PHY324 Franck-Hertz Experiment

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1 Abstract

This experiment is a variation of the original experiment carried out by James Franck and Gustav Hertz where they were able to show that collisions could lead to optical emission at the known spectral energies. In this experiment, the energy transferred from the electrons to the Hg atoms was found to be 5.25 +/- 0.01eV and the wavelength of the emitted photon was found to be $2.36 \times 10^{-7} + / - 0.000000001m$.

2 Introduction

In this lab, the Franck-Hertz experiment was carried out to show that when mercury atoms were bombarded with a beam of electrons, the electrons lost discrete amounts of energy as they collided. The Franck-Hertz experiment provided one of the experimental bases for the quantum theory, as it showed strong evidence against classical mechanics and in favour of the Bohr model.

This experiment involves the inelastic collisions of electrons and Mercury atoms. Note that electrons carry an energy equal to

$$E = eV \tag{1}$$

where e is the electron charge and V is the accelerating voltage in this case. This energy will be transferred to the mercury atoms and will be the energy of the emitted photon as the mercury atoms decay from the first excited energy state to the ground state. Note that this wavelength is given by:

$$\lambda = \frac{hc}{eV} \tag{2}$$

3 Setup and Methods

Below is the setup for this experiment:

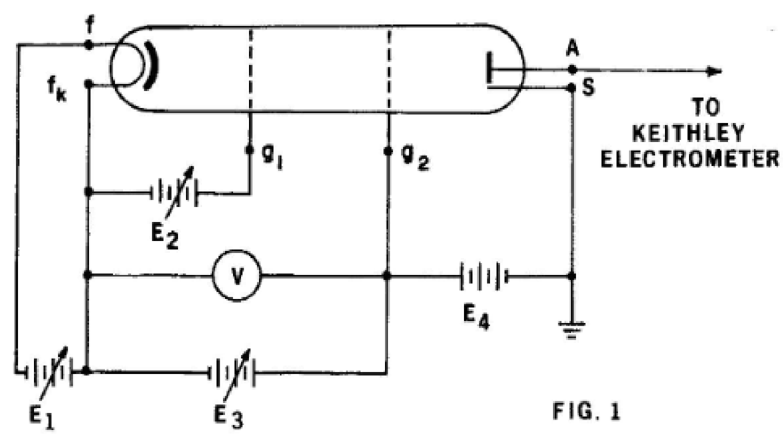

Figure 1: Circuit Setup

This setup includes the Frank-Hertz apparatus, a Keithley electrometer, a multimeter, a light bulb oven, and the light bulb.

There are four DC voltages required for this experiment. E1 is the filament supply where the electrons are emitted. E2 is the screen grid voltage. E3 is the accelerating voltage. Lastly, E4 is a fixed voltage to repel low energy electrons.

Electrons are emitted by a filament and are accelerated through the E3 voltage. When an electron hits a vaporized Hg atom, its energy will be transferred. A large enough accelerating voltage will ensure no energy loss in the collisions and will allow them to pass through the grid and continue to the collector electrode S. The electrometer measures the electron flow. The current vs accelerating voltage plots will show equally spaced dips as the accelerating voltage is increased. These dips are due to the lowest energy transitions the electrons can excite in the Hg atoms.

For this lab, a tube with Hg gas inside of it was heated in an oven at 170 degrees Celsius. After the tube was heated, data acquisition began. The E3 voltage was slowly swept from 0V to 30V and the current vs voltage graph was plotted accordingly. This was repeated 5 times to minimize uncertainties.

4 Results

As mentioned above, five plots were created for this experiment. Each plot was generated by the FranckHertz.vi program provided. The data from these plots was taken and imported into python where the plots could be generated there. From there, the minima of each plot were detected using the following algorithm:

```
plt.plot(fh1a, fh1b)
plt.title("Current vs Accelerating Voltage")
plt.xlabel("Accelerating Voltage (V)")
plt.ylabel("Current (A)")

minima1x = []
minima1y = []

for i in range(fh1b.size -1):
    if fh1a[i] > 5:
        if i == 0:
            i = 1
        if fh1b[i] < fh1b[i+1] and fh1b[i] < fh1b[i-1]:
            minima1x.append(fh1a[i])
            minima1y.append(fh1b[i])
plt.scatter(minima1x, minima1y, color = "orange")
plt.xticks(np.arange(-5,35, step = 2))
plt.axvline(17.1, color = "black")
plt.axvline(22.3, color = "black")
```

This produced plots that looked like Figure 2 below:

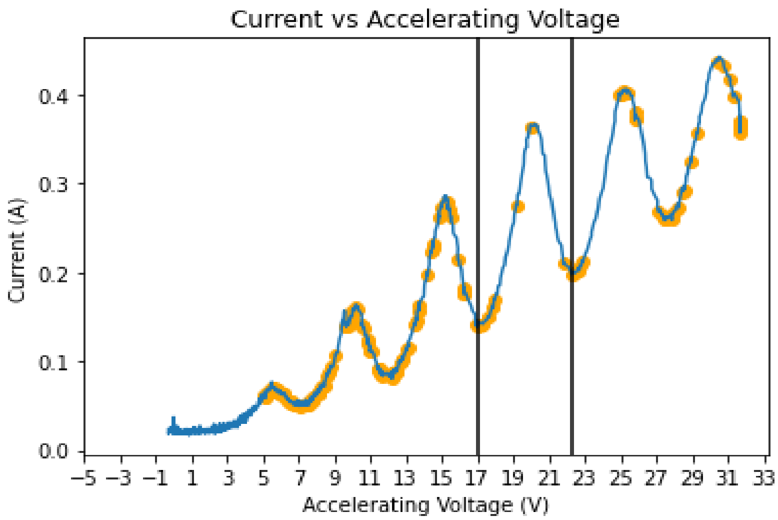

Figure 2: Current vs Accelerating Voltage with minima detected

Notice that do to the noise in the data, many minima (orange dots) were detected in odd places. In order to find the correct minima, the plot was zoomed in using plt.xlim(). The difference between two minima were found for each plot and average amongst the five plots to find the average accelerating voltage. The average accelerating voltage was 5.25 +/- 0.01V.

5 Discussion

With the accelerating voltage found, the energy transferred to the Hg atoms can be found by calculating the energy of the electrons:

$$E = eV = 5.25 + / - 0.01eV \tag{3}$$

With this, the wavelength of the emitted photons can be calculated using equation 2. This gives a wavelength of $2.36 \times 10^{-7} + / - 0.000000001m$

Notice that in this experiment, Franck and Hertz used vaporized Mercury instead of Hydrogen gas because the atoms the electrons were colliding with had to be big enough to allow for an inelastic collision to take place. Hydrogen only has one electron, and therefore it would be too light for that to happen.

Lastly, the dips from the current vs. accelerating voltage graph are not sharp sawtooth patterns because the collision between the electrons and the

Hg atoms is not instant. The collisions take some amount of time to take place and thus the dips are curved. This made it a lot more difficult to detect the minima allowing for some uncertainty to take place.

6 Conclusion

To summarize, the energy transferred from the electrons to the Hg atoms was found to be 5.25 +/- 0.01eV and the wavelength of the emitted photon was found to be $2.36 \times 10^{-7} + / - 0.000000001m$.

7 References

- 'THE-FRANCK-HERTZ Lab Manual

8 Appendix

The following is the plotted data for each of the five trials:

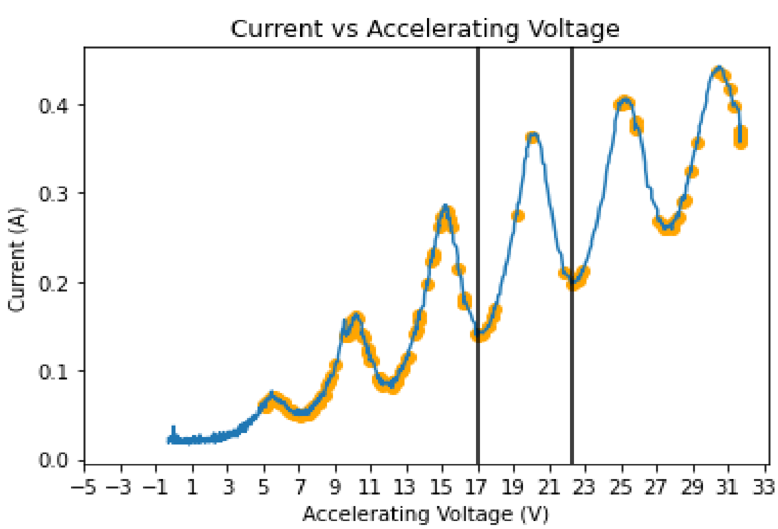

Figure 3: Current vs Accelerating Voltage with minima detected

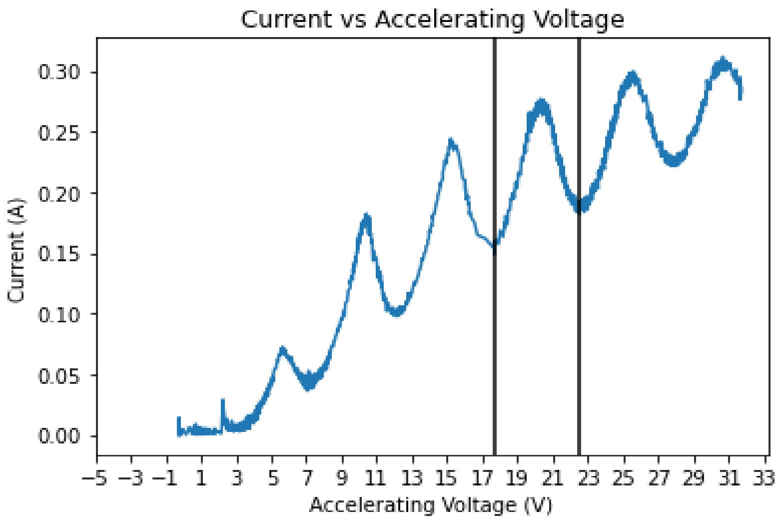

Figure 4: Current vs Accelerating Voltage with minima detected

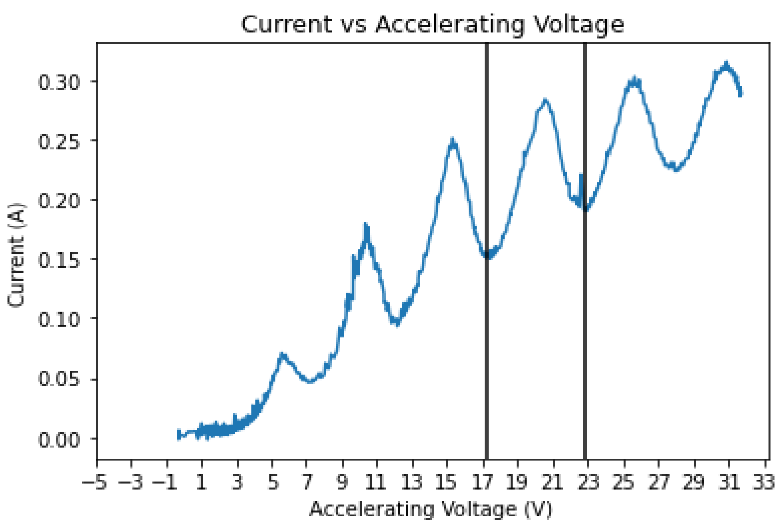

Figure 5: Current vs Accelerating Voltage with minima detected

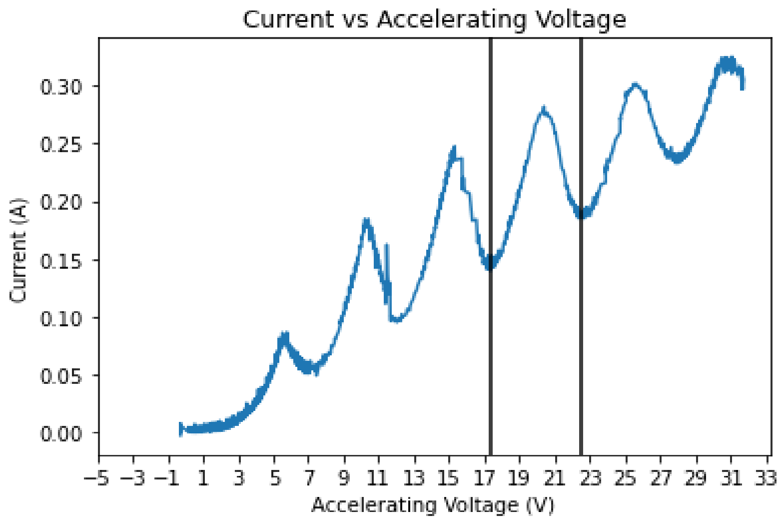

Figure 6: Current vs Accelerating Voltage with minima detected

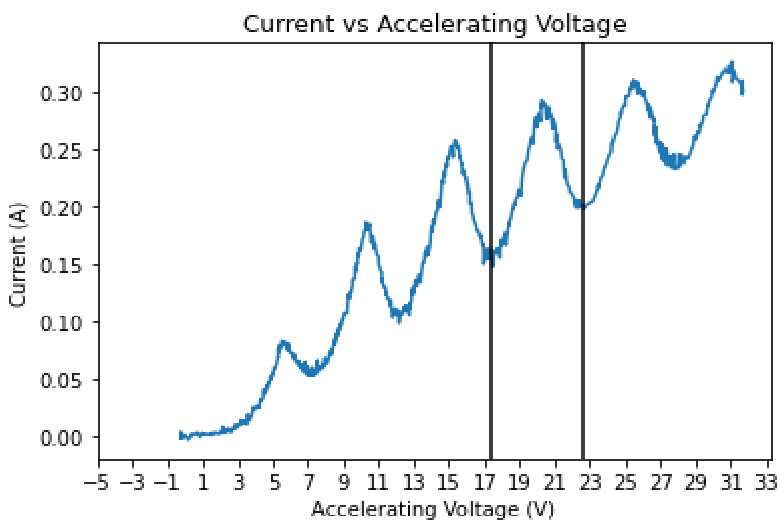

Figure 7: Current vs Accelerating Voltage with minima detected