§4. Dielectronic Recombination Rate Coefficients to Excited States of Boronlike Oxygen and Dielectronic Satellite Lines

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Energy levels, radiative transition probabilities, and autoionization rates for B-like oxygen (O^{3+}) including $1s^22s^2nl$, $1s^22s2pnl$, and $1s^22p^2nl$ (n=2-8, l≤n-1) states were calculated by multi-configurational Hartree-Fock method (Cowan code) and relativistic many-body perturbation theory method (RMBPT code). Autoionizing levels above three thresholds ($1s^22s^2\ ^1S$, $1s^22s2p\ ^3P$, $1s^22s2p\ ^1P$) were considered. Configuration mixing ($2s^2nl + 2p^2nl$) plays an important role for all atomic characteristics. Branching ratios relative to the first threshold and intensity factor were calculated for satellites lines and dielectronic recombination rate coefficients for the excited 105 odd-parity and 94 even-parity states. The dielectronic recombination rate coefficients were calculated including $1s^22s^2nl$, $1s^22s2pnl$, and $1s^22p^2nl$ (n=2-8, l≤n-1) states. The contribution from the excited states higher than n=8 was estimated by extrapolation of all atomic characteristics to derive the total dielectronic recombination rate coefficient. The orbital angular momentum quantum number l distribution of the rate coefficients shows a peak at l=5. The total dielectronic recombination rate coefficient was derived as a function of electron temperature. The dielectronic satellite lines were also obtained. The state selective dielectronic recombination rate coefficients to excited states of B-like oxygen were obtained, which are useful for modeling O IV spectral lines in a recombining plasma.

Dielectronic recombination (DR) to the excited states from O^{3+} to O^{4+} is defined by the following sequence of processes :

$O^{4+}(2s^2)+e \rightarrow O^{3+}(2s2pnl+2p^2nl) \rightarrow O^{4+}(2s^2+2s2p)+e$
$\rightarrow O^{3+}(2s^2nl+2s2p3l+2s2p^2+2p^3) + h\nu$

As an initial state we consider the ground state of O^{4+}, $2s^2$. The $2s2pnl$ and $2p^2nl$ states are taken into account as doubly excited intermediate states.

The DR rate coefficients $\alpha_d(\gamma'|\alpha_0)$, to the excited state are obtained by summing up the intensity factor $Q_d(\gamma,\gamma'|\alpha_0)$ multiplied the exponential factor over the autoionization levels γ as follows,

$$\alpha_d(\gamma'|\alpha_0)=3.3\times10^{-24}\left(\frac{I_H}{T_e}\right)^{3/2}\sum_{\gamma}e^{-\frac{E_S}{T_e}}Q_d(\gamma,\gamma'|\alpha_0)/g(\alpha_0)$$

where

$$Q_d(\gamma,\gamma'|\alpha_0)=g_\gamma A_r(\gamma,\gamma')K(\gamma,\alpha_0)$$

$$K(\gamma,\alpha_0)=\frac{A_a(\gamma,\alpha_0)}{(A_r(\gamma)+A_a(\gamma))},$$

$$A_r(\gamma)=\sum_{\gamma''}A_r(\gamma,\gamma''),A_a(\gamma)=\sum_{\alpha'}A_a(\gamma,\alpha')$$

Here $A_r(\gamma,\gamma')$ are radiative transition probabilities and $A_a(\gamma,\alpha_0)$ are autoionization rates.

The total DR rate coefficients are obtained by summation of the rate coefficients of DR processes through all possible intermediate singly and doubly excited states: For total DR rate coefficients we need to consider contribution from doubly excited states with high n levels s and also the contribution from single excited states with high n, $2s^2nl$ states. Tabulated data $\alpha^{total}_d = \alpha^a_d+\alpha^b_d+\alpha^c_d$ are given in Table 1.

Table 1. Total DR rate coefficients (α^{total}_d in cm^3/s): $\alpha^{total}_d = \alpha^a_d+\alpha^b_d+\alpha^c_d$ as function of electron temperature (T_e in eV) for B-like oxygen. Contributions of α^a_d and α^c_d are sum from excited states with n=2-8 and n=9-30000, respectively. Contribution of α^b_d is from scaling of the $2s^2nl$-$2s2pnl$ transitions from n=9 up to n = 30000.

T_e	α^a_d	α^b_d	α^c_d	α^{total}_d
0.1000	3.06[-11]	1.00[-83]	0.00[00]	3.06[-11]
0.1300	3.63[-11]	8.00[-67]	0.00[00]	3.63[-11]
0.1690	4.16[-11]	6.90[-54]	0.00[00]	4.16[-11]
0.2197	4.61[-11]	3.00[-28]	1.00[-24]	4.61[-11]
0.2856	4.98[-11]	1.10[-24]	7.00[-22]	4.98[-11]
0.3713	5.28[-11]	3.52[-22]	1.90[-19]	5.28[-11]
0.4827	5.48[-11]	3.10[-20]	1.52[-17]	5.48[-11]
0.6275	5.53[-11]	1.10[-18]	4.25[-16]	5.53[-11]
0.8157	5.44[-11]	1.89[-17]	5.25[-15]	5.44[-11]
1.0604	5.24[-11]	2.34[-16]	3.45[-14]	5.25[-11]
1.3786	4.97[-11]	3.87[-15]	1.38[-13]	4.98[-11]
1.7922	4.63[-11]	5.28[-14]	3.73[-13]	4.67[-11]
2.3298	4.23[-11]	4.05[-13]	7.42[-13]	4.34[-11]
3.0287	3.75[-11]	1.82[-12]	1.16[-12]	4.05[-11]
3.9374	3.24[-11]	5.29[-12]	1.51[-12]	3.92[-11]
5.1186	2.73[-11]	1.10[-11]	1.70[-12]	4.00[-11]
6.6542	2.23[-11]	1.78[-11]	1.71[-12]	4.18[-11]
8.6504	1.78[-11]	2.34[-11]	1.57[-12]	4.27[-11]
11.2455	1.38[-11]	2.64[-11]	1.35[-12]	4.16[-11]
14.6192	1.04[-11]	2.65[-11]	1.10[-12]	3.80[-11]
19.0049	7.75[-12]	2.43[-11]	8.62[-13]	3.29[-11]
24.7064	5.65[-12]	2.07[-11]	6.52[-13]	2.70[-11]
32.1184	4.05[-12]	1.67[-11]	4.81[-13]	2.12[-11]
41.7539	2.87[-12]	1.30[-11]	3.47[-13]	1.62[-11]
54.2800	2.01[-12]	9.73[-12]	2.47[-13]	1.20[-11]
70.5640	1.40[-12]	7.12[-12]	1.74[-13]	8.70[-12]
91.7332	9.65[-13]	5.12[-12]	1.21[-13]	6.21[-12]

We take into account doubly excited states 2s2pnl and $2p^2nl$ (n≥8, l≤7) as intermediate resonance states with n up to 30000 to calculate the DR rate coefficients. Most of state selective DR rate coefficients show double peaks as a function of electron temperature. The transitions through intermediate states 2s2pnl make a peak in the rate coefficients at $T_e \cong$ 2-10 eV. Configuration mixing [$2s^2nl + 2p^2nl$] plays an important role for the DR rate coefficients of $2s^2nl$ levels with n≤8 at low temperature. The state selective rate coefficients can be used in a collisional-radiative model for investigating population kinetics and plasma diagnostics for recombining plasma.