THE EFFECT OF RESONANCES ON THE EXCITATION RATES FOR THE IONS OF THE HE-LIKE ISOELECTRONIC SEQUENCE

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The Helium-like resonance, intercombination and forbidden lines ($1s^2\ ^1S-1s2p\ ^1P$, $1s^2\ ^1S-1s2p\ ^3P$, $1s^2\ ^1S-1s2s\ ^3S$ respectively) can be observed from hot, low density plasmas such as coronal or tokamak plasmas. They can be used either to measure the electron temperature from the ratio of their intensity to that of the corresponding satellite lines ($1s^2 n\ell'-1s2\ell n\ell'$) as described by Gabriel (1972) or directly as a density diagnostic (Gabriel and Jordan, 1972). The soft X-ray spectra obtained from these plasmas have been observed from space satellite experiments such as the Solar Maximum Mission (Acton et al., 1980), Hinotori (Tanaka et al., 1982) and P78-1 (Doschek et al., 1982) or from tokamaks such as PDX, PLT (Princeton, USA), TFR (Fontenay-aux-Roses, France). The analysis of some of these spectra, for example, Mg XI (Faucher et al., 1983), Ti XXI (Bely-Dubau et al., 1982b) and Ca XIX (Bely-Dubau et al., 1982a, Jordan and Veck 1982) show that these diagnostics are sensitive to the accuracy of the atomic data and demonstrate the need for improved calculations of the excitation rates for the He-like ions.

The doubly excited states of the Li-like ions which give rise to the satellite lines can either autoionize to a He-like continuum or decay radiatively. Thus, when these states are above the $2\ ^3S$, $2\ ^3P$ or $2\ ^1P$ thresholds, they produce resonances in the ($1\ ^1S-2\ ^3S$), ($1\ ^1S-2\ ^3P$) and ($1\ ^1S-2\ ^1P$) collision strengths which are numerous enough to enhance the effective rate coefficients. However, as these states can also decay radiatively with transition probabilities scaling as Z^4, it is clear that their effect decreases for increasing Z.

Previous calculations were carried out for the effect of resonances on the intensity of the forbidden line for various He-like ions: O, Mg, Ca, Fe (Steenman-Clark and Faucher, 1984). This line is the most sensitive to this effect, $2\ ^3S$ being the lowest-lying level in the n=2 complex. Results were obtained using the quantum defect theory developed by Gailitis (1963) and Seaton (1969) including the possibility for the resonant states to decay radiatively. The effect of the $1s2\ell' n\ell$ resonances on the excitation rate coefficients has been estimated by comparing the rates derived from the direct collision strengths computed in intermediate coupling with the D.W. method with those obtained similarly but including the resonant states. At the temperatures of maximum abundance of each ion, the effect of resonances was estimated to be 37% for O VII (10^6K), 17% for Mg XI (4.10^6K), 6% for Ca XIX (15.10^6K) and 5% for Fe XXV (20.10^6K).

Recent investigations of Pradhan (1983) and Tayal and Kingston (1984) emphasize the importance of the resonances due to the autoionizing states $1s3\ell' n\ell$ ($n \geq 3$). To estimate the effect of these resonances we used the method developed for the autoionizing states $1s2\ell'n\ell$ and found it to be negligible (Steenman-Clark and Faucher, 1984). However, such a method is valid only for large values of n as the corresponding collision strengths are calculated averaging over all the resonances within a small energy interval where the reactance matrix is assumed to be constant.

New calculations are presented here to estimate the effect of the resonances due to the autoionizing levels $1s3\ell'n\ell$ with $n \leq 5$. As these resonances are well separated and situated in a limited energy range, their contribution over the direct excitation rates were calculated from the following process:

$$1s^2\ {}^1S + e \rightarrow 1s3\ell'n\ell \rightarrow 1s2\ell'' + e' \quad . \qquad (1)$$

The corresponding excitation rate C can be expressed as:

$$C\ (cm^3\ s^{-1}) = F_1(T_e) \times F_2{}^*(s) \qquad (2)$$

where

$$F_1(T_e) = 3.27\ 10^{-24} \left(\frac{E_H}{kT_e}\right)^{3/2} \exp(-E_s/kT_e) \qquad (3)$$

$$F_2{}^*(s) = \frac{g_s}{g_1} \frac{A_a^1(s)\ A_a^2(s)}{\sum_i A_a^i(s) + \sum_j A_r^j(s)} \quad . \qquad (4)$$

E_s is the energy difference between the autoionization state s and the ground state of the He-like ion of statistical weight $g_1=1$. $A_a^i(s)$ and $A_r^j(s)$ are respectively the autoionization and radiative probabilities with

$$A_a^1(s) = A_a\ (s \equiv 1s3\ell'n\ell\ {}^{2s+1}L_J \rightarrow 1 \equiv 1s^2\ {}^1S_o) \qquad (5)$$

$$A_a^2(s) = A_a\ (s \equiv 1s3\ell'n\ell\ {}^{2s+1}L_J \rightarrow 2 \equiv 1s2\ell''\ {}^{2s+1}L'_{J'}). \qquad (6)$$

The summations over $A_a^i(s)$ and $A_r^j(s)$ are extended respectively to all the possible continua from the autoionizing level s and to all radiatively allowed lower states.

We can express the excitation rate for a given transition as the summation of three contributions:

$$C = C_1 + C_2 + C_3 \qquad (7)$$

where C_1 is the direct excitation rate
C_2 is the excitation rate due to the autoionizing levels $1s2\ell'n\ell$ $(n > n_c)$
C_3 is the excitation rate due to the autoionizing levels $1s3\ell'n\ell$ (n = 3, 4, 5).

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Table 1 shows the results obtained for Fe XXV for the resonance and forbidden lines w and z respectively at three temperatures of interest for this ion.

TABLE 1. Relative Importance of the Different Contributions to the Excitation Rates for the Resonance (w) and Forbidden (z) Lines in Fe XXV.

	w			z		
T_e (10^6K)	C_1	C_2	C_3	C_1	C_2	C_3
10	.303(-14)	0	.886(-16)	.396(-15)	.391(-16)	.108(-15)
20	.119(-12)	0	.192(-14)	.116(-13)	.633(-15)	.230(-14)
30	.398(-12)	0	.413(-14)	.310(-13)	.123(-14)	.494(-14)

The effect of the autoionizing levels $1s3\ell'n\ell$ ($n \leq 5$) is very important for the z-line with respect to the contribution due to the $1s2\ell'n\ell$ ($n > 16$) autoionizing levels.

Table 2 shows, for the z-line, that this contribution decreases rapidly with n, thus confirming that the contribution due to the $1s3\ell'n\ell$ autoionizing states for large values of n is negligible.

TABLE 2. Contributions of Each N to the Excitation Rate C_3 Obtained for Fe XXV at 20.10^6K ($C_3 = C_3^3 + C_3^4 + C_3^5$)

T_e (10^6K)	C_3^3	C_3^4	C_3^5
20	1.383(-15)	6.966(-16)	2.224(-16)

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