Absorption and Scattering

Definitions – Sometimes it is not clear which process is taking place

Absorption and Scattering

- Scattering: Photon interacts with the scatterer and emerges in a new direction with (perhaps) a slightly different frequency
  - No destruction of the photon in the sense that energy is added to the kinetic pool
- Absorption: Photon interacts and is destroyed and its energy is converted (at least partially) into kinetic energy of the particles composing the gas.
- Scattering is mostly independent of the thermal properties of the gas and depends mostly on the radiation field.

Absorption and Scattering

- Absorption processes depend on the thermodynamic properties of the gas as they feed energy directly into the gas.
- NB: thermal emission couples the thermodynamic quantities directly to the radiation field!

Scattering Processes

- Bound-Bound Transitions followed by a direct reverse transition:
  - $a \rightarrow b : b \rightarrow a$
  - There can be a small ΔE as the energy states have finite width (substates)
  - $\Delta E \sim 0$ and "only" the direction changed!
- Photon scattering by a free electron (Thomson) or molecule (Rayleigh)
  - Thomson: $0.6655\ (10^{-24})\ N_e$
  - Rayleigh: $\propto \lambda^{-4}$

Absorption Processes

- Photoionization / bound-free transition
  - Excess energy goes into KE
  - Inverse Process: Radiative Recombination
- Free-Free Absorption: an electron moving in the field of an ion absorbs a photon causing a shift in the “orbit” (hyperbolic).
  - Inverse Process: Bremsstrahlung
- Bound-Bound Photoexcitation followed immediately by a collisional de-excitation ==> photon energy shared by partners and goes into the kinetic pool.
  - Inverse Process: ----------
- Photo-excitation followed immediately by a collisional ionization.
  - Inverse Process: Collisional Recombination

Caveats

- These lists are not exhaustive. In many cases the line between the two processes is not clear, especially with bound-free events.

Absorption Coefficient

- Absorption Coefficient κ_ν per gram of stellar material such that:
  - A differential element of material of cross section dA and length ds absorbs an amount of energy from a beam of specific intensity I_ν (incident normal to the ends of the element):
  - $dE_\nu = \rho\, \kappa_\nu\, I_\nu\, d\omega\, dt\, dA\, ds\, d\nu$

Scattering Coefficient

- Similarly, σ_ν governs the amount of energy scattered out of the beam.

$$dE_\nu = \rho\, \sigma_\nu\, I_\nu\, d\omega\, dt\, dA\, ds\, d\nu$$

- We assume that both κ_ν and σ_ν have no azimuthal dependence. The combined effect of κ_ν and σ_ν is to remove energy from the beam.
- The total extinction coefficient is: $K_\nu = \kappa_\nu + \sigma_\nu$
- K_ν is called the "mass absorption coefficient"

The Simple Slab

$dI_\nu = -\rho\kappa_\nu I_\nu dz$

I_ν: ergs Hz^{-1} s^{-1} cm^{-1} $sterad^{-1}$

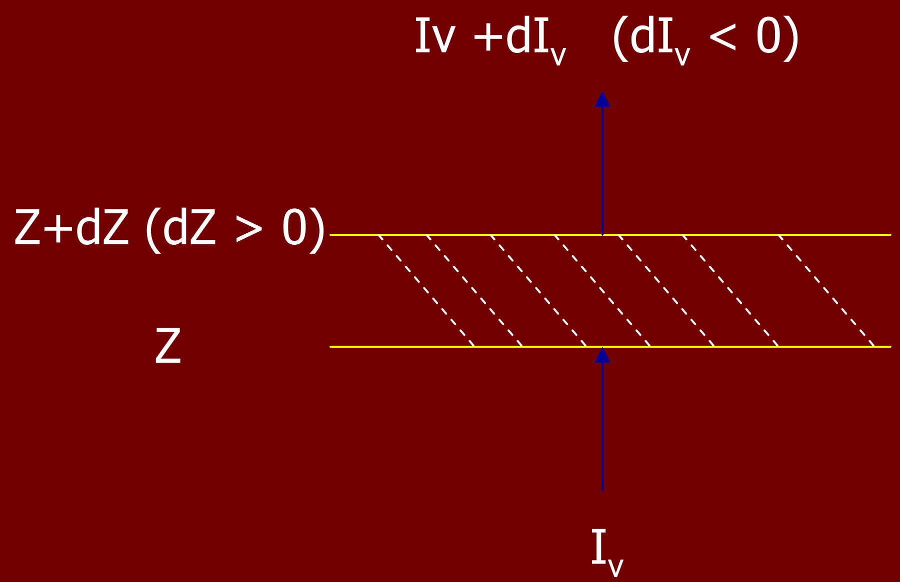
κ_ν: cm^2 gm^{-1}

$\rho\kappa_\nu$: cm^{-1}

$$\frac{dI_\nu}{I_\nu} = -\kappa_\nu \rho dz$$

$$\ln I_\nu |_{I_{\nu 1}}^{I_{\nu 2}} = -\int_{z_1}^{z_2} \kappa_\nu \rho dz$$

$$I_{\nu_2} = I_{\nu_1} \exp(-\int_{z_1}^{z_2} \kappa_\nu \rho dz)$$



The Simple Slab Continued

- In the above 1 and 2 are arbitrary limits
- Let us now integrate over the slab (assign physically meaningful values to the integration limits). We want the "output" at the top ($Z=0$) coming from depth X in the slab (star?!)
  - $I_{\nu 1}$ = Initial intensity = $I_\nu(X)$
  - $I_{\nu 2}$ = Output Intensity
  - Z_1 = Level of Origin
  - Z_2 = Level of Output (= 0)

$$I_\nu(0) = I_\nu(X)\exp\left(-\int_X^0 \kappa_\nu \rho\, dz\right)$$

The Optical Depth

The Dimensionless Quantity τ

$$d\tau_\nu = -\kappa_\nu \rho dx$$

$$\tau_{\nu_2} - \tau_{\nu_1} = -\int_{x_1}^{x_2} \kappa_\nu \rho dx$$

Note that τ and X increase in opposite directions. Boundary Conditions: At the surface $\tau_{\nu 1} \equiv 0$ and at the "base" $X_1 \equiv 0$. Therefore:

$$\tau_{\nu_2} = -\int_0^{x_2} \kappa_\nu \rho dx$$

$$-\tau_\nu = -\int_x^0 \kappa_\nu \rho dx$$

$$\therefore$$

$$I_\nu(0) = I_\nu(x) e^{-\tau_\nu}$$

Optical Depth

Surfaces and Probability

- The optical depth of a slab determines how much light escapes from a given level:
  - If $\tau = 2$ then $I = I_0 e^{-2}$ ==> 0.135 of I_0 escapes
- The usual definition of "continuum" (AKA the "surface" of a star) is where a photon has a 50% chance of escaping:
  - $e^{-\tau} = 0.5$ ==> $\tau = 0.693$
- An exercise in atmospheric extinction. A cloud can easily contribute 3 magnitudes of extinction:
  - $1/(2.512)^3 = e^{-\tau}$ ==> $\tau = 2.763$.

Emission Processes

If there is a sink then there must be a source!

- Emission coefficient: j_ν
  - $dE_\nu = \rho\, j_\nu\, d\omega\, d\nu\, dt\, dA\, ds$
  - Or per unit mass in an incremental volume:
  - $dE_\nu = j_\nu\, d\omega\, d\nu\, dt$
- Let us consider thermal emission. Consider a cavity of uniform temperature T which is a blackbody. This demands
  - $j_\nu^t = \kappa_\nu B_\nu(T)$ – Kirchoff-Planck Law
  - κ_ν is absorption only
  - Strict Thermodynamic Equilibrium applies
  - Thermal absorption and emission independent of angle.

TE and Stellar Atmospheres

- Energy is transported in a stellar atmosphere
- This means the radiation field is anisotropic
  - There is also a temperature gradient which is demanded by the energy flow (2^{nd} Law)
- Strict Thermodynamic Equilibrium cannot hold!
- For convenience we shall assume that local thermodynamic equilibrium holds ==> T, N_e, etc locally determine occupation numbers.