Atomic transitions 6

From the previous section the transition rate is

$$R_{a\to b} = \frac{\pi e^2}{3\varepsilon_0\hbar^2}\left|\langle\psi_b|\mathbf{r}|\psi_a\rangle\right|^2\rho(\omega_0)$$

Interchange ψ_a and ψ_b by the identity

$$\left|\langle\psi_a|\mathbf{r}|\psi_b\rangle\right|^2 = \left|\langle\psi_b|\mathbf{r}|\psi_a\rangle\right|^2$$

to obtain

$$R_{b\to a} = \frac{\pi e^2}{3\varepsilon_0\hbar^2}\left|\langle\psi_a|\mathbf{r}|\psi_b\rangle\right|^2\rho(\omega_0)$$

The stimulated emission coefficient is

$$B_{b\to a} = \frac{R_{b\to a}}{\rho(\omega_0)} = \frac{\pi e^2}{3\varepsilon_0\hbar^2}\left|\langle\psi_a|\mathbf{r}|\psi_b\rangle\right|^2$$

The spontaneous emission rate is

$$A_{b\to a} = \frac{\hbar\omega_0^3}{\pi^2c^3}B_{b\to a} = \frac{e^2\omega_0^3}{3\pi\varepsilon_0\hbar c^3}\left|\langle\psi_a|\mathbf{r}|\psi_b\rangle\right|^2 \tag{1}$$

Verify dimensions.

$$A_{b\to a} \propto \frac{\underset{\mathrm{C}^2}{e^2}\quad\underset{\mathrm{s}^{-3}}{\omega_0^3}}{\underset{\mathrm{C^2\,J^{-1}\,m^{-1}}}{\epsilon_0}\quad\underset{\mathrm{J\,s}}{\hbar}\quad\underset{\mathrm{m^3\,s^{-3}}}{c^3}} \times \underset{\mathrm{m}^2}{\left|\langle\psi_a|\mathbf{r}|\psi_b\rangle\right|^2} = \mathrm{s}^{-1}$$

By Planck's law

$$\rho(\omega_0) = \frac{\hbar\omega_0^3}{\pi^2c^3}\frac{1}{\exp\left(\frac{\hbar\omega_0}{kT}\right)-1}$$

Hence the absorption rate is

$$R_{a\to b} = \frac{e^2\omega_0^3}{3\pi\varepsilon_0\hbar c^3}\left|\langle\psi_b|\mathbf{r}|\psi_a\rangle\right|^2\frac{1}{\exp\left(\frac{\hbar\omega_0}{kT}\right)-1} \tag{2}$$

and the stimulated emission rate is

$$R_{b\to a} = \frac{e^2\omega_0^3}{3\pi\varepsilon_0\hbar c^3}\left|\langle\psi_a|\mathbf{r}|\psi_b\rangle\right|^2\frac{1}{\exp\left(\frac{\hbar\omega_0}{kT}\right)-1} \tag{3}$$

where

$$\omega_0 = \frac{E_b - E_a}{\hbar}$$