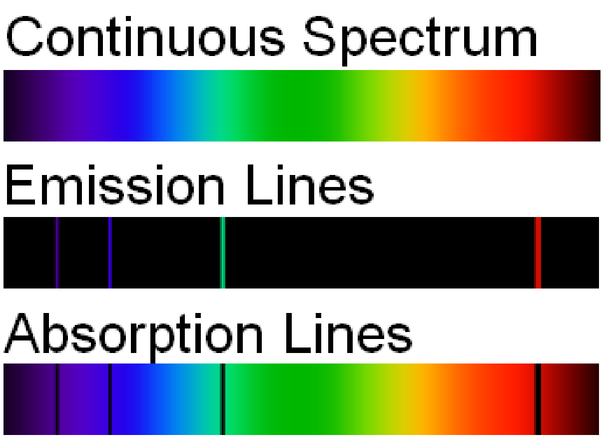
Spectra Student Guide

Introduction:

In this lab, you'll use a high-quality spectrometer, made by Project STAR, to examine the spectra of a variety of light sources. The main goals are to practice accurately observing and recording the appearance of a spectrum and to think about the different types of spectra and the characteristics of the objects that create them.

Background material:

The spectrum of a light source shows how the light intensity varies with the wavelength of light. Basically, a spectrum records how much light is produced at each color. There are three main categories of the spectrum, which are produced in the following three situations:



1. A hot opaque body, such as a dense gas or solid, produces a continuous spectrum – a complete rainbow of colors. The intensity varies smoothly with wavelength.
2. A hot, low-density gas produces an emission line spectrum – a series of bright spectral lines against a dark background. Light is only emitted at specific wavelengths.
3. A cool, low-density gas in front of a hot opaque body produces an absorption line spectrum - similar to a continuous spectrum, except with dark lines (dips in intensity) at specific wavelengths.

Emission and absorption lines have a characteristic pattern that is determined by the composition of the gas involved. For a given type of gas, the bright lines in an emission spectrum, where the hot gas emits light, occur at exactly the same wavelengths as the dark lines in the absorption spectrum, where the cool gas absorbs some of the continuous spectrum's light.

By measuring the spectrum of stars and nebula, and comparing them to spectra observed in labs on Earth, astronomers are able to learn about the temperature and composition of distant objects.

Review the background material on light and spectra:

http://astro.unl.edu/naap/hydrogen/light.html

http://astro.unl.edu/naap/blackbody/spectra.html

Using the Spectrometer:

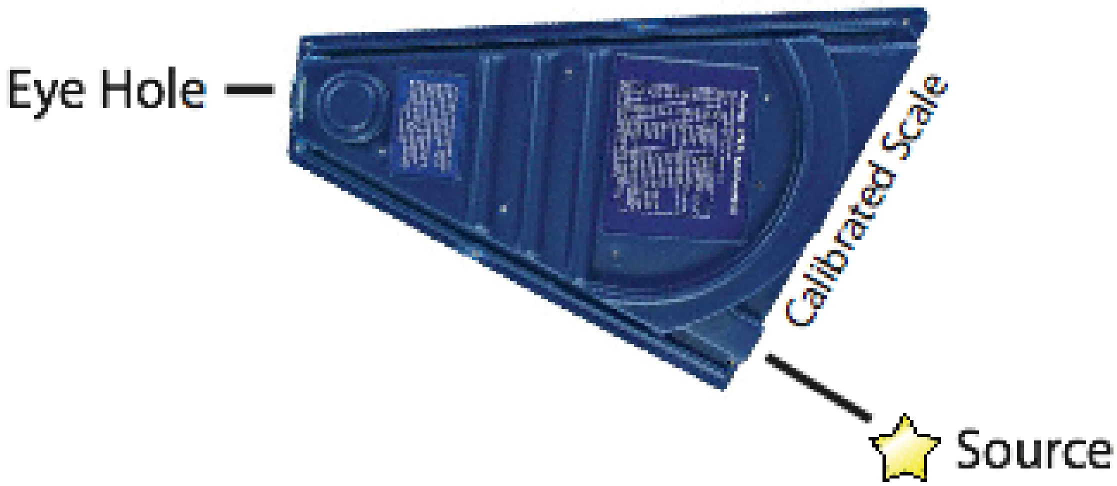


Figure 1: The STAR Spectrometer. Note the locations of the eye hole, the calibrated scale that you look at through the eye hole and the position of the source with respect to the spectrometer. This is explained in detail below.

Hold the spectrometer so that you can look through the grating in the narrow end. You should be able to see two rows of calibration marks and numbers. Pay attention to the lower row, which gives the wavelength (in nanometers, or nm) of the light in the spectra above it.

To observe a spectrum, keep holding the spectrometer up to your eye, and turn your whole body until the slit at the right-hand side of the front is pointed at the source of light you want to examine. (This is the most counter-intuitive part of the whole procedure. Most people are tempted to just aim the middle of the spectrometer at the light source. **The light source should be lined up with the right side**.) When you have the spectrometer aimed properly, a spectrum of the light source should appear above the wavelength scale.

This procedure takes a little practice. If you need help, ask your TA.

Observing Spectra

Your TA will set up a variety of light sources for you to study in the lab, similar to the ones we saw in class. We will use:

- Two light bulbs with different brightnesses.
- An emission tube of hydrogen gas.
- Two emission tubes labeled “Source A” and “Source B.”

- A white fluorescent light (i.e., a regular white strip light).

In this lab, you will be asked to make observations of the spectra of these different sources and answer questions about them. You can make the observations of the spectra in any order you like (it will help to prevent crowding if people do these in different orders). You can answer the questions at any time during the lab, but you should make sure you have observed all the spectra before you leave the lab. Observe each source with your eyes and through the STAR spectrometer and answer the questions below.

Incandescent Light Bulbs.

In part one of this lab, we will study a common blackbody in everyday use: a light bulb. You will observe incandescent light bulbs at two different brightnesses (which correspond to two different temperatures).

Start by observing either light bulb:

1. What type of spectrum do you see when you look at a light bulb through the spectrometer?

2. Where in the light bulb does the light come from? Describe the nature of this source of light.

Bright light bulb:

3. What color does the lightbulb appear?

4. What is the smallest wavelength of light you can see when you view the bright light bulb through a spectrometer (in nanometers) and what is its color?

5. What is the longest wavelength of light you can see when you view this source through a spectrometer (in nanometers) and what is its color?

Dim light bulb:

6. What color does the lightbulb appear?

7. What is the smallest wavelength of light you can see when you view this source through a spectrometer (in nanometers) and what is its color?

8. What is the longest wavelength of light you can see when you view this source through a spectrometer (in nanometers) and what is its color?

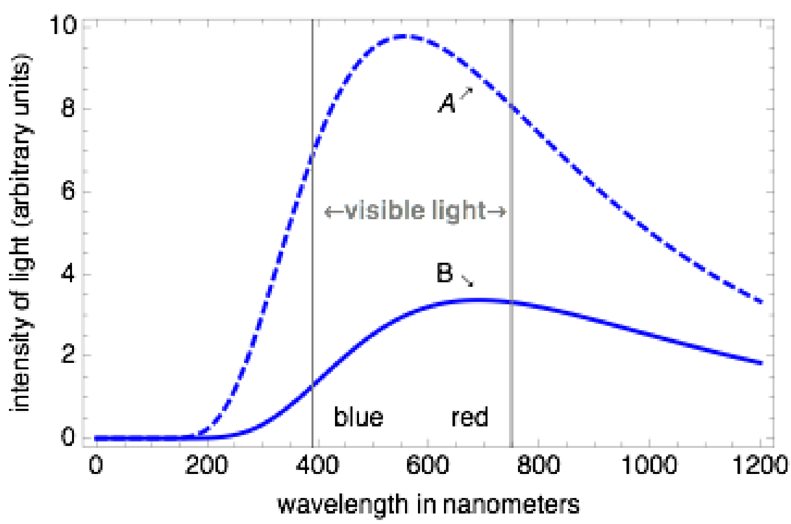
Comparing light bulb observations:

9. Describe the differences between the two light bulb spectra. Specifically, how do they differ in the relative amount of light produced at different wavelengths?

Plotting spectra:

For a hot dense source, the amount of light produced at different wavelengths depends on the temperature. This is difficult to judge by eye, so we have plotted the intensity of light versus wavelength for a hot dense light source on a bright (A) and a dim (B) setting in the plot to the right.

The wavelengths of light which are visible, and the regions that appear blue and red, are also marked.



10. What are the wavelengths with the highest intensity for the bright source A and the dim source B plotted on page 4? What is the corresponding brightest color for each source?

11. Wien's law says that the temperature T of a light source producing a continuous spectrum is inversely proportional to the location of the peak of a light intensity curve (the wavelength of light with the highest intensity, λ_{max}):

$$T = (2.89 \times 10^6 \text{ K nm}) / \lambda_{max}$$

Estimate the temperature of the plotted on the bright setting (A) and on the dim setting (B). Which is hotter? Show your work below:

12. Betelguese is a Red Giant Star found in the constellation Orion. Sirius, the brightest star in the sky, is much hotter than Betelguese. How do you expect the colors of these two stars to differ?

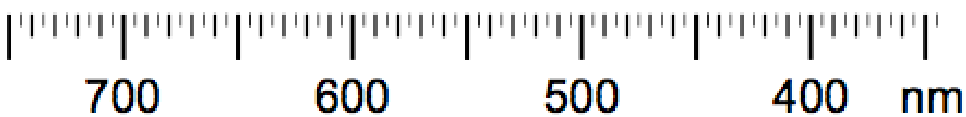
Hydrogen Gas Lamp.

A gas lamp is filled with a diffuse gas. Electricity is used to excite the gas, adding energy to the electrons. As the electrons return to their original energies, they emit light.

1. What color does the hydrogen lamp appear to be when you view it with your eyes?

2. What type of spectrum do you see when you look through the spectrometer at the hydrogen gas lamp?

3. Carefully make a sketch of the spectrum that you see through the spectrometer on the scale below. Draw a vertical pencil line at each wavelength where you observe a line in the hydrogen spectrum. Label each line with its color.



A bright line is produced when electrons in the hydrogen atoms move from a particularly high energy level to a particularly low energy level. In one of these transitions, the electron loses 1.9 eV of energy. This energy is converted to light.

The energy of light is proportional to frequency ($E = hf$), and the frequency is inversely proportional to wavelength ($f = c / \lambda$). By combining these formulas, and converting units, one can show that wavelength of the light produced, λ, is inversely proportional to the energy, *E*:

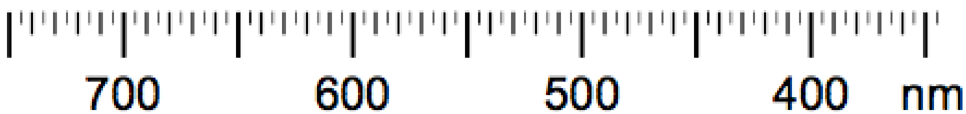
$$\lambda = (1240 \text{ eV nm}) / E$$

4. Calculate the wavelength (in nm) that corresponds to 1.9 eV. Show your work below, then circle the line in the drawing above.

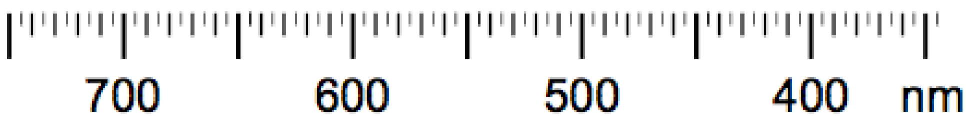
Sources A and B.

Sources A and B are emission tubes set up near the front of the class. One of these tubes contains mercury vapor, and the other contains helium gas. They are both hot gas sources, so they both produce emission spectra. Make a careful sketch of the emission spectra viewed through the spectrograph on the scales below. Make sure you do not mix up sources A and B, or you will not be able to answer the questions below.

Source A



Source B



The tables below show some of the visible spectral lines emitted by the elements helium and mercury:

Wavelength (nm)	Element	Wavelength (nm)	Element
447	Helium	436	Mercury
502	Helium	546	Mercury
588	Helium	579	Mercury
668	Helium		
706	Helium		

1. Using your drawings of the spectra and the tables above, determine which element is in each emission tube A and B. Circle the correct answers below.

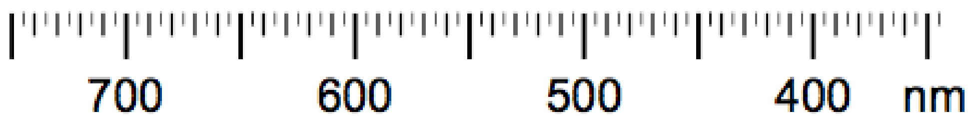
Source A: ☐ Mercury ☐ Helium

Source B: ☐ Mercury ☐ Helium

Fluorescent Lamp.

Observe the white fluorescent lights overhead through your spectrometer. Notice that although the spectrum has some continuous regions, there are bright lines in the spectrum. A fluorescent tube is a gas-discharge lamp that uses electricity to excite a gas inside the lamp, which emits visible light as well as high-energy ultraviolet light. The ultraviolet light causes a phosphor coating on the inside of the lamp to fluoresce, producing additional visible light. In this lab, we want to determine which gas is inside the lamp, making the phosphor coating fluoresce.

1. Carefully make a sketch of the spectrum that you see through the spectrometer on the scale below. Draw a vertical pencil line at each wavelength where you observe the brighter lines in the spectrum of the fluorescent lamp



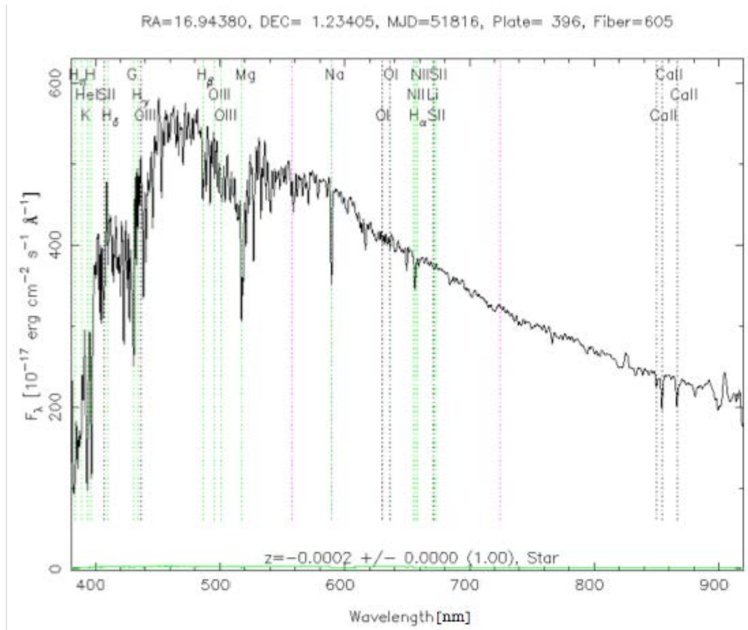
2. Once you have observed all the spectra in the lab (the white light, source A and B and the hydrogen lamp), compare the florescent light spectrum to the spectra from the previous exercises to determine what gas is inside the fluorescent lamp. Note that the phosphor coating will add additional wavelengths of light to the gas spectrum. Circle your answer below.

☐ Hydrogen ☐ Mercury ☐ Helium

Explain your reasoning:

Star spectrum: (requires observation of light bulbs)

Below is a spectrum that was measured from a particular star. The intensity of light at different wavelengths is plotted for a range of wavelengths, including visible light. Several dips in the intensity are labeled. Note that the wavelength increases from left to right in this plot, while the spectrometer showed you wavelength decreasing from left to right.



5. What type of spectrum is plotted in the figure?

6. At approximately what wavelength is the star emitting the most light? What color is this?

7. How do you think the temperature of this star compares to the light bulbs you observed earlier? Why?

8. One dip in intensity is labeled "Na," for sodium: this star has sodium gas in its atmosphere. If you made a sodium vapor lamp, it would emit light at the same wavelength as this dip. What wavelength is this, and what color would a sodium vapor lamp appear?