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Effect of resonances on the excitation rates of He-like Fe XXV ion

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The effect of the autoionizing states $1s\,3l'nl$, with $n\geq 3$ on the He-like effective excitation rates of ${}_{26}$Fe XXV is examined. Results are obtained by computing directly the excitation rate coefficient for the processes $1s^2+e\rightarrow 1s\,3l'nl\rightarrow 1s\,2l''+e$, with $n=3$, 4, and 5, and by extrapolating them to $n>5$. For this ion, contribution of these autoionizing states to the excitation rate coefficients is more important than the corresponding contribution due to the $1s\,2l'nl$ autoionizing states. Nevertheless, the effect of all these resonances is much smaller than the effect of the radiative cascades.

I. INTRODUCTION

The heliumlike resonance, intercombination, and forbidden lines ($1s^2\,{}^1S-1s\,2p\,{}^1P$, $1s^2\,{}^1S-1s\,2p\,{}^3P$, and $1s^2\,{}^1S-1s\,2s\,{}^3S$, 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 ($1s^2nl'$-$1s2lnl'$) as described by Gabriel[1] or directly as an electron density diagnostic.[2] The soft-x-ray spectra obtained from these plasmas have been observed from space satellite experiments such as the Solar Maximum Mission,[3] Hinotori,[4] and P78-1,[5] or from tokamaks such as PDX (Poloidal Divertor Experiment) and PLT (Princeton Large Torus) at Princeton, New Jersey and TFR (Tokamak Fontenay-aux-Roses) in France. The analysis of some of these spectra, for example, ${}_{12}$Mg XI,[6] ${}_{22}$Ti XXI,[7] and ${}_{20}$Ca XIX,[8,9] shows that these diagnostics are sensitive to the accuracy of the atomic data and demonstrates 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: ${}_{8}$O VII, ${}_{12}$Mg XI, ${}_{20}$Ca XIX, and ${}_{26}$Fe XXV.[10] 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[11] and Seaton[12] including the possibility for the resonant states to decay radiatively.[13,14] The effect of the $1s\,2l'nl$ 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 distorted-wave (DW) 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 ${}_{8}$O VII (10^6 K), 17% for ${}_{12}$Mg XI (4×10^6 K), 6% for ${}_{20}$Ca XIX (15×10^6 K), and 5% for ${}_{26}$Fe XXV (20×10^6 K).

Recent investigations of Pradhan[15] and Tayal and Kingston[16] emphasize the importance of the resonances due to the autoionizing states $1s\,3l'nl$ ($n\geq3$). It is possible to estimate the effect of these resonances using the formalism developed by Gailitis and Seaton. However, such a method is valid only for large values of n as the corresponding collision strengths are calculated averaging over all the closed resonances within a small energy interval where the reactance matrix is assumed to be constant. In particular, this method is not appropriate to evaluate the contribution due to the $1s\,3l'nl$ autoionizing states for small values of n as the corresponding resonances are well separated and situated in limited energy ranges. Steenman-Clark and Faucher[10] used this method to estimate the effect of the autoionizing states $1s\,3l'nl$ for large values of n and found it to be negligible.

New calculations are presented here to obtain the effect of the resonances due to the autoionizing states $1s\,3l'nl$, with $n\leq5$. To evaluate the contribution due to large values of n ($n>5$) an extrapolation process has been done from the $n=5$ calculated results.

II. THEORETICAL CALCULATIONS

Resonances due to the autoionizing states $1s\,3l'nl$, with $n\leq5$, are well separated and situated, for each n, in a limited energy range. Their contribution over the direct excitation rates were calculated from the following electron-atom collision process:

$$1s^2\,{}^1S_0+e\rightarrow 1s\,3l'nl\,{}^{2S+1}L_J\rightarrow 1s\,2l''\,{}^{2S'+1}L'_{J'}+e'' \ . \qquad (1)$$

After integration of the corresponding cross-section over the Maxwellian electron distribution, the excitation rate

TABLE I. Atomic data related to the principal autoionizing states $1s\,3l'3l$ of Fe XXIV. A_a^i represents the autoionization probability to the He-like state i. In (a), $1 \equiv 1s^2\,{}^1S_0$, $2 \equiv 1s\,2s\,{}^3S_1$, $6 \equiv 1s\,2s\,{}^1S_0$, $7 \equiv 1s\,2p\,{}^1P_1$. In (b), $1 \equiv 1s^2\,{}^1S_0$, $3 \equiv 1s\,2p\,{}^3P_0$, $4 \equiv 1s\,2p\,{}^3P_1$, $5 \equiv 1s\,2p\,{}^3P_2$. A_a, $\sum A_a$, $\sum A_r$, and $\tilde{F}_2(s)$ are in units of 10^{13} s^{-1}.

						(a)				
Autoionization state	g_s	A_a^1	A_a^2	A_a^6	A_a^7	$\sum A_a$	$\sum A_r$	$\tilde{F}_2^2(s)$	$\tilde{F}_2^6(s)$	$\tilde{F}_2^7(s)$
$1s\,3s^2\,{}^2S_{1/2}$	2	0.763	9.170	3.596	0.291	14.71	1.63	0.856	0.336	0.027
$1s\,3s\,3p\,{}^2P_{1/2}$	2	0.139	0.452	5.663	4.534	14.35	8.981	0.005	0.067	0.054
${}^2P_{1/2}$	2	0.327	14.49	3.702	10.96	55.93	5.711	0.154	0.039	0.116
${}^2P_{3/2}$	4	0.457	9.679	7.769	6.811	52.95	2.538	0.319	0.256	0.224
$1s\,3s\,3d\,{}^2D_{3/2}$	4	0.257	14.91	6.332	8.793	51.83	5.341	0.268	0.114	0.158
${}^2D_{5/2}$	6	0.256	14.90	7.038	8.427	51.39	4.663	0.409	0.193	0.231
$1s\,3p^2\,{}^2D_{5/2}$	6	0.363	6.273	1.258	3.282	22.24	4.761	0.551	0.101	0.288
${}^2D_{3/2}$	4	0.371	6.359	1.459	3.551	22.47	5.134	0.342	0.078	0.191
${}^2S_{1/2}$	2	0.078	7.384	2.705	21.58	91.80	6.738	0.012	0.004	0.034
$1s\,3p\,3d\,{}^2F_{5/2}$	6	0.035	0.283	0.012	0.634	2.113	8.769	0.005	0.000	0.012
${}^2F_{7/2}$	8	0.062	0.195	0.002	0.539	1.249	10.72	0.008	0.000	0.022
${}^2F_{7/2}$	8	0.180	8.664	3.337	15.22	72.81	7.217	0.156	0.060	0.274
${}^2F_{5/2}$	6	0.188	8.512	3.250	15.02	71.84	7.897	0.121	0.046	0.213
${}^2P_{1/2}$	2	0.065	0.124	0.053	7.221	27.23	6.102	0.001	0.000	0.028
${}^2P_{3/2}$	4	0.063	0.073	0.118	7.999	27.03	7.132	0.001	0.001	0.059
$1s\,3d^2\,{}^2D_{5/2}$	6	0.163	1.482	0.635	6.108	26.72	4.965	0.046	0.020	0.189
${}^2D_{3/2}$	4	0.159	1.455	0.577	6.008	26.10	5.159	0.030	0.012	0.123

						(b)				
		A_a^1	A_a^3	A_a^4	A_a^5	$\sum A_a$	$\sum A_r$	$\tilde{F}_2^3(s)$	$\tilde{F}_2^4(s)$	$\tilde{F}_2^5(s)$
$1s\,3s^2\,{}^2S_{1/2}$	2	0.763	0.202	0.468	0.218	14.71	1.630	0.019	0.044	0.020
$1s\,3s\,3p\,{}^2P_{1/2}$	2	0.139	0.946	2.546	0.064	14.35	8.981	0.011	0.030	0.001
${}^2P_{1/2}$	2	0.327	6.899	13.59	5.999	55.93	5.711	0.073	0.144	0.064
${}^3P_{3/2}$	4	0.457	1.381	7.320	19.60	52.95	2.538	0.046	0.241	0.646
$1s\,3s\,3d\,{}^2D_{3/2}$	4	0.257	3.488	10.59	7.458	51.83	5.341	0.063	0.190	0.134
${}^2D_{5/2}$	6	0.256	1.337	4.430	15.00	51.39	4.663	0.037	0.121	0.411
$1s\,3p^2\,{}^2D_{5/2}$	6	0.363	0.160	3.756	7.146	22.24	4.761	0.013	0.303	0.576
${}^2D_{3/2}$	4	0.371	4.510	4.148	2.069	22.47	5.134	0.243	0.223	0.111
${}^2S_{1/2}$	2	0.078	4.185	16.02	39.85	91.80	6.738	0.007	0.025	0.063
$1s\,3p\,3d\,{}^2F_{5/2}$	6	0.035	0.116	0.916	0.329	2.113	8.769	0.002	0.018	0.006
${}^2F_{7/2}$	8	0.062	0.013	0.043	0.395	1.249	10.72	0.001	0.002	0.016
${}^2F_{7/2}$	8	0.180	1.265	8.221	35.92	72.81	7.217	0.023	0.148	0.646
${}^2F_{5/2}$	6	0.188	8.862	22.52	13.48	71.84	7.897	0.125	0.319	0.191
${}^2P_{1/2}$	2	0.065	0.623	3.338	15.82	27.23	6.102	0.002	0.013	0.062
${}^2P_{3/2}$	4	0.063	2.152	6.802	9.856	27.03	7.132	0.016	0.050	0.073
$1s\,3d^2\,{}^2D_{5/2}$	6	0.163	3.007	8.014	7.312	26.72	4.965	0.093	0.247	0.226
${}^2D_{3/2}$	4	0.159	0.004	2.334	15.56	26.10	5.159	0.000	0.048	0.317

C^3, in units of cm^3 s^{-1}, for the transition $1 \rightarrow f$, can be expressed as

$$C^3_{1\rightarrow f} = F_1(T_e)\tilde{F}_2^f(s) , \tag{2}$$

where

$$F_1(T_e) = \frac{1}{2}\left[\frac{2\pi\hbar^2}{mkT_e}\right]^{3/2} \exp(-E_s/kT_e) , \tag{3}$$

$$\tilde{F}_2^f(s) = \frac{g_s}{g_1}\,\frac{A_a^1(s)A_a^f(s)}{\sum\limits_i A_a^i(s) + \sum\limits_j A_r^j(s)} . \tag{4}$$

E_s is the electron capture energy, i.e., the energy between the autoionizing 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

$$A_a^1(s)=A_a(s\equiv 1s\,3l'nl\,{}^{2S+1}L_J\to 1\equiv 1s^2\,{}^1S_0)\ , \tag{5}$$

$$A_a^f(s)=A_a(s\equiv 1s\,3l'nl\,{}^{2S+1}L_J\to f\equiv 1s\,2l''\,{}^{2S'+1}L'_{J'})\ . \tag{6}$$

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.

To calculate the energy levels (or wavelengths λ), the radiative probabilities A_r^j and the sum of all the probabilities to all lower levels $\sum_j A_r^j$ we used the program SUPERSTRUCTURE developed by Eissner *et al.*[17] This program uses multiconfigurational wave functions calculated in scaled Thomas-Fermi potentials different for each l orbital. For the calculation of the atomic data for highly ionized atoms (such as $_{26}$Fe XXV) it is necessary to include in the Hamiltonian some of the Breit-Pauli relativistic corrections. The development of the wave function of a level ΔJ on the multiconfiguration basis in intermediate coupling tJ, called "level," is obtained by diagonalization of the total Hamiltonian H. This is expressed as

$$\psi(\Delta J,M_J)=\sum_t C(tJ,\Delta J)\phi(tJ,M_J)\ , \tag{7}$$

where ϕ is obtained from the LS coupling wave function of the "term" $t=(C,\beta,S,L)$ by

$$\phi(tJ,M_J)=\sum_{M_S,M_L} C^{LSJ}_{M_LM_SM_J}\phi'(tM_LM_S)\ , \tag{8}$$

where β is a degeneracy parameter taking into account those cases where a configuration C gives rise to more than one term with the same LS. The coefficients $C(tJ,\Delta J)$ are the "level" mixing coefficients. $C^{LSJ}_{M_LM_SM_J}$ are Clebsch-Gordan coefficients and M_L,M_S,M_J are the projections of the momenta L,S,J.

For highly ionized elements, autoionization processes are sufficiently weak to be treated by perturbation theory. The autoionization probability $A_a^i(s)$ is given by

$$A_a^i(s)=(2\pi/\hbar)\,|\,\langle\psi_f^i(E_s)\,|\,H-E_s\,|\,\psi_s\rangle\,|^2\ , \tag{9}$$

where

$$E_s=\langle\psi_s\,|\,H\,|\,\psi_s\rangle\ , \tag{10}$$

and where ψ_s and ψ_f^i are the initial "bound" state and final "free" state, respectively. The energy E of the free state ψ_f^i is taken to be the same as that of the bound state ψ_s, E_s. The wave functions ψ_f^i are normalized to the Dirac functions,

$$\langle\psi_f^i(E)\,|\,\psi_f^{i'}(E')\rangle=\delta(E-E')\delta_{ii'}\ . \tag{11}$$

As for the bound wave function, the free wave function is calculated using the same statistical model potentials. To satisfy the normalization to the Dirac function, asymptotic boundary conditions have to be applied to the free wave function for $r=0$ and $r\to\infty$.

The free wave function ψ_f^i corresponds to an autoionization channel: i.e., a level ΔJ_i for the autoionized ion and a free electron (ϵ,l), where ϵ and l are the energy and the angular moment of the free electron, respectively. As long as only large autoionization probabilities are required, the relativistic behavior of the free electron can be ignored, then the operators **K** and **J** commute with the Hamiltonian:

$$\mathbf{J}_i=\mathbf{L}_i+\mathbf{S}_i,\quad \mathbf{K}=\mathbf{J}_i+\mathbf{l},\quad \mathbf{J}=\mathbf{K}+\mathbf{s}\ , \tag{12}$$

and s is the free-electron spin ($s=\frac{1}{2}$) and

$$A_a^i(s)=\frac{2\pi}{\hbar}\sum_{l,k}\left|\sum_{t,t_i} C(\Delta J_i,t_iJ_i)X(SLJS_iL_iJ_i,lK)\langle t_ilLS\,|\,(H-E_s)\,|\,tLS\rangle C(tJ,\Delta J)\right|^2\ , \tag{13}$$

where $t_i=(C_i,\beta_i,S_i,L_i)$ is a "term" for the $(Z+1)$ ion and $X(SLJS_iL_iJ_i,lK)$ have been expressed by Saraph,[18] as a function of the Racah recoupling coefficient W:

$$\begin{aligned}&X(SLJS_iL_iJ_i,lK)\\&\quad=W(LlS_iJ_i;L_iK)W(LJS_i\tfrac{1}{2};SK)\\&\qquad\times[(2S+1)(2L+1)(2K+1)(2J_i+1)]^{1/2}\ .\end{aligned} \tag{14}$$

As an example, shown in Tables I(a) and I(b) are the atomic data for the $1s\,3l'3l$ autoionizing states which contribute significantly to the excitation rates [$F_2(s)>10^{11}$ s^{-1} only]. The SUPERSTRUCTURE calculations use a multiconfigurational basis which contains 20 configurations and the following scaling parameters: $\lambda_s=1.985$, $\lambda_p=1.836$, and $\lambda_d=1.5$. Similar data were calculated for the autoionizing states $1s\,3l'4l$ and $1s\,3l'5l$. However, for

TABLE II. $\sum_{(n)}\tilde{F}_2^f(s)$ (in units of 10^{13} s^{-1}) obtained for $n=3,4,5,6,7-\infty$ ($f=2\equiv 1s\,2s\,{}^3S_1$, $3\equiv 1s\,2p\,{}^3P_0$, $4\equiv 1s\,2p\,{}^3P_1$, $5\equiv 1s\,2p\,{}^3P_2$, $6\equiv 1s\,2s\,{}^1S_0$, $7\equiv 1s\,2p\,{}^1P_1$).

n \ f	2	3	4	5	6	7
3	3.310	0.791	2.215	3.643	1.327	2.558
4	2.116	0.564	1.803	2.930	0.848	1.939
5	0.742	0.228	0.685	1.142	0.347	0.698
6	0.412	0.106	0.319	0.532	0.200	0.273
$7-\infty$	0.890	0.230	0.690	1.150	0.432	0.590

TABLE III. Contribution $C^{3,n}_{1\to 2}$ ($\mathrm{cm}^3\,\mathrm{s}^{-1}$) versus n, of the autoionizing states $1s\,3l'nl$ to the $_{26}$Fe XXV z-line excitation rate. C^3_z represents the total contribution.

T_e (10^7 K)	$C^{3,3}$	$C^{3,4}$	$C^{3,5}$	$C^{3,6}$	$C^{3,7-\infty}$	C^3_z
1	0.709(−16)	0.287(−16)	0.820(−17)	0.365(−17)	0.716(−17)	0.119(−15)
1,5	0.558(−15)	0.263(−15)	0.805(−16)	0.385(−16)	0.781(−16)	0.102(−14)
2	0.138(−14)	0.701(−15)	0.222(−15)	0.110(−15)	0.227(−15)	0.264(−14)
3	0.285(−14)	0.157(−14)	0.513(−15)	0.265(−15)	0.554(−15)	0.575(−14)

each n, in order to have no prohibitive calculations, two complementary sets of configurations were used in SUPERSTRUCTURE. Each set contained the even (odd) configurations for the autoionizing levels and the odd (even) configurations for the lower levels radiatively allowed. For example, for the $1s\,3l'4l$ calculations one of the sets contained the following 17 configurations: $1s\,3s\,4s$, $1s\,3s\,4d$, $1s\,3p\,4p$, $1s\,3p\,4f$, $1s\,3d\,4s$, $1s\,3d\,4d$, $1s\,2s\,4p$, $1s\,2s\,4f$, $1s\,2p\,4s$, $1s\,2p\,4d$, $1s\,2s\,2p$, $1s\,2p\,3s$, $1s\,2p\,3d$, $1s^2 2p$, $1s^2 3p$, $1s^2 4p$, and $1s^2 4f$. Such a process is more valid when the different Layzer complexes are well separated and this is satisfied for $_{26}$Fe XXV. For the autoionizing states $1s\,3l'6l$, the corresponding data were extrapolated from the $n=5$ results assuming that A_a scales as n^{-3} and that $\sum A_r$ tends to the sum of all radiative decay rates of the corresponding parent term $1s\,3l'\,{}^{2S+1}L_J$. For $n>6$, $\sum A_a$ becoming increasingly smaller than $\sum A_r$, the results are extrapolated from the $n=6$ results assuming that $\tilde{F}_2(s)$ scales as n^{-6}.

In order to examine the contribution with n of the autoionizing states $1s\,3l'nl$, we calculate for each n, and for each transition $1\to f$, the corresponding excitation rate,

$$C^{3,n}_{1\to f}=\sum_{(n)} F_1^s(T_e)\tilde{F}_2^f(s)\ \mathrm{cm}^3\,\mathrm{s}^{-1}\ , \qquad (15)$$

where the summation is extended to all the autoionizing states s of a given n. According to (3), F_1^s depends on s only with E_s. As the autoionizing states for each n are relatively close in energy, E_s is taken the same for a given n. [$E(n=3)=508$ Ry, $E(n=4)=537$ Ry, $E(n=5)=550$ Ry.] The formula (15) can be rewritten

$$C^{3,n}_{1\to f}=F_1^n(T_e)\sum_{(n)}\tilde{F}_2^f(s)\ \mathrm{cm}^3\,\mathrm{s}^{-1}\ . \qquad (16)$$

Table II shows the results obtained for $\sum_{(n)}\tilde{F}_2^f(s)$ for each value of f and for $n=3,4,5,6,7-\infty$.

From the relation (16) and the data of Table II, we obtain, for a given transition, contribution to the excitation rate of each group n of autoionizing states $1s\,3l'nl$. For example, this contribution is shown in Table III for the $_{26}$Fe XXV forbidden (z) line at four temperatures of interest for this ion. This contribution decreases rapidly with n confirming that the contribution due to the $1s\,3l'nl$ autoionizing states becomes negligible for large values of n.

The contribution to the excitation rate for a given transition ($1\to f$) of all the autoionizing states $1s\,3l'nl$ is obtained by summing the n partial contributions:

$$C^3_{1\to f}=\sum_n C^{3,n}_{1\to f}\ . \qquad (17)$$

III. RELATIVE IMPORTANCE OF THE DIFFERENT CONTRIBUTIONS TO THE EXCITATION RATES

In order to estimate the importance of these $1s\,3l'nl$ autoionizing states in the excitation rate of a given transition, their contribution must be compared to the direct excitation and to the excitation due to the $1s\,2l'nl$ autoionizing states. In this last case, only large values of n, $n>n_c$, for which the autoionizing states are energetically above the final states can contribute to the excitation rate. This contribution was given for the $_{26}$Fe XXV z line by Steenman-Clark and Faucher.[10] We can express the excitation rate C for a given transition as the summation of three contributions:

$$C=C^1+C^2+C^3+\cdots\ , \qquad (18)$$

where C^1 is the direct excitation rate, C^2 is the excitation rate due to the autoionizing levels $1s\,2l'nl$ ($n>n_c$), and C^3 is the excitation rate due to the autoionizing levels $1s\,3l'nl$.

Table IV shows the comparison of the results obtained for the $_{26}$Fe XXV z line. For this important line, the effect of the autoionizing states $1s\,3l'nl$ is much more important than this of the autoionizing states $1s\,2l'nl$.

For $_{26}$Fe XXV, the effect of the resonances due to the autoionizing states $1sn'lnl$ with $n'=2$ and 3 is to increase the direct excitation rate by a factor which decreases with temperature (1.4 at 10^7 K, 1.2 at 3.10^7 K for the z line). In order to estimate the importance of these resonances, their effect must be compared with the other processes which contribute to populate the He-like levels. Previous

TABLE IV. Relative importance of the different contributions to the excitation rate for the forbidden (z) line in $_{26}$Fe XXV.

T_e (10^7 K)	C	C^1	C^2	C^3
1	0.554(−15)	0.396(−15)	0.391(−16)	0.119(−15)
1,5	0.522(−14)	0.392(−14)	0.280(−15)	0.102(−14)
2	0.149(−13)	0.116(−13)	0.633(−15)	0.264(−14)
3	0.380(−13)	0.310(−13)	0.123(−14)	0.575(−14)

TABLE V. Excitation rate coefficients ($cm^3 s^{-1}$) for the $_{26}$Fe XXV *z* line showing *A*, direct excitation only; *B*, contribution due to resonances; *C*, contribution due to cascades.

T_e (10^7 K)	*A*	*B*	*C*
1	0.396(−15)	0.158(−15)	0.612(−15)
1,5	0.392(−14)	0.130(−14)	0.755(−14)
2	0.116(−13)	0.327(−14)	0.253(−13)
3	0.310(−13)	0.698(−14)	0.785(−13)

results obtained by Bely-Dubau *et al.*[19] show that the excitation rate coefficients for $_{26}$Fe XXV are very sensitive to the effect of the cascades. Table V shows for the $_{26}$Fe XXV *z* line that the effect of cascades is more important than that of resonances from a factor 4 at 10^7 K to a factor 11 at 3×10^7 K.

IV. CONCLUSION

We have examined, for $_{26}$Fe XXV, the effect of the autoionizing states $1s\,3l'nl$ on the effective excitation rates. For this ion, contribution of the autoionizing states $1s\,3l'nl$ is more important than that of the autoionizing states $1s\,2l'nl$. All these resonances increase principally the direct excitation rate of the forbidden *z* line by a factor which decreases with temperature. Inclusion of resonance improves the effective rate coefficients. However, their effect is much less important than the cascade's effect.

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