Topics: Wrapping up radiation transport and moving on to finishing up radiation and matter with a focus on thermal equilibrium with applications to Boltzmann and Saha as well as Planck

Summary of reading:

- Simply review the material assigned over the last few classes; for clarity and convenience, I’m leaving the two itemized readings from last time, that cover material we didn’t discuss in class on Tuesday; here they are:

- Skip section 5, except do study Fig. 5.10 and think about under what circumstances the depth of a line scales linearly with the number of absorbing particles.

- Reread sections 6 and 7 of Ch. 5, but focus on: pp. 134 and the definition of local thermodynamic equilibrium (LTE); and the definition of the Boltzmann and Saha equations on p. 135. Fig. 5.13 is a key application. It is complicated – study it carefully and look back at the beginning of the section to make sure you understand what all the symbols mean. In sec. 7, you can read the derivation of the Planck function but don’t be concerned if you have trouble following it. The properties of the function itself (eqns. 5.86 and 5.90, Figs. 5.14 and 5.15) are much more important than the derivation. The Stefan-Boltzmann law (eq. 5.96) and the behavior of the peak wavelength as a function of temperature (governing equation of which you’ll derive for homework this week, but which was discussed and shown graphically in the Openstax textbook reading from week 2) is also important.

Summary of work to submit:

- Nothing to submit for Thursday’s class...but do come with questions.

Here are the things you should be thinking about:

Thermal equilibrium – the criterion for having blackbody spectral emission (described by the Planck function) – also enables us to make several other very useful approximations: that particle velocities are described by the Maxwell-Boltzmann distribution, that energy level populations inside atoms are described by the Boltzmann distribution (related to, but simpler than, the M-B distribution), and the ionization distribution (how many neutral atoms of a given element compared to how many ionized atoms of that element) is described by the Saha equation. Keep in mind that some of these approximations (e.g. Maxwell-Boltzmann) are likely to be valid even when the thermal equilibrium approximation is not that good and the local radiation field is far from being Planckian. For example, the air molecule velocity distribution in our classroom is well-approximated by Maxwell-Boltzmann, but the radiation field in the room is not (it’s dominated in the optical by the ceiling lights and the distant Sun) and in the IR by the thermal emission of the walls and furniture.

Although stars are not perfectly in thermal equilibrium, they are often close enough to make the Planck function a good approximation to the overall spectral energy distribution of the light they emit from their surfaces and the Boltzmann and Saha equations are often good descriptions of the excitation and ionization balance in the plasma/gas on their surfaces. Understanding the temperature dependence of these properties will enable us to understand the spectral classification of stars, which is the primary way stellar surface temperatures are measured. Figure 5.13 is the key application.

Commentary on the reading:

A repeat of the thermal equilibrium commentary from last time.
Local is the key to LTE. A star’s temperature decreases as you go from the core to the surface, but if we can treat each individual layer as if it were in thermal equilibrium, it’ll make it so much easier to model the properties of the star. A given layer of the Sun may be 10,000 degrees, and just below it is a layer that’s 10,100 degrees and just above it a layer that’s 9,900 degrees. And in each layer, the spectrum of light that’s produced locally is given by the Planck function, but at the specific, local temperature. Ditto the particle speeds (M-B), the excitation of electrons in atoms (Boltzmann), and the ionization balance (Saha). The key to the validity of this LTE approximation is that the mean free path of photons, electrons, and atoms (how far the average one travels before interacting with something) is small compared to the length scale on which properties like temperature change appreciably.

We’ll discuss Boltzmann and Saha in detail and see their applications. To solidify and test your understanding of these concepts (and applications of the equations), carefully review Fig. 5.13. We’ll discuss it extensively in class. Make sure you can explain what each of the three curves means, what equations govern each one, and how the concepts in Fig. 5.13 lead us to the conclusion (on p. 126) that “stars with atmospheric temperatures around 10,000 K are those that produce the strongest Balmer absorption lines.” You might want to review what the Balmer absorption lines are (perhaps consulting Fig. 5.2). The key is – under what conditions do we maximize the number of neutral hydrogen atoms with their bound electron in the \( n = 2 \) state?

Please review both the functional/mathematical aspects of Planck (its form for a given temperature, how it changes as we consider hotter or cooler temperatures) and (a) how the peak of the Planck function shifts with temperature and (b) how the surface flux scales as temperature to the fourth power. Think about the concept of surface flux, it’s closely related to the flux in the inverse square law – same units – but the per area is best thought of not as describing the area of a detector but rather the area of the emitting surface of the hot object.