Recombination ("Free-Bound")

ASTR 300B

The recombination rate into a level (n,ℓ) ← bound state is given by $\alpha_{n\ell}(T) = \langle \sigma v \rangle$ where the average $\langle\rangle$ is over $\sigma(E)$ and the distribution of speeds/energies of the electrons. For a thermal gas, this distribution is a Maxwell-Boltzmann Distribution:

$$\alpha_{n\ell}(T) = \int_0^\infty \sigma_{rr,n\ell}(E) \left(\frac{8kT}{\pi m_e}\right)^{1/2} \frac{E}{kT} e^{-E/kT} \frac{dE}{kT} \quad cm^3 s^{-1}$$

NOTE: this is related to σ_{pi} through "Milne Relation"

See Hummer & Story 1987 for H atom calculation of $\alpha_{n\ell}$

There are 2 limiting cases: (Baker & Menzel 1938)

① CASE A — High T ($\sim 10^6$ K) shocks, collisionally ionized environments

Optically thin to ionizing radiation ⇒ ionizing photons emitted during recombination escape

$$\alpha_A(T) = \sum_{n=1}^{\infty} \sum_{\ell=0}^{n-1} \alpha_{n\ell}(T)$$

② CASE B — HII regions, Planetary Nebulae etc.

Optically thick to radiation with $h\nu \geq 13.6$ eV ⇒ ionizing photons emitted during recombination are re-absorbed. Recombination to $n=1$ does NOT affect ionization - only recombination to $n \geq 2$ reduces/balances ionization.

$$\alpha_B(T) = \sum_{n=2}^{\infty} \sum_{\ell=0}^{n-1} \alpha_{n\ell}(T) = \alpha_A(T) - \alpha_{1s}(T)$$