Radiation and Conduction

Radiation and Condution

- Following HKT Ch. 4.4-
- Carroll & Ostlie Ch. 9 also serve as a reference for these notes

Radiative Opacities

- We will not go deeply into the forms of the various opacities that contribute to the total opacity in the star
  - Your book gives a bit more of a physical motivation
- We break things down into
  - Bound-bound transitions
  - Bound-free absorption
  - Free-free absorption
  - Scattering
  -
- Some processes work over a wide range of photon wavelengths: these are sources of the continuum opacity

Electron Scattering

- Thompson scattering describes the interaction of a photon scattering from a free electron
- Cross-section at low energies is independent of energy
- Opacity is simply:

$$\kappa = \frac{\sigma n_e}{\rho}$$

- The Thompson cross-section is ~ to the classical electron radius squared
  - Value is small, but in massive stars / interiors where everything is ionized, this will dominate (no ions)
- Opacity: $\kappa_{es} = 0.2(1 + X) \text{ cm}^2 \text{ g}^{-1}$
- At high densities (degeneracy) and energies (relativity) the form will differ.

Free-Free Absorption

- A free electron cannot absorb a photon
  - Momentum and energy need to be conserved
- But in the presence of an ion, the electromagnetic force can allow the ion to help carry the momentum and energy
  - Inverse process is bremsstrahlung
- Continuous range of wavelengths of photons can be absorbed
- Follows a Kramers' law form:

$$\kappa \propto \rho T^{-3.5}$$

- Note that the cross-section goes like $1/m^2$, so ions/protons don't contribute

Bound-Free and Bound-Bound

- Bound-Free: absorption of a photon by a bound electron (aka photoionization)
  - Photon has enough energy to ionize—this means that a range of photon energies (above some threshold) participate
  - Requires detailed atomic physics input
  - Takes a Kramers' form:

$$\kappa \sim Z(1+X)\rho T^{-3.5}$$

- Bound-bound: this is the absorption of a photon resulting in the electron switching to a higher (bound) energy level
  - One operates at specific wavelengths—needs input on the absorption line profiles for atomic energy levels
  - Again Kramer's form, but smaller in magnitude than bound-free or free-free

H^- opacity

- In cooler stars, H- ions form
  - Extra electron only very weakly held on (ionization potential of 0.75 eV)
  - Photoionization process
  - Very important source of continuum opacity in cooler stars

Opacity Regimes

(C&O CH 9)

- Cooler stars (later than A): H- dominates
- A,B stars: photoionization of H atoms and free-free dominate
- O stars: electron scattering
- Total opacity is the sum of all these processes:

$$\kappa_\nu = \kappa_{\nu,bb} + \kappa_{\nu,bf} + \kappa_{\nu,ff} + \kappa_{es}$$

Conduction

- At high densities, conduction can dominate (think WDs)
- Fick's law applies again:

$$F_{\rm cond} = -D_e \frac{dT}{dr}$$

- We usually like to bundle things together into a total opacity, so we define a conductive opacity:

$$\kappa_{\rm cond} = \frac{4acT^3}{3D_e \rho}$$

- Conductive flux is then:

$$F_{\rm cond} = -\frac{4ac}{3\kappa_{\rm cond}\rho} T^3 \frac{dT}{dr}$$

- Total flux is additive:

$$F = F_{\rm rad} + F_{\rm cond}$$

- Total opacity is:

$$\frac{1}{\kappa} = \frac{1}{\kappa_{\rm rad}} + \frac{1}{\kappa_{\rm cond}}$$

Opacity Tables

- Opacity values are usually tabulated for use in evolution codes

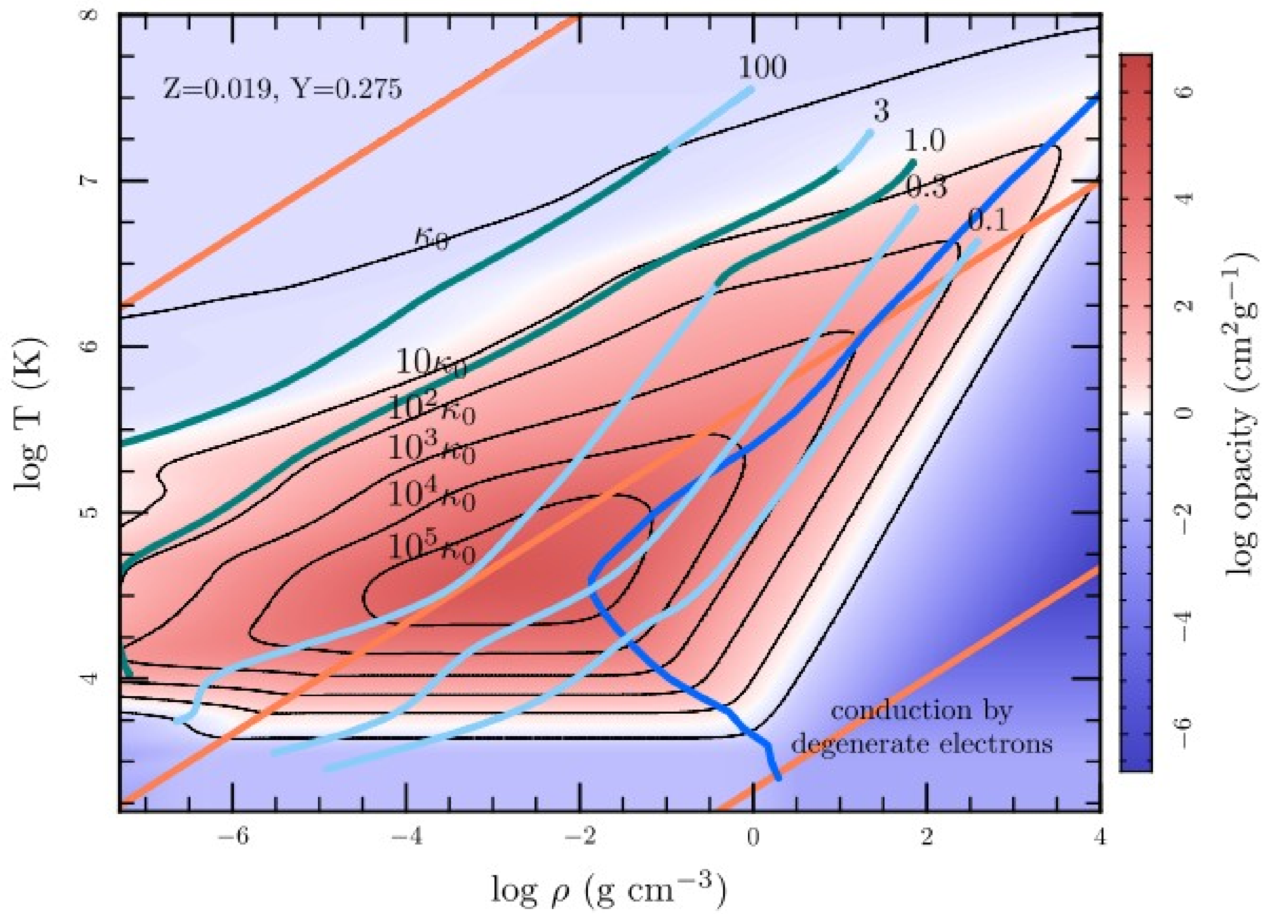

Figure 3. Resulting MESA opacities for $Z = 0.019$, $Y = 0.275$. The underlying shades show the value of κ, whereas the contours are in units of the electron scattering opacity, $\kappa_0 = 0.2(1 + X)$ cm^2 g^{-1}. The orange lines show (top to bottom) where $\log R = -8$, $\log R = 1$, and $\log R = 8$. Stellar interior profiles for main sequence stars of mass $M = 0.1, 0.3, 1.0, 3.0,$ and $100\ M_\odot$ are shown by the green (radiative regions)–light blue (convective regions) lines. Electron conduction dominates the opacity to the right of the dark blue line (which is where the radiative opacity equals the conductive opacity).