Introduction

At the turn of the twentieth century the scientific community was beginning to turn their attention to understanding the structure of the atom. A new understanding of physics was beginning to emerge through quantum mechanics. It was discovered that electrons in atoms can only have certain discrete energy level as oppose to the conventional wisdom of a continuous spectrum. Frank and Hertz showed these discrete energy levels by bombarding a gas with electrons causing electrons of those gas to excite to another energy level. They showed that these gas can only accept certain amounts of energy and that energy corresponds to the difference in energy between levels. In this experiment we will show the first four excitation of helium gas by bombarding them with electrons of specific energy. The experiment revolves around a glass bulb with a filament. Once a voltage is applied to the filament electrons are emitted. If the electrons emitted have certain energy then it would inelastically collide with the He atoms. The collision would render the electron with no kinetic energy and it would be attracted to the positive collector ring inside the bulb. As a result a current versus potential plot can be created to show helium's discrete energy levels.

Theoretical Background

The theory of this experiment revolves around Niels Bohrs hypothesis of the atom, where electrons can only be at discrete energy levels inside the helium. Inside the glass bulb is a filament, collector ring and anode. Once a voltage is applied to the filament then electrons leave the cathode are further accelerated by the anode inside the bulb. If the electron doesn't hit any helium atom then it would leak back into the anode through the wall of the glass. However at certain filament potentials the electrons emitted from the cathode will hit a helium atom and perform an inelastic collision. The collision saps the electron of almost all of its energy and it would be attracted towards the collector ring recording a small increase in current. As the filament potential is increase in a current versus voltage plot peaks will appear and they represent the critical energy required to excited the electrons of the helium atom to higher states. From these peaks the energy levels of helium can be obtained and compared to the theoretical values.

Analysis

The scans of 2.0V, 2.3V, and 2.6V excitation can be found in the appendix section. To calculate the location of peaks on the scans we had to first find a way to measure the associated voltages of each peak. To do so each plot has two points of measured voltages located. From this we used the image viewing program "Faststone Image Viewer" to find the pixel distance from the two points. This gives us a scale of $\frac{Votlage}{Pixel}$. Below is a figure of the filament voltage of 2.6V and focused in area of 10V-35V.

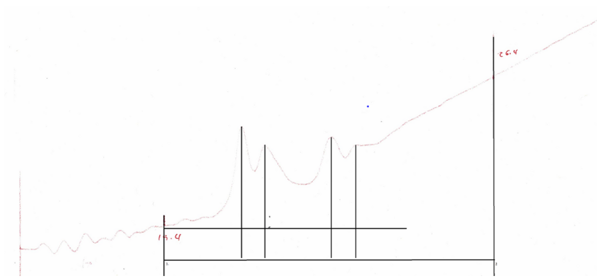

Figure 1: 2.3V Scan

To obtain the scale the points "1" and "2" on the graph will give us the $\frac{Votlage}{Pixel}$. From there we find the pixel coordinates of each of the peaks and add 15.4V in this example to the value of the peaks. Below are the tables summarized for each of the three filament voltages 2.0, 2.3, and 2.6. For both 2.0 and 2.3 we did one scan but for 2.6 we decided to use two to have more data to analyze. The value of the table already accounts for the shift in the peak. The expected value from the table were taken from the course text [Helium Ionization]. Next following analysis would be dedicated to calculating the uncertainty in calculated excitation potential for the filament voltage 2.0V and energy level $n = 1$.

First step is to calculate the voltage difference between the two points on the graph (May refer to the first figure of the appendix). The two points gives $11 \pm .07V$ where the error of both voltages is 0.05V. For the following uncertainty calculations the error is calculated using the equations for multiplication:

$$e_a\% = \sqrt[2]{(e_b\%)^2 + (e_c\%)^2} \quad (1)$$

For addition (Both equations is from [Treatment of Errors]:

$$e_a = \sqrt[2]{(e_b)^2 + (e_c)^2} \quad (2)$$

Next is to calculate the pixel distance between the two points which gives us $1980 \pm 21 pixels$ where the pixel error for both points is 15 pixels. This error was determined by approximating how thick the crayon line is, the thicker the line the higher the error is. With both values we can get the scale of the image in units of $\frac{Votlage}{Pixel}$, doing so gives a scale factor of$(555.56 \pm 6.9)x10^{-5}\frac{Votlage}{Pixel}$. Next is to calculate the pixel difference between the first voltage point to the first peak. This gives us a pixel difference of $463 \pm 21 pixels$. With this we can calculate the difference in terms of voltages using the scale factor and this gives us $2.57 \pm 0.12V$. Now most of the heavily calculation is done and the final error is calculate by adding this value to the first voltage point. Finally this gives us $17.97 \pm 0.13V$. Lastly to calculate the offset the theoretical value of 19.8 is subtracted by 17.97. This gives us that the offset is 1.83 ±0.13. This process of uncertainty is calculated for energy level n=1,2,3,4 and also for the three filament potential 2.0, 2.3, and 2.6.

Energy Level	Calculated Value (V)	Excepted Value (V)	Percent Difference%
1	19.8 ±0.13	19.8	0
2	20.59±0.14	20.9	1.49
3	22.81±0.16	22.9	0.38
4	23.61±0.17	23.21	1.70

Table 1: Filament Potential of 2.0V (Peak shift of 1.83 ±0.13)

Energy Level	Calculated Value (V)	Excepted Value (V)	Percent Difference%
1	19.8 ±0.19	19.8	0
2	20.70±0.20	20.9	0.96
3	23.31±0.23	22.9	1.79
4	24.23±0.25	23.21	4.37

Table 2: Filament Potential of 2.3V (Peak shift of 1.74 ±0.19)

Energy Level	Calculated Value (V)	Excepted Value (V)	Percent Difference%
1	19.8 ±0.25	19.8	0
2	20.58±0.26	20.9	1.55
3	22.84±0.29	22.9	0.25
4	23.67±0.31	23.21	1.97
Energy Level	Calculated Value (V)	Excepted Value (V)	Percent Difference%
1	19.8 ±0.17	19.8	0
2	20.56±0.19	20.9	1.62
3	22.82±0.23	22.9	0.37
4	23.68±0.26	23.21	2.03

Table 3: Filament Potential of 2.6V (Peak shift of 2.34 ±0.25 for first table and 2.38 ±0.17) for second.

Overall the results were agreed very well with the theoretical predictions. The largest deviation was about 4.37% difference from the expected value.

Appendix

Scans of Voltages 2.0, 2.3, 2.6

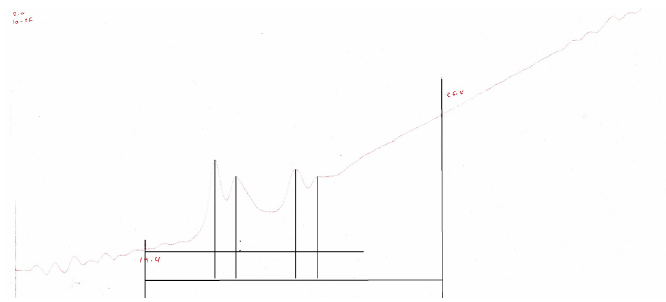

Figure 2: 2.0V Sca)

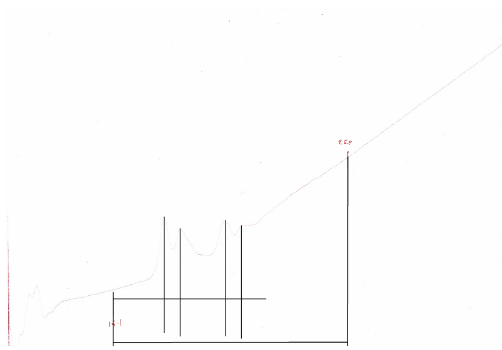

Figure 3: 2.3V Scan

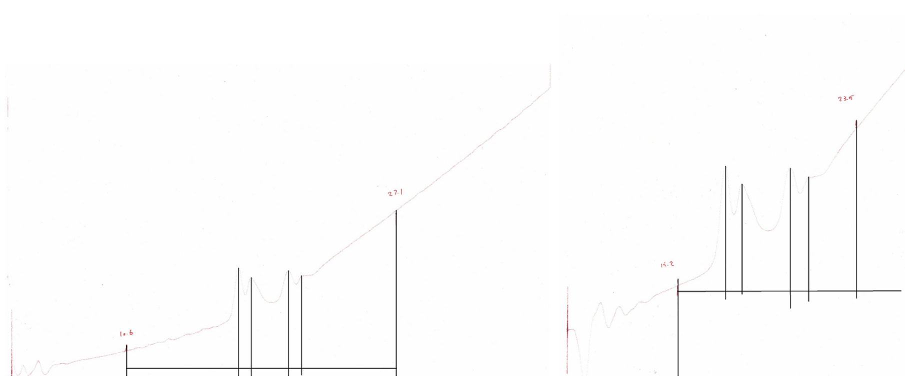

Figure 4: 2.6V Scans

References

[Treatment of Errors] Gardiner, Jeff. n.d. Treatment of Errors. Waterloo (On): University of Waterloo.

[Helium Excitation] Gardiner, Jeff. n.d. Helium Excitation. Waterloo (On): University of Waterloo.