General Astronomy (29:61)
Fall 2012
Lecture 17 Notes, October 10, 2012

1 Kirchoff's Laws of Radiation

A compact set of statements about what kind of spectral appear under what circumstances are given by *Kirchoff's Laws.* These are given on p122 of the textbook. See online diagrams and plots.

1.1 The Planck Function

There is a more modern way to express Kirchoff's 1st Law. A *blackbody* produces a spectrum of radiation which is described by a function called the Planck function. This is given in Equation 5.86, and plotted in Figure 5.14 and 5.15.

⟶ See diagram in online plots and diagrams.

2 The Maxwell-Boltzmann Distribution of Atomic Speeds

A spectrum gives the distribution of photon energies of some source of light. A gas at finite temperature has a range of atomic (or molecular) speeds. Knowing what this distribution is will be useful for applications this semester and next semester.

This distribution was first derived on theoretical grounds by physicists in the 19th century. It is defined as follows. Let dN be the number of atoms with speeds in the range $v \to v + dv$. Let N_0 be the total number of atoms in the sample (say, the number of atoms/m^3). Then,

$$dN = N_0 F(v) dv \tag{1}$$

$$F(v) = 4\pi \left(\frac{m}{2\pi k_B T} \right)^{3/2} v^2 e^{-\frac{mv^2}{2k_B T}} \tag{2}$$

Our next fundamental physical constant is the *Boltzmann's constant*, $k_B = 1.381 \times 10^{-23}$. This equation is given in Equation 5.40. A plot of it is given in the online diagrams and graphs.

Let's look at some of the properties of this function.

The most probable speed (the mode in statistics) is given by

$$v_{mp} = \sqrt{\frac{2k_BT}{m}} \tag{3}$$

The *mean speed* is slightly higher,

$$< v >= \sqrt{\frac{8k_BT}{\pi m}} \tag{4}$$

The important point to note in looking at the diagram for this function is that there are many atoms moving faster than the mean speed.

2.1 Connection with the University of Iowa

The Maxwell-Boltzmann distribution was derived from fundamental statements of physics in the latter half of the 19th century. However, it was not verified in experiments at that point. The equipment and techniques had not yet been developed. A number of experiments were done in the period 1910 - 1930, that showed that the distribution of atomic and molecular speeds in a gas did, indeed, obey Equation 5.40. One of the most important and convincing experiments was done here at the University of Iowa by Professor John A. Eldridge, and published in 1927. You can look at the article yourself, John A. Eldridge, Physical Review, Vol 30, p931, 1927.

3 Absorption Lines

Absorption lines are very common in astronomical objects. The reason for this is that we often see light which is passing through a “cool” gas before it gets to us. In many cases of the planets, we are seeing sunlight that has passed through the atmosphere, reflected off a cloud layer or the surface, then passed through the atmosphere again before coming to us. The absorption line arises during this passage of the atmosphere. ⟶ Diagram in online graphs and diagrams.

These absorption lines are sometimes weak, so they can hardly been detected, and sometimes deep and wide. Look at figure 5.10 of the textbook. The strength of a line is determined by the number of atoms or molecules /unit volume, the thickness of the layer where the absorption is taking place, and how readily the atom absorbs the light.

4 The Doppler Effect

One of the most important results in physics for astronomy is the *Doppler Effect.* It is a very general property of waves, including electromagnetic waves.

The Doppler Effect states that when a source of waves is in motion relative to an observer, the frequency or wavelength changes. The amount of change depends on how fast the source and observer are approaching or receding from each other. If the speed of the source and/or observer is very small compared to the speed of light, this shift depends only on the component of velocity along the line of sight.

The formula for the Doppler Effect is

$$\frac{\lambda - \lambda_0}{\lambda_0} = \frac{v_r}{c} \tag{5}$$

where λ_0 is the "rest wavelength", or wavelength that the atom or molecule truly emits or absorbs, and λ is the measured wavelength. v_r is the "radial velocity" or component of the velocity toward or away from the observer. $v_r > 0$ corresponds to the source and observer moving away from each other. $v_r < 0$ corresponds to the source and observer approaching each other.

The Doppler Effect is extremely useful in astronomy because it allows us to measure velocities of astronomical objects.