Importance of a spectrometer

A. Hamou[*]

(Dated: September 30, 2022)

Measurements of different lights using a Spectrometer. The measured data sets include Mercury, Hydrogen, and Sodium. This report will show how the 3 different atoms are related to one another in terms of lights, the results shows how to find Rydberg's constant within 0.1% error, the difference in energy between a fine structure of sodium within 10% error, and the wavelengths of different light spectrum's of all the atoms listed earlier.

I. THEORY AND PROCESS

Spectrometer is the process of breaking down a light using a prism and mirror. It allows for different light sources such as the sun to be broken down to its lights emitted. The main components of a spectrometer are the slit that allows the light to enter, the prism which allows the light to be diffracted, a telescope to observe the emitted lights, and a mirror to reflect the light. In this experiment, a Mercury, Hydrogen, and a Sodium gas filled tubes are broken down into their primary colors. Figure 1 will demonstrate the breakdown of Mercury into a non-linear graph. the reason we do this is to find the distance between the slits, in other words d from Formula 1. Next order of business will be Rydberg's constant within 0.1% accuracy, this is achieved through the hydrogen Blamer series. Later on for sodium a slit is apparent between two yellow lines, a change in energy between the two slits is necessary to achieve, this change in energy though will not be as accurate as achieving Rydberg's constant, it will be within 10%, the reason for this is because of systematic error.

II. MERCURY SPECTRUM AND ENERGY CHANGE FOR FINE STRUCTURE

Mercury is the first order of business, the value for d is already known to us, but we need to verify it with our data and achieve increased accuracy when testing our other atoms. Achieving d thorough our experiment is done through the following formula:

$$m\lambda = d(sin(\theta_d \pm \theta_i) - sin\theta_i) \tag{1}$$

Where m is the order of the color, λ is the wavelength of the different colors, d is the distance between the slits, θ_d is the measured degrees clockwise being positive, and counter-clockwise being negative, and θ_i is the margin for d.

If we plot this into a graph where our measured Data is plotted on the x-axis, and the y-axis was mλ we would get:

A. Figure 1: Mercury data set from experiment

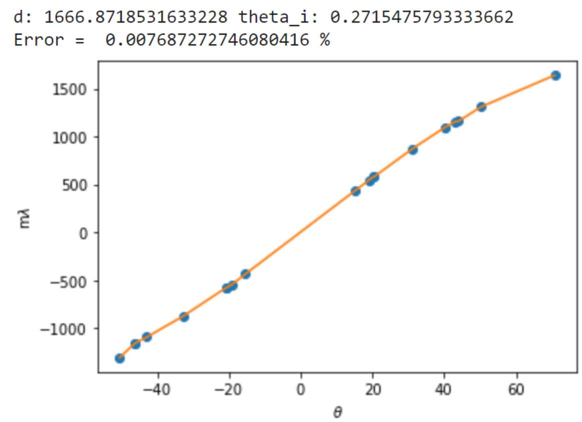


Figure 1 represents $m\lambda$ vs θ_d where θ_d is positive when looking clockwise, and negative when looking counter-clockwise.

With a little manipulation in certain software's, you can fit this into a non-linear fit and receive a value for d. The method used here comes from SciPy in python. The value for d is already know to us from the prism itself; however we tested our data on it and achieved a result within 0.1%. Our true value for d is 1/ 600 nm^{-1} which comes out to be 1,666.67 nm. Additionally; θ_i is achieved as well here, this is the margin of error for d; in other-words our plus or minus in the data to fit a more accurate result.

With these result we can now pinpoint exactly what wavelength will be for each color observed. For mercury, the following table will list the λ appropriate with the color, order, and θ_d. For additional information on how to get λ from data, the CRC handbook of chemistry and physics has a bunch of tested atoms and their wavelengths with different intensities. This experiment takes advantage of the already provided data to get a more accurate plot. Additionally, We have 2 yellow lines right next to each other, there are three but we can only observe two. These two yellow lines have a energy difference between them. They can be achieved, however; as mentioned in the introduction, the error margin is 10% Formula 2 will achieve this result for us. But for now I will show figure 2 which list's the data and the accurate λ from CRC.

[*] Also at Lab 265Physics Department, University of Nevada Las Vegas.

B. Figure 2: Mercury data set with calculated λ

	Order	θ_{d1}	θ_{d2}	λ	λ_0
Purple	1	15.242	15.383	435.833	435.887
Purple	2	31.175	32.583		
Purple	3	50.267	50.442		
Green	1	19.125	19.183	546.074	546.121
Green	2	40.125	42.792		
Green	3	70.800			
Yellow 1st	1	20.167	20.667	578.966	579.037
Yellow 1st	2	42.992	45.983		
Yellow 2nd	1	20.492	20.775	579.066	578.137
Yellow 2nd	2	43.975	46.167		

where θ_d is in degrees, λ is in nm representing the true value, λ_0 is also in nm representing the experimental value. and order in orbital period

The experimental values here are within 0.1% which is extremely accurate and thus little to no change in λ_0. Note that the difference between the the 1st and 2nd yellow line is extremely slim. we will use formula to to achieve the difference in energy between the two lines using:

$$\Delta E = hc\Delta\bar{v} \tag{2}$$

Where E is energy, hc is a constant that comes from planks constant equaling 1240 eV * nm, and v is the inverse of λ

plug all the know values in and we achieve a value of E to be 0.00036976 eV. this is definitely within 10% of our data, in fact this number is within 0.1% of the theoretical value of 0.0003698 eV. This indicates that our values were accurately measured and thus validating the test values for future experiments. Finding the change in energy here was not necessary to prove our values, its just an additional precaution and will be necessary for our Sodium experiment in which only one spectrum was apparent.

III. HYDROGEN AND THE BLAMER SERIES

The Blamer series is unique to hydrogen, in which it cannot be used on any other atom. It uses one of our fundamental constants known as Rydberg's constant. Now to get Rydberg's constant we must use the Blamer series. But first lets list the data we have on hydrogen, that way we can see where we need to plug values in to achieve Rydberg's constant. Before all that I want to mention what the accepted value is for Rydberg's constant, and what the error is for my data to be acceptable. R_H = 1.09677576 x 10^7 m^{-1} our accepted value should be within 0.1% of that value. Additionally I want to mention before hand that my data is not accurate and I will go more in-depth later on, but for now here are the original values from the experiment performed.

A. Figure 3: Hydrogen Data set from experiment

	Order	θ_d	λ	Blamer n
Purple	1	15.83	439.193	5
Purple	2	30.58		
Cyan	1	17.02	487.551	4
Cyan	2	35.12		
Cyan	3	58.72		
Red	1	23.95	661.523	3
Red	2	50.25		

where θ_d is in degrees, λ is in nm representing the expirmental value and Balmer n is the order in the blamer series

Note that their are only three colors and not four.

We have all the data we need to find Rydberg's constant. first lets identify Rydberg's constant in the following formula:

$$1/\lambda = R_H(1/4 - 1/n^2) \tag{3}$$

Where λ is the wave length, R_H is Rydberg's constant, and n is the balmer series.

Next we want only Rydbergs constant and we rewrite it to achieve:

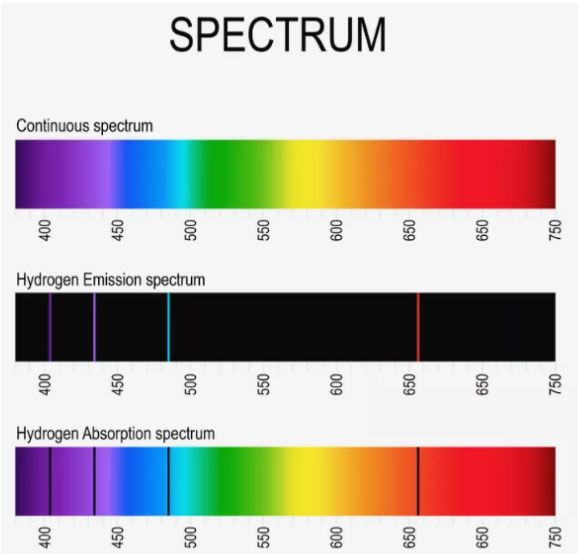
$$R_H = (\sum p_i^2)/(\sum \lambda_i * p_i) \tag{4}$$

Where p_i is:

$$p_i = (4n^2)/(n^2 - 4) \tag{5}$$

With all the values available, using formula 3 4 and 5 we achieve a Rydberg's value of 1.075650 $*$ 10^7 m^{-1} Comparing this value to the accepted value we get a difference of approximately 2%, the reason for this is due to the lack of colors observed, in other words a human error. Hydrogen is known to have 4 different colors, which are Indigo, purple, cyan, and Red. In this data set we only observed three. Which means we lack data to get an accurate value for Rydberg's constant. With Indigo in the data set, a more accurate Rydberg's constant would have been achieved. I will now show you the light spectrum of Hydrogen, in-case a replicated experiment were pursued.

B. Figure 4: Hydrogen Light spectrum



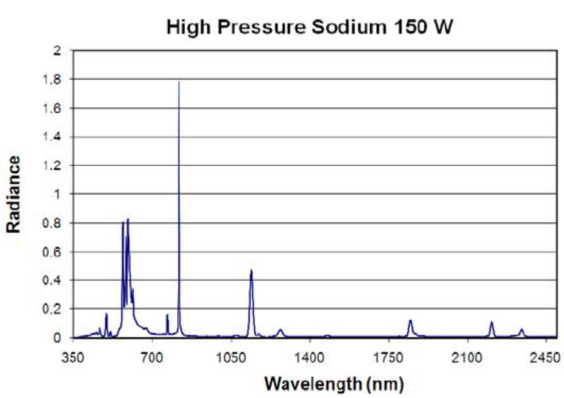
From A. M. Helmenstein

Note the 4 different absorption lines

IV. SODIUM AND THE FINE STRUCTURE

Sodium's light spectrum is very special, It has 1 very obvious color that outshine all else, for this paper I want to focus only on that one wavelength and achieve its fine structure and the change in energy between the line. As mentioned earlier, the way to achieve the change in energy is by using formula 2. We did this earlier to find the fine structure of mercury. Wow we are going to do it for sodium. Our value should be within 10% the margin of error of the true value which is $\Delta E = 0.0021$ eV. I will first demonstrate what the spectrum of sodium looks like with a scale for radiance.

A. Figure 5: Sodium prominence



From C. D. Elvidge

Note the prominence of the wavelength in the 550-600 range where the color Yellow lies, and how they have 2 different peaks both at .8 radiance. There is also the radiance is the in fared range, sadly though we cannot observe this with the naked eye.

Now we will calculate the change in energy for our yellow line. Our experiment gave us these values and the calculated values respectively to achieve the change in energy. They will be shown by figure 6.

B. Figure 6: Sodium Fine structure for Yellow

	Order	θ_d	λ	λ_0
Yellow 1st	1	21.47	592.244	589.0
Yellow 1st	2	45.4		
Yellow 2nd	1	21.412	593.281	589.6
Yellow 2nd	2	45.354		

Note the very small difference in θ_d between the first and second line. Where λ is our calculated value and λ_0 is our true value or accepted value for the yellow lines.

Additionally we calculated λ from formula 1 with our found value of d. they are very close to the true value which means that the calculations and data from experiment and accurate. Now we will find ΔE from formula 2. Plug in our values and we get a $\Delta E = 0.0036$ eV. this value unfortunately is not within the 10% margin we had hoped for, it is more within 72% which if it isn't obvious not very good. The reasoning here is most likely a human error when collecting data, or the sodium used in the experiment was a little inadequate for an accurate experiment.

V. CONCLUSION

Mercury gas has three different color sources which are purple, green, and yellow. They are very good determiners for the value of d to find the color spectrum of different atoms. Next we moved on to hydrogen and found the wavelength for each color. sadly tho we did not record all the data required due to a human error. Finally we calculated the difference in energy for Sodium, this is important to differential between two different wavelength emitting the same color. Similar to the hydrogen we did not have a very accurate data we can rely on since the error lies within our equipment, and human error. Now this experiment is very important for many reasons. Firstly being able to determine all these spectrum's emitted by gas will help identify the gas if observed in nature, an example of where we would observe it is in gas giants or stars. Those objects in space are made up of gasses that we can determine because of the light spectrum they absorb. Secondly they are not only emitting visible light, but also in fared and ultra violet, these are important because they can be dangerous if handled incorrectly. Finally its important to understand the world we live in, this concept helps us to understand why the sky is blue, why the sun appears orange, etc.

[1] A. C. Melissinos and J. Napolitano, *Expirments in Modern Physics* (1966).
[2] A. M. Helmenstine, Balmer series definition in science, Science (2019).
[3] C. D. Elvidge, Emission spectrum of a high pressure sodium lamp., (2010).
[4] Auroras paintings in the sky, Exploratium (2001).
[5] M. W. Davidosn, Education in microscopy and digital imaging.
[6] K. Walker, Spectrometer technology and applications, (2013).