DIELECTRONIC RECOMBINATION CROSS SECTIONS FOR HELIUM-LIKE IONS

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الخلاصـــة :

عينت المقاطع المستعرضة لإعادة الربط الثنائي الإليكتروني للأيونات الشبيهة بالهيليوم (Ar^{16+}, Fe^{26+}, Mo^{40+}). وقد تَمَّ الحصول على هذه المقاطع المستعرضة من الحسابات المباشرة لكلٍّ من إحتمالات الانتقال الإشعاعي والإليكتروني. ولقد تمّت هذه الحسابات باستخدام الإقتران الزاوي المغزلي، وباستخدام الدوال غير النسبِّية المسماة (هارتري - فوك)، وأخذ متوسط المقاطع لمقدار من الطاقة يساوي مقدار (ريدبرج) واحد وذلك لتسهيل المقارنة المباشرة مع النتائج التجريبية.

ABSTRACT

Dielectronic recombination cross sections are estimated for the helium-like isoelectronic sequence (Ar^{16+}, Fe^{24+}, and Mo^{40+}). The cross sections are obtained from direct evaluation of the Auger and radiative transition probabilities. These are calculated in LS coupling, using non-relativistic Hartree–Fock wave functions, and averaged over an energy bin of size $\Delta e_c = 1.0$ Ry, to facilitate direct comparison with experimental data.

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INTRODUCTION

The process of dielectronic recombination [DR] has attracted much attention over the last decade. Recently review articles by Hahn [1], and Hahn and LaGattuta [2] covered this area in great detail. The DR process plays an important role both as a diagnostic tool and as a cooling mechanism in both laboratory and astrophysical plasmas. Since the available data for helium isoelectronic are calculated for DR rate coefficients $\bar{\alpha}^{DR}$ [3,4], so, our objective here is to calculate and provide data on the DR-cross sections $\bar{\sigma}^{DR}$ for helium-like ions. Such data are useful in studying other recombination processes such as resonant-transferexcitation (RTE) [5,6].

The theoretical procedure used here is the same as that employed in the previous work [1,2]. Therefore, the main assumptions involved are summarized here. In order to do so, it is convenient to define [1] an energy-averaged cross section $\bar{\sigma}^{DR}$, and rates $\bar{\alpha}^{DR}$ for given initial and intermediate states, as

$$\bar{\sigma}^{DR} \equiv \frac{1}{\Delta e_c} \int_{e_c - \Delta e_c/2}^{e_c + \Delta e_c/2} \sigma^{DR}(e'_c) de'_c, \qquad (1)$$

$$\bar{\sigma}^{DR} = \frac{4\pi(\text{Ry})}{e_c(\text{Ry})} \tau_o V_a(i \to d)\omega(d) \frac{1}{\Delta e_c} (\pi a_o^2), \qquad (2)$$

$$\bar{\alpha}^{DR} = \left(\frac{4\pi(\text{Ry})}{kT(\text{Ry})}\right)^{3/2} a_o^3 V_a(i \to d)\omega(d) e^{-e_c/kT}, \qquad (3)$$

where $V_a(i \to d)$ is the radiationless excitation capture probability and is related, by detailed balance, to the Auger emission probability $A_a(d \to i)$ by $V_a = \left(\frac{g_d}{2g_i}\right) A_a(d \to i)$. Here g_d and g_i are the statistical weights of the intermediate and initial states respectively. Further, $\omega(d) = \Gamma_r(d)/\Gamma(d)$, is the fluorescence yield of the intermediate state d. $\Gamma(d) \equiv \Gamma_a(d) + \Gamma_r(d)$ with $\Gamma_a(d) = \Sigma_i A_a(d \to i)$, $\Gamma_r(d) = \Sigma_f A_r(d \to f)$, and A_r is the radiative transition probability. Also, a_o and τ_o are the Bohr radius and the atomic unit of time. In general, the cross section $\bar{\sigma}^{DR}$, and the rate $\bar{\alpha}^{DR}$ are related by the equation:

$$\bar{\sigma}^{DR} = 4.06 \times 10^{-9} \left(\frac{kT}{(\text{Ry})}\right)^{3/2} \frac{e^{e_c/kT}}{e_c \Delta e_c} \bar{\alpha}^{DR}. \qquad (4)$$

The intermediate resonance states considered here are defined in LS coupling as $((n_a l_a, n_b l_b) L_{ab} S_{ab}) 1s) LS)$ with $n_a = 2$, $l_a = 0$ and 1 $n_b = 1, 2, 3, 4$, and 5 and with $l_b = 0, 1, 2, 3$, and 4. The initial ground state configuration is given by $((1s^2) L_t S_t), k_c l_c) L'S'$. Contributions from higher intermediate resonance states are estimated using the n^{-3} asymptotic dependence of the autoionizing rates and radiative transition probabilities. Target excitation to states with $n_a \geq 3$ are found to be small and negligible.

PROCEDURE

The following theoretical procedure was adopted in the evaluation of the DR cross sections, which amounted to calculation of all the relevant A_a and A_r, as well as the transition energies.

(*a*) Accurate energy level for all initial and low lying intermediate states were evaluated using Cowan's code [7], in single-configuration Hartree–Fock approximation and in full *LS* coupling.

(*b*) Radiative decay probabilities, A_r, were calculated using our MATRIX code, which used nonrelativistic Hartree–Fock (HF) bound orbitals, in LS coupling and with electric-dipole approximation.

(*c*) Auger transition probabilities, A_a, require both bound and continuum wave functions. As in the previous work [1,2], the continuum wave functions were generated by a distorted-wave method using the HF potential.

RESULTS

Our results for the ions Ar^{16+}, Fe^{24+}, and Mo^{40+} are given in Figures 1, 2, and 3, respectively. Figure 1 displays the average energy cross-section for Ar^{16+} in units of 10^{-22}cm^2 as a function of the incident continuum electron energy, e_c(Ry).

Figure 2 shows the averaged energy cross-section for Fe^{24+} in units of 10^{-22}cm^2 as a function of the incident continuum electron energy, e_c(Ry). Figure 3 shows the averaged energy cross-section for Mo^{40+} in units of 10^{-22}cm^2 as a function of the incident continuum electron energy, e_c(Ry). It should be noted that the forbidden values of e_c do not appear in the figures.

CONCLUSION

In conclusion, our study shows that: (1) For these highly charged ions, only few intermediate states are dominant. (2) The radiative transition probability

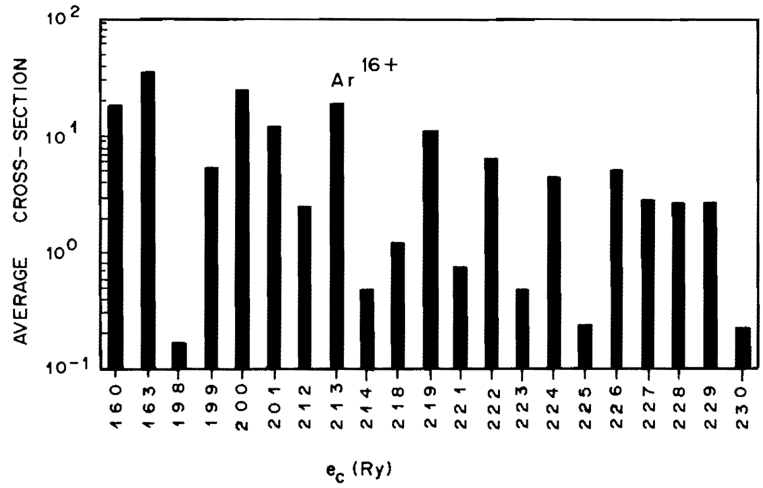

Figure 1. The DR Cross-Sections for Ar^{16+} in Units of 10^{-22} cm^2 Averaged Over an Energy Bin Size Δe_c = 1.0 Ry, are Presented as a Function of the Incident Electron Energy, $e_c(Ry)$. It should be noted that, the forbidden values of e_c do not appear in the Figure.

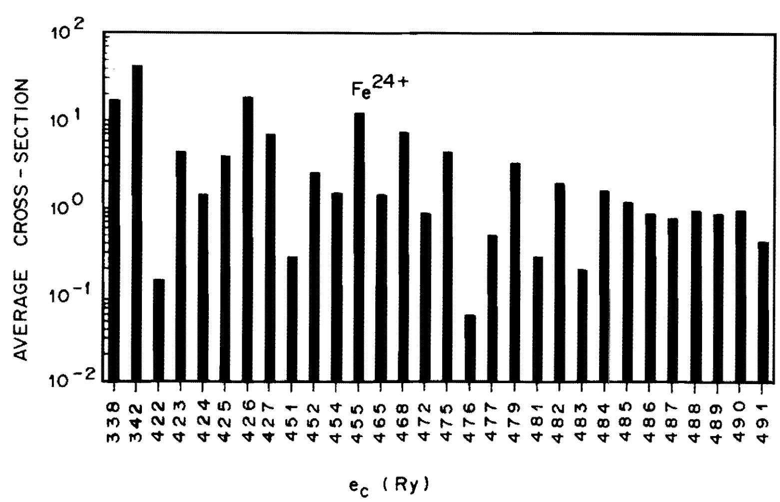

Figure 2. Same as Figure 1, but for Fe^{24+}

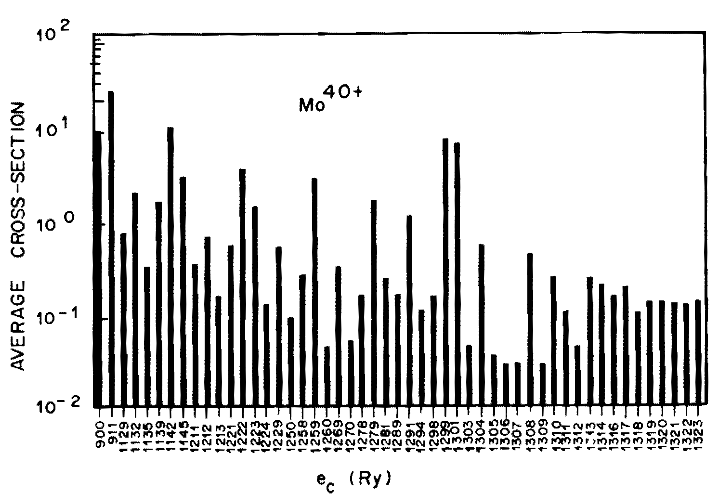

Figure 3. Same as Figure 1, but for Mo^{40+}.

$A_r(2p \rightarrow 1s)$ is large compared with the other allowed transition probabilities, and this is reason for which the radiative cascade effect was neglected in our calculation. This effect, however, might have a sizable contribution for low ionized charged ions case. (3) Refering to equation (2), for high values of n ($n \leqslant 5$); *i.e.* high values of e_c, the cross sections $\bar{\sigma}^{DR}$ decrease sharply as n^{-3}, due to the scaling behavior of $A_a(d \rightarrow i)$. Finally, we expect that, our calculations here are reliable within a factor of $\pm 10\%$, as compared to Chen [4], who included the relativestic correction, and configuration interactions in his calculations for dielectronic recombination rate coefficients.

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