

Experiment 3: Rydberg constant derived via optical methods

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ABSTRACT

The computation of the Rydberg constant not only provided a model for the emission spectrum for hydrogen but also a highly accurate measurement of many quantum constants. In our lab we examined the emission spectrum for hydrogen in the visible wavelengths. To accomplish this we used a precision spectrometer with a vernier scale. Specifically we observed the angle of diffraction of specific color lines the hydrogen was emitting, from there we constructed a mathematical model of how the spectrum would evolve using the Rydberg constant, from which we then applied our old data to provide the constants that are necessary to calculate the Rydberg constant. Inevitably the Rydberg constant is able to dramatically reduce the error and we were given a value within 99% of the true value.

I. INTRODUCTION AND THEORY

This experiment was performed to calculate our own personal Rydberg constant. The initial principal that begins our experiment is the energy of electromagnetic radiation. The energy of electromagnetic radiation is dependent on the frequency of the wave multiplied by planks constant which is $h = \hbar 2\pi$

$$E = hf \quad [1]$$

This equation shows that emitted photons from the electron of an atom will have frequencies associated with the level of excitation. From this development scientist began then to develop equations to match the displayed light. Initially in 1884 a scientist named Balmer was able to produce an equation to match the initial 4 wavelengths of the hydrogen spectrum.

$$\lambda_n = 364.6 \frac{n^2}{n^2 - 2^2} \times 10^{-9} \text{meters} \quad [2]$$

This shows that the wavelength of light emitted from hydrogen was equal to a constant multiplied by a fraction composed of n integers that are related to the quantum numbers. Balmer's results were highly accurate but to further generalize the equation to match any atomic structure. To do this the scientist Rydberg and Ritz were able to develop the equation

$$\frac{1}{\lambda} = RZ^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right) \quad [3]$$

This equation demonstrates that the wavelengths for emitted light from any atom, the n_1 and n_2 are principal quantum numbers given by the excitation of the electron in the atom, $n_1 < n_2$. Z is the number of protons in the nucleus. R is the Rydberg constant which is found to be

$$R_\infty = \frac{m_e e^4}{8\epsilon_0^2 h^3 c} = 10.97373 \mu\text{m}^{-1} \quad [4]$$

In this equation ϵ_0 is the permittivity of free space, e is the charge of the electron, m_e is the mass of the electron, and c which is the speed of light. In this approximation the Rydberg constant is determined to have a infinite mass nucleus which does not change the constant to much.

To gather data we used a spectroscope to observe the spectrum of light emitted from the hydrogen atom. Emitted spectrum's range from lines that are separated to full continuous spectrum's. For hydrogen only lines were displayed, which we accomplished with a diffraction grating. This allows us to gather the wavelengths experimentally and then learn the quantum numbers, the equation goes as follows

$$d \sin(\theta) = m\lambda \quad [5]$$

where m is the order number, d is the diffraction grating spacing, and θ is the angle of diffraction. From this equation we are able to deduce the wavelength of the emitted light and then from there move on to construct our own equation that can predict the wavelengths of other spectral lines.

II. EXPERIMENTAL ARRANGEMENT AND PROCEDURE

This experiment was able to be performed using two major devices this was hydrogen tube with a connection to a voltage supplier. The other device was a Spectrometer that was able to mechanically observe the light emitted by the hydrogen tube. We also used some wooden blocks to level the spectrometer and the lighting, for help

we also had 2 spectral charts that had a series of wavelengths and some other equipment initially used to test before the experiment was preformed. Before we conducted the major part of the experiment which was to collect data on hydrogen wavelengths via diffraction angles; we tested our equipment and did minor experiments with sodium light and a tube of boron gas that sat in the same holder as the hydrogen and given power with the voltage provider.

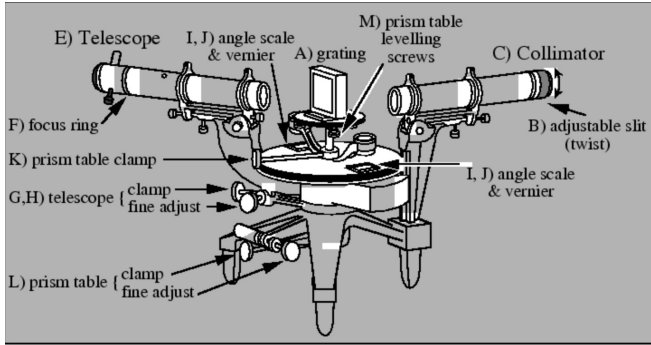


Figure 1: The spectrometer we used was able to measure the diffraction angle with the Vernier scale attached at the base of the device.

To conduct the main part of our experiment we had to use a Spectrometer that was connected to a diffracting plate and Vernier scale. The Spectrometer itself is composed of a Collimator and a Telescope. The Collimator collects the light and has a small grating at the tip to make sure the light does not exceed 2mm in width. The light would then travel down the collimator to the diffracting plate.

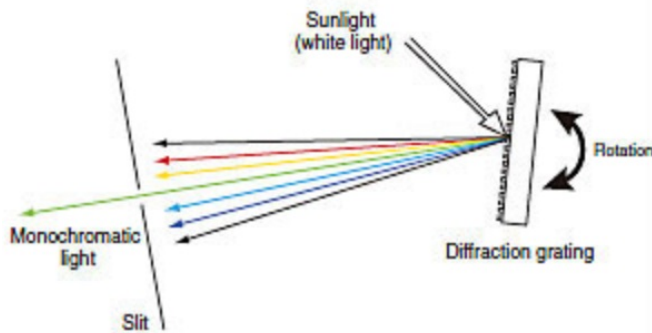


Figure 2: The Diffraction grating slit the light into 590 lines per millimeter segments that were then emitted into the Telescope of the Spectrometer, in the image it proposes sunlight passes but in the experiment it was excited hydrogen radiation.

The diffraction grating diffracts the beam into many different beams, that had scattering angles based on their order and wave length. That is why the use of the Vernier scale is imperative to the accuracy of this experiment.

A Vernier scale is accurate to the arc minute meaning its $1/60^{th}$ of a degree. The last part of the spectrometer was the telescope as it was the one we had to adjust according to how the hydrogen diffracts. The first part of our experiment we first worked with sodium light. While waiting for the sodium light machine to heat we adjusted the spectrometer placing the collimator in front of the source and then manipulating the knobs to make sure everything was in place especially the Vernier scale as the reference for measurement was needed. Then I adjusted the cross hairs of the telescope so that the cross hairs were centered with the diffracted light. After making sure all adjustments were complete we began to take the data for the first order diffraction maximums on both sides of the spectroscope, the different sides produced angle's that were of the same magnitude of each other. Then we took measurements of the doublet that is formed by the second order maxima. Then for the last part we tested an unknown lamp and it turned out to be neon.

To get our main set of results we set the variable voltage to about 40 Volts and placed a hydrogen tube in the lamp holder and then began to measure the left and right first and second order diffraction for beams of blue, green, and red.

III. DATA, ANALYSIS, AND RESULTS

The results of our labor lead us to this point here. For the first order of diffraction of the sodium light lead to an angle of 20 degrees on both sides so one side was 340 degrees. For the second order of diffraction the maximum was a doublet and the separation for the right side was 11 arc minutes and for the left side it was 5 arc minutes. At this point possible sources of systematic error lay within the equipment itself being faulty though the accuracy with the Vernier scale is high. We then checked the spectrum of a mystery tube that turned out to be neon, we were able to deduce this from a large spectrum ranging from purple to red as well as the wavelengths of the red and orange light were within the accepted values of neon. The trade off between a large slit and resolution is that the larger slot will be larger but less focused.

In the main part of our experiment we measured the first and second order of diffraction for emitted light from hydrogen gas. In our prior experiments the intensity of light helped provide better data as it maximizes the amount of photo electrons in the system, in this particular experiment we are looking for the angle not observing the beams themselves though for locating the beam the intensity was important. To get the best results you need a narrow slit and low order as it would provide you a very accurate and visible line which you can measure. After we did that we then calculated our results of the wavelengths we go and it lead to

	Calculated Values		
	Blue Wavelength	Red Wavelength	Green Wavelength
	444.2 \pm .1 nm	482.7 \pm .1 nm	663.5 \pm .1 nm
	437.3 \pm .1 nm	487.9 \pm .1 nm	644.4 \pm .1 nm
	432.3 \pm .1 nm	482.3 \pm .1 nm	652.1 \pm .1 nm
	426.6 \pm .1 nm	487.8 \pm .1 nm	637.9 \pm .1 nm
Average:	435.1 \pm .1 nm	485.2 \pm .1 nm	649.4 \pm .1 nm

Figure 3: This picture shows the wavelengths we calculated during from the spectroscope in the experiment.

The values we calculated at first glance fits the model of what an atom should do and shows how little variation there was overall when calculating these values. Though to make sure the values we were receiving would fit the Balmer and Rydberg models we had to calculate the expected values of what the wavelengths should be.

N1-N2	Expected Wavelengths			
N1=2	N2= 2,3, 4, 5, 6	3,4,5,6,7	4,5,6,7,8	5,6,7,8,9
1	121.5022908	102.5175578	97.20183262	94.92366467
2	656.1123702	486.0091631	433.9367528	410.0702314
3	937.303386	640.7347365	546.7603085	502.3360334
4	1350.025453	874.8164936	721.6499694	648.0122175
5	1863.955597	1162.814892	934.633006	823.8018041
6	2473.038934	1499.685418	1181.002266	1025.175578

Figure 4: This chart shows the expected values of wavelength that we could possibly get from the hydrogen atom we use equation 3 to calculate and change the quantum n's depending on the case.

Then we calculated the ratio of the wavelengths as the change from quantum number to quantum number and what this showed was a slope between the wavelengths and that there was an ability to predict the next number. Though the overall change between numbers was dramatic as higher integer quantum numbers for N1 and smaller quantum numbers for N2.

Wavelength Ratio		
1.185185185	1.0546875	1.024
1.35	1.12	1.058201058
1.462857143	1.171875	1.088435374
1.543209877	1.212244898	1.113636364
1.60296846	1.244140625	1.134536246
1.649038462	1.26984127	1.152

Figure 5: This is the ratio of the expected wavelengths, this shows the ratio of wavelengths depending on the quantum positions of the electron.

After learning the possible wavelengths and their ratios I calculate the error I received small errors that are very

close to the predicted values. Not only does this show little systematic error in the set up but the Rydberg constant itself is naturally proportioned to have little error. Which then leads to our result of the Rydberg constant where we apply our received wavelengths and lead to the following wave lengths.

Error		
435.1	485.2	649.4
433.9367528	486.0091631	656.1123702
1.002680684	0.9983350867	0.9897694808
.2% Error	.2% Error	1.1% Error

Figure 6: The Error we received for the wavelengths was placed here it was not dramatic less than 1% for most cases except for the green which had a 1.1% error which is still highly accurate.

Rydberg Constant		
N1= 2 N2=4		Error:
$1/\lambda = RZ(1/N_2^2 - 1/N_1^2)$		R=10.97373
$1/\lambda = R(3/16)$		my R= 10.992
$(16/3\lambda)=R$		1.001664885
0.01099203078		100.1664885
10.992		.17 % Error

Figure 7: The Rydberg constant was found by us and had a astounding low error of .17% which should be found, our Rydberg constant is viable for use.

IV. CONCLUSION

The overall guiding principle of this lab is the reliance of electromagnetic radiations energy on the frequency of the wave that is released. The whole phenomena of emitted spectrum shows that the color of the light is determined by its frequency. This allowed us to learn a systematic way to chart and predict the emitted light from particular atoms, eventually leading to a generalized equation for the wavelengths of the light but it was noted a constant was required for the results, after time it was found this constant was equal to many natural constants in nature and the value can be calculated from those values. So after performing two prior experiments gathering the mass and charge for an electron we can use our results here to get our own Rydberg constant and we would be able to use it to model the hydrogen atoms emission spectrum. In our specific calculation the error

we received was less than 1% for the Rydberg value itself, the calculations of the individual wavelengths was off less than 1% with the exception of 1 at 1%. Ultimately we have calculated the near exact values for Rydberg constant, this is possible because the unique properties

of how the Rydberg constant is calculated which causes minimal error to occur. The Rydberg constant was necessary for the calculation for predicting the wavelengths for many atomic structures and then eventually a fully fledged model of the atom.