PHY324H5S
Lab Report Title Page
All information is required

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Experiment Name: Fertz Laboratory

Date Performed: 05/02/21

Due Date: 21/02/21

Report Mark: **Marked By:**

- Adhere to class policies, specifically the code of behavior and academic honesty. Lab reports are to be written individually.
- The report should be written using a computer and word processing and spreadsheet software such as Word and Excel.
- You can find the two lab manuals: "Introduction to Experimental Physics" and "Instruments and Measuring Devices" and complete write-ups for all experiments on Quercus.
- Late reports are not accepted.

Abstract

The purpose of this laboratory was to understand different part of quantum physics. Demonstrating energy levels in atoms and what happens when electrons jump from one orbit to another. As well as, understanding what happens to a mercury atom when it collides with electrons going at specific accelerated voltages. Moreover, proving theoretical models of Bohr-Rutherford and classical. Lastly, understanding the quantum description of an atom.
Theoretically, the predictions were that the mercury atom when hit with a specific accelerated electron at $4.9eV$ will excite the atom, causing the atom to create ultraviolet light. This happens due to the electron releasing radiation, some time later the atom goes to normal until hit with another multiple of $4.9eV$. Experimentally, that notion was proven, during the experiment, the mercury atoms inside the apparatus were emitting light, not to the point of ionizing. Also, after some calculations, the average accelerated voltage difference for each peak was $4.9 \pm 0.1eV$. Meaning, the experimental value to excite the mercury atom was less than 1% of an error from the theoretical.
Knowing that the accelerated voltage equates to the kinetic energy, helps determining the graphs. Graph 1 resembles exactly what the kinetic energy graph would look like in respect of seconds. Since the kinetic energy and the current a proportional to each other. Graph 1 resembles the predicted graph in figure 1.
The experimental values followed perfectly with the theoretical and predicted values of the laboratory of Frank-Hertz.

Introduction

The purpose of the experiment is to demonstrate the discrete/quantized energy levels in atoms by observing energy losses by electrons that scatter from atoms. This experiment helped to prove the theorized predictions of the model, as well as, established a key lead into the quantum description of an atom.
The laboratory was conducted with the help of a hot cathode which will be used to accelerate the electrons through the apparatus; a collecting plate such as an anode, which will be showered with electrons and will transform the kinetic energy from the electrons into current; As well as, mercury vapour tube, which the electrons will be colliding with elastically and inelastically to give a linear sinusoidal wave due to high kinetic energy and atoms getting excited. The electrons will get shot out of the cathode into the mercury vapour towards, just like figure 1, to land on the anode, which is kept at a small, negative reverse-bias voltage. Any electrons that reach the anode will produce current, and current is proportional to kinetic energy. The accelerating voltage can be adjusted so that the electrons have higher or lower kinetic energies. The convenience is that, by definition, an electron put through an accelerating voltage of 1V will receive 1eV of energy, which means the accelerating voltage you set is roughly equal to the average kinetic energy of the electrons in electron Volts (eV).

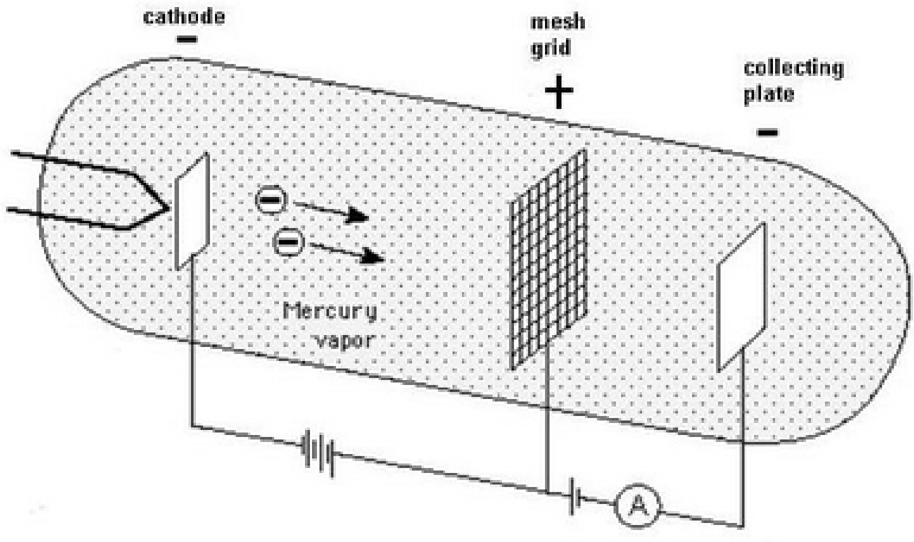


Figure1: This is a schematic of how the electrons are going to be launched by the cathode through the mercury vapor. An electron being showered on the mercury vapour will lose energy due to inelastic collision, and will reach the collecting plate (anode). The information collected is the remainder of the energy. The energy produces a current that we measure. Illustration: "https://torekkunagulchemhl.wordpress.com/2014/09/08/the-franck-hertz-experiment-on-energy-levels/"

In a diode filled with gas there's a high temperature cathode and an anode, to which the diode is going in a reverse bias. A reverse bias takes the negative battery terminal to the positive terminal, and the positive battery to the negative terminal; contrary to the forward bias which take the positive to positive and negative to negative. The point of a reverse bias is to have no current flowing and for the traveling electrons to have final contact with the anode. Until the electrons have contact with the anode, the electrons need to go through collisions between the mercury vapor molecules to reach the anodes. Some collisions are elastic and some are inelastic; during the inelastic collisions the atom gets excited due to the electron, resulting in the electron losing energy. When electron loses energy due to inelastic collisions, the mercury get excited, and the whole point of the experiment is to demonstrate the discrete energy levels in atoms by observing energy losses by electrons. Thus, if every stray electron reach the anode, then the observation would be purely kinetic energy of electrons. Moreover, with the excitement of the atoms and the increase of voltage of electrons, the current resembles a linear sinusoidal graph:

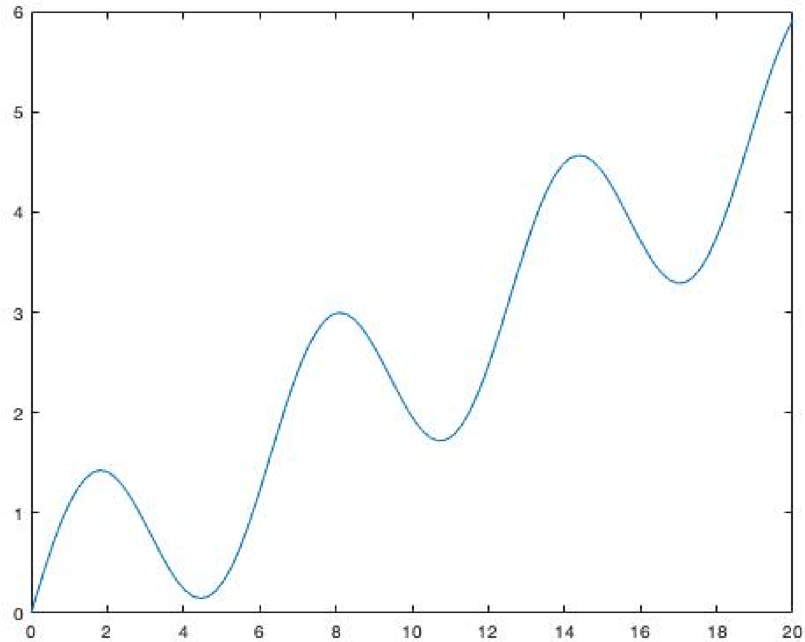


Figure2: This is a simulation (not to scale) of what the current should look like. The independent x values are the voltage measured in volts and the dependant value y is the current measure in ampere. This graph is a sketch, the real graph will have maximums at $4.9eV$ due to mercury vapour.

From Bohr-Rutherford model has it that the electrons orbit the nuclei and each orbit from the nuclei has a certain size and energy. Also, radiation can be absorbed or emitted when an electrons jumps from one orbit to another. The Bohr model predicted that when an electron from its excited energy level jumps to a lower energy level, light would be emitted. Thus, when an electrons exceeds a kinetic energy level of $4.9eV$, the mercury atom releases an uv (ultraviolet) light. Later goes back to its original state. Looking at figure 2 for reference, every $4.9eV$ would be the peak of the graph due to such high energy from kinetic energy.

$$4.9eV \cdot n \text{ , where } n \in \mathbb{N}$$

Since the current is proportional to the kinetic energy, the the kinetic energy model would resemble the same as the current graph (Figure 2). Due to the Bohr-Rutherford model, and what happens when the electrons interact and excite the mercury molecules, the kinetic energy will be absorbed by the molecules reducing the current and kinetic energy. Resulting in a linear sinusoidal graph.

Procedure

Start by turning on the oven unit. Set the temperature to around 200°C. Connect the oven to the control interface using ports A, K, F, and E and the compatible cables for each. The control interface should already be connected to the oscilloscope. It should just be turned on.

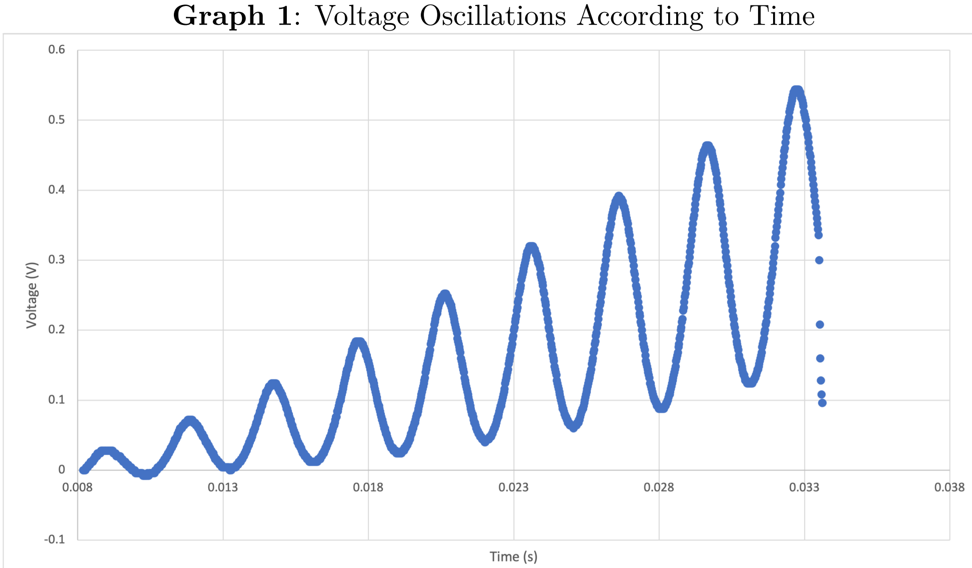
Ensure that the filament voltage starts at around 7.5V (you may turn it up to at most 10V during

the experiment if you want) and the reverse bias is set to about 1.5V. The minimum of the accelerating voltage should remain at 0V, feel free to vary the maximum between 0 and 80V. The light coming from the mercury oven should be a pale bluish-green when it's functioning properly. In a brightly lit environment, you might not even see the pale light given off by the equipment, so don't be concerned if it is not visible. If you see it turn to a bright white, this means your accelerating voltage is too high and you have begun ionizing the mercury; turn down the accelerating voltage when this happens as it can throw off your results.
Benefits of using the accelerating voltage instead of anything else, helps with the acquisition of the kinetic energy involved in this lab.

Data and Analysis

This experiment allowed us to investigate quantized energy levels in atoms by observing energy losses by electrons through collisions. Also, prove the theorized predictions of the model.
Firstly, From the Bohr-Rutherford model it has been said that electrons orbit the nuclei on different energy levels and when electrons jump from on orbit to another it can either absorb or emit radiation. Theoretically, working with mercury atoms, when it gets into an inelastic collision with an electron with kinetic energy of $4.9eV$, it emits ultraviolet light due to it the electron jumping to a lower level; thus, by Bohr's model, it'll emit radiation.
First, the data collected from this experiment came from the oscilloscope. The oscilloscope also came with a graph (Appendix Graph) that shows two channels. First channel being the linear graph of the voltage per time. Channel two being the oscillations of volts and time. However, being that the oscilloscope analogue is old and just sweeps through the domain; results, in the horizontal axis to display time and the vertical axis to display voltage. Now, theoretically the graph looks like the current against accelerated voltage graph (Figure 1 in introduction). Since it is a sinusoidal graph and the vertical axis is the voltage, then each peak represents the maximum amount of volts used at a specific time.

Graph 1: Voltage Oscillations According to Time



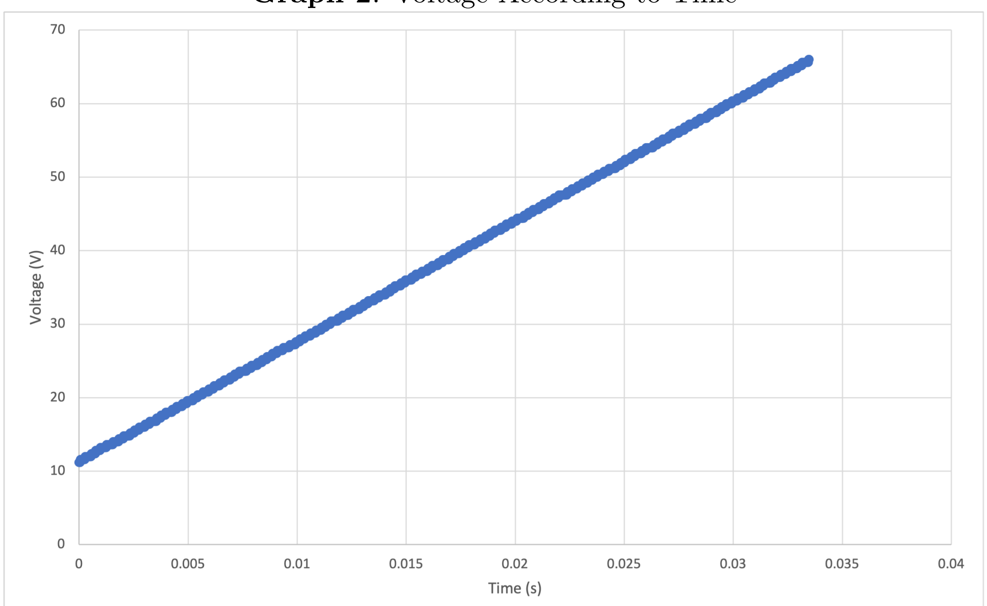
Graph 1: From the raw data collected in table 1, this graph represents the data collected from the oscilloscope. The independent x value of the graph is the time escalated in seconds. The dependent y value

of the graph is the Voltage measured in volts. This graph demonstrates a linear sinusoidal graph similar to Figure 1 in the introduction but less steep. This is part of channel 2 if you look at the appendix graph. Channel two is useless since the

When going through the data and collecting points for the peaks, the voltage for each peak is smaller by a factor of 100. When calculating the difference between each peak the difference is 100 factors away then the theoretical value of $4.9eV$. The approximate experimental value of channel 2 is $0.049eV$. However, graph 1 is not completely useless due to the fact that the peaks are at specific time interval. The specific time interval helps to determine the maximum voltage on channel 2.

Following the appendix graph, the second channel is a linear graph that indicates the voltage against time. From taking the time interval from all the peaks in Graph 1, matching the voltage at the same time, provides an insightful knowledge on the exact voltage. Since there were time intervals beyond 10 data points, taking the average of the voltage between the exact time intervals would give an average voltage for each peak. Looking at each peak in the appendix table 2 and doing the difference would give an approximate voltage of 4.9 for each difference. Doing the average of the differences of voltages for each peak gives a value of $4.88 \pm 0.101eV$. This value falls right into the theoretical value of $4.9eV$. With that fact, the mercury atom released ultraviolet light due to the kinetic energy. That shows due to graph 1.

Graph 2: Voltage According to Time



Graph 2: From the raw data collected in table 1, this graph represents the data collected from the oscilloscope. The independent x value of the graph is the time escalated in seconds. The dependent y value of the graph is the Voltage measured in volts. This graph represents the actual voltage used at specific times. Since the first graph did not provide accurate voltage counts, channel 2 will. From the time intervals taken from the peaks in the first graph, will be used to find the voltage according to the time intervals for the 2nd graph.

Discussion and Conclusion

To conclude, the experiment carried out confirmed by the theory. The calculation for the experimental maximum voltage it takes to excite the mercury atom was $4.9 \pm 0.1 eV$ which is less than 1% error. From the graphical observation, every sinusoidal peak was amount of kinetic energy/volts it needed to excite the atom and start emitting ultraviolet light. Since there is a lot of kinetic energy in the diode with the electrons continuously hitting the anode, the collecting plate only gets hotter and creates current. Thus, explaining why the sinusoidal graph is linearly going up. Since every accelerating voltage of $1V$ receives $1eV$ of kinetic energy, then Graph 1 confirms the theory.

The only issue in this laboratory, resulted in the oscilloscope graph obtained and data acquisition. Al thought, the graph resembles identically the theory in figure 1; the data registration for this oscilloscope registers in Voltage and Seconds, and not in Current and Accelerating voltage, which would directly prove the theory.

Lastly, it was impressive to see and understand what James Franck, Gustav Hertz, and Bohr-Rutherford were able to foresee. Taking and understand the classical concepts and dissecting the molecular physics. To understand that certain atoms can produce light under a certain amount of voltage/kinetic energy caused a massive industries in LED lights.

If I were to redo the lab, I would make it so that the data collected would be in the oscilloscope would provide current against accelerating voltage, to prove my figure 1 predictions clearer. However, understand the theoretical aspect of the data proves the theory.

Appendix

Wagih, Ghobriel: Lab manual I: Introduction to Experimental Physics.
"Instructions for Regression Analysis in Excel 2010"
Giora Hon and Bernard R. Goldstein: "Centenary of the Franck-Hertz experiments", 2013
website: https://onlinelibrary-wiley-com.myaccess.library.utoronto.ca/doi/pdfdirect/10.1002/andp.201300744
"The Franck-Hertz Experiment pdf"

Table 1: Data Points from The Oscilloscope

	Record Length	2.50E+03	Time(s)	Chanel 1 Voltage (V)	Chanel 2 Voltage (V)
	Sample Interval	2.00E-05	-0.0116	2.4	0.044
	Trigger Point	5.80E+02	-0.01158	2.4	0.04
Source	CH1	CH2	-0.01156	2.4	0.04
Vertical Units	V	V	-0.01154	2.4	0.036
Vertical Scale	1.00E+01	1.00E-01	-0.01152	2.4	0.036
Vertical Offset	-2.88E+01	-2.92E-01	-0.0115	2.8	0.036
Horizontal Units	s	s	-0.01148	2.8	0.032
Horizontal Scale	5.00E-03	5.00E-03	-0.01146	2.8	0.032
Pt Fmt	Y	Y	-0.01144	2.8	0.028
Yzero	0.00E+00	0.00E+00	-0.01142	2.8	0.028
Probe Atten	1.00E+01	1.00E+00	-0.0114	2.8	0.024
Model Number	TDS2001C	TDS2001C	-0.01138	2.8	0.024
Serial Number	C013965	C013965	-0.01136	2.8	0.024
Firmware Version	FV:v24.26	FV:v24.26	-0.01134	2.8	0.02

Table1: This is an example of the data collected from the oscilloscope that helped creating graph 1. There Chanel 1 Voltage which helped determining the peak value, and Chanel 2 Voltage that is a representation of what Figure 2 should look like. Due to this being an old model of an oscilloscope it managed to capture voltage and time and not current and accelerated voltage.

Table 2: Calculations from The Peaks of The Sinusoidal Graph

AVG	difference	AVG of differences	STDEV of differences
30.577778	4.8	4.881746032	0.101609993
35.377778	4.8222222		
40.2	5		
45.2	4.7428571		
49.942857	4.8571429		
54.8	4.96		
59.76	4.99		
64.75			

Table2: From the raw data collected in table 1, the calculation in table 2 are from the table 1. Since channel 1 and channel 2 have the same time frame, Find the peak from channel 2. Since there was multiple time frames for one peak in channel 2, using the same time frame for channel 1 resulted in accurate result when computing the average. Doing this process for each peak and calculating the difference resulted in this table.

Calculation of the differences between the averages of peaks:

$$\text{Last peek - Before Last peek } = 64.75 - 59.76 = 4.99$$

Calculation of the average of all the differences:

$$\frac{\sum_{i=1}^{n} Y_i}{n} = \frac{4.8 + 4.822222 + 5 + 4.7428571 + 4.8571429 + 4.96 + 4.99}{7} = 4.881746032$$

Uncertainty of the averages is the standard deviation:

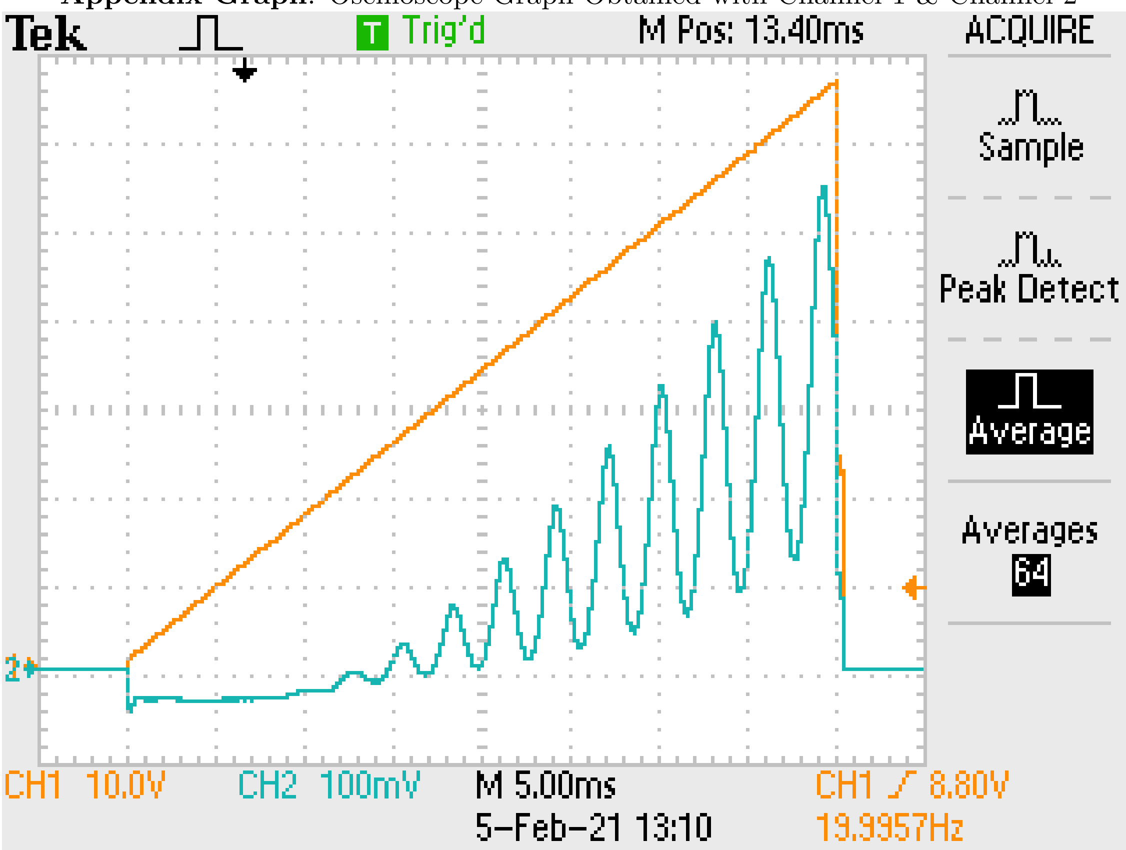
$$s = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \bar{x})^2}{N-1}} = \sqrt{\frac{(4.8 - 4.881746032)^2 + ... + (4.99 - 4.881746032)^2}{7}}$$

$$s = 0.101609993$$

Code for the sine graph (Figure 2) in introduction:

```
t=linspace(0,20,100);
y=(1/4)*t+sin(t);
plot(t,y)
```

Appendix Graph: Oscilloscope Graph Obtained with Channel 1 & Channel 2



Appendix Graph: The oscilloscope collects the data and creates a graph from all the other graphs combined. To get the average between all graphs. Channel 1 is in orange and Channel 2 is in blue, the independent value x is the time in seconds and the dependent value y is the voltage.