**Temperature and Luminosity of Stars:**

**Wein’s Law and the Stephan-Boltzmann Law**

**Learning Objectives**

* To understand thermal spectra
* To understand Wien’s Law and the Stephan-Boltzmann Law
* To understand how thermal spectra can be used to evaluate the temperature of a star
* To understand how temperature and radius of a star determine a star’s luminosity

**Introduction:** In this activity we will learn how light from a star can tell us its temperature and how much energy per second the star is emitting – its *luminosity*.

Light that is emitted from stars, like light from any hot object made of many closely packed atoms, forms a continuous spectrum called a *thermal spectrum.* The range of wavelengths emitted and the relative intensity of the light for each wavelength are dependent on the temperature of the object.

In this activity we will use a PhET simulation to study the thermal spectra of stars in order to understand the relationship between these spectra and temperature. We will see how this relationship results in two laws that describe these spectra -- Wein’s Law and the Stephan-Boltzmann Law.

Go to <http://phet.colorado.edu/sims/blackbody-spectrum/blackbody-spectrum_en.html>

As you work through this activity, please answer the questions on a separate page – neatly handwritten or typed.

**Part 1: Understanding the graph**

This simulation plots a graph that describes the spectrum emitted by a hot object. The horizontal axis indicates the wavelength of the emitted photons and the vertical axis indicates the amount of energy per second (power) emitted by *one square meter of the object* at a particular wavelength.

To investigate this further, set the temperature to 5800 K. Either move the slider or type the numbers in the temperature box. 5800 K is approximately the temperature of the Sun.

Note that the horizontal axis specifies the emitted wavelengths (λ) in units of micrometers, µm. One micrometer equals 1000 nanometers. (1µm = 1000 nm.) For example, look at the visible spectrum. The longest wavelength of the visible spectrum is approximately 0.7µm = 0.7x1000nm or 700 nm.

**Question 1.** Approximately, what is the shortest *visible* wavelength? Express your answer in µm and nm.

Observe the peak of the curve. The Sun emits the most energy at this wavelength. We will label this wavelength λ*peak*-- the wavelength where the curve is at its peak.

**Question 2**: What color corresponds to λ*peak*?

**Question 3.** Approximately, what is the value for λ*peak*? Express your answer in µm and nm. (Check the box “show ruler” and use the ruler to help approximate the value for λ*peak*.)

The vertical axis indicates for each wavelength the amount of energy per second emitted by one square meter of the surface of the emitting object, the Sun in this setting. Recall that “energy per second” is “power,” measured in watts, W. MW indicates “megawatts.” 1MW = 1Million Watts. Thus the vertical units are MW/m2. Note that the only values on the graph are 0 and 100. You can use the ruler to estimate values in between. For example, to measure value for the peak wavelength, rest the bottom of the ruler on the horizontal axis, and note that 30cm corresponds to 100 MW/m2. The peak measures 24 cm. So the value at this wavelength = (24/30) x 100 MW/m2 = 80 MW/m2.

***Hit the “save” button!***

 Enter your values for the Sun in Table 1 on the next page.

**Part 2: Other Stars at other Temperatures**

**A.** Change the temperature to 3800K. Compare this curve to the saved one for the Sun.

**Question 4:** In what two ways does this peak differ from that of the Sun?

For easier viewing, magnify the curve by pressing the + button on the left. Note that the maximum reading on the vertical axis changes. Make measurements to complete the Table 1 entries for this temperature.

**B.** Change the temperature to 6600K. Compare this curve to the saved one for the Sun. For easier viewing, press the - button on the left. Make measurements to complete the Table 1 entries for this temperature.

**Question 5:** In what two ways does this peak differ from that of the Sun?

**C.** Make measurements to complete the Table 1 entries for a temperature of 8300 K, adjusting the scales as necessary.

**Table 1: Thermal Spectra Characteristics for Different Temperatures**

|  |  |  |  |
| --- | --- | --- | --- |
| Temperature | λ*peak* (nm) | λ*peak* (color, UV, or IR) | Peak Energy/sec/m2(MW/m2) |
| 3800 K |  |  |  |
| 5800 K (Sun) |  |  |  |
| 6600 K |  |  |  |
| 8300 K |  |  |  |

**Part 3: Wien’s Law**

**A.** Qualitative discussion

**Question 6:** Based on your values in Table 1, how does the value of λpeak change as the temperature increases?

Wien’s Law states: *Hotter objects emit photons with a higher average energy, which means a higher frequency and, therefore, a shorter wavelength.*

**Question 7:** Do the values in Table 1 support this law or not? Explain your choice.

**B.** Quantitative discussion

Quantitatively, Wien’s law reflects this inverse relationship between temperature and peak wavelength. It states that if wavelength is measured in nm and temperature is measured in Kelvin, then



Use the values you measured for λ*peak* and Wien’s law to determine T and compare to the values from the PhET. Enter the values in Table 2.

**Table 2: Comparison with Wien’s Law**

|  |  |  |  |
| --- | --- | --- | --- |
| Temperature (From PhET) | λ*peak* (nm)  | Temperature(Wien’s Law) | % error |
| 3800 K |  |  |  |
| 5800 K (Sun) |  |  |  |
| 6600 K |  |  |  |
| 8300 K |  |  |  |

**Part 4: The Stephan-Boltzmann Law**—

**A.** Qualitative discussion



The picture above is a screen shot of the 5800K and 6600K thermal spectra.

**Question 8:** Which radiates more MW/m2 at infrared wavelengths?

**Question 9:** Which radiates more MW/m2 at visible wavelengths?

**Question 10:** Which radiates more MW/m2 at ultraviolet wavelengths?

The Stephan-Boltzmann Law states: *Each square meter of a hotter object’s surface emits more light at all wavelengths.*

**Question 11:** Do your observations of this figure support this law or not? Explain your choice.

**B.** Quantitative discussion

The Stephan-Boltzmann law can be expressed mathematically as follows:

The energy per second (power) emitted by one square meter of a star’s surface =

where the temperature *T* is measured in *K* and the constant = 5.7 x 10-8 watt/(m2 K4).

We will not be putting numbers into this equation. We are most interested in noting the following:

* The energy emitted per second varies as the fourth power of the temperature so that, for example, doubling the temperature results in 2x2x2x2 = 16 times as much energy per second.
* This only tells us the energy per second emitted by *one square meter* of the star’s surface.

**Part 5: Luminosity**

Luminosity, *L,* is the **total** power (energy per second) that a star radiates into space.

The Stephan-Boltzmann law tells us how much energy per second one square meter of the star radiates into space, so to obtain the *total* energy radiated we must multiply by the surface area of the star, 4π*R2.*

*L = T*4 x 4π*R2*

where *T* is in Kelvin, *R,* the radius of the star is in m (meters) and *L*  is in watts.

**Question 12**. What two properties of a star determine its luminosity?

**Question 13**. Can two stars have the same temperature and different luminosities? Explain.

**Question 14**. Can two stars have the same luminosity and different temperatures? Explain.

**In conclusion…**

Summarize what you learned from this activity by:

1. listing the key scientific terms encountered in the activity.
2. constructing a bulleted list that utilizes these key words (and, as needed, words from previous activities) in summarizing what you learned.