Franck-Hertz Experiment

Luis A. Flores & Rosemary Cortés
University of Puerto Rico at Río Piedras
FISI 4076 Intermediate Laboratory
Dr. Ratnakar Palai

Abstract
The purpose of our experiment was to replicate J. Franck and G. Hertz experiment which helped establish the existence of discrete energy levels in mercury atoms. The aim is to find the excitation energy from the distance between equidistant maxima or minima of electron current in a variable opposing electric field. Our results using the Franck-Hertz curve show an error of 2.04% in the excitation levels of mercury atoms.

1 Introduction

German physicists J. Franck and G. Hertz conducted an experiment in 1914 which provided strong evidence that Bohr's model of the atom with quantized energy levels was correct. However, they were not aware of Bohr's atomic theory and interpreted their experimental results somewhat incorrectly. They believed that collisions between electrons and mercury atoms resulted in ionization instead of the excitation of the atom. It was not long before other scientists confirmed that the atoms were making transitions between discrete energy states. For this experiment they were awarded the physics Nobel prize in 1925 for their outstanding contribution. In our experiment we used PHYWE's equipment to replicate their experiment and obtain the excitation levels of the mercury atom.

2 Experimental Theory

The Franck-Hertz apparatus used a straight wire cathode, heated electrically to produce electrons by thermionic emission ***(fig1)***. The emission occurs because the thermal energy given to charge carriers overcomes the work function of the material. The wire was immersed in an atmosphere of mercury vapor at a temperature around 120 °C with a vapor pressure of around one millimeter. Electrons emitted by the cathode were collected by a platinum anode after passing a mesh screen, or grid. A voltage applied between cathode and grid accelerated the electrons toward the grid ***(fig2)***. A small retarding voltage between the anode and grid prevented electrons with very low energy from being collected. As Franck and Hertz increased the voltage, the current collected by the platinum cylinder anode increased as well. This meant that the electrons passed through the mercury vapor almost without energy loss. Given the dimensions of the cell and the collision cross-section for electrons with the mercury atoms, the electrons would have several hundred collisions with the atoms on passing from the cathode to the platinum net. Thus, the collisions were elastic, with little energy loss by the electrons to the atoms.

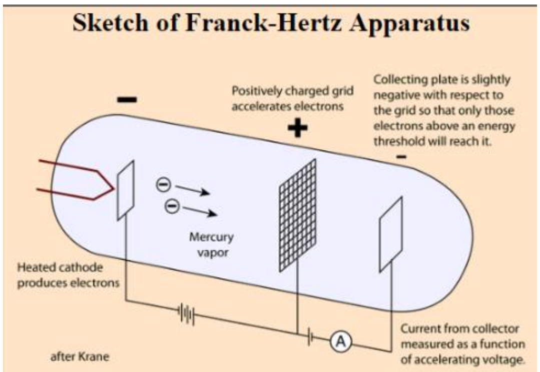

FIGURE 1. Sketch of the Franck-Hertz tube with all the components. Retrieved from HyperPhysics website.

However, when the voltage reached around 4.9 eV, suddenly the current fell nearly to zero ***(fig3)***. This meant that, at 4.9eV, an electron lost nearly all its energy in an inelastic collision and could no longer overcome the retarding voltage and reach the anode. The electron transferred most of its kinetic energy to the mercury atom, boosting the atom to the second energy level, and leaving the electron with little kinetic energy. If the anode voltage were to be increased again, the kinetic energy of the electron would be enough to surmount the opposing field and the current would increase until reaching the 4.9eV interval. They showed that the wavelength of the light emitted by the mercury atom ***(fig2)*** corresponded exactly to the 4.9eV of energy that the electron had lost. At first, Franck and Hertz believed that this was due to ionization of the mercury atoms by collision with electrons, but they soon understood that this energy loss was due to the existence of a discrete energy level between the ground state and the ionization level of the mercury atom. This was the first experimental demonstration, outside of spectroscopy, of the discrete atomic energy levels hypothesized in Bohr's theory of the hydrogen atom, published shortly before.

FIGURE 2. PHYWE vacuum tube used for the Franck–Hertz experiment. The cathode is hot and glows orange. It emits electrons which pass through the metal mesh grid and are collected as an electric current by the anode.

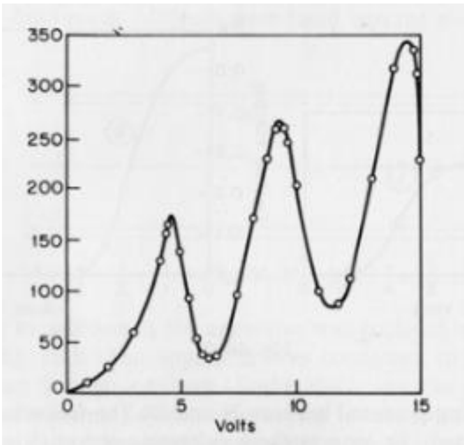

FIGURE 3. Anode current vs. grid voltage based on the original 1914 paper by Franck and Hertz. Each collision costs the same amount of energy, because almost all the mercury atoms are in the ground state: the mercury atoms jump back down from the excited n=2 state to the n=1 state in a short time.

3 Equipment & Experimental Procedure

The equipment used was the PHYWE Franck-Hertz tube and oven, a power supply unit, a DC measuring amplifier, voltmeter, various connecting cords, and an oscilloscope. To set up the equipment we followed the instruction manual for the PHYWE Franck-Hertz Experiment. The tube was already mounted in the oven and we only had to properly connect the equipment with the chords following the pictures in the instruction manual. To generate the anode voltage, the power supply unit for the Franck-Hertz tube was used. The anode voltage was set at 0.5V and it increased in a logarithmic way if we opened the switch in the circuit board. A current got generated by electrons striking the counter electrode in the range of 10^{-9} A, this current was then amplified and recorded in the oscilloscope. The amplifier will output a voltage signal proportional to the collecting plate current, this will be one of the data channels to monitor. The heat of the oven was approximately 165°C and the DC amplifier was set to 0.1μA ***(fig4)***. We note that some of the connecting cords were not functioning correctly and we tried a few of them until we got a proper signal in the oscilloscope. The oscilloscope recorded in two channels, one channel was used for the collected current and the other for the potential difference between the cathode and the grid also the accelerating voltage. The scales in the oscilloscope were adjusted to obtain a proper graph for both channels used. Once a satisfying graph was generated, we transferred the data from the oscilloscope to a flash drive and proceeded to analyze it.

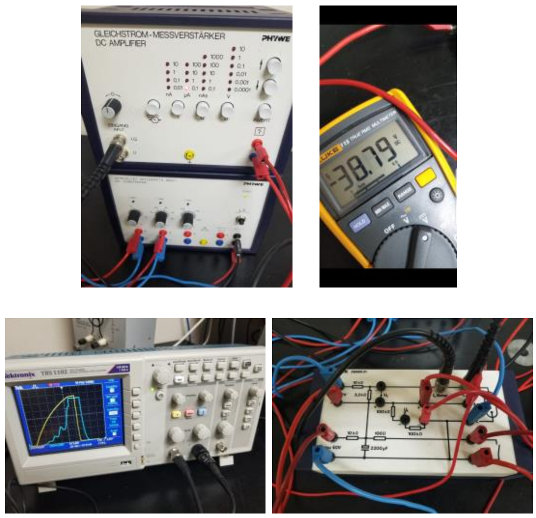

FIGURE 4. PHYWE equipment used for the Franck-Hertz experiment. In the top left we have the DC amplifier on top of the power supply. The oscilloscope showing the signal of the two channels. The voltmeter displaying the voltage at which the Franck-Hertz tube began to glow, and the circuit board.

4 Experimental Data & Results

For the anode voltage a value of -38.79V was obtained when the mercury began to emit light ***(fig2)***. The detection was also seen as the top horizontal line in the blue graph generated by the oscilloscope which corresponds to the accelerating voltage ***(fig5)***. It is to my understanding that the mercury atoms could not obtain any more energy from this point forward and stayed in the same excitation level. Therefore, we had to close the switch in the circuit board to not damage the equipment and allow the atoms to jump back down to their ground state. The oscilloscope was the main instrument for obtaining the data that allowed us to determine the excitation levels of the mercury atoms. The intense drop in the graph is due to closing the switch in the circuit board.

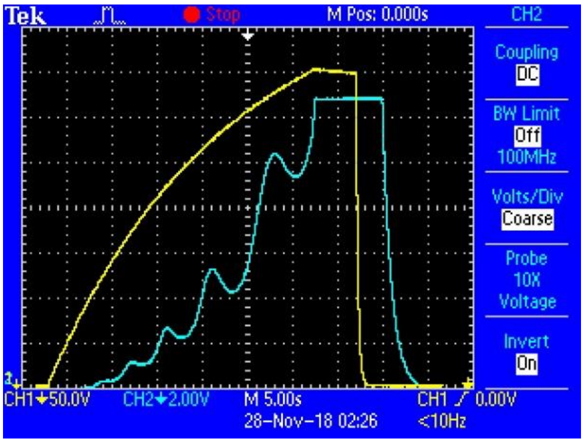

FIGURE 5. Graph obtained from the oscilloscope for both channels. The yellow graph corresponds to the accelerating voltage and the blue to the collecting plate current.

The oscilloscope generated separated .CSV files containing the data for the channels and an image file representing the data as seen in the oscilloscope screen. Having the data from both channels we proceeded to create a graph relating the accelerating voltage to current of the plate ***(fig6)***. This graph is known as the Franck-Hertz curve and allowed us to determine the excitation energy of mercury atoms from the distance between equidistant maxima or minima. The measured separation of the peaks or minima corresponded to the excitation energy of the involved mercury transition. The data for separation between peaks or minima can be seen in ***(table 1)*** along with the percentage of error when compared to the theoretical value obtained by Franck and Hertz ***(fig3)***. The minima were found by following the pattern of the data and the graph to determine the lowest set of values between two peaks. The data in ***(table 1)*** begins from the right side of ***(fig6)*** and the difference between minima or maxima is calculated with the next corresponding value found to the left of the first minima or maxima following the x-axis. This difference is then divided by ten to obtain the excitation levels of the mercury atom in volts. The X value in the table means that there were no additional peaks to the right of the graph. The closest values to the theoretical value of 4.9 were 4.8 and 5.0 giving an error of 2.04%. The highest error was of 5.2 with a percentage of 6.12%.

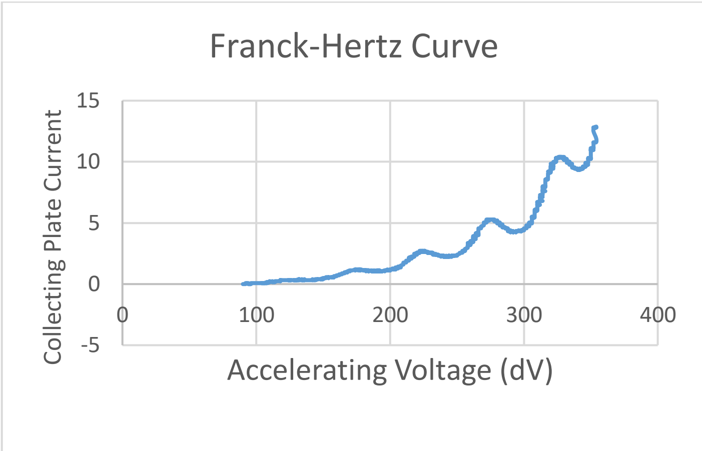

FIGURE 6. Franck-Hertz curve relating the increasing current displayed as voltage (dV) to the accelerating voltage.

Minima (dV)	Maxima (dV)	ΔMinima (V)	ΔMaxima (V)	Error Min	Error Max
340	328	X	X	X	X
292	276	4.8	5.2	2.04%	6.12%
240	224	5.2	5.2	6.12%	6.12%
190	176	5.0	4.8	2.04%	2.04%

TABLE 1. Applied voltages at maxima or minima, their differences and the percentage of error compared to the theoretical excitation level of mercury of 4.8eV.

5 Conclusion

The Franck-Hertz experiment was and still is a great contribution to physics and many other areas. The idea behind the experiment is not difficult to follow and our results prove that the excitation levels of mercury atoms occur at every increase of 4.9eV as seen in the Franck-Hertz curve. With the use of PHYWE's equipment we replicated Franck-Hertz experiment and obtained an error of 2.04% which corresponds to 4.8eV instead of the theoretical value of 4.9eV. We note that the maxima and minima were found using the x-axis or the accelerating voltage. However, the accelerating voltage could also be used to find the excitation levels, but we got only one result instead of three if we used the y-axis.

6 References

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