P19 Lab 4 – Hydrogen Spectrum

Overview:
In the late 1800’s, it was known that when a gas is excited by means of an electric discharge and the light emitted is viewed through a diffraction grating, the spectrum observed consists not of a continuous band of light, but of individual lines with well defined wavelengths. Experiments had also shown that the wavelengths of the lines were characteristic of the chemical element emitting the light. They were an atomic fingerprint which somehow resulted from the internal structure of the atom. In this lab you will

- use a diffraction grating and a ruler to measure the wavelengths of several lines in the hydrogen spectrum
- use the results to test Bohr’s model of the hydrogen atom
- observe spectra from at least two gases other than hydrogen and compare the spectra to hydrogen

Measuring Wavelength:
A diffraction grating is a series of lines that separates light into its component colors. Different wavelengths come off the diffraction grating at different angles. The angle between the original path of the light and the path of a given color can therefore be used to measure the wavelength of that color. The mathematical relationship is

\[ m\lambda = d \sin \theta, \]

where \( m = 0, \pm 1, \pm 2 \ldots \) and \( d \) is the spacing between the lines on the grating. The same wavelength can be deflected through different angles (depending on the value of \( m \)). In this lab, the angles you will measure are for \( m = \pm 1 \), since these are the easiest to observe.

**Note:** This lab will not explore why the diffraction grating works the way it does.

Apparatus:
- Spectrum tubes with power supply,
- ruler with a slider*,
- diffraction grating,
- mounts to hold ruler and diffraction grating in fixed positions.

Precautions:
- Spectrum tube power supply produces **HIGH VOLTAGE!** Do not touch the metal connectors on the power supply when the power supply is turned on.
- This lab is performed in the dark. Plan accordingly.
- Diffraction gratings are expensive optical components. **Do not touch the optical surfaces.** Handle the gratings by the edges.
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Basic Setup (top view)

 Procedure
1. Set up the apparatus. The diffraction grating and the ruler should be at right angles to the line of sight. The ruler should be set up so that you can see its markings when you look through the diffraction grating. A slider with a pointer should sit on the ruler. This will allow you to measure the positions of the images of the lines in the spectrum.

2. Turn off the room lights.

3. Turn on the spectrum tube power supply.

4. The next few steps are to help you understand the optics behind the image you see in the grating and to help you figure out what quantities to measure. Look at the spectrum by looking through the diffraction grating at the spectrum tube. You may need to put your eye quite close (~1 cm) to the diffraction grating to see the entire pattern. While looking at the pattern, put your finger between the grating and one of the lines. Can you make the line disappear? Each person should try this.

   Q1: Is light actually coming from the images you are seeing through the grating? Explain, based on your observation.

   Q2: On the diagram above, trace two paths taken by red light from the lamp to your eye.

Prediction: What will happen to the spacing between the lines (as measured on the ruler) if you move the ruler closer to you (without changing the location of anything else)? What will happen to the spacing of the lines if the spectrum tube is moved closer to you (without changing the distance between the grating and the ruler)? Explain your reasoning.

5. Check your predictions and resolve any inconsistencies.
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6. Use your observations to plan your data taking. What distances should you measure? Where should you place the ruler, grating and spectrum tube to get the best quality data? (Hint: To get the measurement with lowest relative uncertainty, should the lines be close together or far apart?) Should you measure from the center line to the spectrum line or measure from one line to another of the same color and divide by two?

Q3: Answer the questions outlined above and explain the logic behind your choices.

7. Take the data you need to determine the wavelength of the three prominent lines you see. Use the space below to record your data. (Don’t forget appropriate labels and units).

8. Determine the wavelengths from your data. Show one sample calculation in detail.

9. Share your three wavelength values with the rest of the class (use a blackboard, perhaps). Determine class average for each value and determine the uncertainty in that average. Explain how you estimated the uncertainty.
10. There are discharge tubes containing other gases available in the lab. Observe the spectra of at least two other gases and compare them to the hydrogen spectrum. Choose one gas from each of the following groups:

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg</td>
<td>I₂</td>
</tr>
<tr>
<td>He</td>
<td>N₂</td>
</tr>
<tr>
<td>Ar</td>
<td>H₂O</td>
</tr>
<tr>
<td>Ne</td>
<td>O₂</td>
</tr>
</tbody>
</table>

**CAUTION:** Do not attempt to change the discharge tube without first turning off the high voltage power supply.

**CAUTION:** After a short period of use, some discharge tubes become quite hot. Allow a few minutes for it to cool before changing it. Store the hydrogen tube in its cylindrical storage container while you are looking at the other gases. When you are done looking at a specific gas, please make sure to put it back into its own cylindrical storage container and return to the main storage box.

Q4: Describe the differences and similarities between the hydrogen spectrum and the spectra of the other gases you observed.

You may want to work on these questions on another sheet of paper...

Q5: Bohr proposed a model for the atom that incorporates discrete energy levels, given by \( E_n = -\frac{|E_1|}{n^2} \) where \( n \) is an integer. Determine the final and initial values of \( n \) for each line observed. You may assume that all atoms have the same value of \( n \) after the photon is emitted. Do not assume any particular value of \( E_1 \). (Hint: consider looking for patterns in the ratios of the photon energies). Explain your reasoning clearly. Make the connection between your data and the model explicit.

Q6: Use the Bohr model to predict other frequencies of light that might be emitted by the hydrogen atom. Use your model to determine how many other transitions (besides the three you observed) emit light are in the visible part of the spectrum (from 400 nm to 750 nm).

Q7: Determine the value of \( E_1 \) from your data. Show your work.

**What to turn in:**
- This handout
- Answers to Q5-Q7 on some other piece of paper
- An abstract for this experiment. An abstract is a short (<300 words) description of the experiment. It should describe what was done, what was found, and how the observations relate to established theory (in this case, Bohr’s model).