PURPOSE: To become familiar with the spectrometer and its use with a diffraction grating, to measure the wavelengths of light given off from the hydrogen atom and to correlate these wavelengths with the energy level diagram for hydrogen.

APPARATUS: Spectrometer High Intensity Lamp Black Cloth
Mercury spectrum tube Hydrogen spectrum tube Grating

Part 1: Diffraction Grating

You will use the diffraction grating relation, which may be written as

\[ \sin \theta_m = m \frac{\lambda}{d} \]  

(1)

\( \theta_m \) is the angle at which the \( m^{th} \) order maximum occurs for light of wavelength \( \lambda \). “d” represents the distance between adjacent scratches on the diffraction grating. Equation 1 was derived using the assumption that parallel rays from the collimator are incident exactly perpendicular to the grating. Refer to fig 1. If the incident rays make an angle \( \theta_i \) with the normal to the grating face, then the rays from two adjacent slits for the \( m^{th} \) order maximum on the same side of the normal have a path difference (see figure 1a) of \( \lambda \). For the \( m^{th} \) order maximum on the other side of the normal the path difference (see figure 1b) is

\[ d \sin \theta_{m,\text{right}} - d \sin \theta_i = m \lambda \]  

(2)

\[ d \sin \theta_i - d \sin \theta_{m,\text{left}} = m \lambda \]  

(3)

Combining equations (2) and (3) yields

\[ \frac{(\sin \theta_{m,\text{left}} + \sin \theta_{m,\text{right}})}{2} = \frac{m \lambda}{d} \]  

(4)
The intense green line of the mercury spectrum has wavelength 546 nm. You will measure angles, and count orders for this line, then solve for the grating spacing $d$.

**Part 1 PROCEDURE.**

1. Adjust spectrometer for parallel light (see Addendum).

2. Set the grating at the center of the prism table and clamp it so that its surface is perpendicular to the light from the collimator (make sure the film side faces the telescope), and so the prism holder post is to one side of the grating. Tighten the locking screw for the prism table. Do not replace the sliding shield or light shield. Use the black cloth to block out external light.

3. Loosen the telescope locking screw and rotate the telescope to one side so that it is out of the way. Look straight into the grating and collimator (not through the telescope) and locate the slit image having the same color as the mercury lamp. Then, moving your head to your left while looking through the center of the grating, find the images of the slit in the various spectral colors of mercury. Repeat moving the head to the right. In the following steps you will use the telescope to look at these spectral lines. Record the colors you see.

4. With the central image in view, rotate the telescope in front of your eye, find the central image through the telescope, get the cross hairs as nearly centered on it as possible, and tighten the telescope locking screw. The tangent screw may now be used as a fine adjustment to center the cross hairs.

5. Tighten the locking screw for the rotating dial, and read the innermost or degree scale with the aid of the vernier. Record this angle. It is the angle for constructive interference of light coming straight through the diffraction grating ($m = 0$). Only the telescope is to be unlocked and rotated hereafter.

6. Loosen the locking screw for the telescope arm and rotate the telescope to the left to the first order ($m=1$) bright green line. Record this angle. Calculate the angle through which you have rotated the telescope arm from the straight through $m=0$ position.

7. Repeat 6 for the first order ($m=1$) image on the right.

8. Repeat 6 and 7 for higher orders of this color line.

**Part 1 CALCULATIONS:** Show all of your calculations in a clear, well organized fashion.

1. Record the position of the $m=0$ order of the slit (light shining straight through the telescope & collimator).

2. Use Eq. (4) and $\lambda = 546$ nm for the green line to find the grating spacing $d$. Calculate $d$ for each order, then average the values.

3. How does your value compare to the manufacturers claim? Your grating has ~6,000 lines per cm.
Part 2: Atomic Energy Levels for Hydrogen

Throughout the nineteenth century many atomic spectral lines were measured. Each element gives rise to a series of spectral lines that is unique to that element. Classical physics could not explain the origin of line spectra and a satisfactory explanation did not occur until the advent of quantum physics in the twentieth century. Johann Balmer, (1825-1898) a Swiss schoolteacher, found that there was order in the spectral lines that were emitted from hydrogen atoms. The equation that he discovered is called an empirical equation because he arrived at it by measuring the wavelengths and playing around with these data until he could relate all of the observed wavelengths through a simple equation. This series of spectral lines is called the Balmer series and the wavelengths can be calculated from the formula:

\[
\frac{1}{\lambda} = 1.097 \times 10^7 \left( \frac{1}{2^2} - \frac{1}{n^2} \right)
\]  

(5)

This formula gives values of \( \lambda \) in meters where \( n = 3, 4, 5, 6, \) etc. The constant \( 1.097 \times 10^7 \text{m}^{-1} \) was a proportionately constant determined empirically by Balmer and was later verified by the Bohr model of the atom. This constant of \( 1.097 \times 10^7 \text{meter}^{-1} \) is now called the Rydberg constant.
Einstein assumed that light is made up of photons that have energy equal to:

\[ E = hf = \frac{hc}{\lambda} \quad (6) \]

where \( h \) is a constant that was determined by Planck and \( f \) is the frequency of the photon. The Bohr model of the atom assumes that photons are given off only when the electron makes a jump from a higher energy level to a lower one. The Bohr energy levels are given by

\[ E_n = \frac{-13.60}{n^2} \text{ eV} \quad (7) \]

The Balmer equation can then be re-expressed in terms of the energy of the photons:

\[ E_{\text{photon},n} = 13.60\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \quad (8) \]

where \( E \) is in electron volts (eV) and \( n = 3, 4, 5, \ldots \), etc.

You will calculate the wavelengths of the visible spectral lines of hydrogen by using angles you measure for these spectral lines and your value of the grating spacing \( d \) measured in Part 1. Then you will use the wavelengths to find the energy level transitions for the Balmer series.

Part 2. PROCEDURE: Report all of your data in a clear, well organized fashion.

1. Turn off your lamp and carefully replace the mercury tube with a hydrogen tube. Ask for assistance if you are unsure.

2. The procedure should be clear for obtaining the angles for all visible spectral lines for hydrogen. (Use steps 6-8 from Part 1 for each color you see.) Be sure to include the order numbers in your data.

Part 2. CALCULATIONS: Show all of your calculations in a clear, well organized fashion.

1. Use the value of \( d \) found in Part 1 and your measured angles to calculate the wavelengths of all hydrogen lines in the visible spectrum. (Use eqs 4 and/or 1.) The theoretical value of the Balmer series wavelengths for hydrogen are: 656 nm (red), 486 nm (blue-green), 434 nm (violet), and 410 nm (violet, maybe very dim). These values are calculated from equation 5 where \( n = 3, 4, 5, \) and 6, respectively. These four lines are the only ones in the visible spectrum (400 nm – 700 nm).

2. Equation 6 relates the energy of a photon to its wavelength. If the energy is expressed in electron volts and the wavelength in nm, Equation 6 becomes

\[ E = \frac{1240 \text{ (eV nm)}}{\lambda \text{ (nm)}} \]

Use this equation to calculate the energy of the visible lines in eV. Express your results to three significant figures. The theoretical values calculated from equation 8 are 1.89eV, 2.55eV, and 3.02eV. These values correspond to the electron transitions to the \( n = 2 \) level from the \( m = 3, 4, \)
5, and 6 levels respectively. Calculate the percent error for each of your values. Enter all the results in the table below. The third column, m, in the table is for the spectral order, not for the energy level.

<table>
<thead>
<tr>
<th>θ_{m, left}</th>
<th>θ_{m, right}</th>
<th>m</th>
<th>( \lambda ) (exper), nm</th>
<th>( \lambda ) (theor), nm</th>
<th>Percent diff. for ( \lambda )</th>
<th>n</th>
<th>E(exper), eV</th>
<th>E(theor), eV</th>
<th>Percent diff. for E</th>
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For at least one of the calculations please show your entire calculation below, beginning with the measured angle and ending with measured and calculated energy in eV.
Addendum: The Spectrometer.

The various parts of the spectrometer are labeled in the photograph above. There is a locking screw for the grating/prism table on the other side of the pedestal that is not shown in the photograph.

Always avoid touching optical surfaces (i.e., those surfaces through which light passes) of lenses, prisms, and gratings.

Remove the light shield (retract the sliding tube on the collimator), and the sliding shield, noting into which grooves on the prism table each fits. Loosen the locking screw for the telescope arm and rotate the telescope. When rotating the telescope always grasp the arm near the tangent screw. Failure to follow this advice later will probably defocus the telescope.

Look into the telescope and bring the cross hairs into sharp focus by sliding the focusing eyepiece in or out. Aim the telescope at some distant object such as a brick wall on another building seen through the laboratory window. Focus the telescope on this distant object by sliding the telescope tube in or out. (Note that this sliding part contains the focusing eyepiece and hairlines so that the previous focus need not be disturbed.) Rotate the telescope arm until it is opposite the collimator and open the adjustable slit so that it can be seen through the telescope. Slide the adjustable slit in or out until it is in sharp focus and parallax is eliminated between it and the cross hairs.

The spectrometer is now in adjustment for parallel light and should remain so throughout the experiment.