2.5: Continuous Spectra - a Planck Spectrum Tells us the Temperature of Objects

Learning Objectives

- You will know that most light seen in the universe is thermal and can be represented by a Planck spectrum
- You will be able to perform calculations and understand conceptually the relationship between temperature and peak wavelength
- You will be able to perform calculations and understand conceptually the relationship between flux and temperature.

? What Do You Think: Hot and Cold

Two students are sitting around after a barbecue, roasting marshmallows and discussing how the color and temperature of objects might be related.

- **Geraldine:** "I like my marshmallows charred, so I want to put mine in the hottest part of the flames. I heard that blue is the hottest, so that's where I'm going to roast my marshmallows."
- **Helen** "No; the convention is that red stands for hot and blue stands for cold. Like on a bathroom sink. So, if you want your marshmallows to get charred, I think you should put them near the redder flames."

Which student do you think has a better chance of burning her marshmallows?

Geraldine

Helen

Neither

Explain your reasoning:

For the most common type of continuous spectrum, which is called a Planck spectrum (named after Max Planck) or blackbody spectrum, the relative brightness of each color follows a distribution that depends on the temperature of the object. Any dense object, such as a person, a desk, or the filament in an incandescent light bulb, will radiate a Planck spectrum.

To better understand what a spectrum is and how it can be used, we will do a short interactive activity on the Planck spectrum.

? Planck Spectrum

Play Activity

For quantitative work it is often convenient to graph a spectrum. This representation plots the brightness of light on the vertical axis and the corresponding frequency or wavelength on the horizontal axis. On the graph shown, a higher value for the relative brightness at a particular wavelength means the spectrum of light is brighter at that wavelength.

In this activity, you will see how the temperature of an object is related to its color, or more specifically, you will note the wavelength at which its Planck spectrum has its peak.

The colors are shown at the bottom of the graph in the activity, but you can also refer back to the discussion of wavebands in Section 2.3 in order to relate wavelength and color.

1. Set the temperature to 5834 K, about the same as the surface of the Sun.

a. What is the peak wavelength for this curve?

nm

b. What color does this correspond to?

red

yellow

blue/green

purple

2. Predict: If you set the temperature higher, the peak wavelength will?

be longer

be shorter

remain the same

3. Test your predictions by setting the temperature to 7,094 K. Describe your results and reconcile any differences. Be sure to note the peak wavelength and corresponding peak color.

4. Predict: If you set the temperature lower, the peak wavelength will?

be longer

be shorter

remain the same

5. Test your predictions by setting the temperature to 4,260 K. Describe your results and reconcile any differences. Be sure to note the corresponding peak color.

6. What waveband will the spectrum peak in if the temperature is set lower, for example 3,000 K?

7. At what waveband will the spectrum peak if the temperature is set much higher, for example 15,000 K?

8. Predict: If you set the temperature higher, will overall brightness be higher, lower, or remain the same?

9. Test your predictions by setting the temperature to 4,260 K, 5,834 K, and 7,094 K. Describe your results and reconcile any differences.

As you have just seen, the peak of the distribution of wavelengths of the emitted light shifts to shorter wavelengths as the temperature increases. So, for example, an object that glows with a blue color (shorter wavelength) is hotter than one glowing with a red color (longer wavelength). While an object with a Planck spectrum is emitting light at all wavelengths, the peak wavelength is the most prominent color. However, the peak of the spectrum need not be a color in the visible range. As a result, very hot objects, those with peaks well into the UV range, all appear bluish-white to our eyes; the part of their spectra in the visible is quite similar regardless of their respective temperatures.

Quantitatively, the temperature (T, measured on the kelvin scale) is inversely proportional to the peak wavelength (λ_{peak}) in meters:

$$T = 2.9 \times 10^{-3} \lambda_{peak}$$

This relationship, called **Wien's Law**, means if λ is *smaller*, T is *bigger*, and vice versa.

You also saw that a hotter object is also brighter overall (when comparing objects of the same size). Brightness is also known as intensity, or flux. It is the amount of light energy passing through a unit of surface area in a certain amount of time. The units for flux are watts/m^2, where 1 watt (W) = 1 J/s. The units of watts should be familiar to you from household light bulbs.

Quantitatively, we find the total flux of light (F) is proportional to the temperature (T) to the fourth power.

$$F = \sigma T^4$$

The constant σ = 5.67 × 10^{-8} W m^{-2} K^{-4} (Greek letter “sigma”) is called the **Boltzmann constant**. This equation is called the **Stefan-Boltzmann Law**. It means, for example, that if the temperature is 2 times hotter, the flux will be 16 times greater.

So, in summary, a hotter object is bluer than a cooler object, and if two objects have the same size, then the hotter object will be brighter than the cooler object. Knowing this helps us interpret the color and brightness of different astronomical objects.