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Calculation of Oscillator Strengths of Dipole Transitions by The Coulomb Approximation

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I. Introduction

In plasma physics it is often necessary to know the values of oscillator strengths f and spontaneous transition probabilities A associated with spectral lines. Since it is not easy to find these values in references especially in the wave length range of X U V and X-rays, we are sometimes obliged to calculate these atomic parameters by ourselves. The Coulomb approximation method of Bates and Damgaard (1949) has been widely used for the computation of the radial part of the matrix element in dipole transitions. Oertel and Shomo (1967) presented extended tables for a wide range of the effective quantum number n and electron angular momentum and new tables for quadrupole transitions to compute radial matrix elements. The angular part of the matrix elements are discussed by Shore and Menzel (1965, hereafter refered to as SM) and E. Dekker (1969).

In this paper we have calculated oscillator strengths for some transitions of rather highly ionized ions.

II. Line Strength

The oscillator strengths and spontaneous transition probabilities can be expressed in terms of the line strengths S

$$f_{12} = \frac{8\pi^2 mc}{3he^2} \frac{S}{g \cdot \lambda} = \frac{3.04 \times 10^2}{g \cdot \lambda} S \qquad (1)$$

$$A_{21} = \frac{64\pi^4}{3h} \frac{S}{g_2 \lambda^3} = \frac{2.02 \times 10^{18}}{g_2 \lambda^3} S \ \mathrm{sec}^{-1} \qquad (2)$$

where λ is the wave length in $\mathring{A}$ and g_1, g_2 are the statistical weiths of lower and upper states, respectively.

Following S M (1965), the line strengths may be factored as

$$S(1, 2) = S(2, 1) = R^2_{line} R^2_{mult} I^2 \quad \delta\ s\ s' \tag{3}$$

where R_{line} and R_{mult} are the line factor and multiplet factor respectively, and I the radial factor. δ s s' is equal to 1 when the spin angular momentum S = S' and zero otherwise.

The sum of transitions beginning or ending on the L' J' level is

$$\Sigma_J S = \frac{(2\ J' + 1)}{(2\ L' + 1)} R^2_{mult} I^2 \tag{4}$$

and the sum of all lines in a multiplet is

$$\Sigma_{JJ'} S = (2\ S + 1) R^2_{mult} I^2 \tag{5}$$

1-Angular factor

For LS coupling and levels without equivalent electrons, the line and multiplet factors can be defined in terms of the Racah coefficients W(a, b, c, d; e, f)

$$R_{line} = [(2J + 1)(2J' + 1)]^{1/2} W(S\ J\ L'\ 1\ ;\ L\ J') \tag{6}$$

$$= [(2J + 1)(2J' + 1)]^{1/2} W(L\ J\ L'\ J'\ ;\ S\ 1)$$

$$R_{mult} = [(2L + 1)(2L' + 1)]^{1/2} \; W(Lc\ L\ \ell'\ 1\ ;\ \ell\ L') \qquad (7)$$

$$= [(2L + 1)(2L' + 1)]^{1/2} \; W(\ell\ L\ \ell'\ L'\ ;\ Lc\ 1)$$

where L is the quantum number of the total orbital angular momentum, J is the total angular momentum and Lc refers to the quantum number for the core (parent term).

The generalization of R_{mult} for equivalent electron configurations requires coefficients of fractional parentage $<\ell^{n-1}(v'\ S'\ L')\ell\ S\ L\ |\}\ell^n\ v\ S\ L>$. For two equivalent electrons, s^2, p^2 and d^2, as well as for closed shells like p^6, the c f p' s are equal to unity for all allowed terms.

The c f p are tabulated in S M.

They considered six basic types of transitions as follows

1) $I\ell - I\ell'$ 2) $\ell^n - \ell^{n-1}\ell'$ 3) $Isp - Is^2$

4) $p^n\ s - p^{n-1}\ s^2$ 5) $\ell^n s - \ell^{n-1}\ \ell s$ 6) $\ell^n s - \ell^{n-1}\ s\ell$

where I stands for some fixed core of electrons.

Dekker calculated R_{mult} for more complicated cases like

1) $\ell_1^n\ \ell_2^m - \ell_1^{n-1}\ \ell_2^{m+1}$ 2) $\ell_1^n\ell_2^m\ell_3 p - \ell_1^{n-1}\ \ell_2^{m+1}\ \ell_3^p$

3) $\ell_1^n\ \ell_2^m\ \ell_3^p - \ell_1^{n-1}\ \ell_2^m\ \ell_3^{p+1}$ 4) $\ell_1^n\ell_2^m\ \ell_3^p - \ell_1^n\ \ell_2^{m-1}\ \ell_3^{p+1}$

S M introduced the notation

$$W_{\ell\ell'}(Lc,\ L\ L') \equiv (2L+1)^{1/2}\ (2L'+1)^{1/2}\ W(Lc\ L\ \ell'\ 1;\ \ell\ L') \quad (8)$$

and tabulated values for s-p, d-p and d-f transitions.

We calculated the oscillator strengths for the following five cases

a) $I\ell - I\ell'$

b) $\ell^n - \ell^{n-1}\ \ell'$

c) $Is^2 - Isp$

d) $\ell_1^n\ \ell_2^m - \ell_1^{n-1}\ \ell_2^{m+1}$

e) $s^2\ p_1^n - s\ p_1^n\ p_2$

and R_{mult} are expressed as follows

a) $R_{mult}(I\ \ell - I\ell') = W_{\ell\ell'}(Lc,\ L\ L')$

b) $R_{mult}(\ell^n - \ell^{n-1}\ \ell') = \sqrt{n}\ \langle \ell^n \{ | \ell^{n-1} \rangle\ W_{\ell\ell'}(Lc,\ L\ L')$

(9)

c) $R_{mult}(Is^2\text{-}Isp) = W_{sp}(L,\ L,\ Lp) \times \left(\frac{2S'+1}{2S+1}\right)^{1/2} (-1)^{s+1/2-s'}$

d) $R_{mult}(\ell_1^n\ \ell_2^m - \ell_1^{n-1}\ell_2^{m+1}) = \sqrt{n(m+1)}\,\psi'(L,S) \times \langle \ell_1^{n-1} | \} \ell_1^n \rangle$

$$\times \langle\ \ell_2^m\ |\}\ \ell_2^{m+1} \rangle \times\ (\hat{L}\times\hat{L}'\times\hat{L}_n\times\hat{L}_{m+1}\times\hat{S}_n\times\hat{S}_{m+1})$$

$$\times\ W(S_{n-1}\ 1/2\ S\ S_m;\ S_n\ S_{m+1})$$

$$\times \begin{Bmatrix} L_n & L_{n-1} & \ell_1 \\ L_m & L_{m+1} & \ell_2 \\ L & L & 1 \end{Bmatrix}$$

where $\psi'(L, S) = (-1)^{L_m+\ell_2-L_{m+1}+S_m+1/2-S_{m+1}}$, $\hat{K}=[2K + 1]^{1/2}$

and

$$\begin{Bmatrix} L_n & L_{n-1} & \ell_1 \\ L_m & L_{m+1} & \ell_2 \\ L & L' & 1 \end{Bmatrix} = \sum_g (-1)^{2g}(2g+1)\begin{Bmatrix} L_n & L_{n-1} & \ell_1 \\ \ell_2 & 1 & g \end{Bmatrix}\begin{Bmatrix} L_m & L_{m+1} & \ell_2 \\ L_{n-1} & g & L' \end{Bmatrix}\begin{Bmatrix} L & L' & \ell \\ g & L_n & L_m \end{Bmatrix}$$

for the case (e), the value $R_{mult}(I\ell - I\ell')$ are taken.

2 - Radial factor

The radial factor I is related to the radial transition integral

$$I_s = \int_0^\infty R(n, \ell)R(n' \ell') \, r^S \, dr$$

by $$I = (-1)^{\ell_>-1} \sqrt{\ell_>} I_s \qquad (10)$$

The radial factor I defined by S M is expressed by

$$I = \sigma(-1)^{\ell_>-1}[\ell_>(4\ell_>^2 - 1)]^{1/2} \qquad (11)$$

where σ is the customary radial factor which Bates and Damgaard (1947) used. $\ell_>$ is the larger angular momentum.

Oertel and Shomo (1967) extended the tables of Bates and Damgaard (1949) to compute the radial part of the matrix element in dipole transitions by Coulomb approximation method. The customary radial factor σ is obtained from

$$\sigma = \frac{1}{C} F(n_{\ell>}, \ell)\ \psi(n_{\ell>}-1, n_{\ell>}, \ell) \qquad (12)$$

in terms of the tabulated functions (Oertel and Shomo, 1967),

$$F(n_{\ell>}, \ell) = \frac{3}{2} n_{\ell>} \left[\frac{|n_{\ell>}^2 - \ell_>^2|}{4\ \ell_>^2 - 1}\right]^{1/2} \qquad (13)$$

$$\psi(n_{\ell>} -1, n_{\ell>}, \ell) = \frac{2\ C}{3\ n_{\ell>}} |\ n_{\ell>}^2 - \ell_>^2|^{-1/2}\ I_1 \qquad (14)$$

where $n_{\ell>}$, $n_{\ell>} -1$ is the effective quantum number. The effective quantum number may be obtained from

$$n = C \left(\frac{109737}{T_\infty - T}\right)^{1/2} \qquad (15)$$

where T_∞ is the series limit $T_\infty(cm^{-1})$, T the measured term value and C is the excess charge on the nucleus when the active electron is moved (C=1 for neutral atoms). (For states with two excited electrons the term value of the parent ion must be added to T_∞).

The radial factor I is expressed by

$$I = \frac{1}{C} G(n_{\ell>}, \ell)\ \psi(n_{\ell>} -1, n_{\ell>}, \ell) \qquad (16)$$

where

$$G(n_{\ell>}, \ell) = \frac{3}{2} n_{\ell>} [\ \ell_> |n_{\ell>}^2 - \ell_>^2|\ ]^{1/2} \qquad (17)$$

III - Results of computations of the oscillator strengths

After calculation of R_{mult} from eq.(9) and I from eq.(16) we can calculate $\sum_{J\,J'} S$ from eq.(5), and also the multiplet oscillator strength from eq.(1)

$$f_{12} = \frac{3.04 \times 10^2}{\sum_{J} g_1 \bar{\lambda}} \sum_{J\,J'} S \qquad (18)$$

where $\bar{\lambda}$ is the mean wave length of the multiplet.

We list the values of oscillator strength in Table 1. In the last column, we put the sign a), b), c) and d) to indicate which R_{mult} we have used in eq.(9).

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TABLE I

Ion	Isoel. seq.	Transition	λ (Å)	f	Case
O IV	B	$2s^2$ (S) 2 p (^{2}P) - 2 s^2 4 d (^{2}D)	195.9	0.104	a
	"	$2s^2$ 2 p (^{2}P) - 2 s 2 p (^{3}P) 3 p (^{2}D)	207.2	0.046	a
	"	$2s^2$ 2 p (^{2}P) - 2 s 2 p (^{3}P) 3 p (^{2}P)	214.	0.069	a
Ne IV	N	$2p^3$ (^{4}S) - 2 p^2 (^{3}P) 4 d (^{4}P)	148.8	0.18	b
	"	$2p^3$ (^{4}S) - 2 s 2 p^3 (^{5}S) 3 p (^{4}P)	169.	0.014	b
	"	$2p^3$ (^{4}S) - 2 p^2 (^{3}P) 3 d (^{4}P)	172.5	0.543	b
Mg III	Ne	$2s^2$ 2 p^6 (^{1}S) - 2 p^5 (^{2}P) 4 d (^{1}P)	171.4	0.10	b
	"	$2s^2$ 2 p^6 (^{1}S) - 2 p^5 (^{2}P) 4 s (^{1}P)	182.2	0.008	b
	"	$2s^2$ 2 p^6 (^{1}S) - 2 p^5 (^{2}P) 3 d (^{1}P)	187.2	0.197	b
Mg IV	F	$2s^2$ 2 p^5 (^{2}P) - 2 s 2 p^5 (^{3}P) 3 p (^{2}D)	120.	0.15	a
	"	$2s^2$ 2 p^5 (^{2}P) - 2 s 2 p^5 (^{3}P) 3 p (^{2}P)	120.	0.09	a
	"	$2s^2$ 2 p^5 (^{2}P) - 2 s 2 p^5 (^{3}P) 3 p (^{2}S)	120.	0.03	a

TABLE I (continued)

Ion	Isoel. seq.	Transition	λ(Å)	f	Case
Mg IV	F	$2s^2\,2p^5\,(^2P) - 2p^4\,(^1D)\,4d\,(^2S)$	124.4	0.015	b
	"	$2s^2\,2p^5\,(^2P) - 2p^4\,(^1D)\,4d\,(^2P)$	124.6	0.012	b
	"	$2s^2\,2p^5\,(^2P) - 2p^4\,(^3P)\,4d\,(^2D)$	129.7	0.078	b
	"	$2s^2\,2p^5\,(^2P) - 2p^4\,(^3P)\,4d\,(^2P)$	130.0	0.029	b
	"	$2s^2\,2p^5\,(^2P) - 2p^4\,(^1D)\,3d\,(^2S)$	140.	0.0001	b
	"	$2s^2\,2p^5\,(^2P) - 2p^4\,(^1D)\,3d\,(^2P)$	140.5	0.0005	b
	"	$2s^2\,2p^5\,(^2P) - 2p^4\,(^3P)\,3d\,(^2P)$	146.5	0.0696	b
	"	$2s^2\,2p^5\,(^2P) - 2p^4\,(^3P)\,3d\,(^2D)$	147.1	0.236	b
	"	$2s^2\,2p^5\,(^2P) - 2p^4\,(^1D)\,3s\,(^2D)$	171.6	0.034	b
	"	$2s^2\,2p^5\,(^2P) - 2p^4\,(^3P)\,3s\,(^2P)$	180.6	0.285	b
Mg V	O	$2p^4\,(^3P) - 2p^3\,(^2P)\,4d\,(^3D)$	95.8	0.0001	b
	"	$2p^4\,(^3P) - 2p^3\,(^2P)\,4d\,(^3P)$	95.9	0.0009	b
	"	$2p^4\,(^3P) - 2p^3\,(^2D)\,4d\,(^3P)$	98.2	0.0124	b
	"	$2p^4\,(^3P) - 2p^3\,(^2D)\,4d\,(^3D)$	98.6	0.0066	b
	"	$2p^4\,(^3P) - 2p^3\,(^4S)\,4d\,(^3D)$	103.9	0.103	b
	"	$2p^4\,(^3P) - 2p^3\,(^2P)\,3d\,(^3D)$	110.8	0.013	b
	"	$2p^4\,(^3P) - 2p^3\,(^4S)\,3d\,(^3D)$	121.6	0.265	b

TABLE (continued)

Ion	Isoel. seg.	Transition	λ(Å)	f	Case
Mg VII	C	$2s^2\ 2p^2\ (^3P) - 2s\ 2p^2\ (^4P)\ 3p\ (^3P)$	78.3	0.045	a
	"	$2s^2\ 2p^2\ (^3P) - 2s\ 2p^2\ (^4P)\ 3p\ (^3D)$	79.	0.096	a
Mg VIII	B	$2s^2\ 2p\ (^2P) - 2s\ 2p\ (^3P)\ 3p\ (^2P)$	71.0	0.048	a
	"	$2s^2\ 2p\ (^2P) - 2s\ 2p\ (^3P)\ 3p\ (^2D)$	69.4	0.079	a
Mg IX	Be	$2s^2\ (^1S) - 2s\ (^2S)\ 4p\ (^1P)$	48.3	0.138	c
	"	$2s\ (^2S)\ 3d\ (^1D) - 2s\ 4f\ (^1F)$	225.	1.1	a
Si VII	O	$2p^4\ (^3P) - 2p^3\ (^2P)\ 4d\ (^3D)$	57.3	0.011	b
	"	$2p^4\ (^3P) - 2p^3\ (^2P)\ 4d\ (^3P)$	57.4	0.0001	b
	"	$2p^4\ (^3P) - 2p^3\ (^2D)\ 4d\ (^3P)$	58.4	0.0003	b
	"	$2p^4\ (^3P) - 2p^3\ (^2D)\ 4d\ (^3D)$	58.6	0.0004	b
	"	$2p^4\ (^3P) - 2p^3\ (^4S)\ 4d\ (^3D)$	60.8	0.127	b
	"	$2p^4\ (^3P) - 2p^3\ (^2P)\ 3d\ (^3D)$	70.0	0.125	b
	"	$2p^4\ (^3P) - 2p^3\ (^4S)\ 3d\ (^3D)$	70.	0.222	b
Si VIII	N	$2p^3\ (^4S) - 2p^2\ (^3P)\ 4d\ (^4P)$	50.	0.31	b

TABLE I (continued)

Ion	Isoel. seq.	Transition	λ (Å)	f	Case
Si IX	C	$2p^2\ (^3P) - 2p\ (^2P)\ 4d\ (^3D)$	44.2	0.175	b
	"	$2p^2\ (^3P) - 2p\ (^2P)\ 3d\ (^3P)$	55.0	0.21	b
	"	$2p^2\ (^3P) - 2p\ (^2P)\ 3d\ (^3D)$	55.3	0.63	b
S VII	Ne	$2s^2\ 2p^6\ (^1S) - 2s\ 2p^6\ (^2S)\ 3p\ (^1P)$	50.0	0.035	a
	"	$2s^2\ 2p^6\ (^1S) - 2p^5\ (^2P)\ 4d\ (^1P)$	52.1	0.42	b
	"	$2s^2\ 2p^6\ (^1S) - 2p^5\ (^2P)\ 4s\ (^1P)$	54.7	0.011	b
S VIII	F	$2p^5\ (^2P) - 2p^4\ (^1D)\ 4d\ (^2S)$	44.4	0.012	b
	"	$2p^5\ (^2P) - 2p^4\ (^3P)\ 4d\ (^2P)$	45.3	0.064	b
	"	$2p^5\ (^2P) - 2p^4\ (^3P)\ 4d\ (^2D)$	45.4	0.18	b
	"	$2s^2\ 2p^5\ (^2P) - 2s\ 2p^5\ (^3P)\ 3p\ (^2D)$	46.	0.021	a
	"	$2s^2\ 2p^5\ (^2P) - 2s\ 2p^5\ (^3P)\ 3p\ (^2P)$	46.	0.013	a
	"	$2s^2\ 2p^5\ (^2P) - 2s\ 2p^5\ (^3P)\ 3p\ (^2S)$	46.	0.0042	a
	"	$2s^2\ 2p^5\ (^2P) - 2p^4\ (^1D)\ 3s\ (^2D)$	61.6	0.014	b
	"	$2s^2\ 2p^5\ (^2P) - 2p^4\ (^3P)\ 3s\ (^2P)$	63.0	0.046	b
S IX	O	$2p^4\ (^3P) - 2p^3\ (^2P)\ 3d\ (^3D)$	47.4	0.20	b
	"	$2p^4\ (^3P) - 2p^3\ (^4S)\ 3d\ (^3D)$	47.4	0.36	b

TABLE I (continued)

Ion	Isoel. seq.	Transition	λ (Å)	f	Case
S X	N	$2s^2\,2p^3\,(^4S) - 2s\,2p^3\,(^5S)\,3p\,(^4P)$	40.2	0.0023	a
Ca VII	Si	$3p^2\,(^3P) - 3p\,(^2P)\,4d\,(^3D)$	155.	0.02	b
	"	$3p^2\,(^3P) - 3p\,(^2P)\,4s\,(^3P)$	203.7	0.1	b
Ca VIII	Al	$3s^2\,(^1S)\,3p\,(^2P) - 3s\,3p\,(^3P)\,4p\,(^2D)$	129.	0.067	a
	"	$3s\,3p^2\,(^2P) - 3s\,3p\,4d\,(^2D)$	133.	0.027	a
	"	$3s\,3p\,(^3P)\,3d\,(^2D) - 3s\,3p\,4p\,(^2D)$	274.	0.0007	a
Ca IX	Mg	$3s^2\,(^1S) - 3s\,(^2S)\,4p\,(^1P)$	110.	0.003	c
Ca XI	Ne	$2s^2\,2p^6\,(^1S) - 2s^2\,2p^5\,(^2P)\,4d\,(^1P)$	25.5	0.61	b
	"	$2s^2\,2p^6\,(^1S) - 2s^2\,2p^5\,(^2P)\,4s\,(^1P)$	26.4	0.008	b
Fe VIII	K	$3p^6\,3d\,(^2D) - 3p^6\,(^1S)\,7f\,(^2F)$	93.	0.042	a
	"	$3d\,(^2D) - 6f\,(^2F)$	98.3	0.06	a
Fe X	Cl	$3p^5\,(^2P) - 3p^4\,(^3P)\,4d\,(^2P)$	76.1	0.04	b
	"	$3p^5\,(^2P) - 3p^4\,(^3P)\,4d\,(^2D)$	77.	0.12	b
	"	$3p^5\,(^2P) - 3p^4\,(^3P)\,4s\,(^2P)$	95.3	0.11	b
	"	$3p^4\,(^3P)\,4p\,(^2P) - 3p^4\,4d\,(^2D)$	222.9	0.83	a

TABLE I (continued)

Ion	Isoel. seq.	Transition	λ(Å)	f	Case
Fe XI	S	$3p^3\ 3d\ (^3D) - 3p^3\ (^4S)\ 4f\ (^3F)$	92.9	0.11	a
	"	$3p^3\ 3d\ (^3F) - 3p^3\ (^2D)\ 4p\ (^3D)$	123.5	0.0048	a
Fe XIV	Al	$3s^2\ (^1S)\ 3p\ (^2P) - 3s\ 3p\ (^3P)\ 4p\ (^2D)$	129.	0.067	a
Fe XVII	Ne	$2s^2\ 2p^6\ (^1S) - 2s^2\ 2p^5\ (^2P)\ 4d\ (^1P)$	12.2	0.70	b
	"	$2s^2\ 2p^6\ (^1S) - 2s^2\ 2p^5\ (^2P)\ 4s\ (^1P)$	12.7	0.035	b
Fe XVIII	F	$2p^5\ (^2P) - 2p^4\ (^3P)\ 4d\ (^2D)$	12.2	0.26	b
	"	$2p^5\ (^2P) - 2p^4\ (^3P)\ 4d\ (^2P)$	12.2	0.087	b
	"	$2p^5\ (^2P) - 2p^4\ (^1D)\ 4d\ (^2S)$	12.2	0.039	b
	"	$2s^2\ 2p^5\ (^2P) - 2s\ 2p^5\ (^3P)\ 3p\ (^2D)$	13.4	0.032	a
	"	$2s^2\ 2p^5\ (^2P) - 2s\ 2p^5\ (^3P)\ 3p\ (^2P)$	13.4	0.12	a
	"	$2s^2\ 2p^5\ (^2P) - 2s\ 2p^5\ (^3P)\ 3p\ (^2S)$	13.4	0.038	a
	"	$2p^5\ (^2P) - 2p^4\ (^3P)\ 3d\ (^2P)$	14.5	0.225	b
	"	$2p^5\ (^2P) - 2p^4\ (^1D)\ 3d\ (^2P)$	14.5	0.225	b
	"	$2p^5\ (^2P) - 2p^4\ (^3P)\ 3d\ (^2D)$	14.5	0.678	b
	"	$2p^5\ (^2P) - 2p^4\ (^1D)\ 3d\ (^2S)$	14.5	0.100	b
	"	$2p^5\ (^2P) - 2p^4\ (^3P)\ 3s\ (^2P)$	15.8	0.0048	b
	"	$2p^5\ (^2P) - 2p^4\ (^1D)\ 3s\ (^2D)$	15.8	0.0027	b

TABLE I (continued)

Ion	Isoel. seg.	Transition	λ(Å)	f	Case
Fe XIX	O	$2p^4\ (^3P) - 2p^3\ (^2D)\ 4d\ (^3P)$	10.8	0.061	b
	"	$2p^4\ (^3P) - 2p^3\ (^2P)\ 4d\ (^3P)$	10.8	0.021	b
	"	$2p^4\ (^3P) - 2p^3\ (^2D)\ 4d\ (^3D)$	10.8	0.11	b
	"	$2p^4\ (^3P) - 2p^3\ (^2P)\ 4d\ (^3D)$	10.8	0.062	b
	"	$2p^4\ (^3P) - 2p^3\ (^2P)\ 4d\ (^3D)$	10.8	0.048	b
	"	$2p^4\ (^3P) - 2p^3\ (^2P)\ 3s\ (^3P)$	14.5	0.0024	b
Fe XX	N	$2p^3\ (^4S) - 2p^2\ (^3P)\ 4d\ (^4P)$	9.7	0.155	b
	"	$2s^2\ 2p^3\ (^4S) - 2s\ 2p^3\ (^5S)\ 3p\ (^4P)$	12.5	0.00003	a
	"	$2s^2\ 2p^3\ (^4S) - 2p^2\ (^3P)\ 3s\ (^4P)$	13.7	0.0018	b
	"	$2s^2\ 2p^3\ (^4S) - 2p^2\ (^3P)\ 3d\ (^4P)$	13.4	1.3	b
Fe XXI	C	$2p^2\ (^3P) - 2p\ (^2P)\ 4d\ (^3D)$	10.3	0.11	b
	"	$2s^2\ 2p^2\ (^3P) - 2s\ 2p^2\ (^4P)\ 3p\ (^3D)$	11.6	0.006	a
	"	$2p^2\ (^3P) - 2p\ (^2P)\ 3d\ (^3D)$	12.3	0.68	b
	"	$2p^2\ (^3P) - 2p\ (^2P)\ 3d\ (^3P)$	12.3	0.23	b
	"	$2p^2\ (^3P) - 2s\ 2p^2\ (^4P)\ 3p\ (^3P)$	12.5	0.058	a
Fe XXII	B	$2s^2\ 2p\ (^2P) - 2s\ 2p\ (^3P)\ 3p\ (^2P)$	11.5	0.012	a
	"	$2s^2\ 2p\ (^2P) - 2s\ 2p\ (^3P)\ 3p\ (^2D)$	11.5	0.020	a

TABLE I (continued)

Ion	Isoel. seg.	Transition	λ(Å)	f	Case
Fe XXIV	Li	$1s^2\,2s\,(^2S) - 1s^2\,5p\,(^2P)$	7.23	0.0012	a
Ni X	K	$3p^6\,3d\,(^2D) - 3p^5\,(^3P)\,3d^2\,(^2D)$	144.3	0.60	a
				0.27	d
Ni XVII	Mg	$3s^2\,(^1S) - 3s\,(^2S)\,4p\,(^1P)$	42.2	0.18	c