MIDDLE EAST TECHNICAL UNIVERSITY

Franck-Hertz Experiment

Author: Bartu Yaman
Lab Partner: Riza Serkan Kaskan
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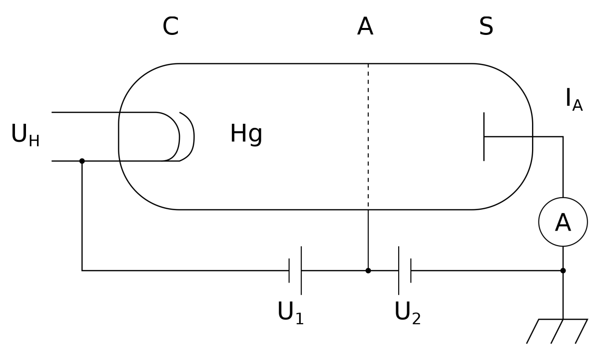

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1 Introduction

1.1 Goal

The goal of this experiment is to determine the first excitation energy of mercury atoms in the vapor to come to the conclusion that atoms have discrete transition energies, thus confirming the quantum theory.

1.2 Theory

The Franck-Hertz experiment is one of the most significant experiments in history since it provided the first experimental conformation for the quantum nature of atoms, verifying the quantum theory with experimental data.

The Bohr atom model states that electrons of atoms occupy certain discrete energy levels and that there are no intermediate levels. The experimental result showed that electrons can occupy higher energy levels if they absorb 4.9 eV of energy, directly verifying the Bohr atom model.

Thermionic emission , which is the liberation of electrons with temperature, is used to eject electrons into the experimental apparatus which provides the energy necessary to excite the electrons in mercury gas. Electrons ejected by the cathode undergo collisions with mercury atoms in the gas. Electrons that have enough energy undergo inelastic collisions to excite the mercury electrons to higher states, resulting in a phase transition; on the other hand, electrons that does not have enough energy undergo elastic collisions and lose little to no energy which does not result in excitation.

The heart of the underlying mechanism in this experiment can be investigated using the resulting current vs accelerating voltage data. When the electrons coming from the cathode elastically collide with the mercury atoms, they lose little to no energy and just change direction since the mercury atom is nearly four hundred thousand times more massive than the incident electrons. The same electrons can collide inelastically with the mercury atoms as their speeds exceed 1.3 million meters per second, which corresponds to a knietic energy of 4.9 electron volts. When the electrons collide inelastically, they transfer some of their energy to the mercury atoms to excite them, thus losing speed and kinetic energy; which results in the spikey behaviour present in the current vs accelerating voltage plot. We can draw a lot of conclusions from these current drops and they will all be carried out in the later sections of this report. A theoretical plot can be seen below.

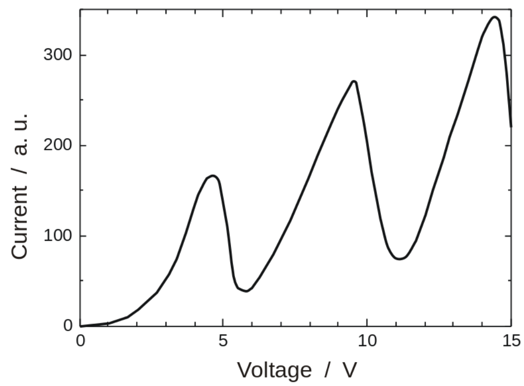

Figure 1: Current vs Accelerating Voltage Plot

2 Experimental Details

2.1 Equipment

The experiment apparatus consisted of a mercury filled tube situated inside an electric oven, a thermocouple with its probe positioned just above the filled tube a power supply and an analog oscilloscope.

The main apparatus had an electric oven to increase the collision probabilities of mercury atoms and incident electrons, a thermocouple connected to a digital thermometer to measure the temperature and a cathode ray tube filled with mercury to observe the actual phenomena. The power supply was specifically tailored for this experiment and allowed us to control the filament voltage, collector voltage and the accelerating voltage. The oscilloscope allowed us to get readouts from the apparatus, generating the same plot from Figure 1.2.

2.2 Procedure

The procedure consisted of turning the thermostat dial to approximately 160 degrees Celsius (the temperature values were quite unstable, we tried not to exceed 200 degrees Celsius), setting the toggle switch to 'Ramp', setting filament to approximately 6 Volts, setting the collector voltage to approximately 2 Volts, adjusting the amplification gain, adjusting the oscilloscope variables to see clear and many peaks and writing down the data measured from the maximum and minimum values of the peaks present on the oscilloscope screen.

3 Measurement And Data Analysis

3.1 Presentation Of Data

3.2 Calculations

4 Results And Discussion

4.1 Discussion Of Results

It is clear from the data and analysis of data that our results agree with the quantum theory of atoms and proves the existence of discrete energy levels. However, there are still two important points to discuss while analyzing the data.

The first one is the fact that we only observe the excitation process to a single energy level. When the electrons coming from the cathode have kinetic energies that are larger than 4.9 eV, excitation occurs and it is clear that each peak happens at multiples of 4.9 eV. This means that we only observe the transition to the first excited state.

The second point to discuss is that even though we say that we only observe the transition to the first excited state, there are multiple peaks in the data. This is because of the fact that if the incident electrons have energies that are multiples of 4.9 eV, they can excite more than one mercury atom by themselves. For example an electron with kinetic energy more than 9.8 eV can excite two mercury atoms, giving 4.9 eV of energy to each one, thus exciting them both to the first excited state.

4.2 Discussion Of Errors

There are two main sources of error in this experiment. The first source of error is the incredibly unstable thermostat, which can't maintain its target temperature and constantly increases its temperature, forcing us to interfere with the thermostat to maintain our target temperature, resulting in thermal fluctuations. The second source of error is our instrument of measurement. We have measured the maximum and minimum values of peaks present on the oscilloscope screen using our eyes which probably contributed to the error a lot.

Using a more modern experimental apparatus and measurement device can mitigate a lot of error from data. Just using a digital oscilloscope instead of an analog one can make great difference in terms of result.

References

[1] IBM. Ibm quantum composer docs, 2021.

[2] Michael A. Nielsen and Isaac L. Chuang. *Quantum Computation and Quantum Information*. Cambridge University Press, 2010.