Winter Quarter Lab Report 1

# PHYS 18L: Investigating the Balmer Series and Determining the Rydberg Constant

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**Abstract**

In this study, we investigate the relationship between the quantization of light and emission lines, using vaporized elements. We study the spectra produced by excited atomic hydrogen gas in an attempt to experimentally verify the known Rydberg constant. We experimentally calculate the angles of spectra lines as well as the wavelengths associated with such angles. Using our data from experiment 3 combined with the known speed of light constant, we are able to calculate wavelength values and ultimately the Rydberg constant to be 12.56544.

## 1 Experimental Objective

The photoelectric effect refers to the phenomenon in which light striking a metal surface will produce photo-electrons. This discovery did not align with the classical theory of physics and alluded to the subsequent discovery of the quantization of light. In the early 1900's, renowned scientist Albert Einstein proposed that light could be related to frequency in the following equation, where h refers to Planck's constant.

$$E = hf \tag{1}$$

This equation forms the basis of quantum mechanics as a theoretical framework where the energy of light is quantized. This discovery then led to the development of the Rydberg and Ritz formula, which calculates the wavelength of quantized light as it shifts from one energy level to another.

$$\frac{1}{\lambda} = RZ^2\frac{1}{n_1^2} - \frac{1}{n_2^2} \tag{2}$$

The Ryderberg constant is defined as a numerical constant.

$$R = \frac{me^4}{8c\epsilon^2h^3} = 10.97373\mu m^{-1} \tag{3}$$

It was discovered that an excited atomic gaseous element will produce its own unique spectrum of light when that light passes through a prism. This established spectroscopy as an effective method of observing the quantization of light. By observing the lines produced by atomic hydrogen, we can observe the Balmer series which typically refers to a series of five visible emission spectral lines. Our experimental objective is to use this theory along with the given equations to experimentally verify the Rydberg constant.

## 2 Experimental Setup

### 2.1 Schematic Drawings

In this lab, we used the method of spectroscopy to observe the diffraction of light as precisely as possible. Spectroscopy is defined as the 'study of the absorption and emission of light and other radiation by matter, as related to the dependence of these processes on the wavelength of the radiation'(Stoner, 2021).The optical spectrometer was used to observe and analyze the line spectra produced by heated elements. A diffraction grating was used to enhance the spectrometer in order to experimentally observe the angle for each spectra. We used the equation given below to calculate this mathematically, where d refers to the slit length, theta refers to the diffraction angle, and lambda refers to the wavelength of light.

$$dsin\theta = m\lambda \tag{4}$$

Our equipment included a spectrometer, diffraction grating, and an atomic spectrum tube in order to produce spectral lines to observe. We also used a transformer to apply voltage to the tube.

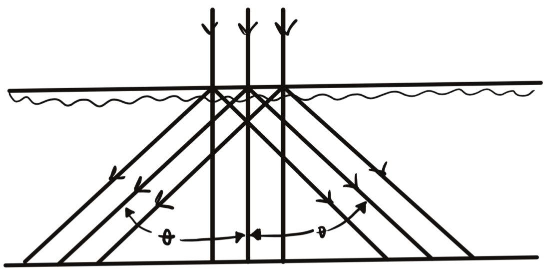


Figure 1: Diffraction Grating
Enlarged depiction of the diffraction grating used to observe the angle of diffraction $\theta$

Our precision spectrometer includes a collamitor, diffraction grating, telescope, and turntable. Light comes in one end while the observer looks from the other end.

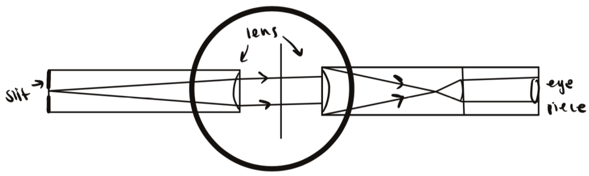


Figure 2: Precision spectrometer
Enlarged depiction of the spectrometer collamitor lens and viewing lens

Finally, we used a vernier scale to measure spectral line diffraction angle.

## 2.2 Measurement Procedure

Our measurement procedure involved the use of the spectrometer and several excited atomic gas tubes. We measured the angle of the first order and second order diffraction maximum of the sodium light on the left and right sides, as seen in Figure 1. Then, we measured the splitting of the diffraction lines as a doublet to the arc-minute with the vernier scale as seen in Figure 4. A doublet refers to the splitting of the spectral lines.

| order | Θ |
|---|---|
| m=1 (right) | 340.6+/-0.0083 |
| m=1 (left) | 20.1+/-0.0083 |
| m=2 (right) | 340+/-0.0083 |
| m=2 (left) | 20.8+/-0.0083 |

Figure 3: Sodium Data
First data set measuring the first and second order diffraction

| order | Θ |
|---|---|
| m=1 (right) | 0.09 +/-0.0083 |
| m=1 (left) | 0.08 +/-0.0083 |
| m=2 (right) | 0.09 +/-0.0083 |
| m=2 (left) | 0.09 +/-0.0083 |

Figure 4: Sodium Doublet Data
Second data set measuring the first and second order diffraction of the doublet

Next, we replaced our sodium lamp with a tube of an unknown element. In Figure 5, we measured the angles of diffraction as well as the wavelengths for the brightest spectra lines.

| order | Θ | λ |
|---|---|---|
| m=4 | 20.1 | $\lambda_{brightest} = 578.552nm$ |
| m=1 | 20.0 | $\lambda_{second\ brightest} = 575.79$ |

Figure 5: Unknown Tube Data
Wavelength and angle measurements for the unknown element

Finally, we replaced our unknown element with a hydrogen tube, at a voltage of 35V and a slit width of 0.50 mm. Here, we measured the first and second order diffraction on both sides of the hydrogen beam. We observed the spectra to have red, green, and blue lines. In figure 6, we varied the variac voltage from 40, 32, and 42 V in order to measure the angle of diffraction.

| order | Voltage | Θ |
|---|---|---|
| m=1 (blue) | 40 V | 10.55-10.50 |
| m=1 (green) | 40 V | 19.7-19.75 |
| m=1 (blue) | 32 V | N/A |
| m=1 (green) | 32 V | 19.65-19.62 |
| m=1 (blue) | 42 V | 10.45-10.5 |
| m=1 (green) | 42 V | 10.65-10.80 |

Figure 6: Hydrogen Voltage Data
Varying the voltage

Next, we varied the slit width from 0.50, 0.25, and 1 mm to measure the angles again, as seen in Figure 7.

| order | Width | Θ |
|---|---|---|
| m=1 (blue) | 0.50 mm | 10.55-10.50 |
| m=1 (green) | 0.50 mm | 19.7-19.75 |
| m=1 (blue) | 0.25 mm | 19.5-19.48 |
| m=1 (green) | 0.25 mm | 19.7-19.68 |
| m=1 (blue) | 1 mm | 19.5-19.40 |
| m=1 (green) | 1 mm | 19.80-19.60 |

Figure 7: Hydrogen Voltage Data
Varying the voltage

These measurements comprise the main data from experiment 3 and allow us to investigate the implications of the photoelectric effect as well as calculate several constants.

# 3 Experimental Results and Conclusions

From our measurements, we can make several conclusions. We observed these spectral lines to have a yellow line for the first order and an orange line for the second order, which is consistent with sodium. Figure 5 which refers to our unknown element was observed to have a slight yellow and orange hue, which is consistent with electromagnetic radiation. We can hypothesize that this unknown element is sodium, which has a yellow hue and a wavelength of 589 nm.

$$dsin\theta = m\lambda \tag{5}$$

$$d = 1/594nm \tag{6}$$

Using this equation, we were able to conclude that the brightest wavelength was around 578 nm, which is close to that of sodium at 589 nm. The angle of diffraction was almost identical for the first and forth order lines. Figure 6 which refers to excited hydrogen shows our diffraction observations when changing the voltage. When changing the voltage from 40V to 32V, we observe that the angle of diffraction decreases, from 0.05 to 0.03. Furthermore, when increasing the voltage from 40V to 48V, we see an increase in the angle of diffraction, from 0.05 to 0.15 respectively. From this data, we observe a linear relationship between voltage and angle of diffraction. Furthermore, Figure 7 shows our measurements for adjusting the slit width at our control voltage of 40V. When we change the width from 0.50 mm to 0.25 mm, we observe the angle of diffraction to decrease from 0.05 to 0.02. Furthermore, when we increase the slit width from 0.05 mm to 1.00 mm, we observe the angle of diffraction to increase by 0.10. Thus, we can conclude that slit width and angle of diffraction have a linear relationship. The best data is directly correlated to more light, a wider slit, and a lower order. Finally, we were able to calculate the Rydberg constant using equation 2. Using our data from the hydrogen tube for the red spectral line with a diffraction angle of 339 degrees. Using equation 2, 5, and 6, we found the Rydberg constant to be 12.56544. Our value has an absolute error of 1.5917 and a relative error of 14.5 percent. Our measured value is off by around 1.59171 when compared to the actual value at 10.97373.

# 4 Further Discussion

Several errors could have been made in this experiment. When measuring the angles of diffraction for hydrogen, we could have made in error when measuring the slit width which would have affected the conclusions made about the linear relationship.

This may explain why we recorded lower angle measurements for higher orders in Figure 3. Furthermore, it is likely that our value for the Rydberg constant is off due to a miscalculation with the vernier scale as it was difficult to read or an error in the adjustment of the spectrometer. We estimated our error to be +/- 0.5 arcminutes which is based only on the quantifiable measurement error and does not accounting for systematic error or random error. Finally, it is possible that we miscounted the order numbers in Figure 5, as it was difficult to visually observe emission lines for the unknown tube. In the future, more experimental data could have been taken when measuring the angles for hydrogen to eliminate error and thus recalculate the Rydberg constant to a lower error. Furthermore, we could complete a more rigorous test of the linear relationship between voltage and angle of diffraction by collecting data for different angles.

## 5 References

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