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Physics 20CL

After Lab Note: Franck-Hertz Experiment

Time: 7:30 pm to 11:59 pm, Apr. 20

12:00 am to 2:30 am, Apr. 21

See appendix for figures

Code: `https://github.com/YizhiJiao/Public`

This experiment was designed by Dr. Franck and Dr. Hertz in the early 20th century and proved that the atom receives quantized energy. Energy in SI unit is Joule, but in this experiment, the energy is measured in electron volts (eV). Since the charge of the partical (i.e., the electron) was given, the energy can be easily measured by voltage. Therefore, this lab does not have too many calculations.

In the lab session, the current at different voltages was measured, and the relationship between the current and the voltage was plotted in Figure 1 (crude data) and Figure 2 (precise data). The current was measured by the electrometer, and the reading was negative when the current was positive. To make the plot more intuitive, the current was multiplied by -1 to make them positive. Also, all data points in both Figure 1 and Figure 2 are connected intentionally to show the trend of the data intuitively. The plot shows that the current does not increase monotonically with the voltage, and it periodically decreases. The loss of the current shows that murcury atoms in the lab setup absorbed the energy of the electrons. By measuring the voltage difference between two adjacent maximum or minimum, the energy of murcury atoms abosorbed can be calculated. Figure 2 shows six periods of the precised data, so there are ten voltage differences of the maximum and minimum. The average of the ten voltage differences is 5.08 ± 0.04 V, so the energy of murcury atoms abosorbed is 5.08 ± 0.04 eV.

Figure 3 shows the relationship between the voltage difference and the average voltage of the two maxima or minima. As the voltage increases, the average voltage difference increases. This model has a χ^2/df of about 25, so this model does not fit the data well. However, the 95% confidence interval of the slope is $[0.006, 0.034]$, so it is hard to reject that they did not have a positive relationship.

The uncertainty of the voltage is determined by the resolution limit of the voltmeter, which is 0.1 V, so the uncertainty of the voltage difference is $0.1/\sqrt{12}$ V. The uncertainty of voltage difference is easily propagated by the following equation:

$$\begin{aligned}
\delta(V_1 - V_2) &= \sqrt{\delta V^2 + \delta V^2} \\
&= \sqrt{2}\delta V \\
&= \frac{0.1}{\sqrt{6}} \\
&= 0.04 \text{ V} \\
\delta(E_1 - E_2) &= 0.04 \text{ eV}
\end{aligned}$$

The uncertainty measured in this way assumes that the voltages measured were right at the maximum or minimum of the current, but the actual voltage is not exactly at the maximum or minimum since the electrometer reading varied frequently. Hence, the uncertainty of the energy is underestimated. In addition, the temperature varied during the experiment, and the temperature was related to the density of the murcury gas. If the temperature was higher, the pressure of the gas is higher, and the density of the gas is higher. The higher density of the gas means that the electrons had a higher chance to collide with the murcury atoms, so the energy of the electrons was more likely to be absorbed. This might indicate that the temperature was increasing slowly during the experiment without being noticed.

In conclusion, the energy of murcury atoms abosorbed is 5.08 ± 0.04 eV, which is a close figure to the theoretical value of 4.9 eV. To improve the accuracy of the experiment, the temperature of the gas should be controlled at the same value during the exepriment, not in a range. More data points should be collected to make the plot more accurate. Only six periods of data were collected in this experiment because the resolution of the voltmeter was too large to make accurate measurements at low voltages. The voltmeter should be replaced by a more precise instrument that has mode digits to measure the voltage. However, measuring more data and controlling the temperature would take more time, and the experiment would not be finished during the three hour session. In all, although the measured excitation energy was not acceptable statistically, this experiment was still a good demonstration of the quantized energy of the atom. Appendix:

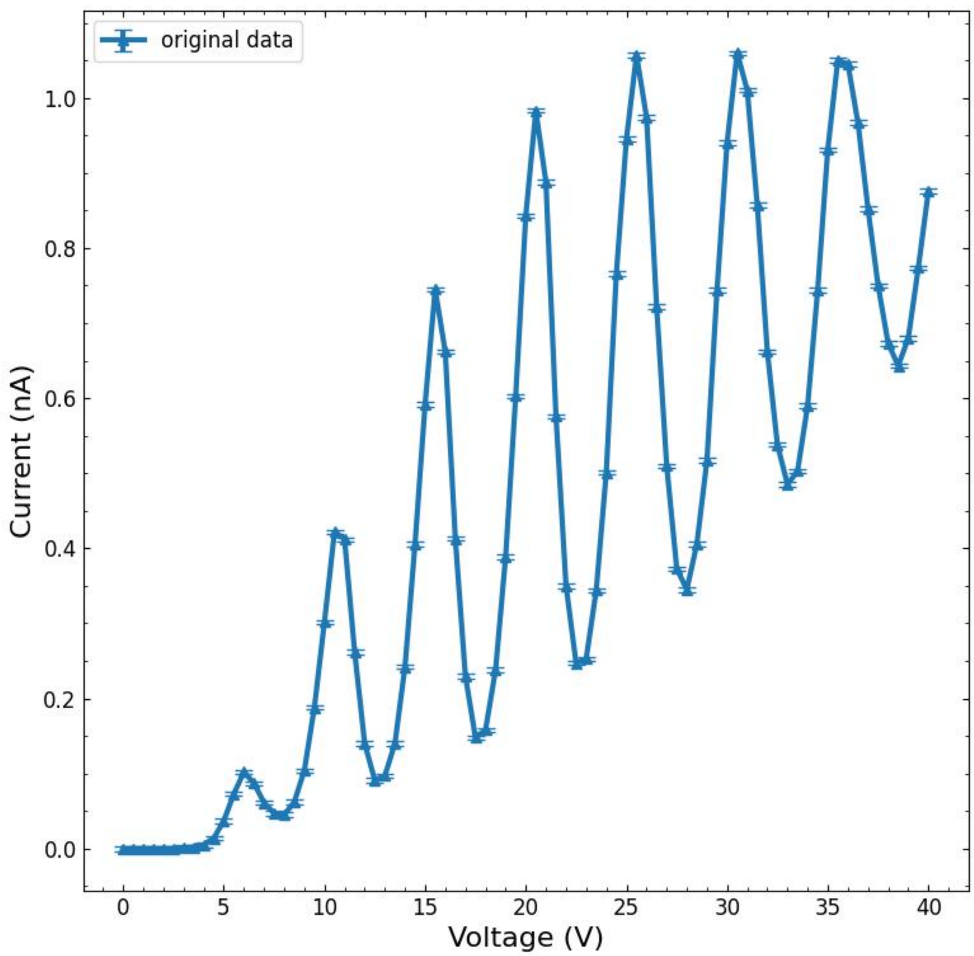

Figure 1: Crude measurements. Line connecting dots is to show the trend. error bars represent the uncertainty of the current.

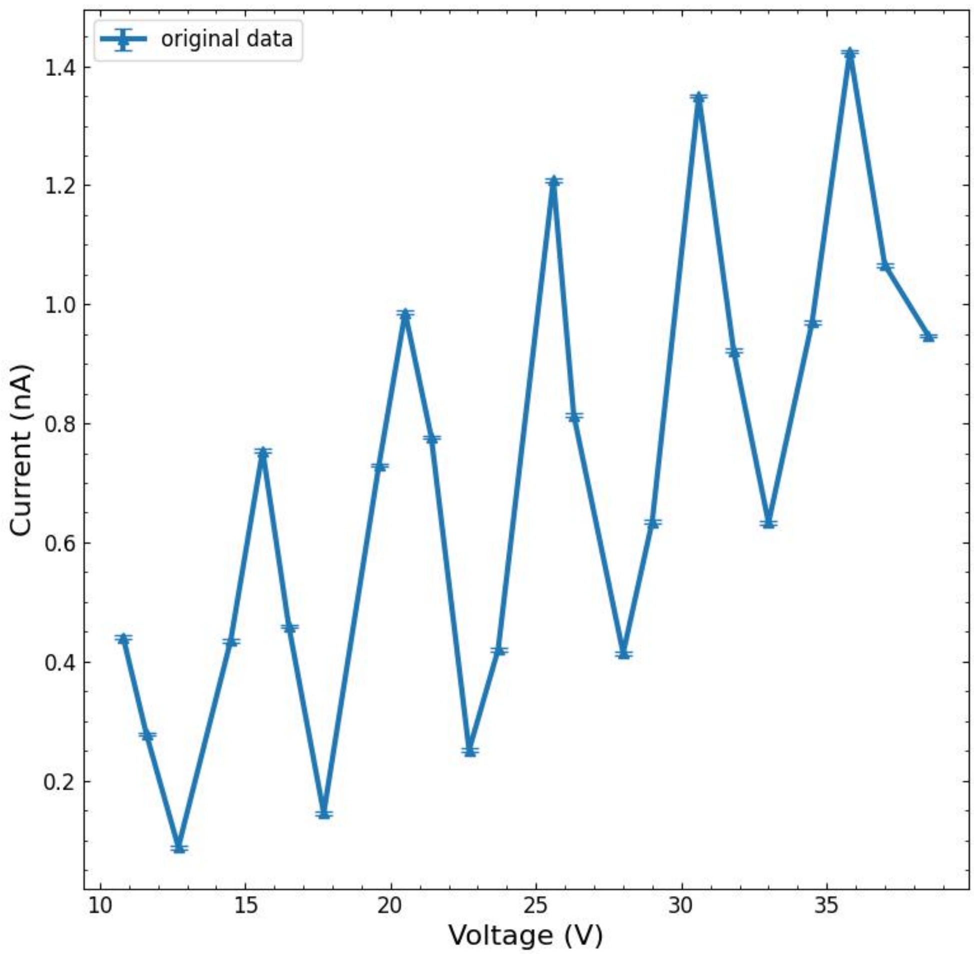

Figure 2: Precise measurements. Line connecting dots is to show the trend.

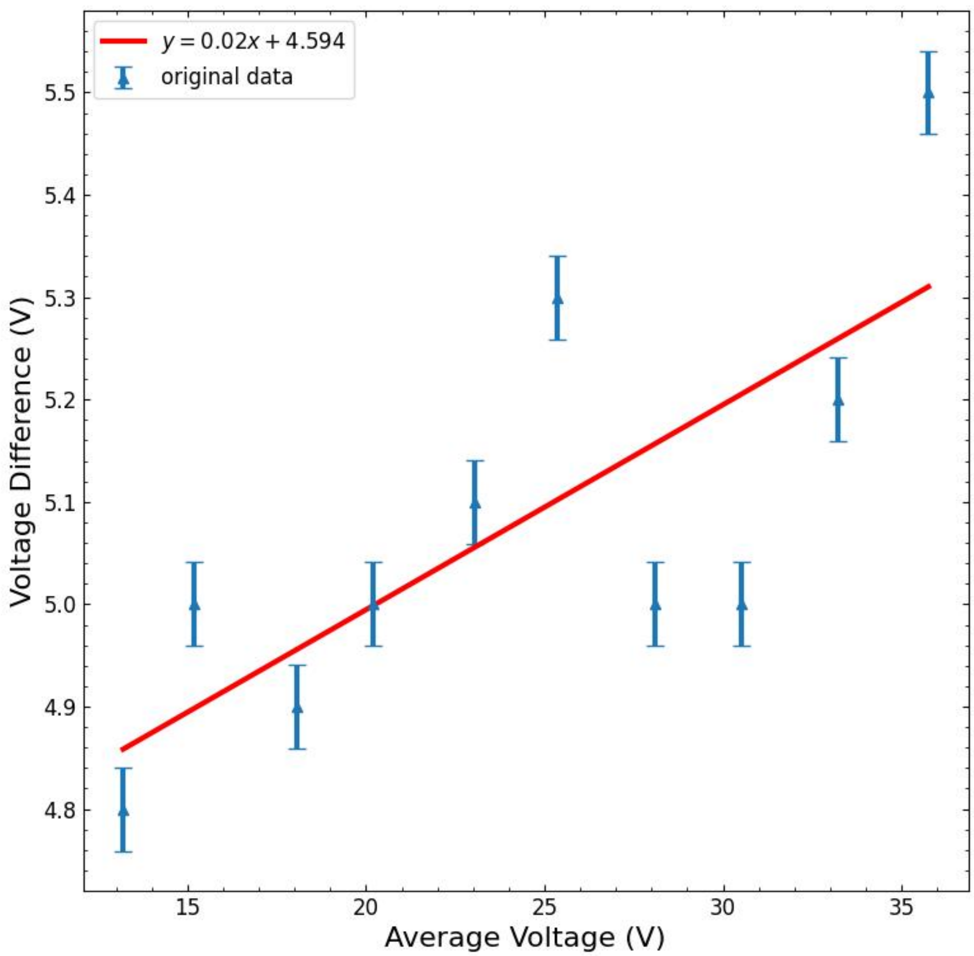

Figure 3: Relationship between the average voltage and the voltage difference between two peaks and two troughs. The best-fit line does not pass all error bars. $\chi^2/df \approx 25$.