Name ______________________

Date ______________________

Lab Partner(s) ______________________

Project Score [ ]

SPECTROSCOPY

PROJECT LEVEL: Intermediate
PROJECT GOALS: Students will measure the wavelength range of the visible colors, and learn about different light emission processes.

1 INTRODUCTION

Spectroscopy is the measurement of the intensity of light at many different wavelengths, and the interpretation of those measurements using theories of physics. ***Spectroscopy is absolutely crucial to astronomy.*** With few exceptions, such as the study of rocks returned from the Moon or data from spacecraft on Mars, almost everything we know about the universe comes from analysis of light from astronomical objects. ***It is from spectroscopy that we have learned of the temperatures, luminosities, and chemical compositions of the stars.***

Spectroscopy is also of importance in other fields of science and technology. It can be used to measure the chemical and physical state of ocean water, glucose levels in human blood, and in industrial procedures. Spectroscopy is one of the better examples of a field of physics that has significantly impacted society.

The purpose of this laboratory exercise is to illustrate some of the capabilities of spectroscopy, using a sophisticated spectroscopic instrument. You will study spectra from different types of objects in the lab and measure wavelengths of spectral lines. You will also be asked to analyze the spectra, and measure the spectral lines of two important elements, hydrogen and helium, and compare your measurements to the known values. Finally, you will observe and measure the spectrum of an extremely important astronomical object, the Sun.

1.1 EXPLANATION OF EQUIPMENT

For much of twentieth century astronomy, the detector was a **PHOTOGRAPH PLATE**. Modern instruments use a CCD (charge-coupled device) in which an electronic wafer builds up an electrical charge when light shines on it. This charge is later read out and measured by a computer.

Most spectrometers are fundamentally simple in design. A thin beam or ray of light passes through, or is reflected from an object which spreads out, or disperses the light according to wavelength. An easy way of visualizing this is to think of a prism which spreads out light into all the colors of the rainbow. The dispersing element (a **PRISM** or **DIFFRACTION GRATING**) sends the violet light in one direction, the yellow light in a slightly different direction, the red light in still a different direction, and so on. This dispersed, polychromatic light is then focused onto the surface of the CCD chip.

1.1.1 Ocean Optics Spectrometer

The spectrometer which is used in this exercise is manufactured by ***Ocean Optics Company***. Depending on your setup, you will use either a model **USB650** or model **USB4000** spectrometer. The control software recognizes either type of device, and performance differences will not be noticeable in this experiment. The spectrometer is an amazingly compact device which has one input (a fiber optics cable which shines the light into the spectrometer) and a USB port to send data to the analysis computer. Software provided with the spectrometer permits display and analysis of the spectra.

An image and diagram of an Ocean Optics spectrometer is shown in the figure below.

FIGURE 1 - OCEAN OPTICS SPECTROMETER

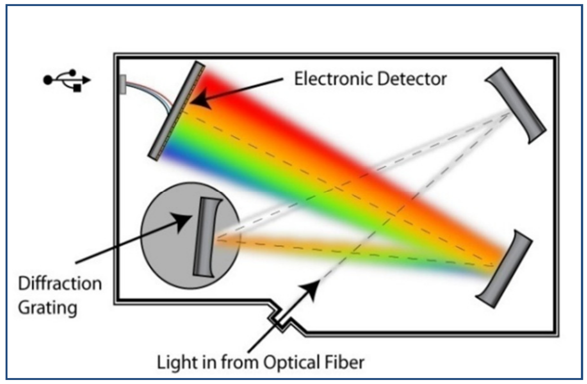


FIGURE 2 - DIAGRAM OF SPECTROMETER LIGHT PATH

When the spectrometer is connected to the computer, and the control program is running, there are a number of simple controls the user has over the display and analysis of the spectrum.

- The green vertical cursor measures the wavelength of observation and gives the intensity of light at that wavelength. It is controlled by the mouse and the wavelength-intensity values are shown in the bottom line of the spectral display. If you do not see this, ask your lab instructor for help.
- Right above the spectrum are a number of data boxes that can be set by the user. The one at the far left gives the integration time (the length of time the device averages the signal before readout). The units are milliseconds. The longer the integration time, the larger the charge on each CCD pixel, and thus the stronger the signal. Next to it is the number of spectra that are averaged before display. A larger number of spectra averaged results in a clearer and less noisy spectrum.
- Finally, at the top of the screen will be a set of menu icons. The one which consists of a magnifying glass with “213” inside can be used to set the ranges in wavelength and intensity which are displayed. It brings up a dialog box with “X-axis range” and “Y-axis range”. This control knob is a very useful feature for making precision measurements of spectral lines, or examining the shape of spectral lines. Each spectrometer is designed to operate in a specific range of abscissa and ordinate values. Experiment and make note of the ranges for the spectrometer at your station (i.e the **USB650** or the **USB4000**).

2 MEASUREMENTS

If the spectrometer program is not already running, double click on the **SpectraSuite** icon to start the program. Look around on the lab table and identify the USB650 or USB4000 unit, the fiber optics cable connected to it, the stand for holding the fiber optics cable, and the USB cable connected to the computer. You're ready to start.

There are a number of steps or parts to this lab, intended to give you a clear idea of what the spectrometer is doing, and the information we have in the light from an object.

1.1 SPECTRA OF LIGHT SOURCES

There is a black plastic box on the lab table with several small light bulbs on the top. These bulbs are labeled and each is a different color. Some bulbs may emit light at a wavelength undetectable by the human eye. For each of the bulbs, measure the central wavelength **(λ CENTER**, wavelength at which the light bulb is brightest), and the range of wavelengths over which the light emits significant amount of light. Record your data in the table below.

QUESTION 1:

Complete the table below.

Bulb #	***Color***	***λ Center* (nm)**	***λ Range* (nm)**	***Comments (if any)***

1.2 SPECTRAL PROPERTIES OF HYDROGEN AND HELIUM

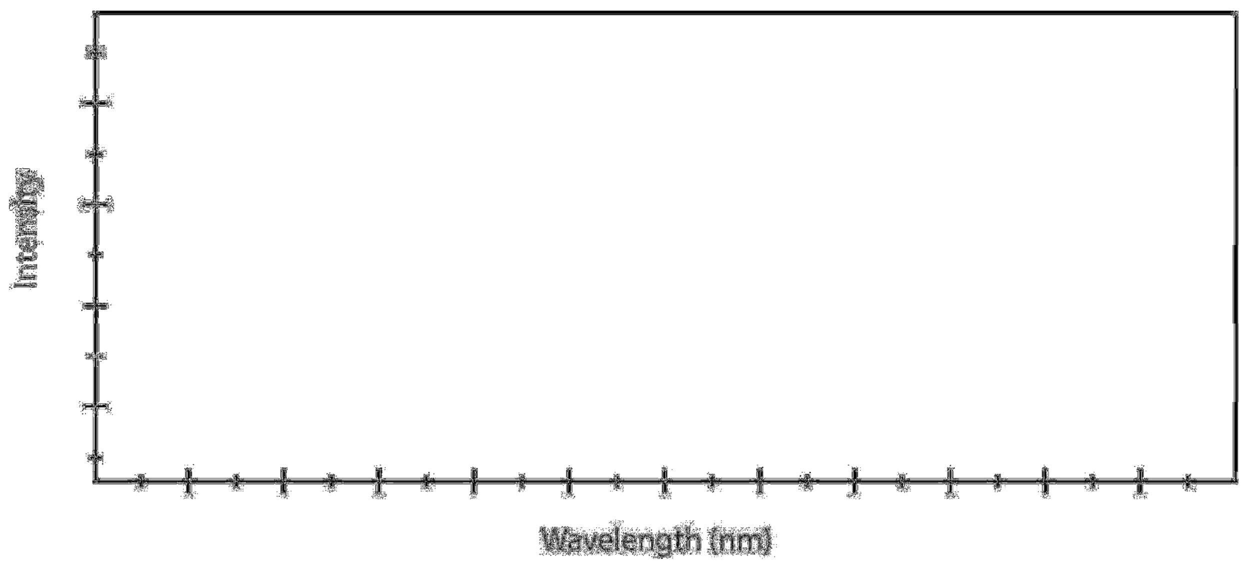
Kirchoff's second law of spectroscopy says that a hot, tenuous gas emits a spectrum which consists of isolated, bright emission lines. The wavelengths at which these lines occur are a unique "fingerprint" of the gas that is being excited. Each lab table will have two discharge tubes, one of hydrogen and the other of helium.

For each source, sketch the observed emission. ***Be sure and put numbers on the axes and use the correct units!*** **Also, try and** identify the 4 strongest spectral lines for each source. You may have the increase the sensitivity of the spectrometer by changing the integration time, or the number of cycles to average. Some lines will be much more intense than the others, so you will need to record these first, then concentrate on the others. Further, when measuring the wavelength of a line, be sure the cursor is exactly in the middle of the line. Otherwise, a significant and avoidable error will result.

SAFETY NOTE: THE POWER SUPPLIES FOR THE SPECTRUM TUBES ARE HIGH VOLTAGE AND THE TUBES WILL GET VERY HOT. FOR YOUR SAFETY, DO NOT TOUCH CONTACTS ON THE POWER SUPPLIES AND ALLOW TIME FOR THE SPECTRUM TUBE TO COOL BEFORE HANDLING.

Question 2:

Make an accurate sketch of the observed Hydrogen Emission Spectrum below.



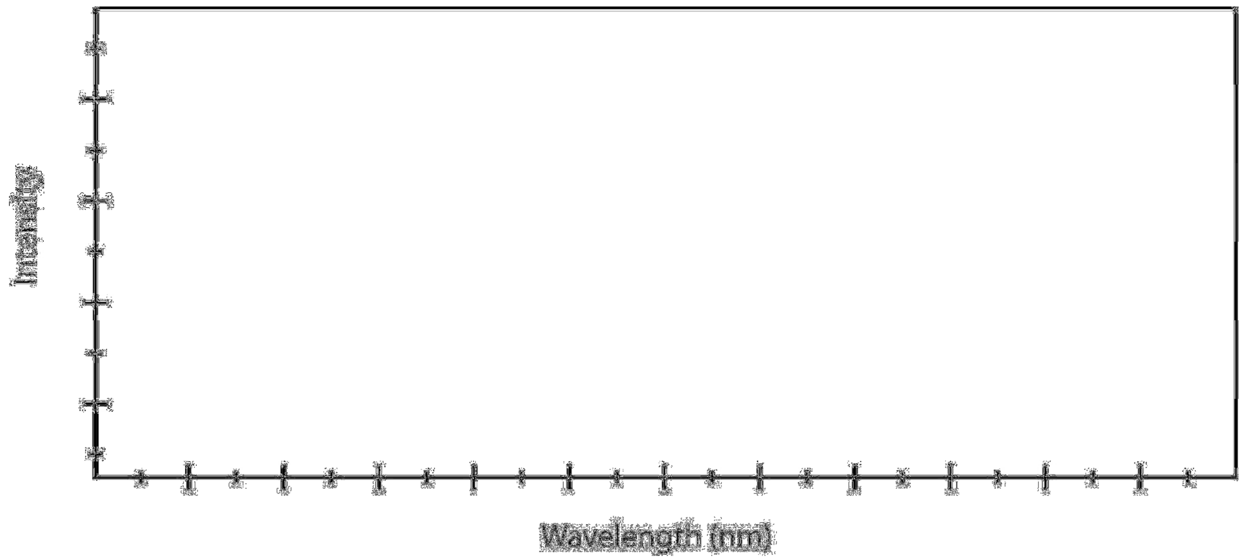
Question 3:

What are the 5 most intense spectral lines in the Hydrogen spectrum?

Relative Intensity	***λ Measured***	***Approximate Color***
1st		
2nd		
3rd		
4th		
5th		

Question 4:

Make an accurate sketch of the observed Helium Emission Spectrum below.



Question 5:

What are the 5 most intense spectral lines in the Helium?

Relative Intensity	λ Measured	Approximate Color
1st		
2nd		
3rd		
4th		
5th		

1.3 Spectrum of a Continuous Source

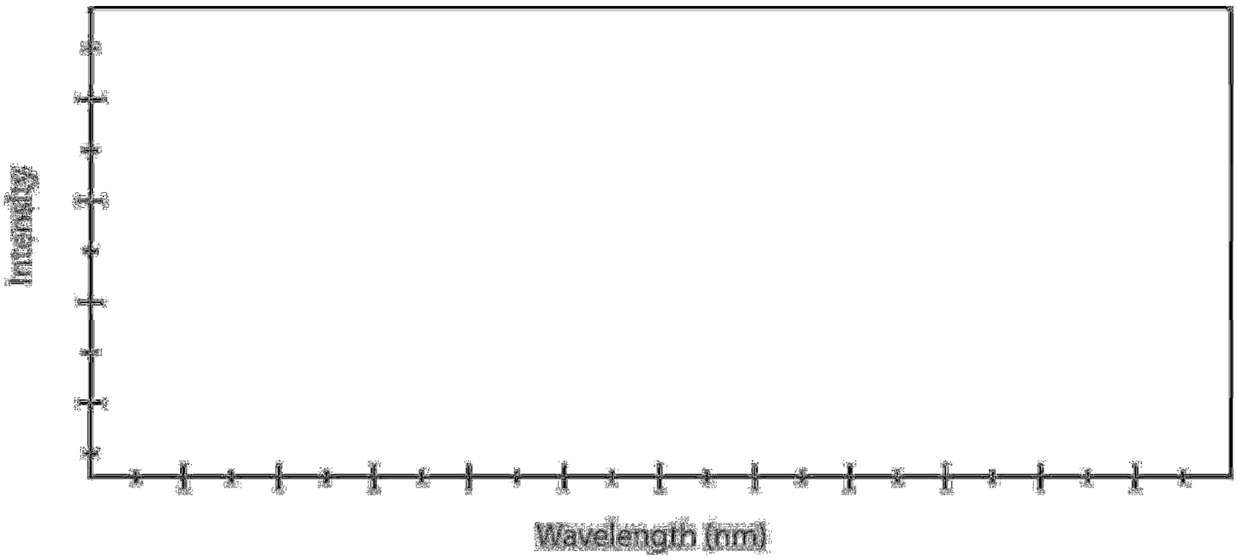
Some sources emit radiation across a continuous range of wavelengths. One example of a continuous source is an incandescent light bulb. Turn on the over-head projector near your station and point the opening of the fiber optic at the light bulb inside. The bulb will be bright, so adjust parameters such as integration time, number of cycles to average, and scale of the spectrum to give you a good display that is convenient for making measurements.

Make a reasonably accurate drawing of the spectrum you see in Figure 3.

It is important to make a fairly accurate sketch here as you will make a calculation based on your sketch later in the lab.

QUESTION 6:

Make an accurate sketch of the observed Continuous Spectrum below.

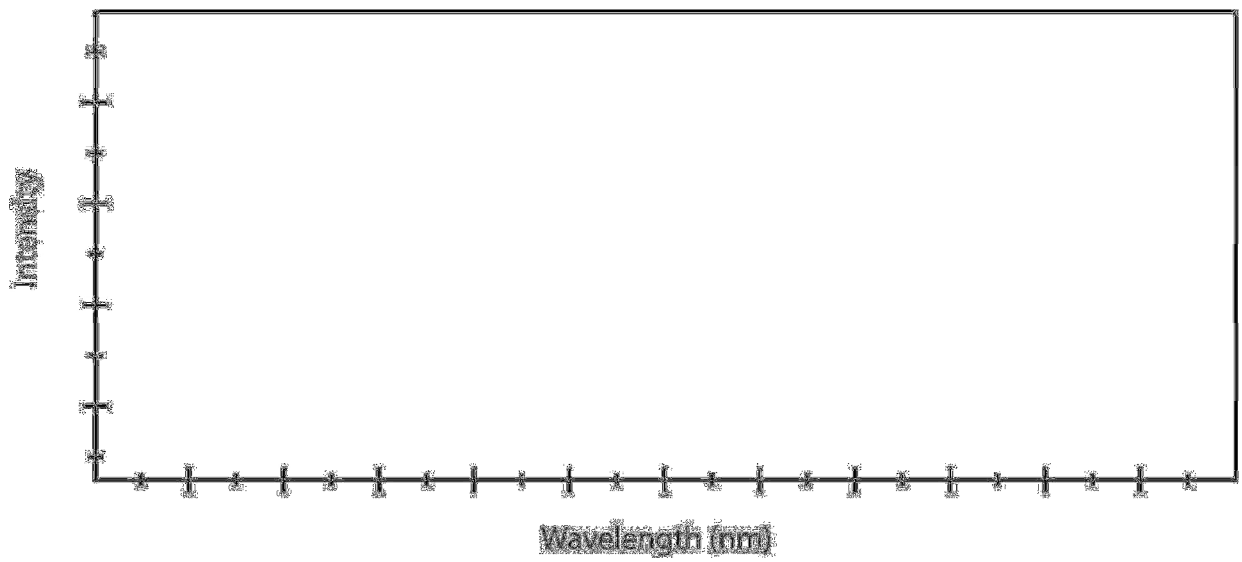


1.4 SPECTRUM OF THE SUN

Now point the entrance to the fiber optics cable at the window of the lab room. Direct sunlight is not necessary, and even on a relatively cloudy day, the light should be bright enough. **Note** that for this part of the experiment, the room lights must be off. Otherwise, the solar spectrum will be contaminated by the light from the fluorescent light bulbs. Despite the similarity to your eye, the spectra of sunlight and fluorescent lights are vastly different. You should use the equipment at your disposal to check for yourself. The spectrum of the light from the window will be the spectrum of sunlight. Draw an accurate sketch of the spectrum below. Again, be careful here as you will use this sketch to make a calculation later.

QUESTION 7:

Make an accurate sketch of the observed Solar Spectrum below.



The solar spectrum is a mix of the continuous spectrum you observed with the light bulb with a second spectrum called an **ABSORPTION LINE SPECTRUM**. An absorption line spectrum is similar to the emission line spectrum examined earlier except in this case, cooler clouds of gas between you and the source absorb radiation from the continuous spectrum. Absorption spectra are described by the 3rd of Kirchoff's Laws of Radiation. Absorption lines can also be used as "fingerprints" for identifying types of gases. Choose 4 of the strongest absorption lines in the solar spectrum and try to identify the gas by using the table on display in the lab room. There are many lines listed, but if you stick to the strong ones, you should be able to identify the element responsible for the absorption line.

QUESTION 8:

What are the 5 most intense spectral lines in the Helium?

Relative Intensity	λ Measured	Element
1st		
2nd		
3rd		
4th		
5th		

NOTE: Spectral Lines are sometime recorded in units of Angstroms (Å = 10^{-10} meters) instead of nanometers. To convert from Angstroms to nanometers, simple divide by 10.

3 Wien's Law

Here is a chance to apply an equation you have learned about in class to a real physical situation. Recall that **WIEN'S LAW** is a relationship between the **TEMPERATURE** of an object and the wavelength at which it is brightest. The relationship is

$$T = \frac{2.9 \times 10^6}{\lambda_{MAX}}$$

Where ***T*** is in degrees Kelvin and λ_{MAX} is the wavelength at which the object emitting the radiation is brightest. The constant in this form of Wien's Law differs from the one you saw in lecture because the wavelength of maximum is now in nanometers rather than meters. This means that for any continuous source (like the sun, or the incandescent light bulb), you can calculate the temperature of source simply by measuring the wavelength that is responsible for the most emission.

Answer the following questions about Wien's Law.

Question 9:

If you were to measure wavelength in Angstroms instead of nanometers, how would you have the change the constant in Wien's Law?

QUESTION 10:

Wien's Law Calculations

T_{SUN} (K)	
T_{BULB} (K)	

You may be surprised to see that the temperate you calculated using Wien's Law for the incandescent bulb is so close to the temperature of the surface of the Sun. Can you think of a reason why these two temperatures are so close? We obviously have no control of the temperature of the solar photosphere, but we can engineer the temperature of the filament of an incandescent light bulb.