19 - REVIEW OF RADIATION MECHANISMS

Atomic processes can be:

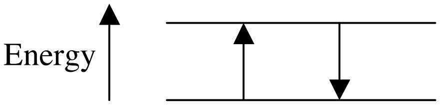
1. Scattering
2. Absorption/Thermal Emission

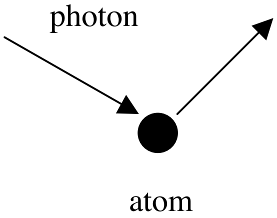
They may also be:

A. Line processes
B. Continuum processes

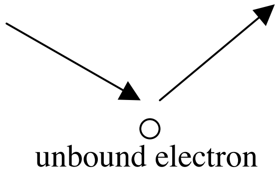
Scattering

Line (bound-bound) Scattering





Continuum Scattering

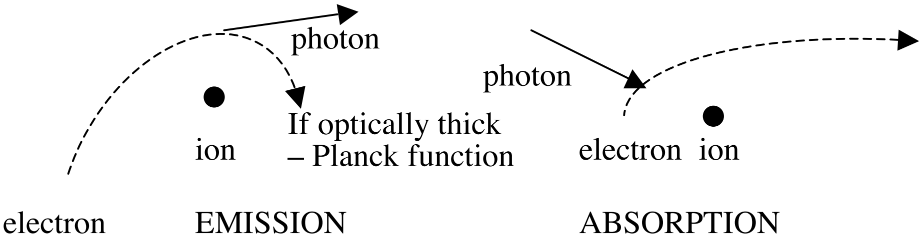


During the scattering process, the frequencies may change a little:
Lines ⇒ widths of energy levels
Continuum ⇒ Thomson scattering (recoil of electron) MORE BELOW!

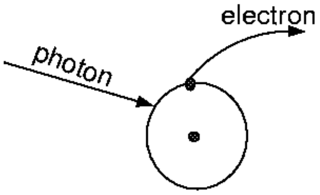
Generally, we will assume isotropic scattering, although the results won't change much when this condition is relaxed.

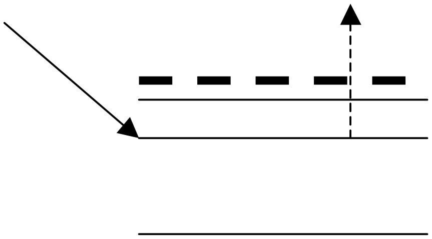
Absorption/Thermal Emission

Free-free (continuum) ("Bremsstrahlung") Emission/Absorption

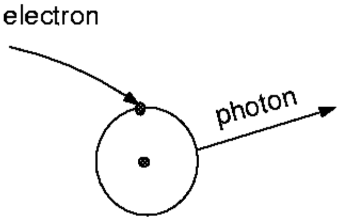


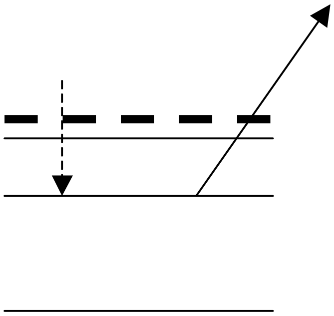
Bound-Free Processes





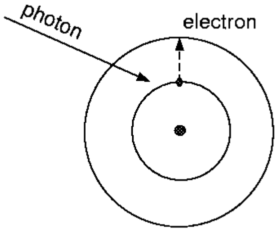
Ionization

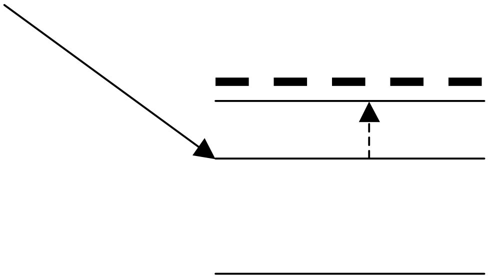




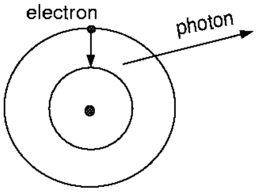
Recombination

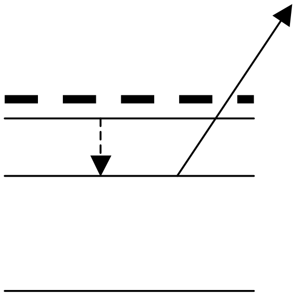
Bound-Bound Processes





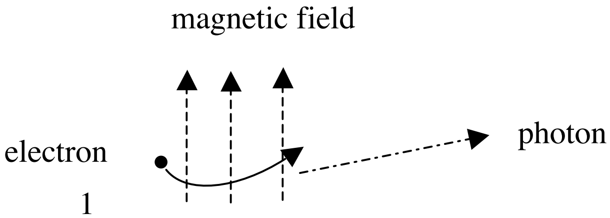
Excitation





Deexcitation

Charged Particle in a Magnetic Field



$$\text{Lorentz factor } \gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

For $\gamma=1$ Cyclotron Radiation – circularly polarized

For $\gamma>>1$ Synchrotron Radiation – linearly polarized with $\vec{E}(photons) \perp \vec{B}(field)$

For a power-law particle energy distribution, $F_\nu \propto \nu^{-\alpha}$

Scattering Regimes:

Thomson

$$\sigma_T = \frac{8\pi}{3}\left(\frac{e^2}{mc^2}\right) \approx 6.65x10^{-25}\,cm^2 \quad for\ \nu < 10^{20}\,Hz$$

(Klein-Nishina)

$$\sigma_{KN} \approx \frac{3}{8}\sigma_T\left(\frac{mc^2}{h\nu}\right)\left[\ln\left(\frac{2h\nu}{mc^2}\right)+\frac{1}{2}\right] \approx \frac{3x10^{-5}}{\nu}\left[\ln\left(1.6x10^{-20}\nu\right)+\frac{1}{2}\right] \quad for\ \nu >> 10^{20}\,Hz$$

Compton

$$\sigma_C \approx \begin{cases} \sigma_T & for\ \gamma h\nu << mc^2 \\ \frac{8}{3}\sigma_T \frac{mc^2}{\gamma h\nu}\left[\ln\left(\frac{2\gamma h\nu}{mc^2}\right)+\frac{1}{2}\right] & for\ \gamma h\nu >> mc^2 \end{cases}$$

$$\nu_{scatt} = \nu_0\left[1+\left(\frac{h\nu}{mc^2}\right)\left(1-\cos\phi\right)\right]^{-1} \quad for\ \gamma << 1\ and\ \gamma h\nu << mc^2$$

$$= \frac{4\gamma^2\nu}{3} \quad for\ \gamma >> 1\ and\ \gamma h\nu << mc^2$$

$$= \frac{\gamma mc^2}{h} \quad for\ \gamma >> 1\ and\ \gamma h\nu >> mc^2$$

Inverse-Compton

$$\sigma_C \approx \begin{cases} \sigma_T\left(1-\dfrac{2\gamma h\nu}{mc^2}\right) \quad and \quad \nu_{scatt} \approx \gamma^2\nu_0 \quad for\ \gamma h\nu << mc^2 \\ \dfrac{8}{3}\sigma_T\dfrac{mc^2}{\gamma h\nu}\left[\ln\left(\dfrac{2\gamma h\nu}{mc^2}\right)+\dfrac{1}{2}\right] \quad and \quad \nu_{scatt} \approx \dfrac{\gamma mc^2}{h} \quad for\ \gamma h\nu >> mc^2 \end{cases}$$

Note: The inverse –Compton scattering can take place in a thermal gas or a non-thermal gas. If a synchrotron-emitting plasma has a high enough density of photons and electrons, then the synchrotron-emitting photons can inverse Compton scatter other photons nearby, This is called synchrotron self-Compton scattering (SSC). (An analogous process to free-free absorption, synchrotron self-absorption (SSA) can also occur).