20CL_FH

April 9, 2025

1 20CL Franck Hertz experiment Out of Lab

1.1 April 9th

1.1.1 Songgun Lee

Goal : I want to summarize the work I did after collecting my in-lab data. My goal in this experiment is to accelerate electrons through mercury vapor and observe sudden drops in the electron current at specific voltages, thereby demonstrating that electrons lose fixed amounts of energy when they inelastically collide with mercury atoms.

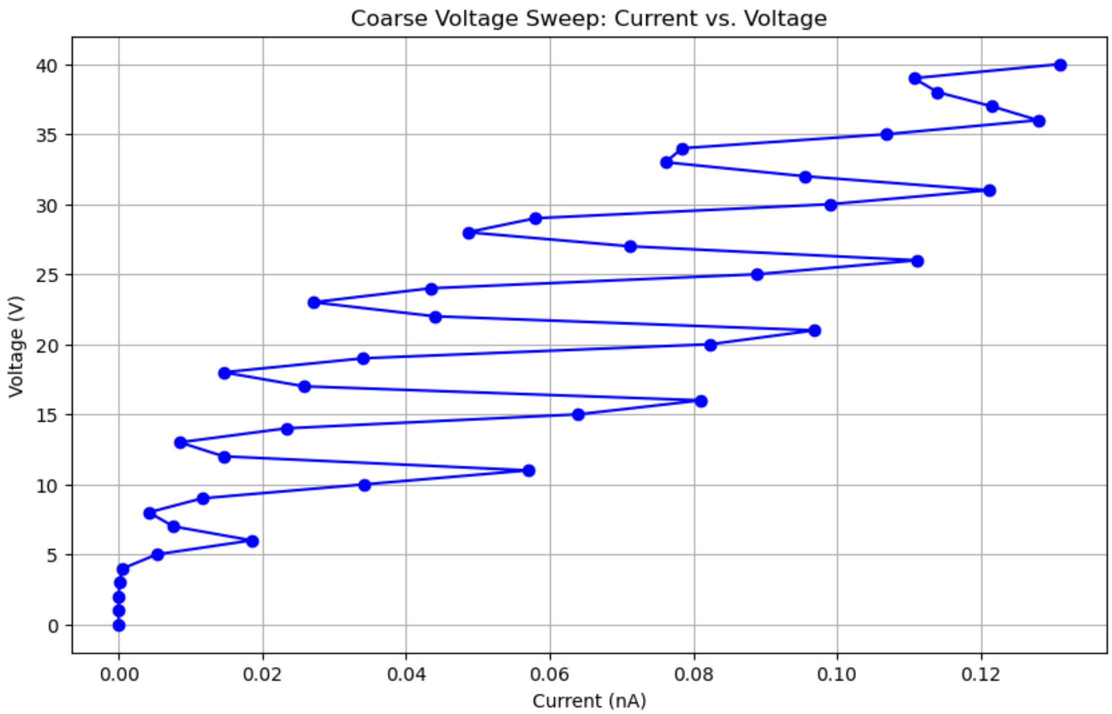
Starting Time: 20:00

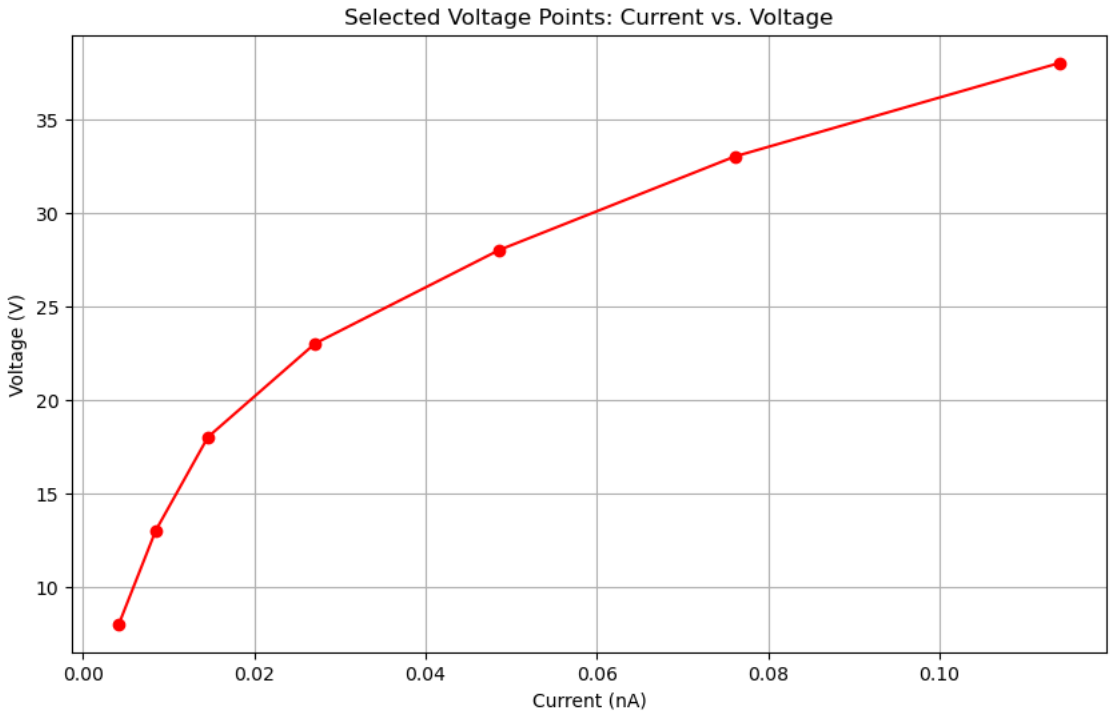
1.1.2 Exercise 5: Plot I vs V_a

I recorded accelerating voltages V_a and the corresponding electron current I. I'll make a well-formatted plot here to show how I changes as I vary V_a from 40 V down to 0 V.

[9]:
```
import matplotlib.pyplot as plt

# Data: Voltage (V) and Current (nA)
voltages = [40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24,␣
↪23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3,␣
↪2, 1, 0]
currents = [0.131, 0.1107, 0.114, 0.1215, 0.128, 0.1069, 0.0785, 0.0761, 0.
↪0955, 0.1211, 0.099, 0.058, 0.0486, 0.0711, 0.1112, 0.0888, 0.0434, 0.0271,␣
↪0.044, 0.0969, 0.0823, 0.034, 0.0146, 0.0258, 0.0811, 0.064, 0.0233, 0.0085,␣
↪0.0146, 0.057, 0.0342, 0.0116, 0.0042, 0.0076, 0.0185, 0.0053, 0.0006, 0.
↪0001, 0, 0, 0]

# Plot 1: All data with points connected by lines
plt.figure(figsize=(10, 6))
plt.plot(currents, voltages, marker='o', linestyle='-', color='blue')
plt.xlabel("Current (nA)")
plt.ylabel("Voltage (V)")
plt.title("Coarse Voltage Sweep: Current vs. Voltage")
plt.grid(True)
plt.show()
```

```
# Plot 2: Subset of data for V = 8, 13, 18, 23, 28, 33, 38
subset_voltages = [8, 13, 18, 23, 28, 33, 38]
# Create a dictionary to map voltage to current
voltage_current = dict(zip(voltages, currents))
subset_currents = [voltage_current[v] for v in subset_voltages]

plt.figure(figsize=(10, 6))
plt.plot(subset_currents, subset_voltages, marker='o', linestyle='-',␣
↪color='red')
plt.xlabel("Current (nA)")
plt.ylabel("Voltage (V)")
plt.title("Selected Voltage Points: Current vs. Voltage")
plt.grid(True)
plt.show()
```



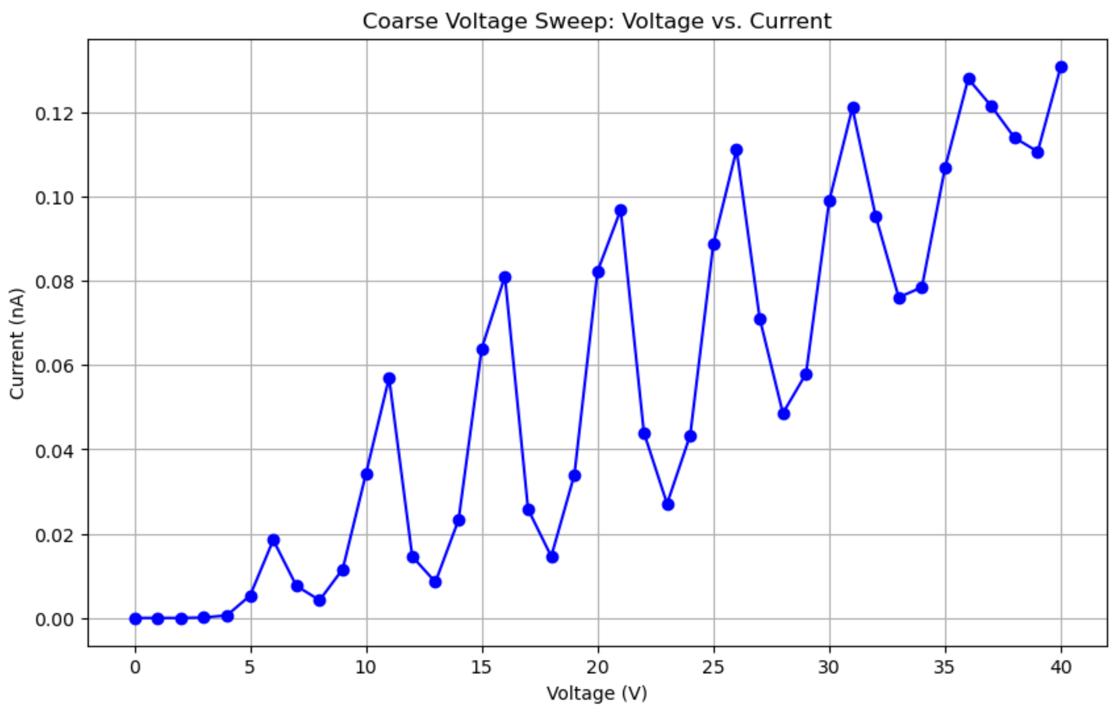


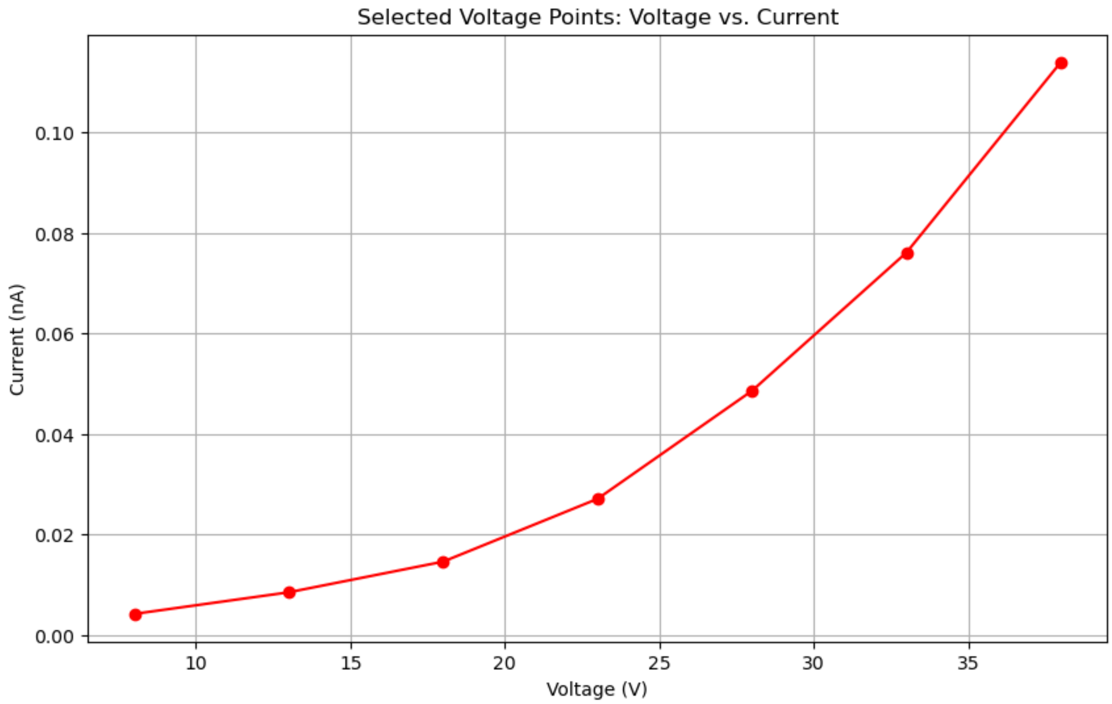
The exercise told me to plot current vs voltage, but I like the voltage vs current better, so I will stick with my standards.

2 Figure 1

[12]:
```
import matplotlib.pyplot as plt

# Data: Voltage (V) and Current (nA)
voltages = [40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24,␣
↪23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3,␣
↪2, 1, 0]
currents = [0.131, 0.1107, 0.114, 0.1215, 0.128, 0.1069, 0.0785, 0.0761, 0.
↪0955, 0.1211, 0.099, 0.058, 0.0486, 0.0711, 0.1112, 0.0888, 0.0434, 0.0271,␣
↪0.044, 0.0969, 0.0823, 0.034, 0.0146, 0.0258, 0.0811, 0.064, 0.0233, 0.0085,␣
↪0.0146, 0.057, 0.0342, 0.0116, 0.0042, 0.0076, 0.0185, 0.0053, 0.0006, 0.
↪0001, 0, 0, 0]

# Plot 1: All data with points connected by lines
plt.figure(figsize=(10, 6))
plt.plot(voltages, currents, marker='o', linestyle='-', color='blue')
plt.xlabel("Voltage (V)")
plt.ylabel("Current (nA)")
plt.title("Coarse Voltage Sweep: Voltage vs. Current")
```

```
plt.grid(True)
plt.show()

# Plot 2: Subset of data for V = 8, 13, 18, 23, 28, 33, 38
subset_voltages = [8, 13, 18, 23, 28, 33, 38]
# Create a dictionary to map voltage to current
voltage_current = dict(zip(voltages, currents))
subset_currents = [voltage_current[v] for v in subset_voltages]

plt.figure(figsize=(10, 6))
plt.plot(subset_voltages, subset_currents, marker='o', linestyle='-',␣
↪color='red')
plt.xlabel("Voltage (V)")
plt.ylabel("Current (nA)")
plt.title("Selected Voltage Points: Voltage vs. Current")
plt.grid(True)
plt.show()
```

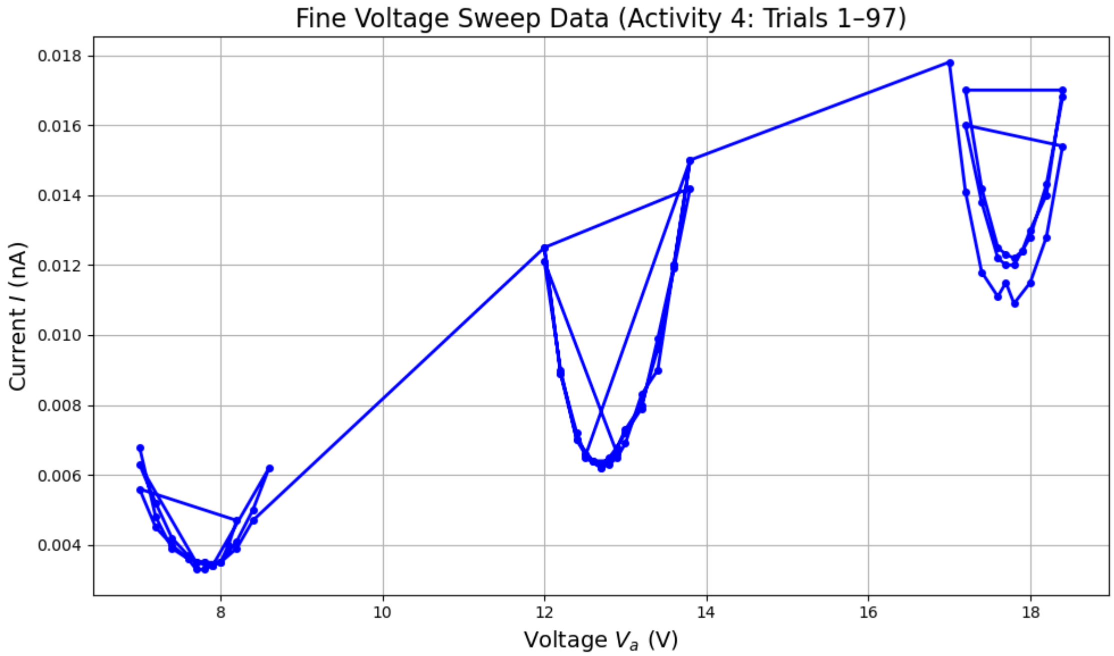




This works better for me because my variable was voltage and the current was changing following that. Now, let me plot the other detailed voltage vs currents.

3 Figure 2

[17]:
```
import pandas as pd
# Read the Excel file
data = pd.read_excel("fhin-labdata.xlsx")


voltages = data["Voltage (V)"]
currents = data["Current (nA)"]

# Create the plot
plt.figure(figsize=(10, 6))
plt.plot(voltages, currents, marker="o", linestyle="-", color="blue",␣
 ↪linewidth=2, markersize=4)
plt.xlabel("Voltage $V_a$ (V)", fontsize=14)
plt.ylabel("Current $I$ (nA)", fontsize=14)
plt.title("Fine Voltage Sweep Data (Activity 4: Trials 1-97)", fontsize=16)
plt.grid(True)
plt.tight_layout()
plt.show()
```



Ignoring the two direct lines connecting the three evident curves, it seems like there are "minimum" currents on certain voltages. The minima in the current occur at specific accelerating voltages because these voltages correspond to electron kinetic energies that are just sufficient for inelastic collisions with mercury atoms. When an electron collides with a mercury atom under these conditions, it loses a fixed quantum of energy—the first excitation energy of mercury—which leaves it with insufficient energy to overcome the retarding potential and reach the collector. In essence, these dips in the electron current are direct evidence of the quantized nature of energy absorption in mercury atoms, which is the fundamental phenomenon demonstrated in the Franck–Hertz experiment.

3.0.1 Excercise 6:

I see 7 different cycles of current peaks and minima according to figure 1. On figure 2, I see 3 specific examples. Figure 2 is simply the first 3 cycles repeated 3 times.

According to figure 1, it seems like the minima occur at $V = 8, 13, 18, 23, 28, 33, 38(V)$. According to figure 2, there is a more detailed number. The minima occur at $V = 7.75, 12.7, 17.8(V)$.

I observed that the minima in the electron current occur at regular intervals. The coarse data suggested approximate minima at 8, 13, 18, 23, 28, 33, and 38 V, while the fine sweep refined these to 7.75, 12.7, and 17.8 V for the first three cycles. I fitted these points with a linear model of the form

$$V = 5x + 7.7$$

where x represents the cycle number of the minima. This indicates that the voltage difference between successive minima is roughly 5 V, meaning each inelastic collision with mercury atoms requires an additional 5 V of accelerating potential. The intercept of approximately 7.7 V suggests a threshold voltage that must be exceeded before the electrons acquire enough energy to cause an excitation. I conclude that this pattern is strong evidence of quantized energy absorption in mercury, which is the foundational concept demonstrated in the Franck–Hertz experiment.

3.0.2 Exercise 7:

I will solely focus on figure 1, because figure 2 was a data plotted to exactly pinpoint the minimum. I am trying to find the V_n^{max} too.

$$V_n^{max} = 6, 11, 16, 21, 26, 31, 36(V)$$
$$V_n^{min} = 8, 13, 18, 23, 28, 33, 38(V)$$

I looked at the data file and plot above and found these values. They seem to fit the linear model form I have mentioned above. The intervals are all 5V.

3.0.3 Exercise 8:

In my analysis, I chose to determine the excitation energy by measuring the voltage differences between consecutive minima, since this approach cancels out any potential offsets and more directly captures the energy lost in inelastic collisions. For example, from my fine-sweep data I obtained minima at approximately 7.75 V, 12.7 V, and 17.8 V, so the voltage differences are roughly 4.95 V and 5.1 V. I then take the average of these differences, which is about 5.03 V, and calculate the first excitation energy as $ E_{1}^{Hg} = e × V_{avg} (1.602 ×10^{-19} , C) ×(5.03 , V) 5.03 , eV $.

I used $ e = 1.602 ×10^{-19} , C $ for this calculation since it is an SI unit.

3.0.4 Exercise 9:

I predict $ E_{1}^{Hg} 4.67 eV $ based on the energy-level diagram in Figure 7, which indicates that the lowest excited state of mercury lies around 4.67 eV above the ground state. Since the Franck–Hertz experiment generally probes that first excitation energy, I interpret the diagram to mean that when electrons gain at least ~4.7 eV, they can inelastically collide with mercury atoms and leave them in the first excited state. This prediction matches the standard accepted value of ~4.7 eV for mercury's first excitation energy.

3.0.5 Exercise 10:

Below is my analysis using the given data.

I used the predicted excitation energy of mercury as $E_{1,accepted} = 4.67\, eV$ and my measured value from the experiment as $E_{1,measured} \approx 5.03\, eV$.
The absolute discrepancy between these values is

$$\Delta E = |5.03\, eV - 4.67\, eV| = 0.36\, eV.$$

To find the proportionate discrepancy, I calculated:

$$\text{Fractional Discrepancy} = \frac{0.36\,eV}{4.67\,eV} \approx 0.077,$$

which is approximately 7.7%.
Thus, the measured excitation energy is about 7.7% higher than the predicted value.

4 Summary:

In this experiment, my goal was to verify that mercury atoms absorb energy in discrete amounts by measuring the electron current as a function of the accelerating voltage. I carefully calibrated my apparatus and collected both coarse and fine sweep data, which revealed distinct peaks and dips in the current corresponding to inelastic collisions between electrons and mercury atoms. By extracting the local minima from the fine sweep data and analyzing the voltage differences between consecutive minima, I determined an average voltage difference of approximately 5.03 V. Multiplying this difference by the elementary charge, I calculated a first excitation energy, E_{1Hg}, of about 5.03 eV, which is roughly 7.7% higher than the predicted value of 4.67 eV. I emphasize that the Franck–Hertz experiment is a crucial milestone in quantum physics, as it provides direct evidence for the quantized nature of energy absorption in atoms and fundamentally validates our understanding of atomic energy levels. Overall, this lab deepened my understanding of experimental uncertainty and data analysis, and it reinforced the importance of this experiment in the historical development of quantum theory.

4.0.1 End time: 23:00

[ ]:
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