

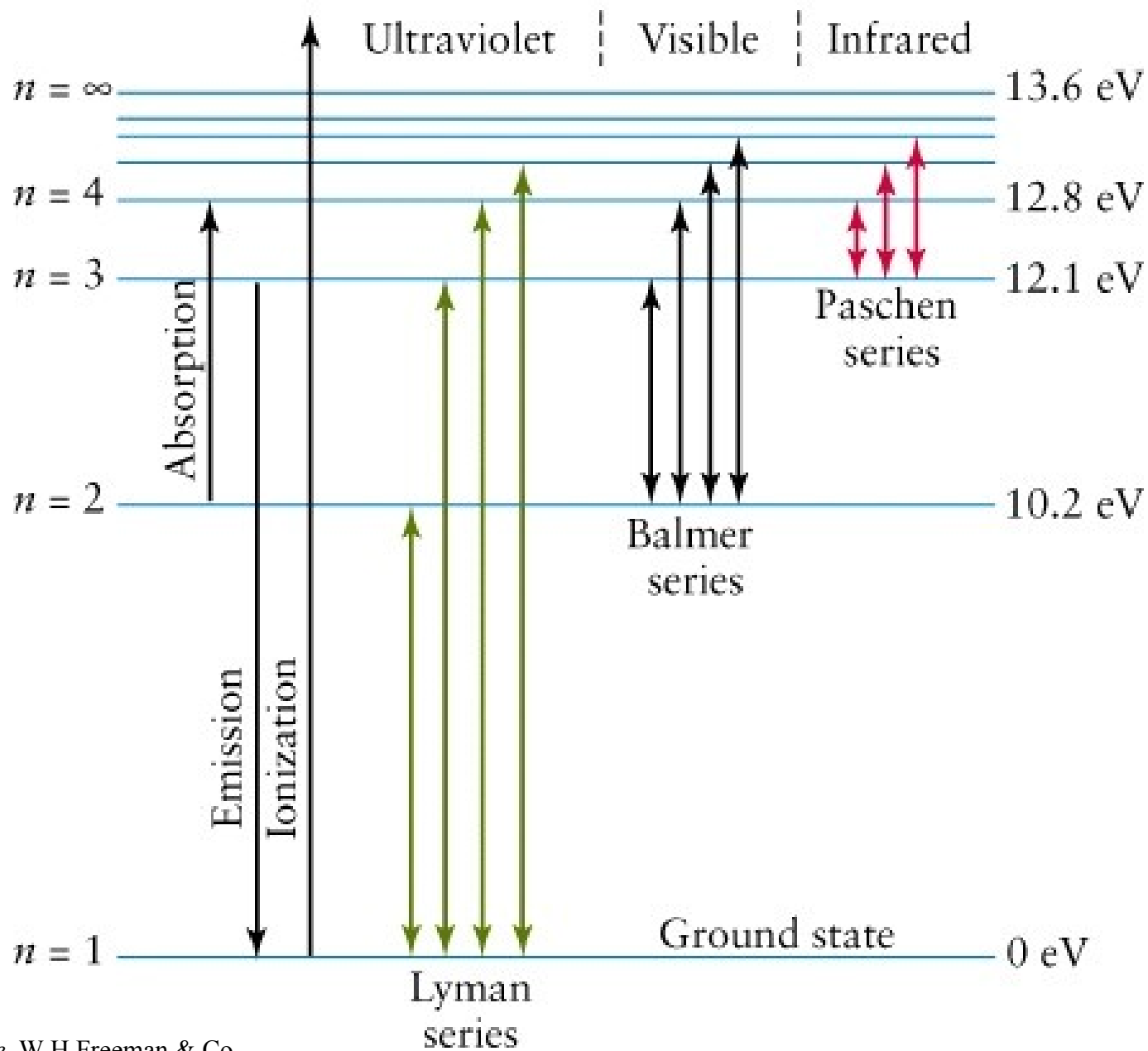
Opacity and Radiative Transfer

- Sources of opacity
 - Absorption processes
 - Scattering
- Radiative transfer equation solution

Opacity

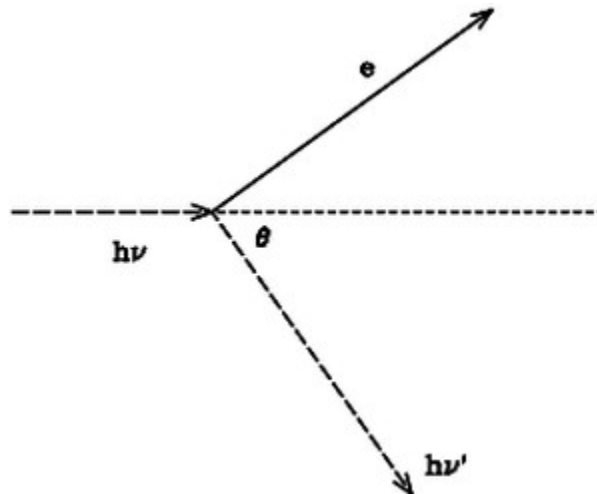
- Absorption processes
 - photon is absorbed (destroyed) (although usually re-emitted a short time later, but in a random direction)
 - can be classified by type of electron transition taking place in the particle doing the absorbing

- bound-bound
 - photon absorbed when e^- undergoes transition between two bound energy levels in an ion, atom or molecule - spectral lines
- bound-free
 - transition from bound level to free the e^- - photoionization – continuum with thresholds
- free-free
 - e^- absorbs photon energy and is accelerated in vicinity of an ion – bremsstrahlung - continuum



Scattering

- photon is re-directed, but frequency unchanged - elastic collision – continuum
- E.g. Thomson scattering by free electrons



Radiative Transfer Equation

- The radiative transfer equation can be written as

$$\frac{dI_{\nu}}{d\tau_{\nu}} = -I_{\nu} + S_{\nu}$$

where

$$S_{\nu} = \frac{j_{\nu}}{K_{\nu}}$$

is known as the source function.

Formal Solution

- The formal solution to this equation is

$$I_{\nu}(\tau_{\nu}) = I_{\nu}(0)e^{-\tau_{\nu}} + \int_0^{\tau_{\nu}} S_{\nu} e^{-(\tau_{\nu}-\tau'_{\nu})} d\tau'_{\nu}$$

- If the source function is constant along the path and there is no incident radiation ($I_{\nu}(0)=0$) then it becomes

$$I_{\nu}(\tau_{\nu}) = S_{\nu}(1 - e^{-\tau_{\nu}})$$

Optical Depth

- This means that if the medium is optically thick ($\tau_v \gg 1$)

$$I_v(\tau_v) = S_v$$

- And if it is optically thin ($\tau_v \ll 1$)

$$I_v(\tau_v) = S_v \tau_v$$

Source Function

- In thermal equilibrium the source function is just the Planck function

$$S_\nu = B_\nu$$

- and in the radio regime we can use the Rayleigh-Jeans approximation so

$$S_\nu = B_\nu = \frac{2kT\nu^2}{c^2}$$

Brightness Temperature

- The Rayleigh-Jeans approximation also means that we can use temperature as a measure of intensity
- Brightness temperature T_B is the temperature a blackbody would have to give the same intensity

$$I_\nu = \frac{2kT_B\nu^2}{c^2}$$

RT Equation in Radio Regime

- Rewrite the transfer equation such that

$$T_B = T(1 - e^{-\tau_\nu})$$

where T is the temperature of the emitting region

- Now when optically thick ($\tau_\nu \gg 1$)

$$T_B = T$$

- And if it is optically thin ($\tau_\nu \ll 1$)

$$T_B = T\tau_\nu$$

Summary

- Opacities determine how photons interact with matter (atomic and molecular physics)
- Spectroscopy of stars, nebulae and galaxies can be used to determine the abundances of elements using their opacities