Quick notes on
Photons and Matter

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Photon Interactions

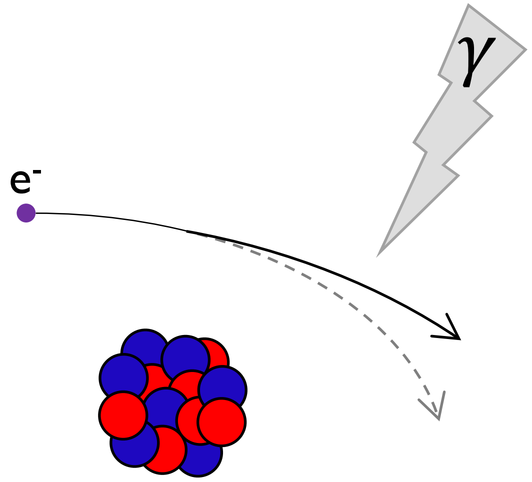
- Processes:
  - Scattering: *photon changes angle and/or energy*
  - Absorption (a.k.a. attenuation): *photon is destroyed*
  - Emission: *photon is emitted* (e.g. atomic de-excitation)
- For scattering and absorption, each process is described by a cross section, σ, which, along with the number density of the environment n, describes the mean free path, $l_{\mathrm{mfp}} = 1/n\sigma$
  - The mean free-path is the length for which the interaction probability $P = 1$.
    For 3-dimensions,
    - $P = (Area\ Obstacles)/(Area\ Object)$, where $(Area\ Obstacles) = (Volumetric\ Density\ of\ Obstacles) * (Volume\ Swept\ by\ Object) * (Area\ of\ Obstacle)$, and $(Volume\ Swept\ by\ Object) = (Area\ of\ Object) * (Path\ Length)$
    - $P = \frac{n_{obs}(A_{obj}l)A_{obs}}{A_{obj}} = nAl = 1,$ so $l = 1/nA$ ..for reactions $A = \sigma$, meaning $l_{\mathrm{mfp}} = \frac{1}{n\sigma} = 1/\kappa\rho$
  - For 2D, *Areas*⟶*Widths* and *Volumes*⟶*Areas*

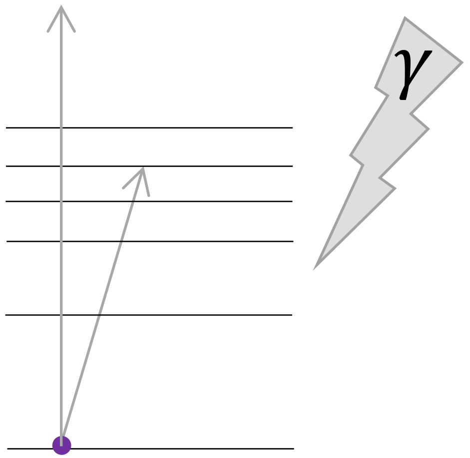
Scattering

- Free electrons (in the absence of a nucleus) can't absorb photons, so photons and electrons will often scatter
- When $h\nu \ll m_e c^2$ (i.e. when $\lambda \gg \lambda_{\text{Compton}} = \frac{h}{m_e c} = \frac{2\pi\hbar c}{m_e c^2} \approx \frac{2\pi(197\text{ MeV fm})}{0.511\text{ MeV}} \approx 2.4\text{ pm}$), then the scattering is elastic (KE conserved) and is known as Thompson scattering
- We can get the correct order of magnitude estimate for the cross section by considering the classical area of an electron, $A = \pi r_e^2$
  - Get the classical electron radius by equating the electrostatic potential energy of the electron to the rest mass energy
  - In cgs: $\frac{e^2}{r_e} = m_e c^2 \;\rightarrow\; r_e = \frac{e^2}{m_e c^2} = \frac{e^2}{m_e c^2}\frac{\hbar c}{\hbar c} \approx \frac{1}{137}\frac{197\text{ MeV fm}}{0.511\text{ MeV}} \approx 2.8\text{ fm}$
- So $\sigma_{\text{Th}} \sim \pi r_e^2 \sim 2.4 \times 10^{-29}\text{ m}^2$ …in practice, E&M adds a factor of 8/3

Absorption

- Free-Free absorption:
  - Photon absorbed by an electron near an ion
  - Essentially the reverse of bremsstrahlung, where a decelerating electron radiates photons
- Bound-Free absorption:
  - Photon absorbed by a non-ionized atom, where the energy goes to ejecting the electron from the atom
- Bound-Bound absorption:
  - Photon is absorbed by a non-ionized atom, where the energy does to exciting an electron to a higher orbital

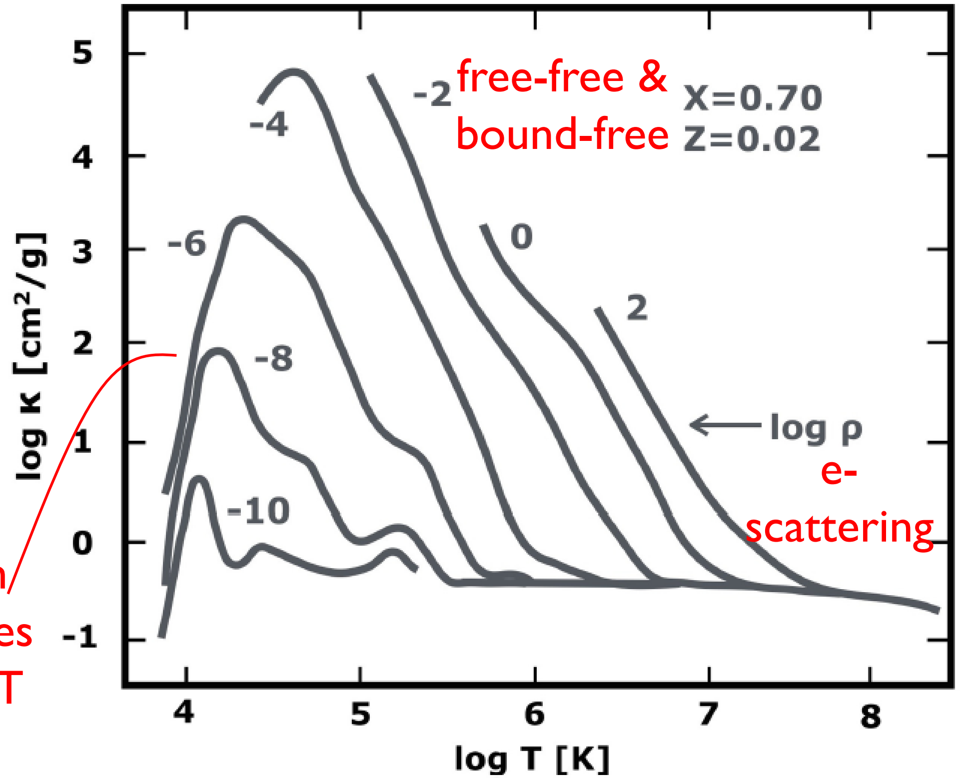




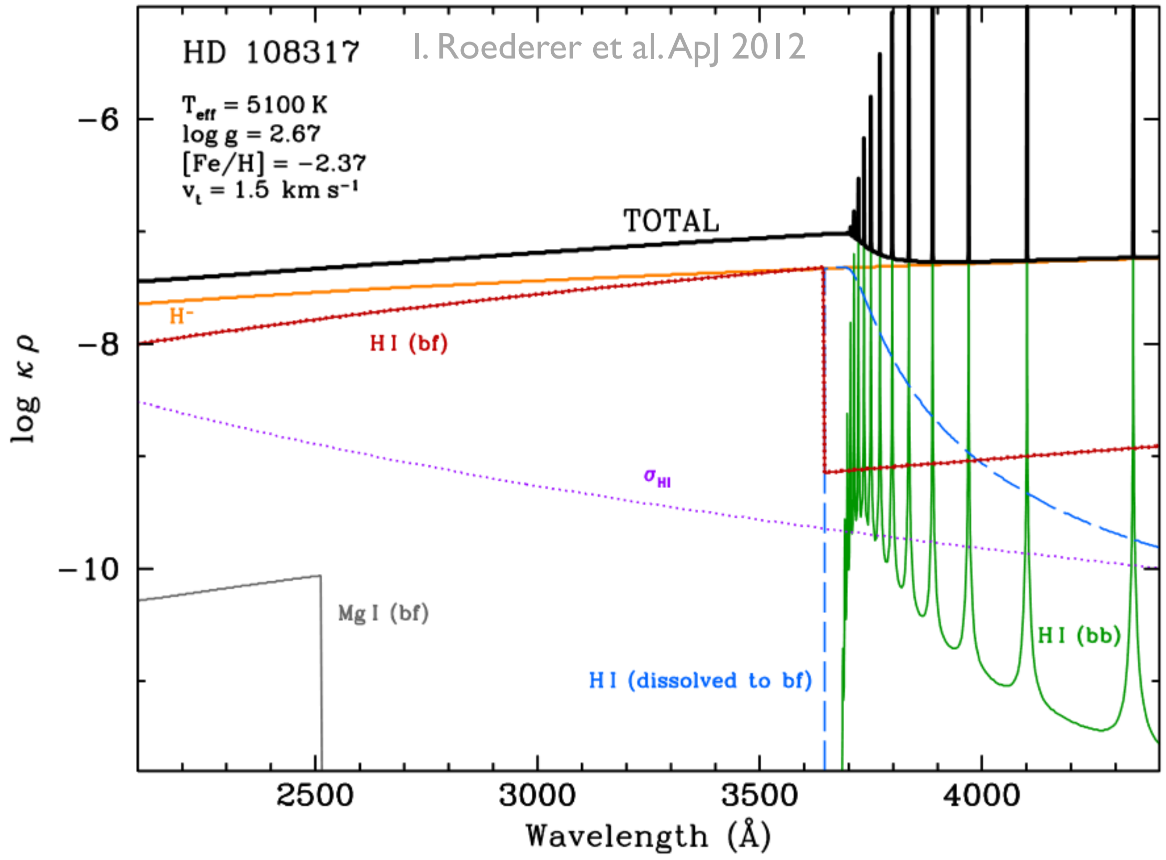
Opacity, κ

- Many different contributions & each is wavelength dependent
- κ_{ff} and κ_{bf} are $\propto \rho T^{-7/2}$, while κ_{bb} is far more complicated

Lamers & Levesque, based on OPAL



H⁻ is only ion left & decreases strongly with T



- All κ are integrated over wavelength and combined into a Rosseland mean opacity
- κ_R must be calculated numerically & tables exist for assumed compositions & nuclear and atomic physics data

Emission

- Matter excited above the ground state can spontaneously de-excite via photon emission
- Electrons can undergo Bremsstrahlung
- This light can be scattered into our out of a cone of light being considered