Quantized Absorption of Energy through Electron Collisions with Atoms

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ABSTRACT

Bohr's proposal that electrons in an atom are restricted to a discrete set of energy levels has helped us into further understanding how an atom is organized. We measured the flow of electrons going through a Mercury/Neon medium, and observed that when the electrons reach a certain energies, the current drops dramatically. We observed an energy difference of $4.86V \pm .05V$ between these current drops. This agrees with the accepted value of the second excited state of a Hg atom of 4.9eV, which implies a relationship between the electron flow and the excitation of the atoms in the medium. These results agree with Planck's postulate about quantized energy and Bohr's subsequent model of the atom.

1 Introduction

By the end of the 19th century, many physicists thought that we had reached the end goal of understanding our universe with the physics we had, until it was found that classical physics did not agree with the black body radiation spectrum.[1] Planck came up with a solution for this problem and theorized that energy was quantized. He did not gave a physical explanation for this but just gave a mathematical solution that solved the problem. It was not until 1913 when Bohr came up with a new model of the atom which would explain this behavior, only allowing atoms to absorb or emit energy exactly equal to the difference between two electron orbits.[2] Energy quantization is not only extremely important in physics, it gave birth to a whole new field of physics which we named Quantum Mechanics.

The experiment we executed was first proposed by Bohr and then carried out by Franck and Hertz[3], whose only purpose was to prove the existence of a discrete set of energy levels that an electron can exist in. They successfully observed results that agreed with Bohr's model.

In our experiment, we used a chamber containing gaseous Hg (we then replicated the experiment with Ne), an anode and a cathode plate. We increased the voltage difference between the plates and measured the current flow between them. We then plotted the Current vs. Voltage and observed several drops in current at equal voltage differences from each other. As expected from theoretical results, these differences matched the kinetic energy that is necessary to excite an Hg/Ne atom.

2 Theoretical Background

Atoms can be excited through collisions with other particles, such as electrons, if they have the required kinetic energy. This is a branch of Quantum Mechanics nowadays called Quantum Theory of Collisions(QTC)[4].

The current should peak and start going down when the electron has enough energy to excite the atom and transfer its energy, therefore not having enough kinetic energy left to reach the collecting plate. Then, the next peak should occur when the electron has enough energy to collide with two different atoms and effectively excite both of them. If this is true, then, the difference between the peaks should be equal to the difference in energy between the two energy levels in the atom.

However, the energy level being excited through collisions is not necessarily the first one. This will depend on the probability of an electron to hit the cross sectional area corresponding to the orbital of the energy level, these cross sectional areas are defined by QTC. For Hg, its most probable energy state to be excited is the second one (4.9eV). For Ne, there is a high probability in 10 energy states in the 3-p orbital which range between 18.4eV and 19eV. These states are more likely to be excited due to the size of their collision cross sectional area being bigger than other energy levels [4].

3 Experimental Procedure

We used a Kep Klinger atomic shell Franck Hertz with Mercury experiment set(Figure 1). First, we connected the heating oven to the back of the supply unit (a). We then connected the current and voltage outputs to the DAQ, which sends the signals to the computer. Then, we inserted the temperature sensor in the back of the heating oven, and plugged it into the supply unit (b). We plugged the Franck-Hertz tube into the supply unit, as well (c), and turned on the supply unit. After 10 minutes the temperature reached 180°C and was stable, so we began to take measurements.

We selected the ramp option, which increases the voltage automatically over time in a steady manner, and started recording data through LabVIEW. The accelerating voltage was increased from 0V to 25V. We took 4 different trials varying the gain to emphasize the peaks and troughs in different ways.

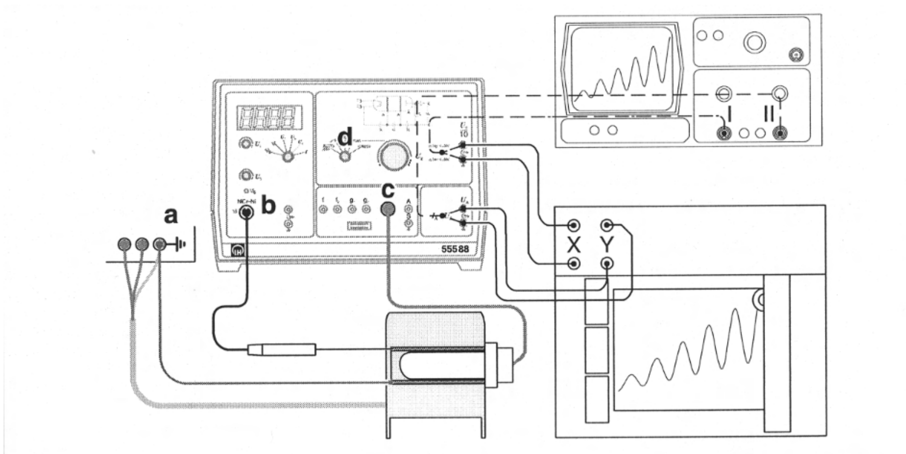

Figure 1: Kep Klinger Franck-Hertz experiment and heating oven[5]

For Ne, we followed the same procedure with the Neva control unit. The heating oven is not needed as Ne is already in gaseous state at room temperature. We increased the voltage from 0V to 80V, and recorded the data through LabVIEW software.

4 Data Analysis

The data was measured in "Current", the quotes are due to the nature of the measurement that takes place in the software, as it in reality measures voltage and then converts that to current. We do not know the actual conversion that takes place so take these as arbitrary units. On Figure 2 we can observe our first trial where we can clearly see some peaks with equal separation between them. We were able to find the accelerating voltages corresponding to the highest point on each peak as 6.44, 11.22, 16.10 and 21.09. If we

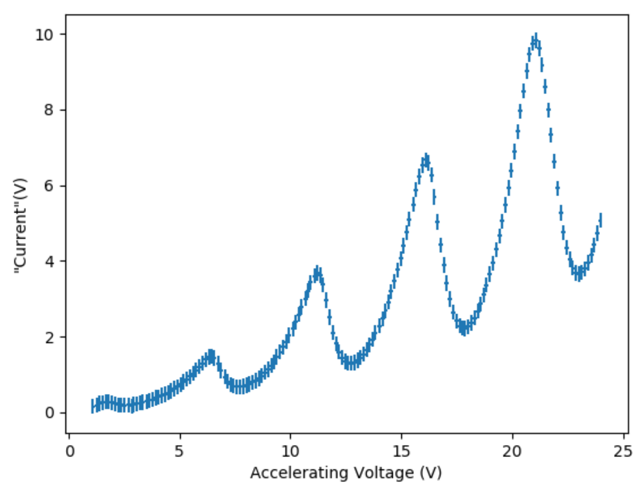

Figure 2: First trial through Mercury chamber

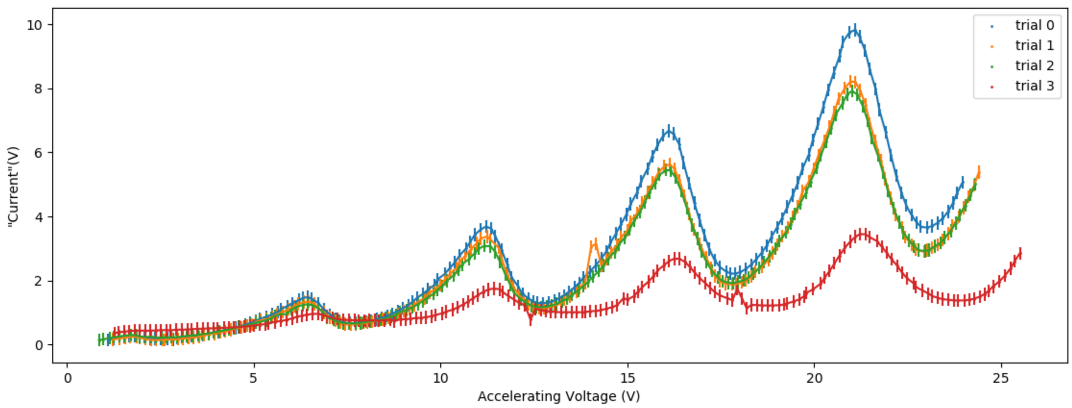

Figure 3: All trials in Mercury chamber varying the gain of the power supply

take the difference between each consecutive X-Value and take the mean we get: $4.88V \pm .11V$ The way that we obtained the peak was by choosing the highest Y-value from our data, and then finding the corresponding X-value. Therefore the uncertainty on this comes from the distance between our point and the next X-value. This is due to the possibility of one of these not measured in-between voltages having a corresponding higher current. Our spacing between voltage values was uniform, thus giving us a .13V uncertainty for every point.

We took several trials varying the gain, which multiplied the current signal. In Figure 3 we can see all the data plotted together. Notice how the peaks and the valleys happen around the same voltage values for all graphs. If we take the mean of all the differences among our four data sets we obtain a total of $4.86 \pm .05V$. This agrees with the known value of 4.9eV for Mercury's second excited state within error bounds.

Changing the medium through which the electrons traveled to Neon did not change the shape of the graphs. As we can see from Figure 4, we obtained the same current behavior, the only difference being the distance between the peaks increased. There is more noise in this as we had to do increase the voltage manually, thus, giving multiple data points for same values of V. Using the same method used for Mercury. We obtained an average of $19.27 \pm 1.18V$, which agrees with Neon atoms being excited to some of the ten different 3-p levels(18.4eV-19eV).

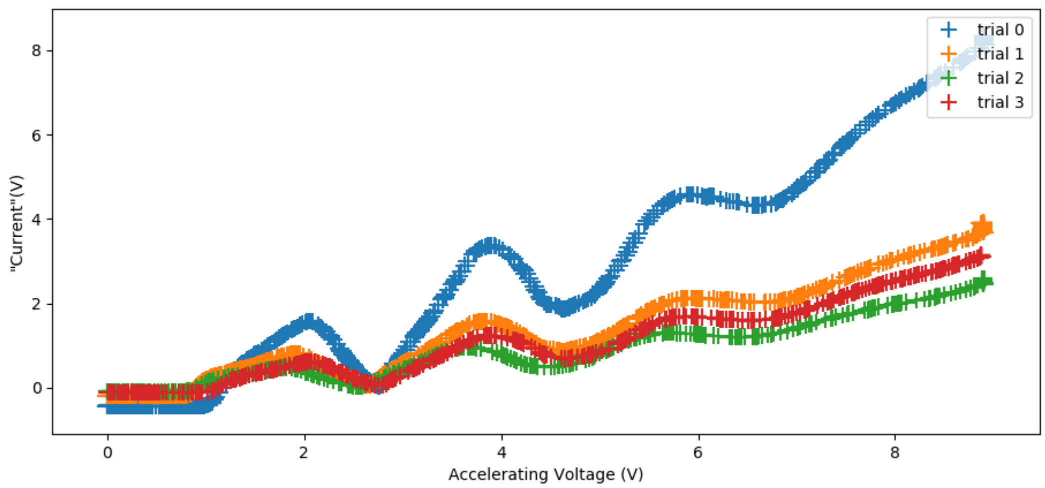

Figure 4: Neon trials varying the gain

5 Conclusion

In this experiment we measured the current of electrons through a Hg medium, and a Ne medium. We were able to successfully observe a drop in current when electrons posses enough energy to excite the atoms in the medium they are traveling at, which is $4.86 \pm .05eV$ for Hg and $19.27 \pm 1.18eV$, both within theoretically accepted values. These results verify Planck's postulate on quantized energy and Bohr's model of the atom.

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