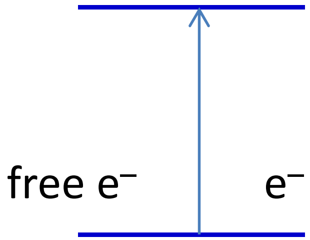
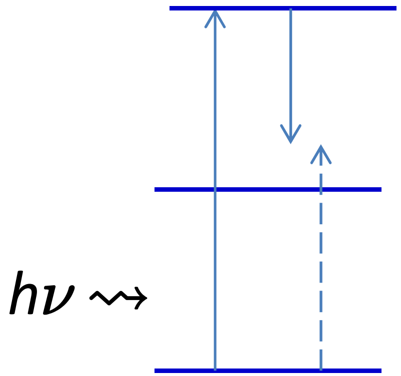
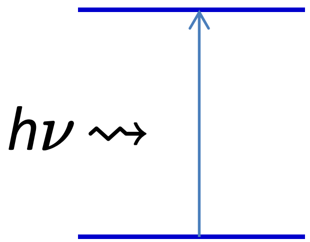
Excitations



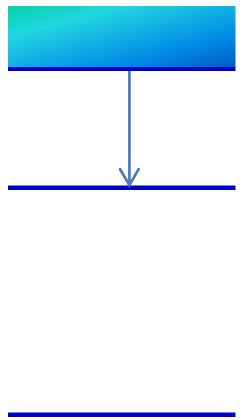
Collision



Photon Pumping



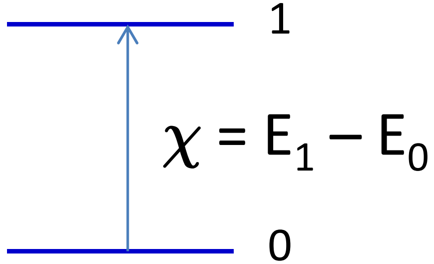
Radiation

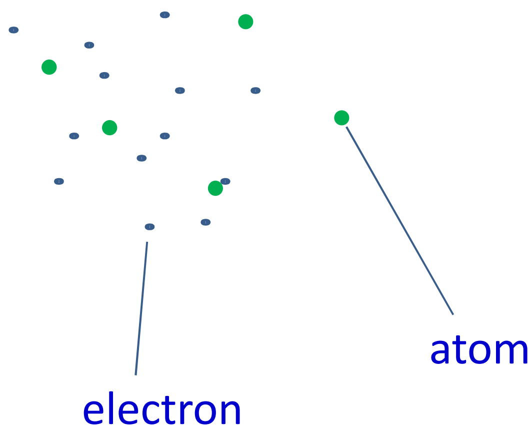


Recombination

Principle of detailed balance

Consider a 2-level system, excitation occurs if the incoming free electrons have kinetic energy $\frac{1}{2}mv^2 > \chi$





Define the **excitation rate coefficient** γ_{01} so that

$$\# \text{ of excitation s}^{-1}\text{ cm}^{-3} (= n_e n_0 v\sigma) \equiv n_e n_0 \gamma_{01}$$

where both n_e and n_0 have units of [cm^{-3}].

$$\gamma_{01} \equiv < \sigma v > = \int_{\chi=\frac{1}{2}mv^2}^{\infty} v\,\sigma_{01}(v)\,f(\vec{f})\;d^3\vec{v}$$

Here σ_{01} is the excitation cross section, and $f(\vec{v})$ is the Maxellian distribution function

$$f(v;T)\,dv = 4\pi(\frac{m}{2\pi kT})^{3/2}\,v^2\,e^{-\frac{mv^2}{2kT}}\;dv$$

So

$$\gamma_{01} = \frac{4}{\sqrt{\pi}}(\frac{1}{2kT})^{1/2}\int_{\chi=\frac{1}{2}mv^2}^{\infty} v^3\,\sigma_{01}(v)\;e^{-\frac{mv^2}{2kT}}\;dv$$

This is the upward transition.

Downward transition:

- spontaneous emission, rate $= n_1 A_{10}$
- deexcitation by collisions, rate $= n_1 n_e \gamma_{10}$, where $\gamma_{10} = \int_0^\infty v\sigma_{10}(v) f(v) dv = \gamma_{10}(T)$

Detailed balance

In steady state, [upwards] $=$ [downwards]

$$n_0\, n_e\, \gamma_{01}(T) = n1[A_{10} + n_e\, \gamma_{10}(T)]$$

$$\boxed{\frac{n_1}{n_0} = \frac{n_e \gamma_{01}}{A_{10} + n_e \gamma_{10}} = \frac{\gamma_{01}}{\gamma_{10}} \frac{1}{1 + \frac{A_{10}}{n_e \gamma_{10}}}} \quad \text{(A)}$$

(i) At **high** densities, i.e., $n_e \to \infty$, (i.e., collisional excitation and deexcitation dominate → in TE)

$$\frac{n_1}{n_0} = \frac{\gamma_{01}}{\gamma_{10}}$$

But since $\frac{n_1}{n_0} = \frac{g_1}{g_0} e^{-\chi/kT}$,

$$\frac{\gamma_{01}}{\gamma_{10}} = \frac{g_1}{g_0} e^{-\chi/kT} \text{ for } n_e >> 1$$

(ii) At **low** densities, i.e., $n_e \to 0$

$$\frac{n_1}{n_0} \to \frac{\gamma_{01}}{\gamma_{10}} \frac{n_e \gamma_{10}}{A_{10}} = \frac{n_e \gamma_{01}}{A_{10}}$$

upward by collision

downward by radiation only

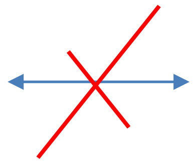
This means every collisional excitation is followed by the emission of a photon.

For a radiative transition, the rate of emission of line photons [s^{-1} atom^{-1}] … recall eq. (A)

$$\frac{n_1}{n_0}A_{10} = A_{10}\,\frac{\gamma_{01}(T)}{\gamma_{10}(T)}\,\frac{1}{1+\frac{A_{10}}{n_e\gamma_{10}(T)}}$$

(i) At **high** densities

$$\frac{n_1 A_{10}}{n_0} = A_{10}\,\frac{\gamma_{01}}{\gamma_{10}} = A_{10}\,\frac{g_1}{g_0}e^{-\chi/kT}$$

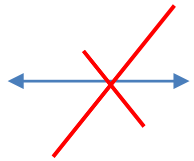


n_e

TE

(ii) At **low** densities

$$\frac{n_1 A_{10}}{n_0} = A_{10}\,\frac{\gamma_{01}}{\gamma_{10}}\,\frac{n_e\gamma_{10}}{A_{10}} = n_e\gamma_{01}$$



T

This is what we had earlier ; i.e., every collisional excitation → emission of a line photon.