San Diego Mesa College Name:___________________________________

Physics 197 Laboratory Experiment Date: ___________________________________

Title: Investigation of Optical Spectra

Objective:

To investigate the characteristic photon emissions of elements and to use this information to calculate the Rydberg constant, and to derive the Balmer equation **Disclaimer – this is a lab in process, so some unexpected situations may be encountered. Patience, please.**

Theory:

The Bohr model of the atom predicts the emission of photons as excited electrons move to lower energy levels. Each specific transition corresponds to the emission of a single photon of a specific energy.

Equipment:

Various gaseous elements Spectral Analyzer
Incandescent Light Fluorescent Light
Diffraction Gratings (A: 300 lines/mm and B:600 lines/mm)

Setup and Procedure: Calibration

Note about the Vernier scale used on the spectroscope. Your scale is marked in arc-minutes. 360 degrees = 2π radians = 60 arc-minutes = 3600 arc-seconds.

1) Place the spectrometer within a few cm of the mercury source.
2) Align the telescope crosshairs with the rightmost edge of the illuminated slit. Ensure that the crosshairs are vertical, and adjust them as needed. Record the angular position as the 'zero error' reference line.
3) Rotate the telescope arm and look through the telescope at a distant object.
4) Adjust the focus until this distant object is in focus. From this point on, try not to adjust the telescope focus. Move the telescope back towards the mercury source.
5) Use the collimator focus to make the image of the slit as clear as possible.
6) Place the A grating perpendicular to the spectrometer axis. Verify that the first order green line from the mercury source is equiangular to the spectrometer axis (your 'zero error' reading). Adjust the grating as necessary.
7) Locate the yellow line from the mercury source. Adjust the width of the slit (if necessary) until it is possible to observe two distinct yellow lines.
8) Record the angular location of each line in Data Table One
9) Replace the A grating with the B grating and repeat steps 1-5.

Data: Dispersion relationship of a diffraction grating

Color	Wavelength (nm)	Theta
Grating A: 300 lines/mm		
Yellow 1	579	
Yellow 2	577	
Grating B: 600 lines/mm		
Yellow 1	579	
Yellow 2	577	
Dispersion A (D_A) = $\Delta\theta_A / \Delta\lambda$		
Dispersion B (D_B) = $\Delta\theta_B / \Delta\lambda$		

Procedure: Known and Unknown Spectra Identification

1) Place the spectrometer within a few cm of the mercury source.
2) Using the grating with the largest dispersion, make sure the grating is perpendicular to the spectrometer axis. Once made perpendicular, do not touch the grating.
3) Locate the angles at which the following spectral lines are located. Use only first order lines, and locate the angular position on either side of 'zero'. Record all angles as between zero and 90 degrees

Data: Mercury Source

Color	Wavelength (nm)	Theta Right	Theta Left
Red 1	623		
Red 2	615		
Yellow 1	579		
Yellow 2	577		
Green	546		
Cyan	492		
Blue	436		
Violet	405		

1) Replace the mercury source with the hydrogen source. Do not touch the grating.
2) Record the absolute angular positions of each of the following first order spectral lines

Data: Hydrogen Source

Color	Theta Right	Theta Left
Red 1		
Blue		
Violet 1		
Violet 2		

1) Do not move the grating, and replace the hydrogen source with an incandescent bulb
2) Identify the angular positions of the red and violet limits of the visible spectrum.

Data: Incandescent Bulb

Color	Theta Right	Theta Left
Red 1		
Violet 2		

Analysis:

Generate the wavelengths of light that correspond to the hydrogen spectra. Enter the results in the table below. Using any reference source, look up the standard accepted values for these same spectral lines and calculate the percent error between your data and the accepted standards. To calculate the wavelength, you will employ the relationship:

$$d \sin\theta = m\lambda$$

Color	Wavelength (calculated, right)	Wavelength (calculated, left)	Wavelength (standard)	% Error (right / left)
Red				
Blue				
Violet 1				
Violet 2				

Show a sample of each type of calculation, with units.

Use this same approach to calculate the wavelengths corresponding to the limits of the incandescent bulb spectrum and list them below:

The spectral lines of hydrogen were found to follow a general relationship developed by Johann Balmer. The 'Balmer Series' is as follows:

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]; n = 3,4,5...$$

where R is a constant called the 'Rydberg Constant'. This implies that a graph of inverse wavelength as a function of $(0.25\text{-}n^{-2})$ should yield a straight line, the slope of which is the Rydberg constant. Construct a properly labeled graph, using your calculated values of the hydrogen vawelengths.

Calculate the percent difference between the slope of your graph and the accepted value for the Rydberg Constant $[1.097776 \cdot 10^7 m^{-1}]$

Use your value for the Rydberg constant and Balmer's equation to calculate the hydrogen transitions in the visible spectrum. Compare your results to the standard accepted values and calculate the percent error.

Color	Wavelength (calculated)	Wavelength (standard)	% Error
Red			
Blue			
Violet 1			
Violet 2			

Show a sample of each calculation, with units.

Derivation: Write each step with units in the space provided.

Begin with Einstein's postulate that light is quantized and that photon energy is proportional to frequency**.**

1)

Use 1) and the relationship between speed, frequency and wavelength to rewrite the photon energy in terms of λ

2)

Equation 2) is proportional to the difference in atomic energy levels ΔE of the electron

3) $\Delta E =$

Bohr postulated that the reason each electron transition is proportional to a fixed energy is that the angular momentum is quantized in multiples *n* of $h/2\pi$ˆ. Use the relationship between linear and angular momentum to express the angular momentum of an electron orbiting at a distance 'r' from the center of the nucleus, having a tangential speed v.

4) $L =$

Now apply Bohr's postulate to relate m, .v, .r. n, and h.

5)

If the electron moves in a circular path, then some centripetal force is responsible for providing the centripetal acceleration required for circular motion. The Coulomb Force seemed appropriate. Write out the Coulomb Force and apply the centripetal force requirements to establish a relationship between the electron mass, charge, speed and the radius of orbit

5) $r =$

Also, establish a relationship between the speed of the orbiting electron, n, h and the electron charge

6) v =

Recall that objects bound in an attractive central potential have a total system energy given by E = U + K, where U is the potential energy and K is the kinetic energy. Using your expression for v found in step 6), write an expression for the kinetic energy of the orbiting electron

7) $K = \frac{1}{2}mv^2 =$

For an electron being acted upon by a proton, the potential energy of the system is written as qV, where V is the potential of the proton. Use your expression for r found in step 5), write an expression for the potential energy of this system

8) U =

So, combine expressions 7) and 8) to establish the total energy of the ‘orbiting’ electron

9) E = K + U =

You’ll note that expression 10) is composed of physical constants and *n*. Now write an expression for the difference in energies of two different values of *n* and compare it to the Balmer series expression. Calculate the Rydberg constant and compare your result to the standard accepted value. Calculate the percent error between the two values.

Conclusion: Briefly discuss the physics involved in the experiment, summarize the data, address potential sources of error and methods to reduce or eliminate them, and state whether or not the experimental results validate the theory.