Atomic Spectroscopy

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1 Purpose

The purpose of this experiment is to demonstrate the emission lines of the electromagnetic spectrum for different elements. Diffraction is the key physical concept in this experiment, since an element will emit light it's light as a combination of its different spectral lines, and it must be diffracted into its components in order to observe them individually. The only controlled quantity is that of the diffraction grating, while measured quantities during the experiment are that of the angles at which emission lines are seen. From these quantities, the wavelength of said emission lines will be determined and an approximation of the Rydberg constant can be achieved.

2 Apparatus and Method

The two essential apparatus for the experiment are the discharge tube and the spectrometer. The discharge tube is lit up with an electric current with a potential of 5 kV. The bright lamp will be used as the light source for the experiment.

The spectrometer consists of two components: the collimator and the telescope. It is mounted on a base with a pivot that allows the telescope to move freely in a 180 degree range.

The collimator has a slit at the front end near the discharge tube, which regulates the amount of light entering the spectrometer. Light then goes through a lens and aligns the incident light to make it into parallel rays. The rays then passes through a diffraction grating with a predetermined size; the grating used was of 600 lines per mm. The light is then decomposed into its various individual wavelength components, and the emission lines can be seen by sweeping the telescope along the pivot. As light from a certain wavelength enters the telescope, a lens converges the incident light into the eyepiece, allowing the user to observe the emission line.

3 Procedure

The procedure was replicated for three different samples. After setting the discharge tube in front of the slit, it is important to align the telescope to the center of the telescope pivot, so it is perpendicular to the parallel beam. This allows for the identification of the central emission line, which will be used as the reference point to find the rest of the lines. The telescope will then be moved to find a new line, and recording of the angle indicated on the base is necessary. This measured angle has at the very least an uncertainty of 0.1 degrees from pure instrumental limitations.

The first run was done with Mercury for calibration purposes and ensuring proper use of the equipment, as the tube has a longer lifetime than that of Hydrogen. Hydrogen will be used to approximate the Rydberg constant. Finally, the spectrum of an unknown source will be used, with the objective of identifying it.

4 Data and Uncertainties

Each member in the team did 2 sets of measurements, one for the left-side lines and another for the right-side. The angle at which the undiffracted light is seen was not set to 0 degrees, and such all measurements were shifted, so only the change in angle from the center line is taken into account. The 6 measurements for each of the lines are then averaged, in order to reach a mean value for the angle at which the color is observed. The standard deviation of the mean is then:

$$\Delta\theta = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(\theta_i - \bar{\theta})^2} \tag{1}$$

With N being the number of measurements, θ_i the ith measurement for an angle, and $\bar{\theta}$ the mean value of that angle. Calculation of the mean and error of the angles for each emission line was done in Python.

Shown in Table 1 is the average measurements for the Mercury discharge tube. The uncertainty in the mean of each of the angles was lower than 0.1 degrees, so our uncertainty in these measurements must be instrument dominated.

Mercury (Hg)			
Degree Shift:	139.4		
Color	$\boldsymbol{\theta}$	$\boldsymbol{\Delta\theta}$	**Order**
Violet	15.1	0.1	First
Green	19.2	0.1	First
Yellow	20.3	0.1	First
Orange	20.4	0.1	First

Table 1: Average Measurements for Hg

For the measurements of Hydrogen emission lines (Table 2), the human error was larger than for the previous measurements. This is possibly due to the lower intensity of the emission lines, making them harder to be seen.

Hydrogen (H)			
Degree Shift:		139.4	
Color	θ	$\Delta\theta$	**Order**
Violet	15.1	0.1	First
Cyan	17.0	0.2	First
Red	23.3	0.2	First
Blue	35.75	0.3	Second

Table 2: Average Measurements for H

The most problems occurred with the Unknown Sample A (Table 3). The emission lines were too faint to be accurately measured, even after attempts of darkening the room. Because of these difficulties and lack of time to take more measurements, our data is very imprecise. This especially can be seen in the last two angles.

Unknown Sample A			
Degree Shift:		139.4	
Color	θ	$\Delta\theta$	**Order**
1	14.4	0.2	First
2	14.4	0.3	First
3	15.5	0.1	First
4	17.7	2.1	First
5	23.2	5.3	First

Table 3: Average Measurements for Unknown Sample A

The separation between the lines of the diffraction grating (slit size), is:

$$d = \frac{1}{600\frac{lines}{mm}} = 1.\bar{6}\mu m$$

And given its precision of 0.01%, as stated in the lab writeup, its uncertainty would then be:

$$\Delta d = 0.1\bar{6}nm$$

So the uncertainty in the incident light is mostly due to the glass from the discharge tube, as this error from the diffraction grating is immensely small.

5 Analysis and Uncertainties

5.1 Mercury

Knowing the angle at which an emission line is seen, and given the spacing of the diffraction grating lines, the wavelengths can be calculated as:

$$dsin\theta = m\lambda$$

$$\lambda = \frac{dsin\theta}{m} \tag{2}$$

Accordingly, when calculating the wavelength, the error from the angle of the emission line propagates as follows:

$$\Delta\lambda = \frac{1}{m}\sqrt{sin^2\theta(\Delta d)^2 + d^2cos^2\theta(\Delta\theta)^2} \tag{3}$$

The results were then calculated in Python using Equations 2 and 3.

For Mercury, the found wavelengths are shown in Table 4. By plotting the found wavelength against the sine of the measured angle for each emission line (radians), one should be able to fit a linear function with a slope equal to that of the spacing between lines in the diffraction grating, since:

$$dsin\theta = m\lambda$$

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

With the uncertainty for $sin\theta$ being:

$$\Delta sin\theta = (\Delta\theta)cos\theta$$

Using a Linear Least Squares fit, the plot of the model and the data can be seen in Figure 1.

Mercury (Hg)		
Color	λ (nm)	$\Delta\lambda$ (nm)
Violet	434.6	2.8
Green	548.6	2.7
Yellow	577.8	2.7
Orange	581.4	2.7

Table 4: Determined wavelengths and $sin\theta$ for Hg

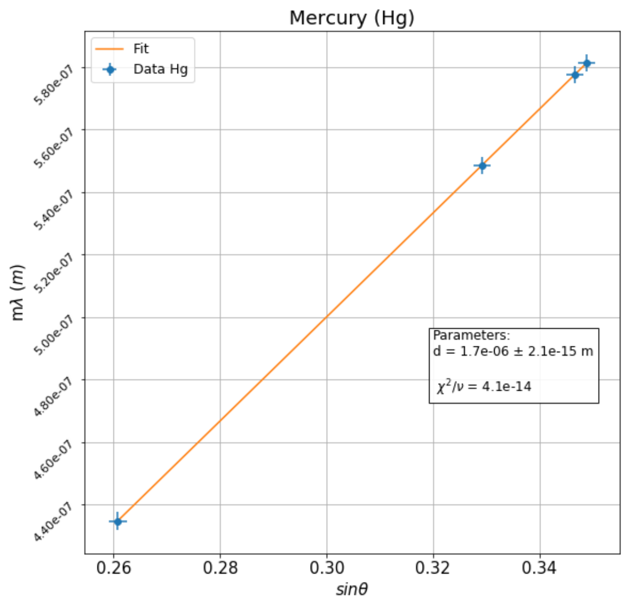

Figure 1: Plot of Mercury's $sin\theta$ against $m\lambda$

The calculated value for the spacing size d is as expected (equal to its nominal value), and well within the uncertainties of the actual spacing.

5.2 Hydrogen

The expected observed wavelengths from the Hydrogen discharge tube can be calculated with the Rydberg formula (Equation 4, Rydberg constant $R = 10973731.6\ m^{-1}$). After calculating the possible emission combinations of n_i and n_f spanning from 1 through 10, the only lines in the visible spectrum are the known Balmer series lines (Table 5).

$$\frac{1}{\lambda} = R(\frac{1}{n_f^2} - \frac{1}{n_i^2}) \tag{4}$$

With our determined wavelengths of the observed emission lines in Hydrogen (Table 6, a comparison is made between the observed and the expected wavelengths (Table 7).

Hydrogen Balmer Series				
	n_i			
n_f	3	4	5	6
2	656.1 nm	486.0 nm	433.9 nm	410.0 nm

Table 5: Expected wavelengths for electron transitions of H

Hydrogen (H)		
Color	λ (nm)	$\Delta\lambda$ (nm)
Violet	435.1	3.5
Blue	486.8	3.1
Cyan	487.3	4.8
Red	657.9	4.0

Table 6: Determined wavelengths for H

The wavelength of 410 nm was missing from the measurements, and this might be due to it being near the lower limit of the visible range and thus making it hard to detect. There is also the repeated lines that, within their uncertainties, include the 486 nm wavelength.

Hydrogen (H)				
n_i	n_f	λ_{th} (nm)	λ_{exp} (nm)	$\Delta\lambda_{exp}$ (nm)
3	2	656.1	657.9	4.0
4	2	486.0	486.8	3.1
5	2	433.9	435.1	3.5
6	2	410.0		

Table 7: Comparison of theoretical and experimental wavelengths for H

An approximation for the Rydberg constant can then be reached by looking at the slope of a function that fits the plot $\frac{1}{n_i^2}$ against $\frac{1}{\lambda}$. This is shown in Figure 2.

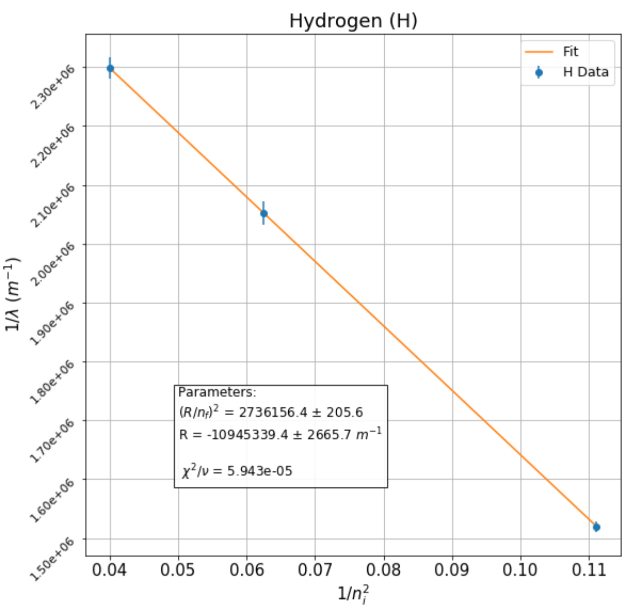

Figure 2: Plot of Hydrogen's $\frac{1}{n_i^2}$ against $\frac{1}{\lambda}$

The experimental value of the Rydberg constant is close to its nominal value, although not within the approximation's uncertainties. This is most likely due to the issues had when attempting to identify the angle at which the various emission lines can be seen for the Hydrogen discharge tube.

$$\left|\frac{R_{exp} - R_{th}}{R_{th}}\right| = 0.3\%$$

5.3 Unknown Sample A

The wavelengths of the seen emission lines were calculated from what few angles obtained. This resulted in imprecise measurements as can be seen in Table 8:

Unknown Sample A		
Color	λ (nm)	$\Delta\lambda$ (nm)
1	415.9	4.2
2	415.9	7.0
3	445.4	3.2
4	506.7	5.8
5	655.2	1.2

Table 8: Determined wavelengths for Unknown Sample A

After comparing to the provided emission wavelengths in the lab writeup, these wavelengths are mostly comparable to those of Argon within 2σ, with both values being compared in Table 9.

Unknown Sample A		
λ_{nom} (nm)	λ_{exp} (nm)	$\Delta\lambda_{exp}$ (nm)
415.9	415.9	4.2
416.4	415.9	7.0
451.0	445.4	3.2
518.8	506.7	5.8
641.6	655.2	1.2

Table 9: Comparison of nominal wavelengths for Ar and experimental wavelengths for Sample A

6 Results

The best results were obtained from the calibration run with Mercury, being able to accurately and precisely determine the value for the slit size of the diffraction grating. Problems arose when attempting to observe elements whose emission lines were fainter, those of Hydrogen and Argon, resulting in imprecise data and inaccurate results. The measured Rydberg constant was off by 0.3% from its actual value, and a precise fit was achieved. Uncertain results where seen with the Unknown Sample A, with the calculated wavelengths not being well descriptive of the exact element in the discharge tube, and the closest match is that of Argon.

7 Conclusions

We were able to complete the objectives of this experiment. The calculated slit size was precise, and the Rydberg constant was somewhat accurate, but determining the unknown sample was inaccurate due to uncertainties propagating from our measurements. This gives insight into taking further care in measurements in future experiments.