29:50 Astronomy Lab #7
Stars, Galaxies, and the Universe

Name		
Partner(s)		
Date		
Grade		
Category	**Max Points**	**Points Received**
On Time	5	
Printed Copy	5	
Lab Work	90	
Total	100	

Spectroscopy

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 spectral properties of two important gasses, (Hydrogen and Helium) and compare your measurements to the known values.

2. Explanation of Equipment

For much of twentieth century astronomy, the detector was a **photograph plate**. Photographic plates are still used in some spectroscopic applications. 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 a surface which acts as a detector.

The spectrometer which is used in this exercise is a **USB2000** device manufactured by **Ocean Optics Company**. It 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 the USB2000 is shown in the figure below.

IMAGE 1 – OCEAN OPTICS SPECTROMETER

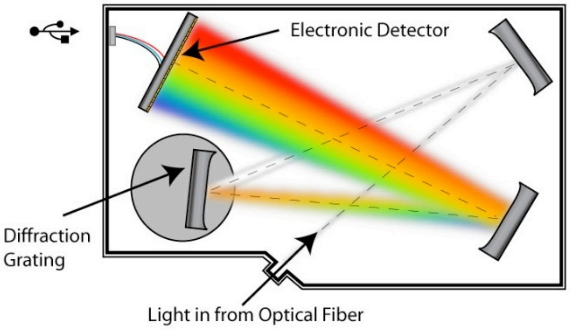


IMAGE 2 – DIAGRAM OF SPECTROMETER LIGHT PATH

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.

1. The green vertical cursor measures the wavelength of observation and gives the intensity of light at that wavelength. It is controlled by the mouse. The wavelength and intensity reading are shown in the lower left corner of the screen. If you do not see this, ask your TA how to turn it on.
2. 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 stronger the signal is recorded. Next to it is the

number of spectra that are averaged before display. A larger the number of spectra average results in a clearer and less noisy the spectrum.

3. Finally, at the top of the screen will be a set of standard Windows menu bars. The one labeled "View" can be used to set the scale of the spectrum. If you bring up the dialog box, you can set the range of the **abscissa** (x coordinate) and **ordinate** (y coordinate). This 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 are for the spectrometer at your station.

3. Procedure

Double click on the **OOI Base 32** icon to start the program. Look around on the lab table and identify the USB2000 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.

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.

TABLE 1 – LIGHT SOURCES

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

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 themselves 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.

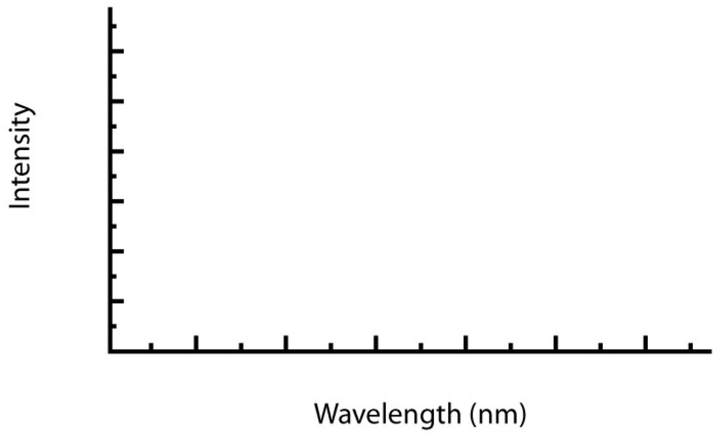


TABLE 2 – HYDROGEN SPECTRAL LINES

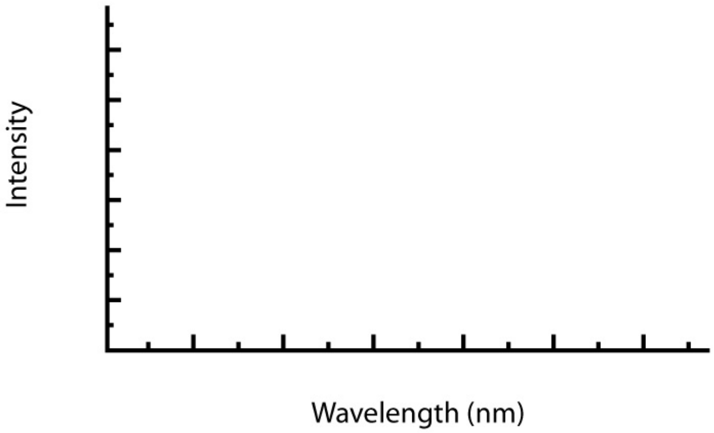
Color	**Relative Intensity (1st, 2nd, etc.)**	**λ Measured**

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 sketch of the spectrum you see on the plot below.

It is important to correctly label your axis as you will make a calculation based on your sketch later in the lab.

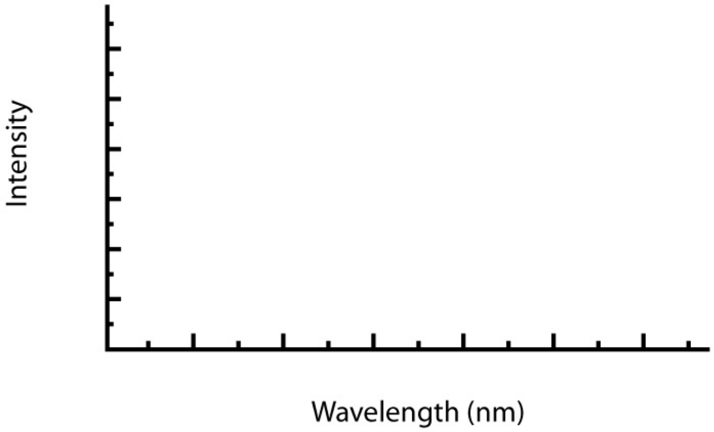
FIGURE 3 - SPECTRUM OF AN INCANDESCENT LIGHT BULB



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. The spectrum of this light 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.

FIGURE 4 – SPECTRUM OF THE SUN



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 are now "stealing" radiation from the continuous spectrum. Absorption lines can also be used as "fingerprints" for identifying types of gasses. Choose 4 of the strongest absorption lines in your 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 the strong ones, you should be able to identify the element responsible for the absorption lines.

TABLE 4 – SOLAR ABSORPTION SPECTRUM LINES

λ Measured	Relative Intensity (1st, 2nd, etc.)	Element

Wein'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

$$T = \frac{2.9 \times 10^{-3}}{\lambda_{MAX}}$$

Where **T** is in degrees Kelvin and λ_{MAX} is the wavelength at which the object emitting the radiation is brightest. **This wavelength must be input in meters**. This means that for a continuous source, the peak in the spectrum can be used to estimate the temperature. Calculate the temperature of the filament inside the incandescent light bulb and the surface temperature of the sun using Wien's Law. Carry out the calculation in the space below.

TABLE 5 – BULB AND SUN TEMPERATURES

Wien's Law Calculations

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

You may be surprised to see that the temperate you calculated using Wein's Law for the incandescent bulb is so close to the temperature at the surface of the sun. This is most likely due to some confusion between the concepts of **TEMPERATURE** and **HEAT**. Heat is a measure of the total energy due to molecular motion in a substance while temperature is a measure of the average molecular motion. Heat energy depends on the speed of the particles, the number of particles (the size or mass), and the type of particles in an object while temperature only depend on the molecular speed. For example, the temperature of a small cup of water might be the same as the temperature of a large tub of water, but the tub of water has more heat because it has more water and thus more total thermal energy.