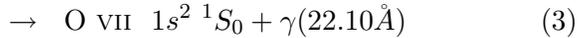
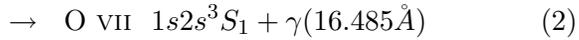
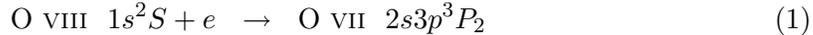


When an electron collides with an atom or ion, it may

- excite the atom/ion ( $I + e \rightarrow I^* + e$ )
- ionize the atom/ion ( $I + e \rightarrow I^+ + 2e$ )
- scatter inelastically ( $I + e \rightarrow I + e + \gamma$ )
- recombine radiatively ( $I + e \rightarrow I^- + \gamma$ )
- recombine dielectronically ( $I + e \rightarrow I^{-*}$ )

This memo will focus on the final process, where an electron recombines with the ion in an excited state and excites a second electron while doing so. The ion is left in a highly excited state, which may then autoionize (thereby inverting the dielectronic recombination and converting the process into a simple scattering event) or it may radiatively decay when one of the excited electrons radiatively decays, creating a *satellite line*. A satellite line is so named because it will be at a slightly longer wavelength than the normal transition from an electron in that energy level. The due to the recombined electron which is also in an excited level.

For a simple example, consider the process of O VIII in the ground state, recombining dielectronically. Thus we may have the following series of events:



In this case, the first photon emitted is a *satellite line* of O VIII, so-called since the strength of the line depends upon the abundance of the parent ion, although the line itself is a transition of the daughter ion.

Dielectronic recombination is a resonance phenomenon. The recombining electron must have a kinetic energy that equals the sum of the energies of the two excited levels. For a Maxwellian distribution, Bates & Dalgarno (1962) shows that in the “isolated resonance approximation,” the dielectronic recombination rate (in units of  $cm^3/s$ ) is

$$\alpha^{DR}(i \rightarrow d) = \left[ \frac{4\pi}{T} \right]^{3/2} a_0^3 \exp\left(-\frac{E_c}{k_B T}\right) V_a(i \rightarrow d) \quad (4)$$

where  $T$  is in rydbergs,  $E_c$  is the energy of the doubly-excited state,  $a_0$  is the Bohr radius in cm, and  $V_a$  is the capture probability in  $s^{-1}$ . Since

dielectronic recombination is the inverse process of autoionization, the capture probability  $V_a$  is related to the autoionization probability  $A_a$  by the principle of detailed balance. So, what is  $V_a$ ? That is given by

$$V_a = \frac{g_s}{2g_l} \frac{A_a A_r}{\sum A_a + \sum A_r} \quad (5)$$

where  $g_s$  is the statistical weight of the doubly-excited state,  $g_l$  is the statistical weight of the parent ion in its initial (ground) state,  $A_a$  is the autoionization rate from the doubly-excited state and  $A_r$  is the radiative rate. The sums in the denominator are over all possible transitions from the doubly-excited state, not just the one we're interested in.

## Satellite Line Emissivity

Now, we need to move from pure theory to something with actual units that can be seen. Most of this discussion is taken from Kato et al. (1997). In that paper, the equation

$$I_S(T, l \rightarrow d) = 3.30 \times 10^{-24} \text{ph cm}^3 \text{s}^{-1} \left(\frac{I_H}{kT}\right)^{-3/2} \frac{Q_d}{g_l} \exp(-E_c/kT) n_l n_e \quad (6)$$

gives the satellite line intensity. The constant  $3.30 \times 10^{-24}$  equal to  $4\pi a_0^3/2$ ;  $I_H$  is the Rydberg constant, and  $Q_d = g_s A_a B_r$ , where

$$B_r = \frac{A_r}{\sum A_a + \sum A_r} \quad (7)$$

After dielectronic recombination occurs, the ion is in an ‘‘Auger unstable’’ state, which can radiatively stabilize to a singly excited state  $j$  of the recombined ion (with rate  $A_r$ ), emitting a satellite line photon. Or, it can autoionize to some state of the parent ion (with rate  $A_a$ ), emitting an electron back into the continuum. Of course, there may be multiple ways for the doubly-ionized state to radiatively decay or to autoionize, which is where the sums come from in the denominator.

## References

- Bates, D. R. & Dalgarno, A. 1962, in ‘‘Atomic and Molecular Processes,’’, ed. D. R. Bates (New York: Academic Press), p. 258
- Kato, T, Safronova, U. I., Shlyaptseva, A. S., Cornille, M., Dubau, J. & Nilsen, J. 1997, ADNDT, 67, 225