Introduction

In this lab you will use a diffraction grating to split up light into its various colors (like a rainbow). You will assemble a spectrometer, incorporating the diffraction grating. A spectrometer is a device that allows you to separate and view the colors present in a light source, and to measure the wavelength for each color. You will then examine light from a variety of different discharge tubes containing gases at low pressure. These emit line spectra. By comparison of the spectrum you observe with that on the chart provided, you will be able to identify the gas in the discharge tube. At the end of the lab, the spectrometer is yours to take home. You can now amaze your friends by identifying the many different types of light sources on campus at night.

Before you start, review the function of a diffraction grating (Hecht, Section 25.8) and the Bohr model of the Hydrogen atom in Chapter 28.

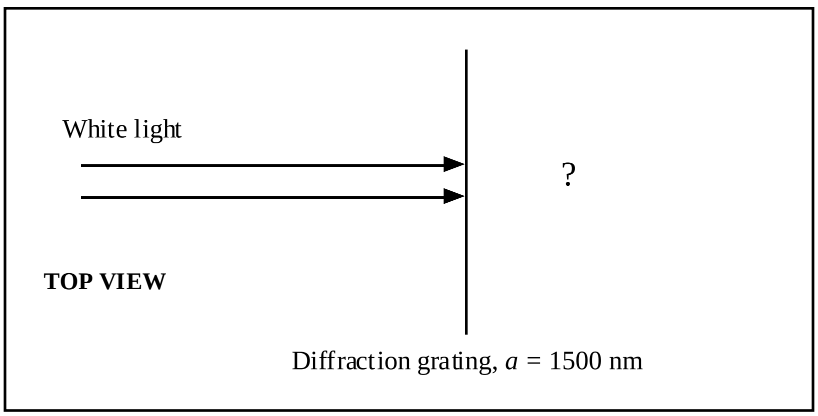
Pre-Lab Homework:

1. The grating equation tells you at what angles different colors of light will appear:

$$a \sin \theta = m\lambda$$

where a is the separation between the lines on the grating,
m is an integer (i.e., $m = 0, \pm1, \pm2, \pm3$, etc.) known as the diffraction order number,
λ is the wavelength (with the same length units as a), and
θ is the angle at which light with wavelength λ is diffracted.

Make sketch based on the figure below to show a narrow parallel beam of white light shining onto a grating with line separation, a = 1500 nm. Show the angles for red and blue light for m = 0, +1, and –1. You can find the approximate wavelengths for red and blue light in Chapter 22.



Show on your figure each of the places where you could place your eye if you wanted to view red light. (Draw an eyeball in the appropriate place and label the rays). What color would you see if viewed the m = 0 beam?

Experiment A: Construct and Calibrate the Spectrometer

Procedure and Questions:

Examine the components of your spectrometer kit. Identify the diffraction grating. Hold it close to your eye and look at the fluorescent lights of the room and a table lamp. While still looking through the spectrometer, look to the side to see the spectrum of the light source. Rotate the grating and watch the spectrum rotate. Review Pre-Lab #1 to understand what you are looking at in this exercise.

A1. Can you see the $m = 0$, $m = +1$ and $m = -1$ orders? Is the blue light or the red light of the $m = +1$ order closer to the $m = 0$ order? Is this what you predicted in Pre-Lab #1? What color is the $m = 0$ order?

Assemble your spectrometer from the kit according to the following instructions (also provided by your TA): As you take the kit apart, **do not throw away the Styrofoam pieces**. They are required for the assembly. Furthermore, **do not peel the film off of the plastic "lens."** The (nearly) transparent film itself *is* the diffraction grating.

In the assembly be sure to:

- Insert the support tube and the two Styrofoam spacers between the cardboard top and bottom body sections.
- Make sure the body sections are parallel to each other with the "pointers" matching.
- Orient the diffraction grating so that the plastic-film-side of the grating is on the *inside* of the spectrometer and away from your eye.
- Align the small slit at one end of the black strip with the pointers on the cardboard body sections.
- Use the black tape to block light leaks around the edges of the black strip, but do not cover the slit.
- Rotate the diffraction grating so that a spectrum appears on the wavelength scale on the black strip.

The spectrometer you have made restricts your view to the $m = 0$ and $m = +1$ orders of the diffraction pattern. Practice holding your spectrometer at the correct viewing angle. The "pointers" on the cardboard body sections mark the position of the slit. *Aim the pointers at the light source to allow light to enter the slit.* You should be able to view the colors along the scale printed on the film.

Look at the scale on the black plastic strip. The top units are electron volts (eV). This is simply an alternate unit of energy. The conversion factor to Joules is 1 eV = 1.6×10^{-19} J. This energy unit is used frequently for the energy electrons have in atoms. The bottom scale is in nanometers (1 nm = 10^{-9} m) and corresponds to the wavelength of the light. Confirm that you see red light at approximately 650 nm and blue light at approximately 450 nm.

Experiment A (continued):

Before you use the spectrometer to precisely measure wavelengths (and hence identify elements), you must confirm that the wavelength scale is correctly installed. To do this, use the bright green line that is present in the spectrum of the fluorescent ceiling lights. This line is known to have a wavelength of 546 nm, as written on the top of the spectrometer. (In fact, there is an additional hash mark on the wavelength scale corresponding to exactly this wavelength.) If necessary you can slide the film scale to the left or right in its curved slot to adjust the calibration. Check that you see this line in the correct place on the scale. If you are unsure if you have properly set up your spectrometer, check with your TA or another member of your lab group.

Pre-Lab Homework:

2. From the Bohr model of the Hydrogen atom, calculate the minimum amount of energy (in eV) an electron in the lowest orbital would need to free it from its proton (i.e., to ionize the atom). How is this problem similar to calculating the escape velocity of a mass from the gravitational effects of a larger mass (e.g., a rocket being launched from Earth into space)?

Experiment B: Measuring the Rydberg Constant

In this part of the lab you will use the glass discharge tubes. These contain gas at low pressure. The gases are excited by a high voltage supply. Please read carefully the warning below before using the discharge tubes. If you are at all uncertain or uncomfortable about how to run the tubes, get help from your TA.

> **WARNING: Discharge tubes are powered by very high voltages (up to several thousand Volts) that can be lethal. Keep your fingers away from the ends of the tube and the sunken electrodes. Before changing tubes, always switch off the power supply. Hold the tube in the middle, away from either end, with a paper towel or handkerchief (since the tube can be extremely hot). Always use only one hand when working with these tubes and the power supply to minimize the danger of an electrical shock. If you use two hands, the current could pass from one hand to the other, via the heart, which could be fatal. *Always turn the power supply off when not in use.***

Procedure and Questions:

First, obtain a hydrogen discharge tube and place it (carefully!) in the holder. Rest the spectrometer flat on a secure horizontal surface so the slit of the spectrometer faces the Hydrogen tube. Adjust the height of the spectrometer to center the slit with respect to the Hydrogen tube. Look through the grating and locate the spectrum of the Hydrogen diffracted into the m = 1 (first) order. Compare the spectrum you see with the color chart on the wall. Next to each of the four Hydrogen lines listed in Table 1 (at the end of this lab manual), record the color of that line as it appears to you. Can you distinguish even the H_δ line in the deep violet, the faintest of the four lines in the visible spectrum?

Experiment B (continued):

Measure and record the wavelengths of all the lines you can see. Compare with the table. Is your spectrometer a reliable calibrated instrument?

Choose one of the Hydrogen lines from your measured values. Identify its quantum number, n, from the table. Use Balmer's equation,

$$\frac{1}{\lambda_n} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \qquad n = 3,\ 4,\ 5,\ 6,\ \ldots$$

to calculate the value of the Rydberg constant, R, from your measured value of the wavelength of your chosen spectral line. Repeat this calculation with a different line. How do the values you calculated compare to the accepted value of $R = 1.1 \times 10^7\ \mathrm{m}^{-1}$.

Experiment C: Identifying an Unknown Element

View at least one of the unknown gas discharge tubes with the spectrometer. By visually comparing the spectrum you see through the spectrometer with those on the chart on the wall, and/or with the wavelengths given in Table 1 in this lab manual, try to identify the unknown element. Record both the label and your identification of each tube.

Experiment D: Identifying Other Light Sources

Procedure and Questions:

If time permits, your TA will perform this experiment for you with the propane torch. However, you must use your own spectrometer to observe the results. Be careful when using or near the propane torch!

D1. Have the TA pour some table salt onto the ring stand and burn it with the propane torch. View with the burning salt with your spectrometer. Can you see any sodium emission lines? Measure and record their color and wavelengths.

D2. Look at the spectrum of the incandescent light bulb attached to the variable voltage supply. Start at a low voltage and slowly increase it. What are the effects of increasing the voltage on the spectral distribution you see with your spectrometer? At low voltage, what wavelengths (or what color) appear the brightest? Does this change as you increase the voltage? Why does this happen?

D3. Once again, view the fluorescent lights on the ceiling of the lab through the spectrometer. Can you identify what is inside of them? How should you clean up and dispose of a broken fluorescent bulb?

Experiment D (continued):

WARNING: Do not point the spectrometer directly at the sun. The intensity is great enough to cause blindness.

D4. Take the spectrometer outside in daylight and look at the sky and the clouds. Can you see any atmospheric/water absorption lines?

Take the spectrometer home and view a gas stove, the moon, etc. Take it outside at night and look through it carefully at various streetlights. There are two common types of street lamps, white ones and yellow ones. Both kinds are conspicuous on campus. Also try "neon" signs of various colors. The Price Center is good for this exercise. Which of these, if any, actually use neon gas?

Pre-Lab Homework:

3. Explore the following web sites: http://zebu.uoregon.edu/~js/ast122/lectures/lec05.html and http://javalab.uoregon.edu/dcaley/elements/Elements.html.

Table 1: Wavelengths (in nm) of the emission lines of various elements.

H	He	Ne	Ar	I	Hg	Kr
410.2 H_δ $n = 6$	453.8	404.4	486.2	404.7	427.4	
434.0 H_γ $n = 5$	470.4	415.9	511.9	435.8	432	
486.1 H_β $n = 4$	471.5	416.4	546.5	546.1	436.3	
656.3 H_α $n = 3$	501.6	482.7	419.1	608.2	577	437.6
	587.6	495.7	434.5	629.4	579.1	445.4
	667.8	503.8	451	656.6		446.4
	706.5	514.5	459.6	695.9		450.2
		534.1	470.2			556.2
		540	518.8			557
		576.4	549.6			587.1
		585.2	565.1			588
		588.2	591.2			599.4
		603	603.2			605.6
		607.4	604.3			642.1
		614.3	605.9			645.6
		616.3	641.6			690.5
		621.7	675.3			758.7
		626.7	696.5			760.1
		640.2				768.5
		650.6				769.4
		659.9				785.5
		692.9				