Part 1
1.1. Atomic Line Spectra.
In this experiment, we will look at the diffraction of light, and how wavelengths can be calculated from diffraction. We’ll also look at atomic line spectra, which actually relate to the quantum-mechanical energy levels that electrons occupy around the nucleus of an atom; the wavelengths of emitted light from an atom relates to these energy levels. The wavelengths of the emission lines in the spectrum are given by the Rydberg formula:

\[
\frac{1}{\lambda} = R Z^2 \left( \frac{1}{n_{\text{final}}^2} - \frac{1}{n_{\text{initial}}^2} \right)
\]

where \( R = 1.097 \times 10^7 \text{ m}^{-1} \), \( Z \) is the atomic number of the atom, \( n_{\text{final}} \) is the principal quantum number of the final (lowest) energy state of the electron, and \( n_{\text{initial}} \) is the principal quantum number of the initial (highest) energy level of the electron. For various values of \( n_{\text{final}} \), different “series” of spectral lines occur. Specifically, for hydrogen, \( n_{\text{final}} = 1, 2, 3, 4 \) gives the Lyman, Balmer, Paschen and Brackett series, respectively. The energy of a photon is related to the corresponding wavelength of light as follows:

\[
\frac{1}{\lambda} = \frac{\hbar}{E}
\]

The shortest wavelengths of light emitted correspond to the greatest loss of energy and occur when the electron falls the greatest possible number of energy levels. This will happen when the initial energy level is the highest one possible, or \( n_{\text{initial}} = \infty \). The longest wavelengths of light emitted corresponds to the smallest loss of energy and occur when the electron falls the least possible number of energy levels. This will happen when the initial energy level is just one principal quantum number above the final level.

1.2 Atomic Transitions: The Demonstration
For this part of the lab, the TA will show you various gas tubes. Each tube contains a different element that, after being excited by running high voltage through it, will emit different spectral lines, which you can view through the diffraction gratings. This happens because the high voltage makes the electrons in the gas jump up to higher energy levels; light is emitted when the electrons “fall” back down again, emitting photons as they fall.

Your task is to draw the lines you see in the demo in the boxes in Table 1, at the locations where they are observed. Once you have been shown all the gas tubes and sketched the spectra you observe, compare your drawing to the diagrams provided in order to identify which element was in each tube element in each tube. Remember that 400 nm is UV light, and 700 nm is infrared.

NOTE: Since this part of the experiment, as well as part 3, involve very high voltages, it is VERY important not to change the tubes yourself; let the TA do it. Also, don’t touch any of
the light bulbs with your fingers – you can damage them, and you can burn yourself – the tubes get hot enough to fry an egg.

Table 1

<table>
<thead>
<tr>
<th>400 nm (Blue)</th>
<th>700 nm (Red)</th>
<th>Element:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas #1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas #2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas #3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas #4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part 2**

**2.1. Interference**

In this part of the experiment, you will look at the interference of light waves, and use the properties of constructive interference to calculate the wavelengths of light in the spectrum you observe. You will be looking at the spectrum from a regular 150 Watt light bulb. This is a continuous spectrum, so you won’t see isolated lines as in Part 1 and Part 3.

Like all waves, light experiences both constructive and destructive interference. In the lecture, we talked about both kinds of interference. Here, we will actually investigate equations for the two different kinds of interference. Constructive interference will occur when the difference in the distance traveled by two light waves is an integer multiple of the wavelength;

$$\Delta path = m\lambda$$, where \(m=1, 2, 3,\ldots\)

Destructive interference will occur when the difference in the distance traveled by two light waves is a half-integer multiple of the wavelength. In other words;

$$\Delta path = \left( m + \frac{1}{2} \right)\lambda$$, \(m=0, 1, 2, 3,\ldots\)
In the diagram, if the two beams of light pass through two slits, separated by a distance $d$, the path difference will be:

$$\Delta \text{path} = d \sin \theta$$

For constructive interference, this means that:

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

So that if you measure $d$ (the distance between the slits) and the angle $\theta$, you can calculate the wavelength $\lambda$:

$$\lambda = \frac{d \sin \theta}{m}$$

This is an equation that gets even easier in our case, since you will just look at the case where $m=1$. In this experiment, you will be calculating the wavelengths of light in the spectrum of visible light from a regular light bulb using this equation. In other words, you will see a given wavelength while looking at a specific angle from the light source. Actually, in our case, we are using a diffraction grating with thousands of slits (1000 per mm!), not just two. But the principle is the same, and you can use the same equations as above.

Note that for destructive interference (which you will not see in this spectrum, since there are no dark bands), these equations would become

$$(m + \frac{1}{2})\lambda = d \sin \theta$$

Solving for the wavelength gives:

$$\lambda = \frac{d \sin \theta}{(m + \frac{1}{2})}$$

2.2 Procedure
Your goal is to measure the wavelength of each color in the visible spectrum. To do this you will have to set up your lab station as shown in the figure on the previous page. You will have to be able to use your trigonometry skills to calculate the angle $\theta$. Feel free to mark the masking tape on the table where each color is located so you can measure all the colors at once. Since measuring the angle correctly is VERY important, make sure to set up the sides of the triangle carefully. The length of the adjacent side is the distance between the light source (the filament in the bulb) and the diffraction grating. It is easiest if you line up the grating exactly with the edge of the table, as described in the paragraph below. The length of the opposite side is the distance from the filament to where you see the band of light with the color you are measuring.

Place the light bulb exactly one meter from the edge of the table. It is important to be lined up with the light bulb to measure exactly one meter. (This means that the length of the adjacent side of the triangle is just equal to 1 meter.) Then place the tape across the table in front of the light bulb. Mark a line on the tape where the filament is located. Turn on the light bulb and look through the diffraction grating, holding the grating at the edge of the table. Again, be sure to line up with the light bulb. Off to the side of the light bulb, you should see a continuous spectrum. Have your lab partner draw a line on the masking tape where you see the middle of each color. Make sure to label each line (green, blue, etc.). Record the distance of each color from the filament (this is the length of the opposite side). Enter your measurements in Table 2; then calculate the angle, and the wavelength. To calculate the wavelength, you will need to know the distance $d$ between the gratings in the diffraction grating. There are 1000 lines per millimeter, which means that $d=1000$ nm. Use $d$ in units of nm, so that you will get the wavelength in nm also.
The mystery gas!

For the final part of the lab, you will do an experiment like the one in part 2, but instead of a continuous spectrum from a regular light bulb, you will look at the atomic line spectrum from a mystery gas! Use the diffraction grating, tape, and rulers, to measure the wavelength of each of the lines you see in the spectrum emitted by the gas in the tube. Then, looking at the attached set of atomic line spectra, see if you can identify what gas is in the mystery tube.

Table 2

<table>
<thead>
<tr>
<th>Color</th>
<th>Adjacent (1 meter?)</th>
<th>Opposite</th>
<th>θ</th>
<th>λ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Violet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

And the mystery gas is ___________________________
**Analysis and Questions**

1. Calculate the wavelengths of the colors in the visible spectrum based on your measurements in Part 2 of the experiment; enter the values in the table in Part 2.

2. Calculate the wavelengths of the colors in the line spectrum for the mystery gas in Part 3; enter the values in the table in Part 3, and see if you can identify the mystery gas.

3. Calculate the longest and shortest wavelengths for the hydrogen Lyman transitions.

4. Calculate the longest and shortest wavelengths for the hydrogen Balmer transitions.

5. Calculate the longest and shortest wavelengths for the hydrogen Paschen transitions.

6. Based on your calculations for questions 3-5, which series (Lyman, Balmer or Paschen) are you observing when you looked at the visible part of the spectrum for atomic hydrogen in Part 1 of the experiment? EXPLAIN!