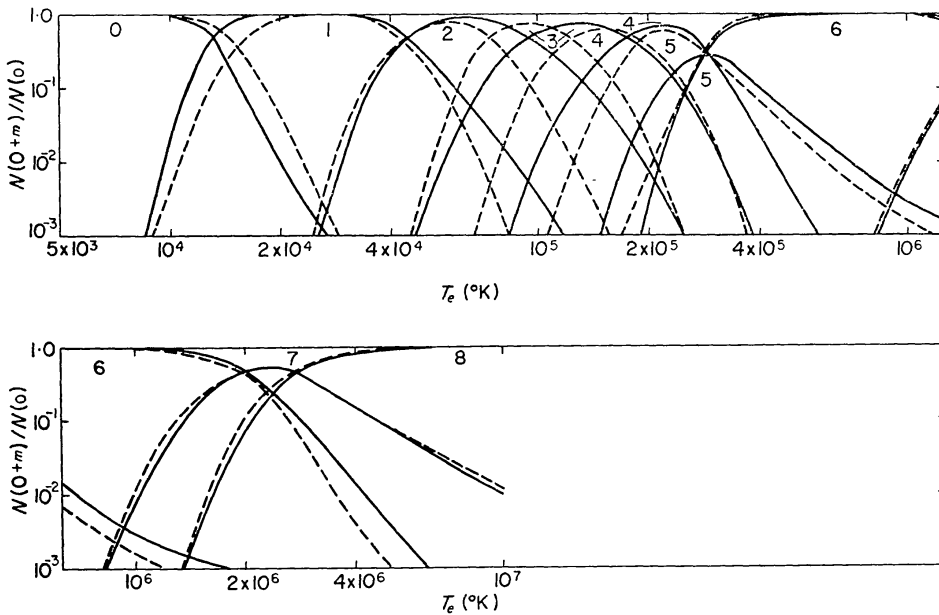


FIG. 1. The ionization equilibrium of O ions. The full lines illustrate the present calculations which are applicable to the Sun. The dashed lines show the results of House (1964).

The recombination rate resulting from collisional de-excitation of levels above the thermal limit ($\alpha_{\text{coll}.b}$) and the three body recombination from the continuum ($\alpha_{\text{coll}.c}$) were calculated using expressions given by Wilson (1967).

$$\alpha_{\text{coll}.b} = 2.0 \times 10^{-20} N_e Z^{-2} T_e^{-2} \exp(\chi_i/kT) n_i^{-2} \text{ cm}^3 \text{ s}^{-1} \quad (14)$$

$$\alpha_{\text{coll}.c} = 6 \times 10^{-21} N_e Z^{-2} T_e^{-2} \text{ cm}^3 \text{ s}^{-1}. \quad (15)$$

It was found that both processes can be neglected in solar conditions. For the first set of calculations the total recombination rate is given by

$$\alpha_{\text{tot}}(X^{+m}) = \alpha(X^{+m}) + \alpha_d(\text{eff}) + \alpha_b.$$

For the second set of calculations the total recombination rate is given by

$$\alpha_{\text{tot}}(X^{+m}) = \alpha(X^{+m}) + \alpha_d.$$

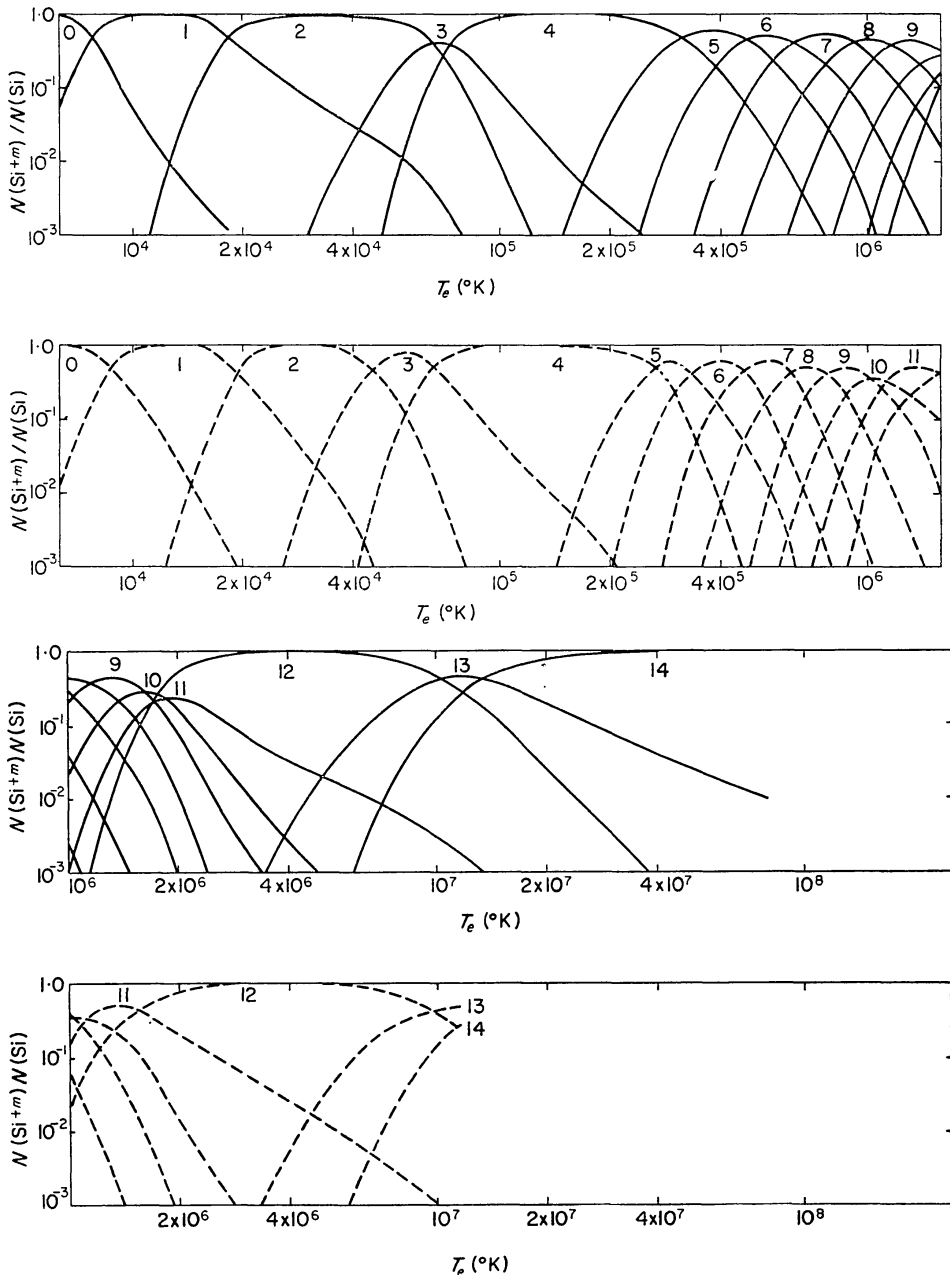


FIG. 2. The ionization equilibrium of Si ions.

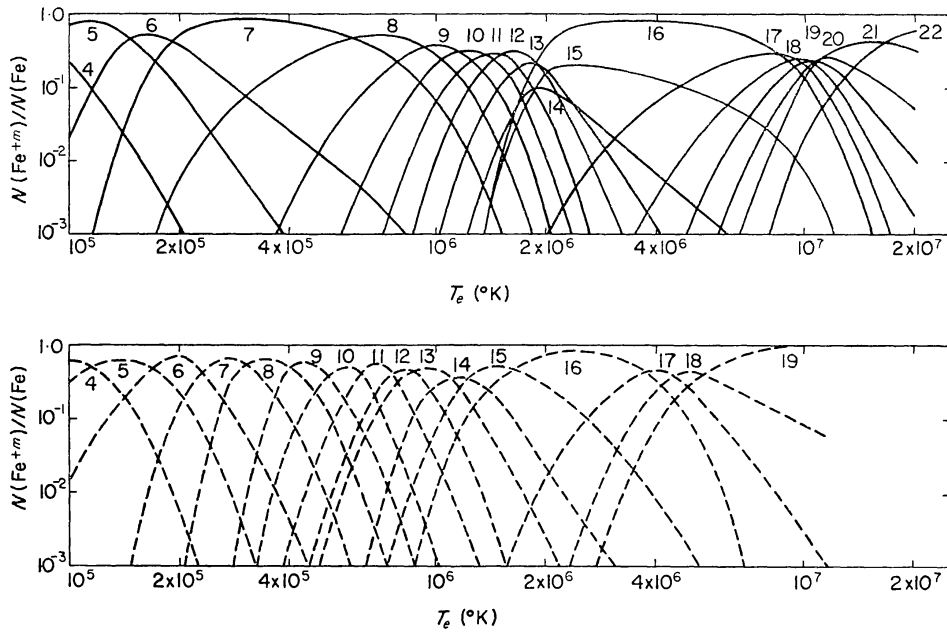


FIG. 3. *The ionization equilibrium of Fe ions.*

RESULTS

Tables III–XI give the ionization equilibrium for ions of C, N, O, Ne, Mg, Si, S, Fe and Ni, in the form of $-\log_{10} N(X^{+m})/N(E)$ as a function of $\log_{10} T_e$, with T_e in °K. These results are applicable to the solar corona and chromosphere. Tables XII–XX give the ionization equilibrium for the same ions, but as no density dependent terms were included, these values are applicable to any low density plasma where the radiation field is negligible.

Figs 1–3 illustrate the ionization equilibrium curves for O, Si and Fe. The full lines show the results of the present calculations, as given by Tables V, VIII and X. The dashed lines show the results of House (1964), who did not include di-electronic recombination or ionization via auto-ionizing levels.

As pointed out by Burgess & Seaton (1964) the inclusion of di-electronic recombination raises the temperature at which each ion has its maximum abundance. The reduction of the di-electronic rate by a density dependent term and the inclusion of ionization via auto-ionizing levels reduces the effect, but the temperatures derived are still up to a factor of two greater than those obtained prior to the inclusion of these processes.

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