DARA Basic Training

NAMIBIA-BOTSWANA 2019

UNIT 1: INTRODUCTION TO ASTROPHYSICS

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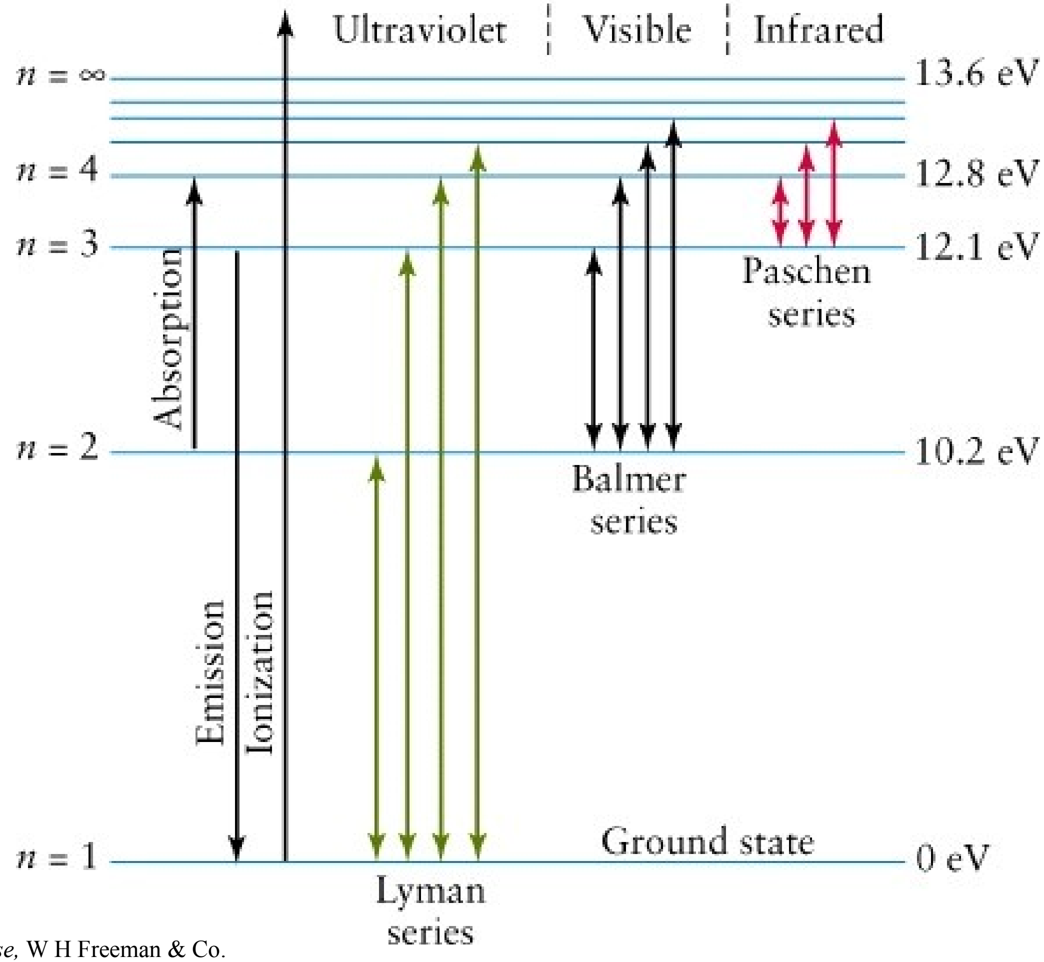
Opacity and Radiative Transfer

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

Opacity

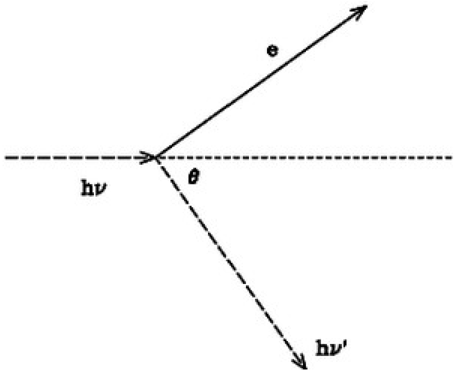
- Absorption processes
  - photon is absorbed (destroyed) (although usually re-emited a short time later, but in a random direction)
  - can be classifed by type of electron transition taking place in the particle doing the absorbing

- 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


Ultraviolet
Visible
Infrared
n = ∞
13.6 eV
n = 4
12.8 eV
n = 3
12.1 eV
Paschen series
Absorption
n = 2
10.2 eV
Balmer series
Emission
Ionization
Ground state
n = 1
0 eV
Lyman series

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

is known as the source function.

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

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 (τ_ν>>1)

- And if it is optically thin (τ_ν<<1)

$$I_\nu(\tau_\nu) = S_\nu$$

$$I_\nu(\tau_\nu) = S_\nu \tau_\nu$$

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 (τ_ν>>1)

$$T_B = T$$

- And if it is optically thin (τ_ν<<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