PHY 324: Measuring Atomic Spectra

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1 Introduction

The main purpose of this lab was to verify the Balmer series of atomic hydrogen by finding the Rydberg constant through the use of a prism spectrometer calibrated using the Hartman relation. The Hartman relation is given by the following equation:

$$y = \frac{m}{\lambda - \lambda_0} + b \tag{1}$$

Where y is the scale reading on the spectrometer, λ is the wavelength and λ_0, m, and b are constants unique to each spectrometer.

Using this relation to calibrate the spectrometer we can verify the Balmer series for atomic hydrogen which is given by:

$$\frac{1}{\lambda} = R_H(\frac{1}{2^2} - \frac{1}{n^2}) \tag{2}$$

For values $n \geq 3$ where n is the atomic energy level of the electron creating the light as it jumps down to $n = 2$, and where R_H is the Rydberg constant.

Having this relation another purpose of the lab was to identify an unknown gas. This was done by observing its spectra of the gas in a spectral tube using the spectrometer and fitting it to the relation obtained using Eq. 1.

2 Materials & Methods

- Prism Spectrometer
- Hydrogen Spectral Tube
- Helium Spectral Tube
- Unknown Gas Spectral Tube

1. Begin by first calibrating the spectrometer using the helium tube and the cited table of helium wavelengths and their corresponding relative intensity and colour[1]. This can be done by first focusing the spectrometer and using the slit width adjustment such that you make see various spectral lines. Then using the adjustment knob line up the spectral line with the cross hair visible through the eye piece. See Fig.1 bellow for a visual diagram of the mentioned components.

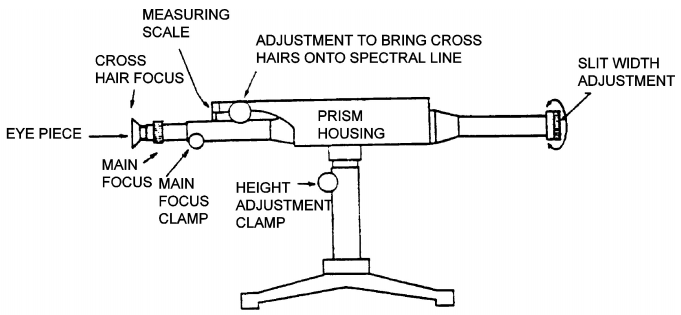

Figure 1: Main parts of the spectrometer[2]

2. Once the spectral line of interest is in the middle of the cross hair record the value you see on the measuring scale. The value is given by the value on the top scale that's lined up with the 0 of the bottom scale. This will give you the ones and tenths value of the measurement. The hundredths and thousandths values of the measurement is given by the first bottom scale number that lines up with any of the upper scale's numbers.

3. Using the cited appendix[1] look for the spectrum lines using the colour and intensity as reference. Record the spectrometer scale number and its corresponding measured wavelength. Fitting this recorded data to Eqn. 1 we get the relation between spectrometer dial measurement and observed wavelength.

4. Switch the helium light source with the hydrogen one and record the spectrometer dial measurement which corresponds to the $n = 3, 4, 5, 6$ energy levels of the hydrogen atom. The line colours will be red, blue-green, and two violet lights.

5. Switch the hydrogen light source with the unknown gas light. Observe the light colour the gas gives off and record it. Then with the spectrometer measure as many spectral lines as you can and record both their colour and their corresponding dial measurement.

3 Results

3.1 Calibration Curve

Following the steps outlined in step 1-3 in the previous section the data for helium was taken. This data consist of the spectrometer dial measurements which were found to correspond to the wavelengths on helium based on information given in the cited appendix[1]. This data is presented in the table below:

Table 1		
Spectrometer Dial Measurements	Uncertainty Spectrometer Dial Measurements	Wavelengths (nm)
6.010	±0.001	706.5
6.550	±0.001	667.8
9.030	±0.001	587.6
11.430	±0.001	508.4
11.500	±0.001	501.6
12.000	±0.001	492.2
13.500	±0.001	447.1
14.500	±0.001	402.6
14.925	±0.001	396.5
15.100	±0.001	388.9

Table 1: Measured dial values of spectrometer and their corresponding wavelengths

This data was then fitted to Eqn. 1 using the Python function `curve_fit` from the `scipy` library. The collected data and the generated curve fit are plotted below:

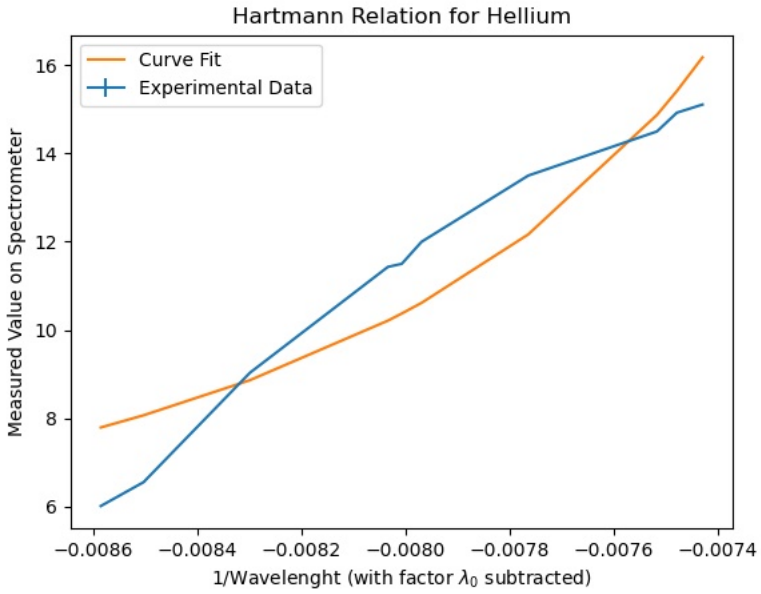

Figure 2: Calibration curve using the helium spectrum

The curve fit returned the following parameters with the following uncertainties:

Table 2		
Parameter	Value of Parameter	Uncertainty in Parameter
m	1142.95 d/nm	$\pm$ 0.12 d/nm
b	5.07 nm	$\pm$ 0.01 nm

Table 2: The return parameter for the curve fit corresponding to Eqn. 1. Note that d is used here as a measure of one dial unit on the spectrometer

The χ^2_{red} for this fit was calculated to be 1683699.3, using the formula:

$$\chi^2_{red} = \frac{1}{\nu}\sum_{i=1}^{N}\left(\frac{c_i - c(x_i)}{\sigma_i}\right)^2 \tag{3}$$

where c_i is the array containing the experimental dial measurements, $c(x_i)$ are the points plotted by the curve generated by `curve_fit`, ν is the number of parameters, and σ_i are the uncertainties in the dial measurements. This algorithm was performed using a `Python` programming function and can be found in the code along side this lab report.

3.2 Rydberg Constant

In order to verify the Balmer series the hydrogen atomic spectra was observed using the spectrometer and values in the table below were recorded. The data was collected in a similar fashion as outlined in the previous section using the spectrometer dial measurements.

Table 3	
Spectrometer Dial Measurements	Uncertainty Spectrometer Dial Measurements
8.350	$\pm$0.001
10.483	$\pm$0.001
12.295	$\pm$0.001
14.589	$\pm$0.001

Table 3: Measured dial values of spectrometer for Balmer Series

These dial measurements were then plugged into Eqn. 1 where m and b where determined by the curve fitting in the previous section. This converted the dial measurements of the Balmer series into wavelengths. Using this and knowing that $n = 3, 4, 5, 6$ respectively for each measurement the data was then fitted to Eqn. 2 to find the Rydberg Constant. The `curve_fit` function generated the following plot:

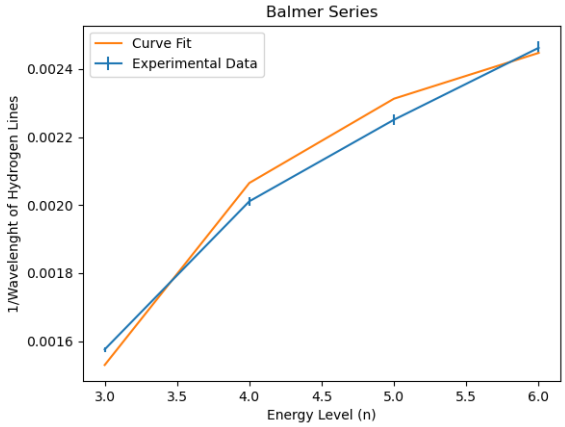

Figure 3: Balmer series for hydrogen following Eqn. 2

The uncertainties in the wavelengths were taken to be ±3nm as recommended in the lab handout[2]. The χ^2_{red} for this fit was calculated with the same steps outlined above, and found to be 162490211772.2. From this curve fitting the Rydberg constant was found to be 0.011nm ± 3.28 $\times 10^{-5}$nm.

3.3 Gas Identification

It was noted that the light given off by the gas was a light pink whitish colour. This hinted that the gas might be xenon and this was verified by observing some of the spectral lines using the spectrometer. The dial measurements for some of the bright spectral lines were recorded and using Eqn. 1 with the fitted parameters the wavelength of the lines were predicted. These results are shown in the table below:

Table 4		
Spectrometer Dial Measurements	Uncertainty Spectrometer Dial Measurements	Wavelengths (nm)
8.177	±0.001	654.1
8.628	±0.001	607.4
11.183	±0.001	473.0
11.351	±0.001	468.0

Table 4: Measured dial values of spectrometer and their corresponding wavelengths for unknown gas

4 Discussion

The calibration curve generated using `curve_fit` did not fit the data amazingly well. This can be seen both visually in Fig. 2 and by the large returned χ^2_{red} value. This could be for multiple reasons that have to do with taking measurements with the spectrometer. Things such as: ensuring the apparatus was in proper focus, making sure the light slit was open enough to let enough light in, but so much that a precise measurement could not be taken, and lining up the cross hairs as perfectly in the middle of spectra line as possible. Things such as misidentifying a line of the same colour but different wavelengths when comparing to the appendix tables could have also led to incorrect measurements leading to a bad fit of the data onto Eqn. 1. Overall however, the fit was not as bad as it would appear from Fig. 2 and the χ^2_{red} value. This is evident from the results of the Balmer series and unknown gas sections of this lab.

The results of the Balmer series experiment are rather good and indeed verify the Balmer series. This can be visually seen in Fig. 3 where despite the still large χ^2_{red} value the fit of the data looks much better than it did in Fig. 2. This would also suggest Fig. 2 bad fit effect was mitigated here as the Balmer series fitting depends on converting spectrometer dial measurements to wavelengths using the fitting seen in Fig. 2. From this experiment we get that the Rydberg constant was found to be 0.011nm $\pm$ 3.28 $\times 10^{-5}$nm. This is fairly close to the theoretical value which we can verify by calculating hcR_H (in units of eV) as discussed in the lab handout[2]. This calculation was done in the Python script accompanying this report and the value was found to be 13.65 eV which is very close in magnitude to the ground state energy of a hydrogen atom (-13.6 eV). This is exactly the result we expect from the Lyman series as it just a generalization of the Balmer series to lower n values. This would eventually become the basis for Bohr's model of the hydrogen atom where the aforementioned ground state energy was established to be $\frac{13.6eV}{hc} = R_H$ which is exactly what was found.

The curve fitting method used on the helium spectra was also the basis for determining the unknown gas. From the colour of the light emitted it could already be guessed that the light was xenon, however using the spectrometer verified this hypothesis. Converting the recorded spectrometer dial measurements to wavelengths as is shown in table 4 and comparing these to the table for xenon in the appendix[1] we see that indeed the gas in xenon. While the wavelengths do not perfectly line up we see: the first corresponds to the intensity 5 red, the second to the intensity 3 yellow, the third to the intensity 5 blue, and the fourth to the intensity 10 blue. From this we can see that the curve fitting did better with tracking the relation of spectrometer dial to wavelength at smaller wavelengths as the blue lines are much closer to their theoretical wavelengths than the red and yellow lines. We can then also conclude that the unknown gas is indeed xenon.

5 Conclusion

In conclusion we have used a helium spectrum in order to calibrate a prism spectrometer according to Eqn. 1. Using this we verified the Balmer series and the Rydberg constant was found to be 0.011nm $\pm$ 3.28 $\times 10^{-5}$ nm. We used this to verify that $hcR_H = 13.65$eV as expected. The relation found by the curve fitting also allowed us to verify an unknown gas as xenon using the spectrometer and the calibration curve to verify the wavelengths of its spectral lines.

References

[1] *Appendix 2 - Spectral Wavelength Tables.*

[2] Ruxandra Serbanescu. *Measuring atomic spectra.*