

Laboratory 15: Spectroscopy

A transmission diffraction grating consists of a large number of closely spaced parallel lines ruled on some transparent material such as glass. The ruled lines scatter light from a plane wave incident normally on the grating as shown in Figure 1a. Each line then acts as a scattering center from which radiation fans out. The scattered light is found to constructively interfere at an angle ϕ if all the different scattered rays have the same phase, i.e. their peaks and troughs of amplitude occur at the same time. Note that the path lengths to the screen for each ray are different. Thus, for constructive interference to occur, adjacent rays must differ in path length by an integer number of wavelengths, i.e.

$$n\lambda = d \sin \phi, \quad (1)$$

where n is an integer representing the order of the constructive interference, λ is the wavelength of the light, d is the distance between grating lines, and ϕ is the angle at which constructive interference is seen.

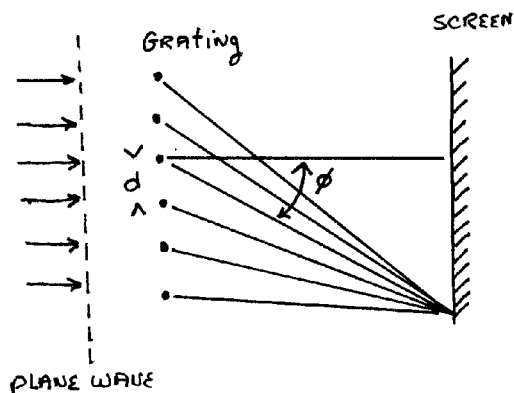


Figure 1a: Scattering From Many Grating Lines

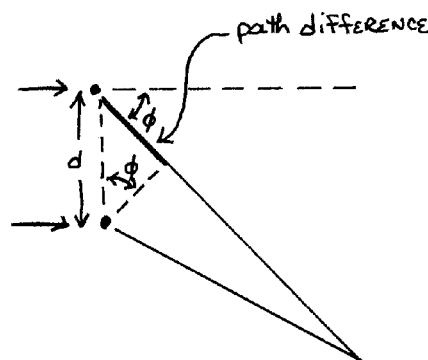


Figure 1b: Scattering From Two Grating Lines

The diffraction grating you will use has six thousand (6,000) lines per centimeter. The distance d between lines is the reciprocal of the number of lines per meter, thus $d = 1.67 \times 10^{-6} \text{ m}$. If the angle is observed at which the first order ($n = 1$) image of a certain color occurs and the grating spacing is known, the wave-length of a that color of light can be determined from equation 1.

We will examine two different light sources, mercury and hydrogen. In these sources a high voltage sent through the gas produces excitation of some of the atoms in the gas. When these atoms de-excite they emit radiation characteristic of the element, some of it in the optical wavelengths. For the most part, these de-excitations produce discrete spectral lines reflecting the quantized nature of energy levels in an atom.

The experimental setup is shown on the next page as Figure 2. The apparatus is arranged in the following way. The source is set up such that it illuminates the diffraction grating normally. A meter stick is placed horizontally at a distance $D = 1$ meter from the grating. The zero of the 2-meter stick should be on your left. Make all of your scale readings from this zero, not from the

center of the meter stick. By looking through the diffraction grating, a given spectral line can be seen on either side of the normal at an angle ϕ . We will determine the sine of this angle by determining L and H .

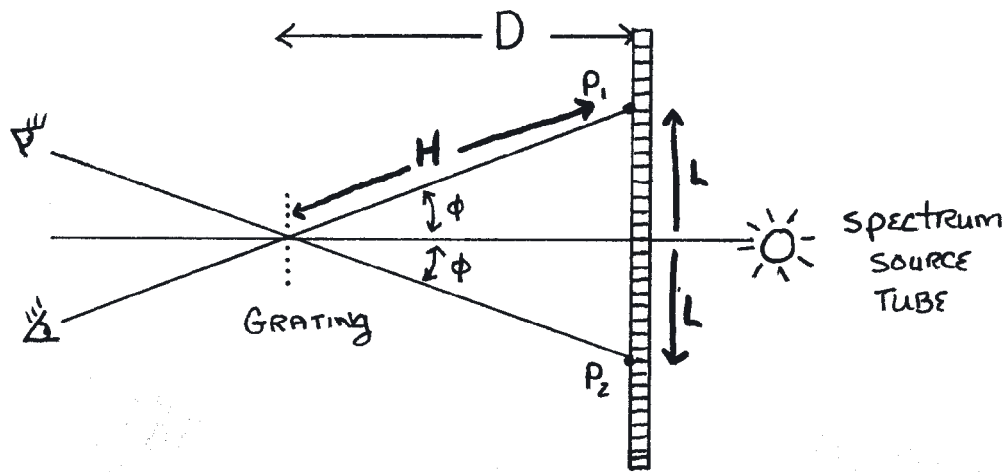


Figure 2: Experimental Setup

It is difficult to determine the exact center of the system, but easy enough to determine the two end points. Thus, to obtain the best value of L take the difference between the absolute scale readings at P_1 and P_2 and divide by two, thus

$$L = \frac{P_2 - P_1}{2}. \quad (2)$$

If you make $D = 1$ m and use the Pythagorean Theorem for the hypotenuse of the triangle H ,

$$\sin \phi = \frac{L}{H} = \frac{L}{\sqrt{D^2 + L^2}} = \frac{L}{\sqrt{1 + L^2}}. \quad (3)$$

Thus, equation (1) for first order ($n=1$) diffraction (where d is a constant) becomes

$$\lambda = d \sin \phi = d \frac{L}{\sqrt{1 + L^2}} \quad (4)$$

The wavelengths of the prominent lines in mercury are purple (405 nm), blue (436 nm), blue-green (492 nm), greenish yellow (546 nm), yellow (577 nm), orange (623 nm), and red (691 nm). Remember that $1 \text{ nm} = 10^{-9} \text{ m}$.

Procedure:

1. Looking through the diffraction grating observe the lines on either side of the spectrum tube. Figure 3 on the next page illustrates the prominent lines and their relative intensities. Light from the outside or the doorway can cause a smear of color across the spectrum. Hold your hand in front of the diffraction grating to block this light without blocking the tube. Since the room will be fairly dark it might help to fold a small piece of paper in two and drape it over the yardstick. Have your partner move the piece of paper until the edge corresponds to the position of a given line. Use an illuminator or flashlight to light the meter stick so you can

read the positions of the lines. Record P_1 and P_2 for each spectral line *in meters*. P_2 should be the higher of the two values so that the difference $P_2 - P_1$ is positive. You may be unable to see the orange and red lines at 623 nm and 691 nm. Don't worry. You should see the other five prominent lines shown in Figures 3 and 4. They are enough. When you have taken all of your data turn the spectrum tube off so it can cool off.

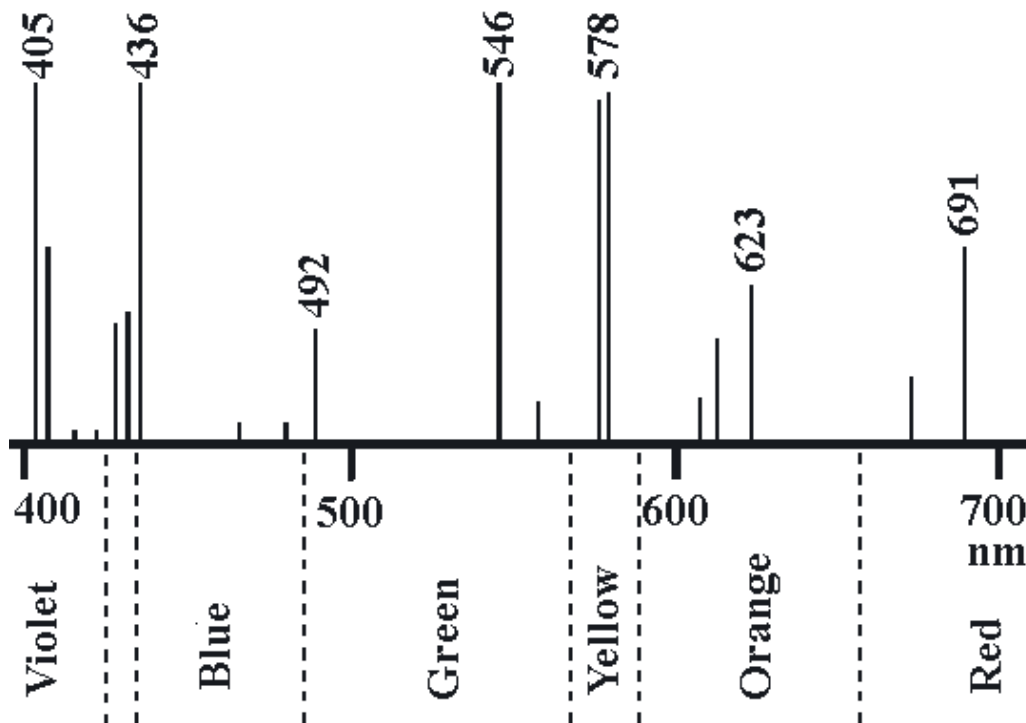


Figure 3: Mercury spectrum (height of line indicates relative intensity)

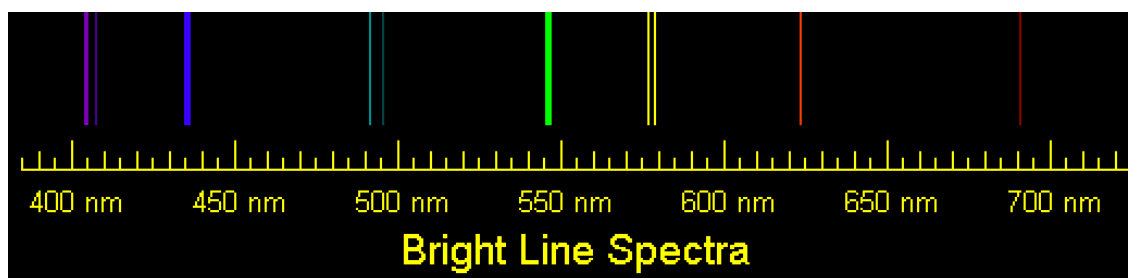


Figure 4: Mercury spectrum in color

- Determine L from half the *difference* of $P_2 - P_1$. **Remember, L must be in meters!** On the graph paper following the Data Sheet, make a plot of wavelength λ versus $\frac{L}{\sqrt{1 + L^2}}$ for each line. It should be a straight line through the origin which you should include in your graph. This is your calibration curve. If the data do not fall on a straight line you have probably misinterpreted which lines are which. When you now look at an unknown spectrum tube with discrete emission lines you can read off the corresponding wavelengths by determining

$\frac{L}{\sqrt{1+L^2}}$ and interpolating from your calibration curve.

3. As a check on your results determine the slope of the line. From Equation 4 you should see that the slope should be d . Compare your result to the value given on page 1. What is the percentage difference?

One of the early applications of the quantum mechanics was to explain the spectrum of hydrogen. According to Bohr's theory, the wavelength of lines emitted in a hydrogen emission spectra are given by

$$\frac{1}{\lambda_{fi}} = R_{\infty} \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) \quad (5)$$

where n_i is the principle quantum number of the initial state and n_f is the principle quantum number of the final state. R_{∞} is Rydberg's constant and has the units of inverse meters. In the visible region you see three lines of the Balmer series corresponding to the transitions ($n_f = 2$, $n_i = 3, 4, 5$). For example, the red line has $n_f = 2$ and $n_i = 3$, so equation 5 would give

$$R_{\infty} = \frac{1}{\lambda_{red}} \frac{1}{\left(\frac{1}{2^2} - \frac{1}{3^2} \right)} = \frac{7.19}{\lambda_{red}} \quad (6)$$

4. Replace the Mercury tube with the Hydrogen tube. Be sure the Mercury tube is not hot.
5. Record the positions of the three hydrogen lines as you did with the mercury tube and calculate $\frac{L}{\sqrt{1+L^2}}$. **Remember L must be in meters!** Convert your wavelength to meters.
6. Determine the wavelengths involved in this series from the calibration plot. Then calculate the Rydberg constant using equation 5. The calculation for the red line in the hydrogen spectrum is shown in Figure 6.

Name: _____ Partner's Name: _____ Day/Time: _____

Data Sheet - Spectroscopy Laboratory**Table 1: Prominent Mercury Excitation Lines**

	λ (nm)	P_1 (m)	P_2 (m)	$L = \frac{(P_2 - P_1)}{2}$	$\frac{L}{\sqrt{1 + L^2}}$
Purple	405 nm				
Blue	436 nm				
Blue-Green	492 nm				
Greenish-yellow	546 nm				
Yellow	578 nm				
Orange	623 nm				
Red	691 nm				

slope = d = _____ % difference with accepted value _____

Table 2: Prominent Hydrogen Excitation Lines

	P_1 (m)	P_2 (m)	$L = \frac{(P_2 - P_1)}{2}$	$\frac{L}{\sqrt{1 + L^2}}$	λ (m)
$n_f = 2, n_i = 3, H_\alpha$ red					
$n_f = 2, n_i = 4, H_\beta$ blue					
$n_f = 2, n_i = 5, H_\gamma$ purple					

Rydberg Constant Calculation

Use your wavelength data in Table 2 (converted to meters) and equation 5 to determine Rydberg's constant R_∞ for each line, then determine the average. **Remember: Calculations must be in meters.**

$$n = 3 \rightarrow 2 \quad R_\infty = \underline{\hspace{2cm}}$$

$$n = 4 \rightarrow 2 \quad R_\infty = \underline{\hspace{2cm}}$$

$$n = 5 \rightarrow 2 \quad R_\infty = \underline{\hspace{2cm}}$$

$$\text{Average } R_\infty = \underline{\hspace{2cm}}$$

Calibration Curve Generated From Mercury Data

