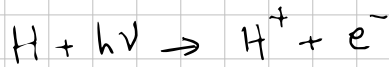


Heating of HII regions



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

Γ_{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

$$\gamma_0 kT_c \equiv \frac{\int_{\nu_0}^{\infty} \frac{B_{\nu}(T_c)}{h\nu} \sigma_{pe}(\nu) (h\nu - h\nu_0) d\nu}{\int_{\nu_0}^{\infty} \frac{B_{\nu}(T_c)}{h\nu} \sigma_{pe}(\nu) d\nu}$$

Another approximation is that all Lyman continuum stellar photons ($h\nu > I_H$) will produce a photoionization somewhere 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
ν_0	0.959	0.922	0.864	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

$$\Gamma_{pe} = \alpha_B n_e n_p + kT_c$$

Cooling of H II 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 ← 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.

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

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

Equate the two

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

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

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

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

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

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

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

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

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

o Project Figures 27.1, 27.2, 27.3 from Draine