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The dielectronic recombination process in laser-produced Au plasmas*

Jiao Rong-Zhen(焦荣珍)[a)†], Cheng Xin-Lu(程新路)[b)], and Yang Xiang-Dong(杨向东)[b)]

[a)] *College of Natural Science, Beijing University of Posts and Telecommunication, Beijing* 100876, *China*

[b)] *Institute of Atomic and Molecular Physics, Sichuan University, Chengdu* 610065, *China*

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The calculations of the rate coefficients for dielectronic recombination (DR) along the NiI isoelectronic sequence in the ground state Au^{51+} through Cu-like $3d^9nln'f$ $(n, n'=4,5,6)$ inner-shell excited configurations are performed using the spin-orbit-split array (SOSA) model. Resonant and nonresonant radiative stabilizing transitions and decays to autoionizing levels followed by radiative cascades are included. Collisional transitions following electron capture are neglected. The trend of the DR rate coefficients and the ratio of dielectronic satellite lines intensities with the change of the electron temperature are discussed.

Keywords: spin-orbit-split array, dielectronic recombination, autoionization coefficients
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For high-temperature and low-density plasmas, dielectronic recombination (DR) is an important recombination process. Knowledge of DR coefficients is essential in the determination of the ionization balance of high-temperature plasmas. Furthermore, dielectronic satellite lines observed in the emission spectra can be used in plasmas diagnostics.[1,2] This knowledge is also important for the research of x-ray lasers of heavy ions.[3–5] In 1995, Behar *et al*[6] analysed the rate coefficients for DR of ten ions (Au^{51+}, etc) along the NiI isoelectronic sequence in the ground state using HULLAC code package. The papers of inland about DR rate coefficients of highly ionized heavy element and level-by-level description of the DR process are very few.[7] But these are necessary parameters for the research of energy level density and ICF. This paper analyses DR coefficients with the change of electron temperature of Ni-like Au^{51+} ions through the $3d^9nln'f$ $(n, n'=4,5,6)$ Cu-like configurations. The calculations are made using the SOSA[8] model. A configuration averaging method is used in calculating the total DR coefficients. The results agree well with that of Behar. At the same time, the relation between the ratio of dielectronic satellite line intensities with electron temperature are analysed. These are very important for diagnosing plasmas through calculating electron temperature under certain density.

The basic equation for the process of DR can be found in the book by Cowan. There is the equation about DR rate coefficients in Ref.[9]. The formula of autoionization coefficients is

$$g_{SC'}A^{\rm a}_{SC'-C} = \sum_{J\in SC'}\sum_{J\in C} g_{J'}A^{\rm a}_{J'-J} = (2\pi/\hbar)Q_{SC'-C}, \quad (1)$$

where g is the statistic weight and there is $g = 2(2j+1)$, $\hbar$ is the Planck constant, C and C' are $3d^{10}$ and $3d^9n'fnl$ respectively, SC and SC' are the relevant subarrays. The expression about $Q_{SC'-C}$ is given in Ref.[8]. The formula of radiative decay coefficients ($A^{\rm r}$) is as following:

$$g_{SC'}A^{\rm r}_{SC'-SC''} = (64\pi^4e^2/3\hbar)\times\alpha^3 S_{SC'-SC''}, \quad (2)$$

where $g_{SC'}$, α and S are the statistic weight, wavenumber and intensities of the subarrays, respectively. We use SOSA model to calculate α and S.

In order to prove the feasibility of this method, we compare the results of Bauche-Arnout who used

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†Tel: 010-62282050, E-mail: jiao218@sohu.com

means of a relativistic parametric potential central-field code to compute the autoionization coefficients of Ta^{45+} with the results of this method under the same condition in the Table 1. They are very close with each other.

Table 1. Compare the autoionization coefficients of Ta^{45+} with the results of Ref.[9].

Configuration	Results of this paper	Results of the Ref.[9]
$3d^9 4d4f$	2.02×10^{16}	2.12×10^{16}
$3d^9 5d4f$	6.16×10^{15}	6.40×10^{15}
$3d^9 6d4f$	2.97×10^{15}	3.00×10^{15}

We also compared the DR coefficients of Au^{51+} ions with that of Ref.[6] at T=200 eV as following: $3d^9 4d4f$, $\alpha = 2.64 \times10^{-10}\,cm^3/s$ ($2.66 \times 10^{-10}\,cm^3/s$);[6] $3d^9 4f5f$, $\alpha = 1.61 \times 10^{-10}\,cm^3/s$ ($1.66\times 10^{-10}\,cm^3/s$).[6] The error is about 10%. The values in the brackets are the results of the reference. This method is reliable because the integral function is the same one.

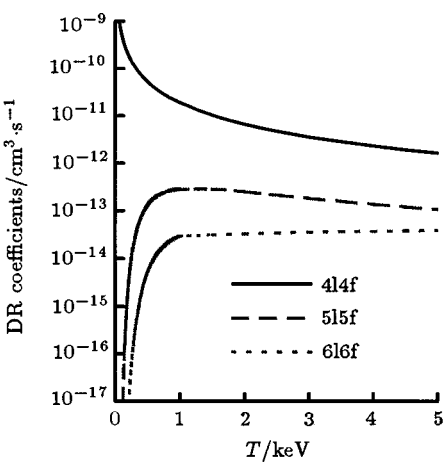


Fig.1. DR coefficients versus T.

The change of the total DR coefficients with the electron temperature is shown in Fig.1. They take into account the radiative decay transition of 3d–4f, 3d–5f and 3d–6f with the spectator electron of 4l, 5l and 6l, respectively. With the exception of the configuration of $3d^9 4l4f$, other DR coefficients reach the peak value at low electron temperature, and then decrease with increasing electron temperature. The trend of DR through $3d^9 4l4f$ shows irregularities at relatively low temperature due to the progressive closing of DR channels as n increases. The reason for this is that the difference between the isoelectronic behaviour of DR through the inner-shell excited levels of $3d^9 4l4l'$ configuration complex lying close to the first ionization limit, and the isoelectronic behaviour of DR through higher lying levels, such as those from the $3d^9 4l5l'$ configuration complex.

The relation between the ratio of dielectronic satellite line intensities and electron temperature are showed in Fig.2. r_1, r_2 and r_3 denote the ratio of dielectronic satellite line intensities in the process of the transitions 3d–5f, 3d–4f and 3d–6f with the change of electron temperature, respectively. The difference between the behaviour of $3d^9 4l4l'$ and other configurations is shown again. It may provide a method for analyse the difference between the 3d–4f and other transition patterns in laser-produced Au plasmas.

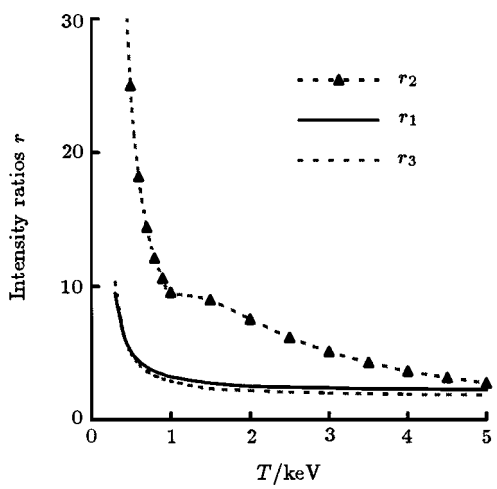


Fig.2. Ratios of dielectronic satellite line intensity r versus T.

From Figs 1 and 2, we know that the contribution of $3d^9 4l4l'$ configuration complex varies irregularly from element to element along the sequence. In this complex a single level lying above but very close to the ionization limit might strongly enhance and even dominate the whole DR process at low electron temperature. Such peculiar levels are of special interest for the research of x-ray lasers, since strong captures to particular inner-shell excited levels may lead to population inversion and a lasing process.

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