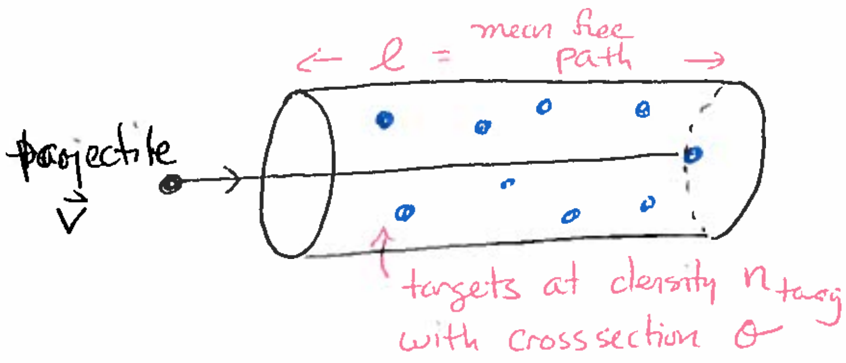
Photoionization & Recombination

ASTR
300B



Mean Free Path : $\ell \sim \dfrac{1}{n_{targ}\,\sigma}$ cm

$\mathrm{cm^{-3}}\ \mathrm{cm^{2}}$

Time between Collisions : $\sim \dfrac{1}{n_t\,\sigma\,v}$ s

$\mathrm{cm^{-3}}\ \mathrm{cm^{2}}\cdot\frac{\mathrm{cm}}{\mathrm{s}}$

Collision Rate : $\sim n_t\,\sigma\,v$ $\mathrm{s^{-1}}$

Collision Rate per unit volume : $\sim n_{proj}\cdot n_{targ}\cdot \sigma\,v$ $\mathrm{cm^{-3}\,s^{-1}}$

Now, in a thermal gas, the projectiles ~~is~~ are not moving at a single velocity v, but instead have a distribution of velocities or energies. Furthermore, for processes like photoionization or recombination, the cross section depends on energy. Thus we must integrate $\langle\sigma v\rangle$ over the energy of particles:

Sometimes called a "Collision Rate" Coefficient

$$\langle \sigma v\rangle = \int_0^\infty \sigma(E)\, v\, f(E)\, dE \qquad \mathrm{cm^{3}\cdot s^{-1}}$$

$\mathrm{cm^{2}}\cdot\frac{\mathrm{cm}}{\mathrm{s}}$

for a thermal gas this is the Maxwell-Boltzmann Distribution

Let's start with photoionization rate (a collision rate for photons)

$$\zeta_{pi} = \int_{\nu_I}^{\infty} \underset{cm^2}{\sigma_{pi}(\nu)}\; \underset{\frac{cm}{s}}{\overset{\uparrow}{c}}\; \underset{\frac{erg\cdot cm^{-3}\,Hz^{-1}}{erg}\cdot Hz}{\frac{u_\nu}{h\nu}}\, d\nu \qquad s^{-1}$$

ionization energy of atom or molecule $\nearrow$

photon velocity

$\uparrow$ Number of photons at $h\nu$ per cm^3

For hydrogenic atoms (ions) $\sigma_{pi}(\nu)$ may be approximated as a power-law when $Z^2 I_H < h\nu \lesssim 100 Z^2 I_H$

$$\sigma_{pi}(\nu) \sim \left(6.304\times10^{-18}\, Z^{-2}\right)\left(\frac{h\nu}{Z^2 I_H}\right)^{-3} \qquad cm^2$$

At higher energies, the power-law steepens to -3.5 until $h\nu \simeq 2.5$ keV where it becomes equal to the Compton Scattering cross section

How MANY IONIZING PHOTONS with $h\nu > 13.6\,eV$ are produced by a star per second?

$$Q_0 = \underset{cm^2}{4\pi R_*^2} \int_{\nu_I = 13.6 eV}^{\infty} \frac{\overset{erg\cdot s^{-1}\cdot cm^{-2}\cdot Hz^{-1}}{\pi B_\nu(T)}}{\underset{erg}{h\nu}}\, \underset{Hz}{d\nu} \qquad s^{-1}$$

Can lookup Q_0 for different types of stars in tables

Also define Q_1 as same integral but for $h\nu_I = 24.6\,eV$ capable of ionizing Helium.