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:

Astronomers are very interested in spectra – graphs of intensity versus wavelength for an object. They basically tell you how much light is produced at each color. Spectra are described by Kirchoff's Laws:

1. A hot opaque body, such as a dense gas or a solid, produces a continuous spectrum - a complete rainbow of colors.

2. A hot, low-density gas produces an emission line spectrum - a series of bright spectral lines against a dark background.

3. A cool, low-density gas in front of a source of a continuous spectrum produces an absorption line spectrum - a series of dark spectral lines among the colors of the continuous spectrum.

Emission and absorption lines have a characteristic pattern that is determined by the composition of the gas. For a given gas, the bright lines in the emission spectrum occur at exactly the same wavelengths as the dark lines in the absorption spectrum. One can think of the absorption spectrum as a continuous spectrum minus an emission spectrum.

Review the background material on light and spectra:


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. **Aim the right side instead.**) 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.

**White Light Bulbs.**

In part one of this lab, we will study a common blackbody in everyday use: a light bulb. You will observe the light bulb 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 white light bulb through the spectrometer?

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

Observe the light bulb on the bright setting:

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

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

5. Which color appears the brightest? What is its approximate wavelength?
Now observe the light bulb on the dim setting:

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

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

8. Which color appears the brightest? What is its approximate wavelength?

Compare your two observations:

9. Describe the changes between the two light bulb observations. What happened to the spectrum as the brightness and temperature of the light bulb increased? Specifically, what happened to the relative amount of light at different wavelengths?

10. Betelguese is a Red Giant Star found in the constellation Orion. Sirius, the brightest star in the sky, is much hotter than Betelguese. Describe how you might expect the colors of these two stars to differ.
11. Wein’s law relates light source temperature to the location of the peak of a blackbody light intensity curve – the most intense wavelength of light.

\[ \lambda_{\text{max}} = \frac{2.89 \times 10^{-3} \text{ K m}}{T} \]

Estimate the temperature of the light-emitting source on the bright setting and on the dim setting. Note that 1 nm = 10^{-9} m. Show your work below:

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.

4. Identify the line corresponding to the 1.9 eV transition that we discussed in class. Calculate the wavelength (in nm) that corresponds to 1.9 eV using the following relationships:

\[
\text{Energy in eV} \times 1.6 \times 10^{-19} = h \times \text{frequency},
\]
\[
c = \text{frequency} \times \text{wavelength}.
\]

The constants and unit conversions you will need are: \( h = 6.626 \times 10^{-34} \text{ m}^2 \text{ kg}/(\text{Planck's constant}) \), \( c = 2.998 \times 10^8 \text{ m/s} \) (speed of light), and 1 nm = 10\(^{-9}\) m.

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 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.

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

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Element</th>
<th>Wavelength (nm)</th>
<th>Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>447</td>
<td>Helium</td>
<td>436</td>
<td>Mercury</td>
</tr>
<tr>
<td>502</td>
<td>Helium</td>
<td>546</td>
<td>Mercury</td>
</tr>
<tr>
<td>588</td>
<td>Helium</td>
<td>579</td>
<td>Mercury</td>
</tr>
<tr>
<td>668</td>
<td>Helium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>706</td>
<td>Helium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 lamp through your spectrometer. Notice that although the spectrum appears somewhat continuous, like the white light bulb, 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. The gas emits visible light as well as high-energy ultraviolet light, and the ultraviolet light causes a phosphor coating on the inside of the lamp to fluoresce, producing more 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.

   ![Spectrum Scale](image)

2. Once you have observed all the spectra in the lab (the white light, source A and B and the hydrogen lamp), use your drawing and the spectra from the previous exercises to determine what gas is inside the fluorescent lamp. Circle your answer below.

   Hydrogen    Mercury    Helium

   Explain your reasoning:
Star spectrum:
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 labelled. 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?

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 labelled “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?