Name: _____

Date: _____

Section: _____

Astron 104 Laboratory #5
Colors of Stars
Section 11.1

Introduction

The night sky in a dark location is full of stars — tiny pinpoints of light. It is pretty obvious from even a casual glance that different stars have different brightness. But a closer look with just the naked eye reveals that different stars also have different **colors**—the sky features brilliant points of blue, white, yellow, orange, and red light. In this lab you'll investigate what the color of a stars reveals about its physical properties.

Learning Objectives

At the completion of this lab, you should be able to:

1. Describe the thermal radiation spectrum shape and how it depends on temperature

2. Define the peak wavelength of a thermal spectrum

3. Interpret a plotted spectrum of thermal radiation

4. Compare the thermal radiation spectra for objects with different temperatures

5. Apply the thermal spectrum to explain how bright objects of different temperatures will appear at different wavelengths

6. Relate the thermal spectrum of a star to its observed color

The Thermal Spectrum

All objects with a temperature above absolute 0 ($0\,\mathrm{K}$ or $-273°\,\mathrm{C}$) emit light. The **thermal radiation** is the result of complicated interactions between the constituent protons and electrons of the matter. The thermal spectrum of an object covers a wide range of wavelengths, but depends on only one factor: the temperature of the object. It doesn't even matter what the object is made of, actually [**5 pts each, 80 pts total**]!

1. Open the PhET *Blackbody Spectrum* simulator[1] (**Blackbody** is a historical term for an object that emits a thermal spectrum). Set the temperature slider to about the temperature of the surface of the Sun, $5800\,\mathrm{K}$. Sketch the shape of the curve on the axes provided
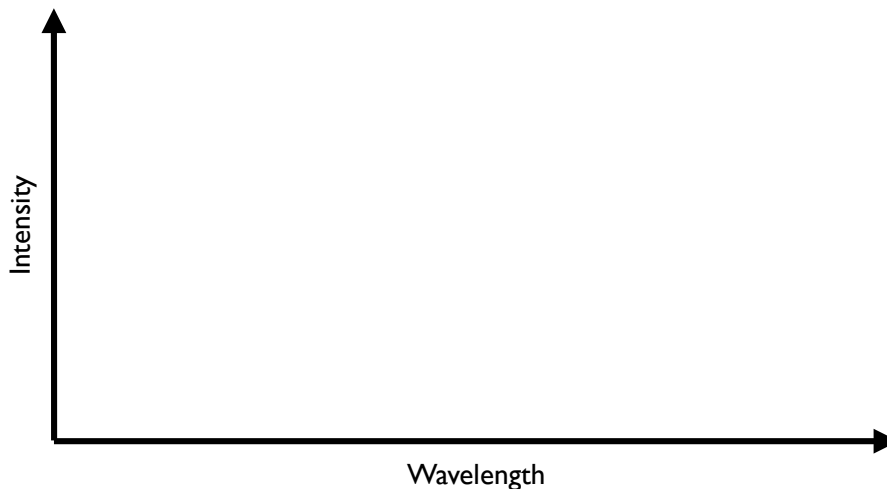

2. Press the *Save* button to keep a copy of the $5800\,\mathrm{K}$ spectrum on the plot. Now reset the temperature to about $3000\,\mathrm{K}$, the temperature of the filament in an incandescent light bulb. Did the general shape of the spectrum change? (Use the $+$ and $-$ buttons on the vertical intensity axis to zoom in to see the shape of the spectrum).

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[1]Available at `http://phet.colorado.edu/sims/blackbody-spectrum/blackbody-spectrum_en.html`.

3. The units on the vertical axis are **intensity**, which is basically a measure of how much energy is emitted by the object at each wavelength. The total area under the curve is therefore a measure of the total amount of energy emitted by the object per square meter. Which object emits more energy per square meter, the one at 3000 K or the one at 5800 K? Is it a little more or a lot more? (How much do you have to zoom in to tell?)

4. The thermal spectrum has a "peak wavelength" where it reaches its maximum intensity. Draw a vertical line at the peak wavelength of the thermal spectrum you drew on the previous plot.

5. What is the peak wavelength of the spectrum emitted by an object with the same temperature as the Sun? Express your answer in microns (μm), where $1\,\mu$m is 1000 nm or 10^{-6} m. You can use the *show ruler* check box to provide a guide to help measure the peak wavelength.

6. You'll notice the rainbow of colors on the plot, which indicates the range of wavelengths visible to the human eye. What color corresponds to the maximum intensity of the sunlight?

7. What are wavelengths longer than visible light (for example, 1 to 10 μm) called? How about wavelengths shorter than visible light (for example, 100–400 nm)?

8. Use the slider to change the temperature. How does the peak wavelength of the thermal spectrum depend on the temperature of the object? You may need to rescale the intensity axis to see the peak of the spectrum.

9. Use the slider to adjust the temperature to different values, measure the peak wavelength at each temperature, and built a plot of the peak wavelength of an object's thermal spectrum versus the object's temperature on the axes below:
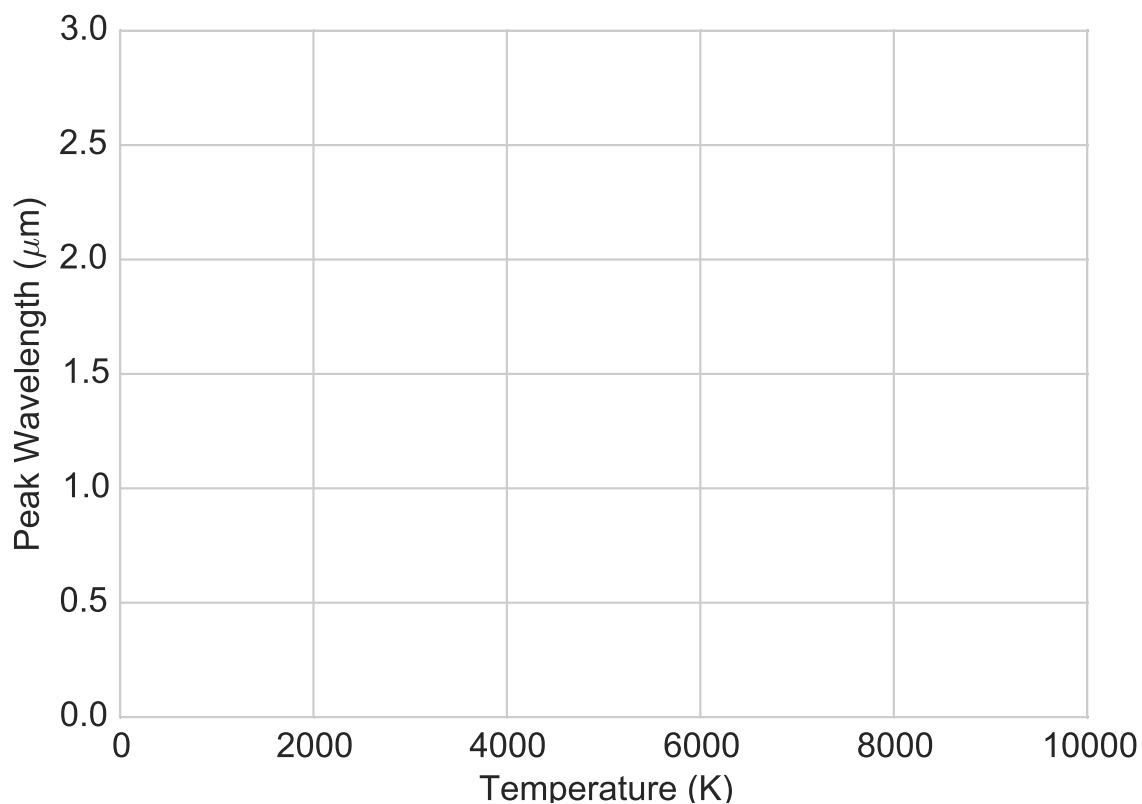
10. How does the peak wavelength change as an object becomes warmer? Longer wavelength or shorter? Is this direction redder or bluer?

11. The phenomenon you are investigating is known as **Wien's Law**, which states that the peak wavelength λ_p multiplied by the object's temperature T is equal to a constant C:

$$\lambda_p T = C$$

Human temperature is a little over $300\,\text{K}$. Use Wien's Law to predict the peak wavelength of the spectrum emitted by your body. [Hint: you don't know the constant in the equation, but you can use a ratio with the Sun's temperature and peak wavelength:

$$\frac{\lambda_{p,\text{you}}}{\lambda_{p,\text{Sun}}} = \frac{T_{\text{Sun}}}{T_{\text{you}}}$$

12. Compare your prediction to peak wavelength shown in the PhET simulator for $300\,\text{K}$. Did you get the same result? (You can use the $+$ and $-$ buttons on the horizontal wavelength axis to zoom in on the spectrum).

13. Set the temperature to $3000\,\text{K}$ for an incandescent light bulb filament. What wavelength is the peak of the spectrum of an incandescent light bulb? Is this ultraviolet, visible, or infrared light?

14. Three students observe the plot and discuss:

    Student 1 The peak wavelength for $3000\,\text{K}$ is in infrared light. Humans cannot see infrared light, so the bulb is invisible at this temperature!

    Student 2 Well, the peak is in the infrared, but the bulb still has some intensity in the visible wavelengths. So we can still see the bulb.

    Student 3 But there is much more light emitted in the infrared, where the area under the curve is largest. All that infrared light overwhelms the visible light, so the bulb will be invisible.

Which (if any) students do you agree with? Resolve their disagreements using your understanding of a thermal spectrum.

15. Imagine you are out camping, and you take a hot rock (480 K) from the campfire to keep your feet warm in your sleeping bag. When you look for the hot rock in the complete darkness inside your tent, what will you see? Explain, with reference to the thermal spectrum of the rock.

16. In the daytime, we can see the rock because it reflects sunlight. Based on your explanations with the PhET simulator, explain what conditions are required for you to be able to see an object by the light of its thermal spectrum if the object is placed in darkness.

The Thermal Spectra of Stars

[5 pts each, 65 pts total]

1. The surface temperatures of stars range from 2200 K up to as much as 100,000 K. Zoom in the wavelength scale in the simulator to show primarily the visible wavelengths (wavelengths shorter than 750 nm).

2. Set the slider to about 2200 K, the temperature of a cool star. How does the amount of intensity compare at each of the following colors: blue, green, yellow, red?

3. What color would a star with a surface temperature of $2200\,\mathrm{K}$ appear to the human eye? Explain your reasoning.

4. Set the slider to the hottest temperature (which is hotter than the Sun, but still not as hot as the hottest stars). How does the amount of intensity compare at each of the following colors: blue, green, yellow, red?

5. What color would a star with this hot surface temperature appear to the human eye? Explain your reasoning.

6. Set the slider to the temperature of the Sun. What color does the Sun appear in the sky?

7. When you hold up a piece of white notebook paper in sunlight, what color does the paper appear? Explain with reference to the thermal spectrum of the Sun.

8. A very hot star may have a temperature of $25{,}000\,\mathrm{K}$. What is the peak wavelength of the spectrum of this star, and what kind of light is this?

9. Does this very hot star emit light at wavelengths other than the peak wavelength? Explain with reference to its thermal spectrum.

10. What color would this hot star appear to the human eye? Explain based on the spectrum.

11. A fellow student states the following:

   A really hot star like this will peak in ultraviolet light, which is invisible to humans. We cannot see stars that hot in the night sky, even if they are there!

   Do you agree or disagree with that conclusion? Explain.

12. Omega Centauri is a large star cluster that contains several million stars. Obtain the color NASA image of the core of the cluster, which shows a small region of the cluster containing about 100,000 stars.[2] Describe the different colors of the stars you see in the image.

13. Based on your understanding of thermal spectra, explain what the different colors of stars in Omega Centauri tell you about the variation between stars in this huge cluster.

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[2]See: http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Core_Omega_Centauri_prt.htm