Heating of HII regions

$$H + h\nu \rightarrow H^+ + e^-$$

Kinetic energy $= h\nu - I_p$
$I_p =$ ionization potential

$\Gamma_{pe} =$ photo-electric heating per unit volume per unit time

$$= n(HI) \int_{\nu_0}^{\infty} \sigma_{pe}(\nu) \left[\frac{U_\nu}{h\nu}\right] (h\nu - h\nu_0)\, d\nu$$

$$I_p = h\nu_0$$

Approximate FUV emission spectrum of stars by a color temperature, T_c

$$\psi = \frac{\langle E_{pe} \rangle}{kT_c}$$

Two approximations:

Near the star there is not much absorption and so the incident spectrum is that of the star

$$\Psi_0 kT_c \equiv \frac{\int_{\nu_0}^{\infty} \frac{B_\nu(T_c)}{h\nu}\, \sigma_{pe}(\nu)(h\nu - h\nu_0)\, d\nu}{\int_{\nu_0}^{\infty} \frac{B_\nu(T_c)}{h\nu}\, \sigma_{pe}(\nu)\, d\nu}$$

Another approximation is that all Lyman continuum stellar photons ($h\nu > I_H$) will produce a photionization <u>somewhere</u> in the nebula.

$$\langle\Psi\rangle kT_c = \frac{\int_{\nu_0}^{\infty} \left[\frac{B_\nu(T_c)}{h\nu}\right](h\nu - h\nu_0)\, d\nu}{\int_{\nu_0}^{\infty} \left[\frac{B_\nu(T_c)}{h\nu}\right] d\nu}$$

T_c	8000	16,000	32,000	64,000
Ψ_0	.959	.922	.864	0.775
$\langle\Psi\rangle$	1.1	1.2	1.4	1.6

The integral above is dominated by the rapid (exponential) drop of B_ν as you approach $h\nu_0$

In steady state the number of recombinations equals the number of ionizations

$$\boxed{\Gamma_{pe} = \alpha_B n_e n_p \psi k T_c}$$

Cooling of HII regions.

- free-free emission

$$\Lambda_{ff} = \alpha_B n_e n_p f(T)$$

- radiative recombination

$$\Lambda_{rr} = \alpha_B n_e n_p \langle E_{rr} \rangle$$

$\langle E_{rr} \rangle$ = mean kinetic energy of the recombining electrons

- collisional losses $\leftarrow$ most important

Consider a pure hydrogen HII region

In steady state

$$\Gamma_{pe} = \alpha_B n_e n_p \psi k T_c \quad \text{heating}$$

Cooling: free-free & recomb.

$$\Gamma_{recomb} = \alpha_B n_e n_p \langle E_r \rangle$$

$$\Gamma_{free\text{-}free} = n_e n_p L_{ff}$$ ← luminosity coeff (cm^{+3} erg s^{-1})

Equate the two

$$\alpha_B n_e n_p \psi k T_c = n_e n_p \left[\alpha_B \langle E_r \rangle + L_{ff}\right]$$

$$\psi k T_c = \langle E_r \rangle + \frac{L_{ff}}{\alpha_B}$$

$\langle E_r \rangle$ has a simple meaning: energy lost at recombination

We see $n_e n_p L_{ff}$ = energy loss per unit time per unit volume

Energy radiated by one electron is $n_p L_{ff}$

The mean time to recombine is $(n_p \alpha_B)^{-1}$

Thus the total energy lost by electron to the point of recombination is

$$n_p L_{ff} \times (n_p \alpha_B)^{-1} = L_{ff}/\alpha_B$$

- Now present your write-up on ~~Z~~ Zero-Z HII regions.

- Project Figures 27.1, 27.2, 27.3 from Draine