Atomic Spectrum
Counting Statistics*

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Abstract: This experiment observed the spectral lines of mercury, hydrogen, and sodium to calculate a least squares fitting to determine a grating spacing of 604.835 lines/mm then using python's curve fit to determine the angle of incidence in the setup resulting with -6.208208 degrees. After determining the grating lines and angle of incidence, the Rydberg's constant was roughly calculated at 10836166.81275329 m**-1 within a 1.199 percent margin of error by using the hydrogen spectra lines to determine this value. The average difference between energy levels was approximately 3e-28.

Usage: Informational Purpose

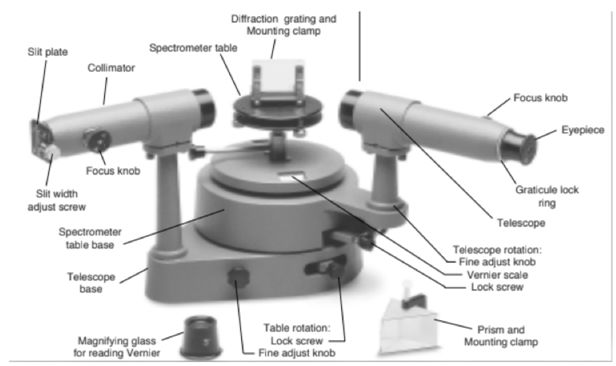
I. INTRODUCTION

Niels Bohr developed an atomic model based off of his research using spectroscopic data in which he was able to develop his postulates that would describe how energy and electrons orbitals behaved by describing that the angular momentum of energy is quantized, where electrons can only move in integral multiples of h/2pi. Electrons accelerating constantly in orbit do not radiate electromagnetic so that energy can still remain conserved but when electrons jump between orbits then they will emit radiation. The frequency of radiation is equal to difference between the initial and final state energy divided by Planck's constant (Resnick 99).

In this experiment, we will be using the spectrometer to observe the spectra lines of varying wavelengths of mercury, hydrogen, and sodium to calibrate the spectrometer to obtain the grating spacing, the Rydberg constant, and the difference between energy levels of the measured wavelengths and visible spectral colors.

II. MEASUREMENTS AND PROCEDURES

In order for to begin collecting data the spectroscope needed to be properly calibrated. First, it was calibrated by assuring that the plane of the grating was completely level. Then the spectrometer needs to be focused to make sure the the cross hairs have a sharp image. Additionally, the cross hairs should be re-aligned with the fine tuners of the setup to ensure that there isn't any displacement of the cross hairs when adjusting eye level. The collimator should be directly opposite of the telescope before beginning any adjustments so that light will come through as a straight line through the diffraction grating that will be placed within the grating holder. Once setup was completed the next step was to calibrate the spectrometer using the mercury light source to evaluate the diffraction grating's spacing. This was done by taking down the measurements of angles at which the cross hairs were right aligned with the visible wavelengths of light.



After measurements were taken, they were then used to do a linear regression to calculate the grating spacing. It was important to make note of where the telescope is zeroed as this was necessary in calculating the angles at which the spectral lines were observed. By using Bohr's postulate and the Balmer series of hydrogen we are able to using the following equations to calculate the Rydberg constant and the differences between energy levels. The variables in these equations represent E - energy, Z-atomic number, n is the state and or orbital of the molecule which will also be denoted by the final and initial state, hc is Planck's constant times the speed of light, k is the Boltzmann constant, Rh is the Rydberg constant that we will solve for, q is the charge of the electron, and m is the mass of the electron. Lambda denotes the wavelength of the spectra which is measured in nanometers, d is the grating lines which will be in units of lines/mm, and proceeding is the angles of incidence and reflection. m is the order number of the spectra as looking through

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the scope there will be repeats of wavelengths.

$$m\lambda = d * (sin(\theta_r - \theta_i) - sin(\theta_i)$$

$$E : \frac{hc}{\lambda}$$

$$E_n : \frac{Z^2}{n^2} E_0 (n = 1, 2, 3...)$$

$$E_0 : \frac{2\pi q_e^4 m_e k^2}{h^2}$$

$$E_n : R_h (\frac{1}{n_f^2} - \frac{1}{n_i^2})$$

$$\frac{1}{\lambda} : R_h (\frac{1}{n_f^2} - \frac{1}{n_i^2})$$

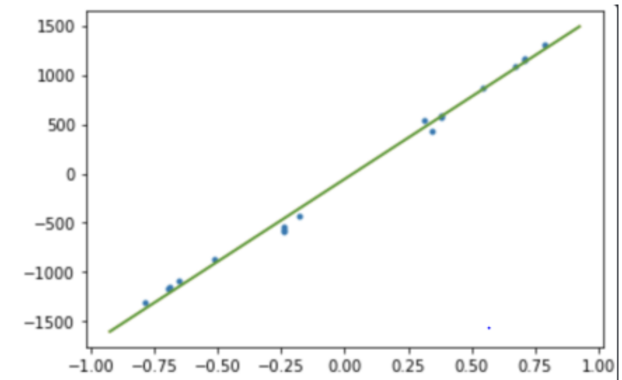
Primarily these equations are provided to give some idea of how they are derived in thought but the full proof can be derived using angular momentum ,centripetal force, coulomb force, and the total mechanical energy equation. The Balmer series equation will be used to calculate the Rydberg constant by diving Energy by using the equivalency of E is equal to hc divided by lambda. And the first equation will be used to calculate wavelengths of n order for all spectra of mercury, hydrogen, and sodium.

III. DATA ANALYSIS

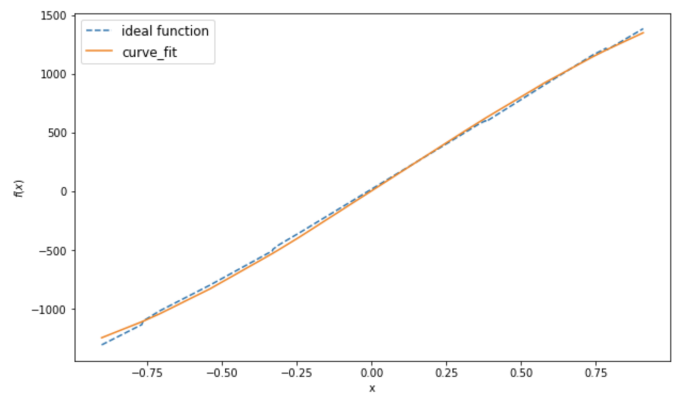
The visible spectrum ranges from about 400nm to 700nm. From 400nm-435nm is the color violet, 435nm-520nm is blue, 520nm-565nm is green, 565nm-590nm is yellow, 590nm-625nm is orange, and 625nm-740nm is red.

Mercury	n	Hydrogen	n	Sodium	n
-1359.56	-3	-1362.18	-2	-559.845	-2
-1194.04	-2	-958.362	-2	-557.036	-2
-1188.34	-2	-861.998	-2	-537.345	-1
-1115.26	-2	-630.812	-1	-535.467	-1
-871.859	-2	-457.365	-1	575.4692	-1
-545.797	-1	-402.704	-1	587.8544	-1
-543.452	-1	467.8079	1	608.234	-2
-511.014	-1	498.307	1	610.3481	-2
-396.749	-1	658.503	1	E	E Diff
464.7775	1	863.9772	2	3.55E-27	3.00E-28
569.6592	1	963.358	2	3.57E-27	3.00E-28
598.884	1	1242.825	2	3.70E-27	2.94E-28
599.7327	1			3.71E-27	2.58E-28
867.4658	2	Rh		3.45E-27	
1061.233	2	1.08E+07		3.38E-27	
1107.904	2	Rh Error%		3.27E-27	
1113.322	2	1.199818		3.25E-27	
1227.252	3				

By obtaining the wavelengths of the mercury spectrum of the colors blue, green, and yellow the data was fitted to a linear regression to obtain the value for the grating. Then after calculating the linear regression a non-linear regression was done since there is an additional sine term in the equation that fit our data. The angle of incidence is unknown so by by using python's curve fit and the obtained grating from the linear regression, the angle of incidence was determined to be roughly -6.2 degrees.



The x axis of the above graph is the measure of angles in radians fitted to d*sin(theta) with the y axis being the wavelengths of the spectra. This was done using the python library function of first order polyfit.



The grating after doing curve fit was adjusted to 604.835 lines/mm. After calculating the angle of incidence and grating spacing the data for hydrogen was calculated of the colors blue, green, red, violet. This data was then used in order to determine the Rydberg constant by using the Balmer series of Hydrogen. The Rydberg constant was determined to be 10836166.81275329 m**-1 within a 1.199 percent of the actual value of the Rydberg constant, 10973731.6m**-1. Last, the data was taken for sodium by taking the wavelengths of the first and second order doublets of orange. The difference between energy levels was calculated using this data in which there was some minor variation in energy level differences but there was some error in this experiment due to human error in which some measurements weren't the most precise. The order of magnitude of the difference between the energy levels of P1/2 and P3/2 are so small that it would reasonable to conclude that the difference between the measurements are the same.

IV. CONCLUSION

The possibilities of error in this experiment can be exceptionally high if not properly accounted for but even with the most cautious of steps it is still possible to make mistakes due to the nature and deceptiveness of human error. Our eyes are not accurate measuring tools and the precision and accuracy required of this experiment can easily mislead any experimenter. The energy levels of the hydrogen atom are proportional to 1/n**2 as we do see this using the Balmer series. Each measurement within the set of sodium measurements gave approximately the same difference with the biggest difference being about 1 percent dissimilar.

[1] Robert Eisberg, Robert Resnick *: Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles. Date Accessed: 10/5/2021*