Franck-Hertz Experiment

Under-Graduate Science Laboratory – BS 192 (Group - 7)

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1 Objective

The objective of this experiment is to determine the excitation potential of argon atoms using the Franck-Hertz tube. By analyzing the behavior of electrons as they collide with argon atoms under varying accelerating voltages, the experiment aims to identify the specific voltage at which the argon atoms absorb energy, leading to a drop in the current. This experiment not only validates the quantized nature of energy levels within atoms but also provides a deeper understanding of the atomic structure of argon.

2 Apparatus Description

- **Franck-Hertz tube**: A glass tube filled with argon gas, equipped with a cathode, grid, and anode. It is used to observe electron collisions with argon atoms.
- **Continuously variable power supply (0-95 V)**: Provides adjustable voltage to control the energy of electrons as they accelerate toward the argon atoms in the tube.
- **Oscilloscope**: Displays the current vs voltage waveform, helping visualize the points where electrons lose energy in inelastic collisions.
- **Digital voltmeter**: Measures the voltage across the tube components, ensuring accurate control during the experiment.

- **Digital ammeter**: Measures the current flowing through the tube, which changes as electrons interact with argon atoms.

Figure 1: Apparatus for Franck Hertz experiment.

3 Theory

3.1 Historical Background[1]

The understanding of atomic structure underwent significant transformation in the early 20th century, largely due to the work of pioneering scientists like Niels Bohr, James Franck, and Gustav Hertz. In 1913, Niels Bohr introduced his revolutionary model of the atom, which postulated that electrons occupy discrete energy levels, or "quantized" states, within an atom. Bohr's model was a significant departure from classical physics, as it suggested that electrons could only transition between these energy levels by absorbing or emitting specific amounts of energy.

Building on this theoretical framework, James Franck and Gustav Hertz conducted a seminal experiment in 1914 that provided direct evidence for Bohr's theory. Their experiment, conducted at the University of Berlin, involved bombarding mercury atoms with electrons in a specially designed vacuum tube. They observed that when the energy of the electrons reached a certain threshold, there was a sudden drop in the current, indicating that the electrons had transferred their energy to the mercury atoms, exciting them to a higher energy state. This discovery confirmed that atomic electrons occupy distinct energy levels and can only be excited when they receive a precise amount of energy, aligning with Bohr's quantized energy levels.

In later years, the Franck-Hertz experiment was adapted using different gases, such as neon and argon, to explore the excitation potentials of various elements. These experiments not only confirmed the generality of Bohr's theory but also provided deeper insights into the electronic structure of atoms across the periodic table. The adaptation of the experiment with argon, as in this report, continues to be a fundamental exercise in understanding atomic excitation and electron energy levels, demonstrating the enduring significance of Franck and Hertz's pioneering work.

3.2 The Franck-Hertz Experiment

3.2.1 Experimental Setup

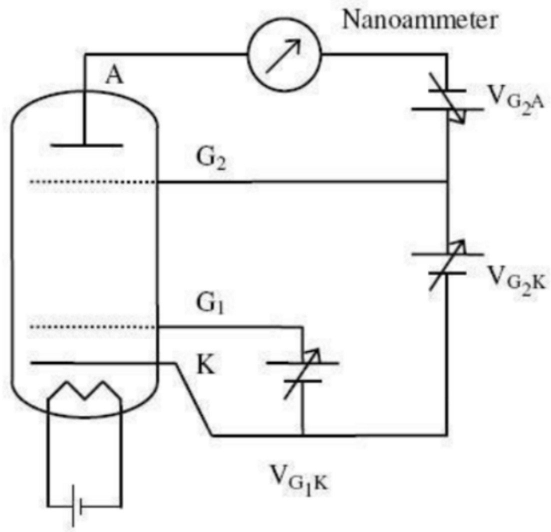


Figure 2: Illustration of Franck Hertz experiment[2].

The Franck-Hertz experiment involved a tube containing argon gas at low pressure, equipped with three essential electrodes:

- A cathode that emits electrons
- A mesh grid to accelerate the electrons
- An anode

The anode was held at a slightly negative potential relative to the grid, but it remained positive in comparison to the cathode. This setup ensured that electrons needed a small amount of kinetic energy to reach the anode after passing through the grid.

3.2.2 Principle

The Franck-Hertz experiment demonstrates the inelastic scattering of electrons by gas atoms and provides evidence for quantized energy states in atoms. As the accelerating voltage increases, several key observations can be made:

1. Initially, the current increases as more electrons reach the anode.
2. Due to the significant mass difference, collisions between electrons and gas atoms are predominantly elastic, meaning the electrons simply change direction without losing much energy.
3. However, when the accelerating voltage matches the excitation potential of the gas atoms, a sudden drop in current is observed. This drop occurs because the electrons lose energy in inelastic collisions, which excites the gas atoms' electrons to a higher energy state.

3.3 Significance

The Franck-Hertz experiment provided strong evidence for Bohr's theory of quantized energy levels in atoms. It demonstrated that:

- Atoms absorb energy in discrete quantities
- These quantities correspond to the differences between specific energy states
- The concept of quantized energy levels is fundamental to quantum mechanics

This experiment was a crucial milestone in the development of quantum theory and our understanding of atomic structure.

4 Experimental Procedure

1. **Initial Setup:**
    - Ensure all control knobs are at minimum position.
    - Set current multiplier knob to 10^{-7} position.
    - Switch ON the power.
2. **Manual Mode Setup:**
    - Turn Manual-Auto switch to manual.
    - Adjust voltage parameters:
        - Filament voltage: mid position
        - V_{G1K}: 1.5 V
        - V_{G2A}: 7.5 V
        - V_{G2K}: 0 V
        - Current multiplier: 10^{-9} A
3. **Data Collection:**
    - Rotate V_{G2K} knob and observe current variation.
    - Record V_{G2K} versus current at 1 V intervals.
    - Plot graph with output current on Y-axis and accelerating voltage V_{G2K} on X-axis.
    - Calculate and tabulate voltage difference between consecutive peaks/valleys.
4. **Oscilloscope Setup:**
    - Minimize all voltage knobs.
    - Turn Manual-Auto switch to Auto.
    - Connect Y, G, and X sockets to oscilloscope terminals.
    - Set oscilloscope to X-Y mode.
    - Adjust Y and X shift for baseline positioning.
5. **Waveform Observation:**
    - Adjust voltage parameters as in step 2.
    - Rotate scanning knob and observe waveform.
    - Adjust Y-gain and X-gain for clear waveform.

- Rotate scanning potentiometer clockwise to end.
- Wait 2-4 minutes for waveform development.

6. **Waveform Recording:**
   - Note X-axis scale on CRO.
   - Trace waveform on paper and attach to journal.
   - Mark voltage differences between consecutive peaks/valleys.

7. **Shutdown:**
   - Minimize all voltage knobs.
   - Switch OFF the apparatus and oscilloscope.

5 Results and Discussion

5.1 Graph Obtained on Oscilloscope (Auto Mode)

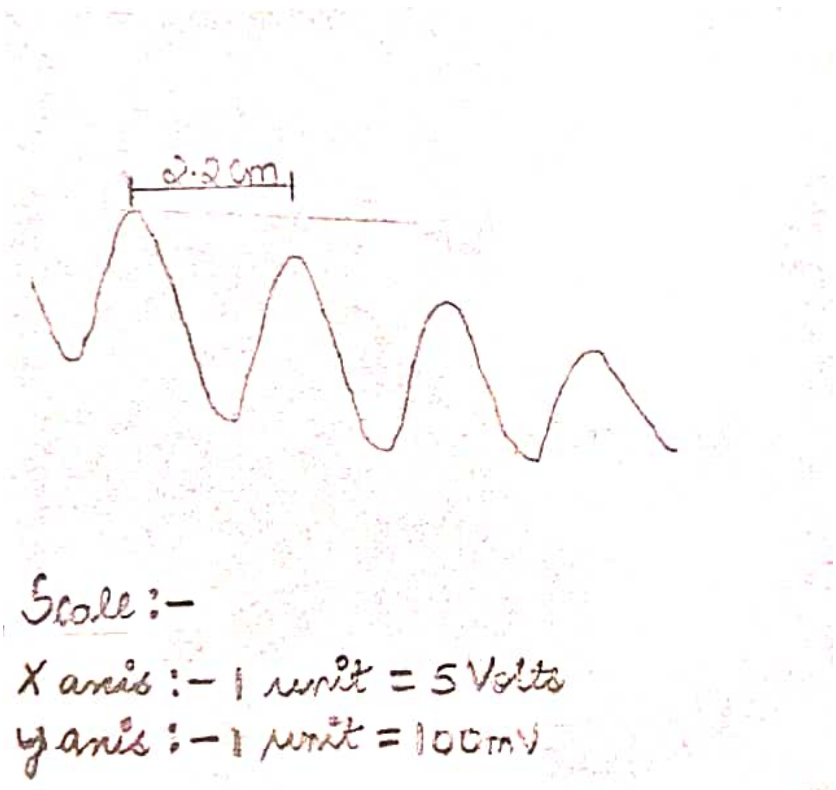


Figure 3: Traced Plot of Current (A) vs V_{G2K} (V) in Auto Mode

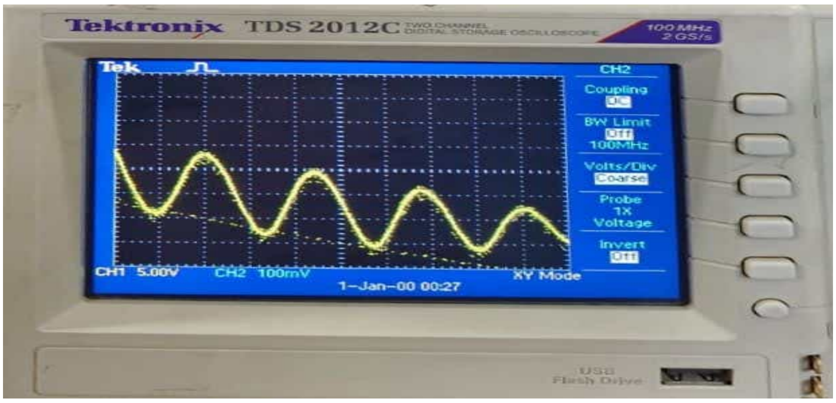


Figure 4: Plot of Current (A) vs V_{G2K} (V) in Auto Mode

5.2 Current (A) vs V_{G2K} (V) (Manual Data Collection)

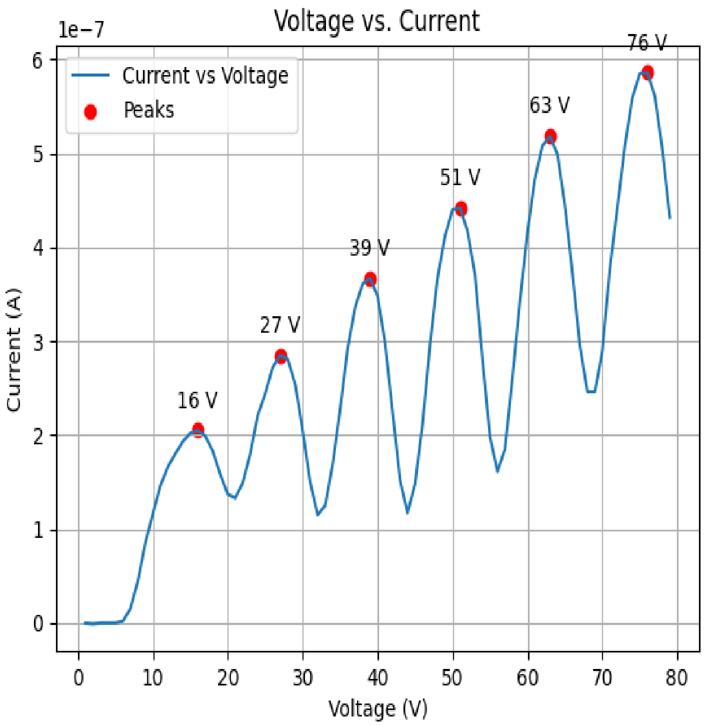


Figure 5: Plot of Current (A) vs V_{G2K} (V)

A plot of current I versus V_{G2K} is shown in Figure 5. This plot was created using Python based on the experimental data listed in Tables 1 and 2.

V_{G2K} (V)	Current (A)
1	-0.24×10^{-9}
2	-1.0×10^{-9}
3	-0.07×10^{-9}
4	-0.05×10^{-9}
5	-0.02×10^{-9}
6	-0.01×10^{-9}
7	1.89×10^{-9}
8	15.11×10^{-9}
9	0.44×10^{-7}
10	0.85×10^{-7}
11	1.16×10^{-7}
12	1.46×10^{-7}
13	1.66×10^{-7}
14	1.80×10^{-7}
15	1.93×10^{-7}
16	2.02×10^{-7}
17	2.05×10^{-7}
18	1.99×10^{-7}
19	1.83×10^{-7}
20	1.58×10^{-7}
21	1.37×10^{-7}
22	1.33×10^{-7}
23	1.49×10^{-7}
24	1.80×10^{-7}
25	2.21×10^{-7}
26	2.44×10^{-7}
27	2.72×10^{-7}
28	2.85×10^{-7}
29	2.81×10^{-7}
30	2.54×10^{-7}
31	2.05×10^{-7}
32	1.50×10^{-7}
33	1.15×10^{-7}
34	1.25×10^{-7}
35	1.69×10^{-7}
36	2.27×10^{-7}
37	2.92×10^{-7}
38	3.36×10^{-7}
39	3.61×10^{-7}
40	3.67×10^{-7}

Table 1: Part 1 of V_{G2K} (V) vs Current (A)

V_{G2K} (V)	Current (A)
41	3.48×10^{-7}
42	2.98×10^{-7}
43	2.24×10^{-7}
44	1.52×10^{-7}
45	1.17×10^{-7}
46	1.48×10^{-7}
47	2.12×10^{-7}
48	2.97×10^{-7}
49	3.67×10^{-7}
50	4.12×10^{-7}
51	4.40×10^{-7}
52	4.42×10^{-7}
53	4.17×10^{-7}
54	3.71×10^{-7}
55	2.80×10^{-7}
56	1.98×10^{-7}
57	1.61×10^{-7}
58	1.85×10^{-7}
59	2.61×10^{-7}
60	3.43×10^{-7}
61	4.16×10^{-7}
62	4.73×10^{-7}
63	5.08×10^{-7}
64	5.18×10^{-7}
65	4.99×10^{-7}
66	4.44×10^{-7}
67	3.73×10^{-7}
68	2.95×10^{-7}
69	2.46×10^{-7}
70	2.46×10^{-7}
71	2.90×10^{-7}
72	3.77×10^{-7}
73	4.42×10^{-7}
74	5.08×10^{-7}
75	5.59×10^{-7}
76	5.85×10^{-7}
77	5.86×10^{-7}
78	5.61×10^{-7}
79	5.04×10^{-7}
80	4.31×10^{-7}

Table 2: Part 2 of V_{G2K} (V) vs Current (A)

5.3 Calculation of Average/Mean Excitation Potential[3]

The mean excitation potential (ΔV) was calculated using the formula:

$$\Delta V = \frac{V_n - V_1}{n - 1} \tag{1}$$

where V_n is the voltage of the nth peak, V_1 is the voltage of the first peak, and n is the number of peaks.

5.3.1 Manual Mode

From the graph (Figure 5), we observed the first four peaks at 16.00 V, 27.00 V, 39.00 V and 51.00 V. The mean excitation potential is calculated as:

$$\Delta V_{\text{manual}} = \frac{51.00\text{ V} - 16.00\text{ V}}{4 - 1} = 11.67\text{ V} \tag{2}$$

Least Count is 1V so decimals not allowed

5.3.2 Auto Mode

From the oscilloscope reading (Figure 4), we observed the first four peaks at -15 V, -3 V, 10 V and 20 V. The mean excitation potential is calculated as:

$$\Delta V_{\text{auto}} = \frac{20\text{ V} - (-15\text{ V})}{4 - 1} = 11.67\text{ V} \tag{3}$$

5.4 Calculation of Standard Deviation

To quantify the precision of our measurements, we calculated the standard deviation using the formula:

$$s = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N - 1}} \tag{4}$$

where s is the standard deviation, x_i are the individual values, $\bar{x}$ is the mean, and N is the number of data points.

5.4.1 Manual Mode

Using the first four peak voltages 16, 27, 39 and 51 V:

Mean ($\bar{x}$):

$$\bar{x} = \frac{16 + 27 + 39 + 51}{4} = 33.25\text{ V} \tag{5}$$

Standard Deviation (s):

$$s = \sqrt{\frac{(16 - 33.25)^2 + (27 - 33.25)^2 + (39 - 33.25)^2 + (51 - 33.25)^2}{4}} = 13.08 \text{ V} \tag{6}$$

5.4.2 Auto Mode

Using the first four peak voltages -15, -3, 10 and 20 V:

Mean ($\bar{x}$):

$$\bar{x} = \frac{(-3) + (-15) + 20 + 10}{4} = 3 \text{ V} \tag{7}$$

Standard Deviation (s):

$$s = \sqrt{\frac{(-15 - 3)^2 + (-3 - 3)^2 + (10 - 3)^2 + (20 - 3)^2}{4}} = 13.20 \text{ V} \tag{8}$$

5.5 Results Summary

- Manual Mode:
  - Mean excitation potential = 11.67 V
  - Standard deviation = 13.08 V
- Auto Mode:
  - Mean excitation potential = 11.67 V
  - Standard deviation = 13.20 V

These results confirm the quantized nature of energy levels in argon atoms, as predicted by Bohr's atomic model. The close agreement between manual and auto mode measurements validates the reliability of our experimental setup and methodology. The standard deviations provide insight into the precision of our measurements, with lower difference in values indicating higher precision.

This experiment not only demonstrates a fundamental principle of quantum mechanics but also showcases the power of the Franck-Hertz experiment in visualizing and measuring atomic energy transitions.

6 Conclusion

The experiment was conducted to determine the average excitation potential of an argon atom by employing both manual and automatic modes. Additionally, the standard deviation was calculated using data collected in both modes to assess the precision of the measurements. The results, including the average excitation potential and associated standard deviations, were recorded to evaluate the reliability and accuracy of the experiment.

7 Author Contributions

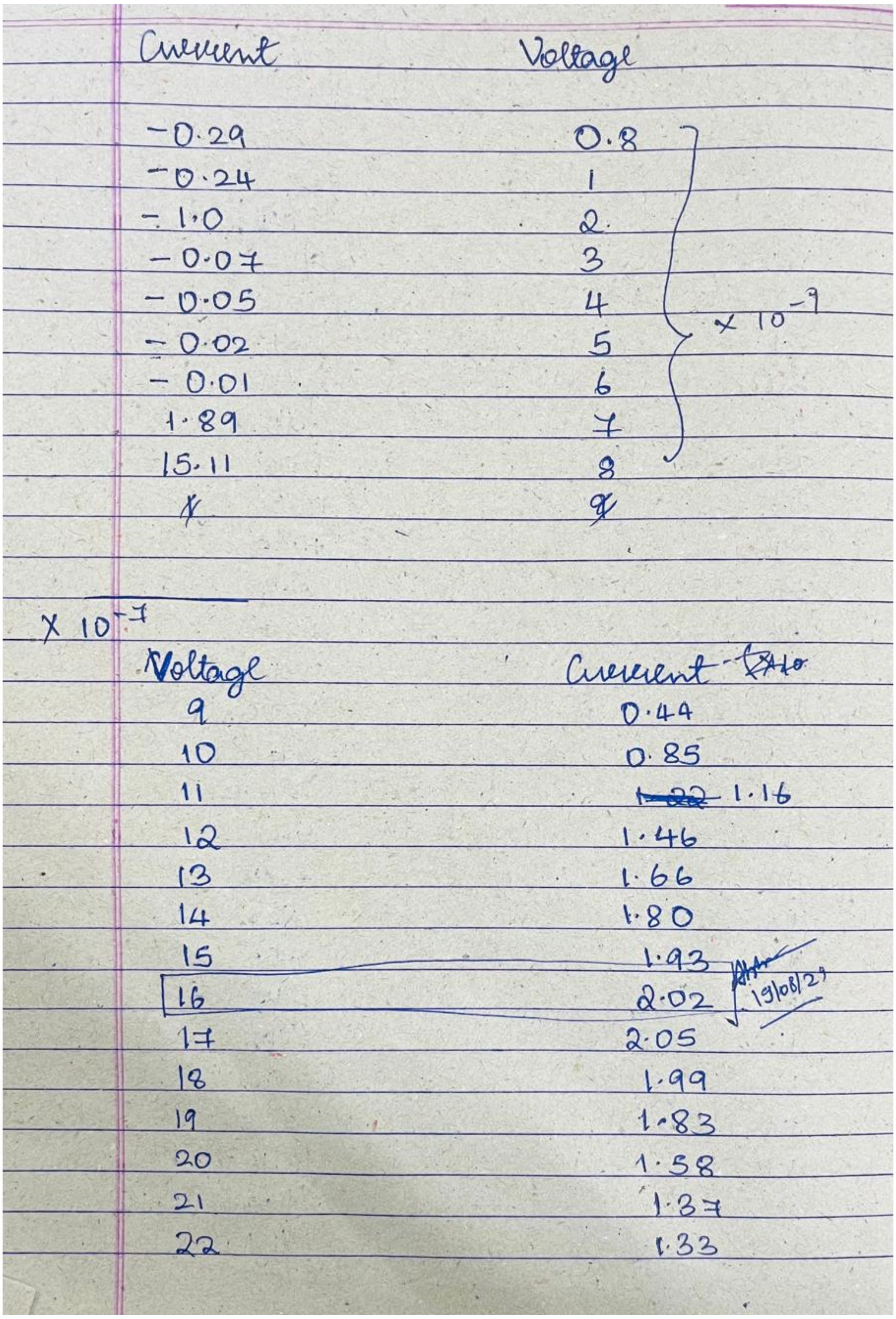
- **Birudugadda Srivibhav**
  - Collected and recorded the experimental data.
  - Created and formatted the tables and figures used in the report.
  - Compiled the results section, including interpreting the data and comparing observed values with theoretical ones.
- **Vubbani Bharath Chandra**
  - Collected and recorded the experimental data.
  - Formatted and finalized the report.
- **Ankeshwar Ruthesha**
  - Collected and recorded the experimental data.
  - Analyzed the data and performed the calculations for the excitation potential of the argon atom
- **Kirtankumar Patel**
  - Generated plots using Python based on the experimental data.

8 References

1 N. Bohr, “On the Constitution of Atoms and Molecules,” Philos. Mag., vol. 26, no. 151, pp. 1-25, 1913.

2 Foothill College, ”4D Lab 8 - The Difference Between 4D and 5D,” Foothill College. [Online].

3 Indian Institute of Technology Roorkee, ”Franck-Hertz Experiment,” Indian Institute of Technology Roorkee. [Online].



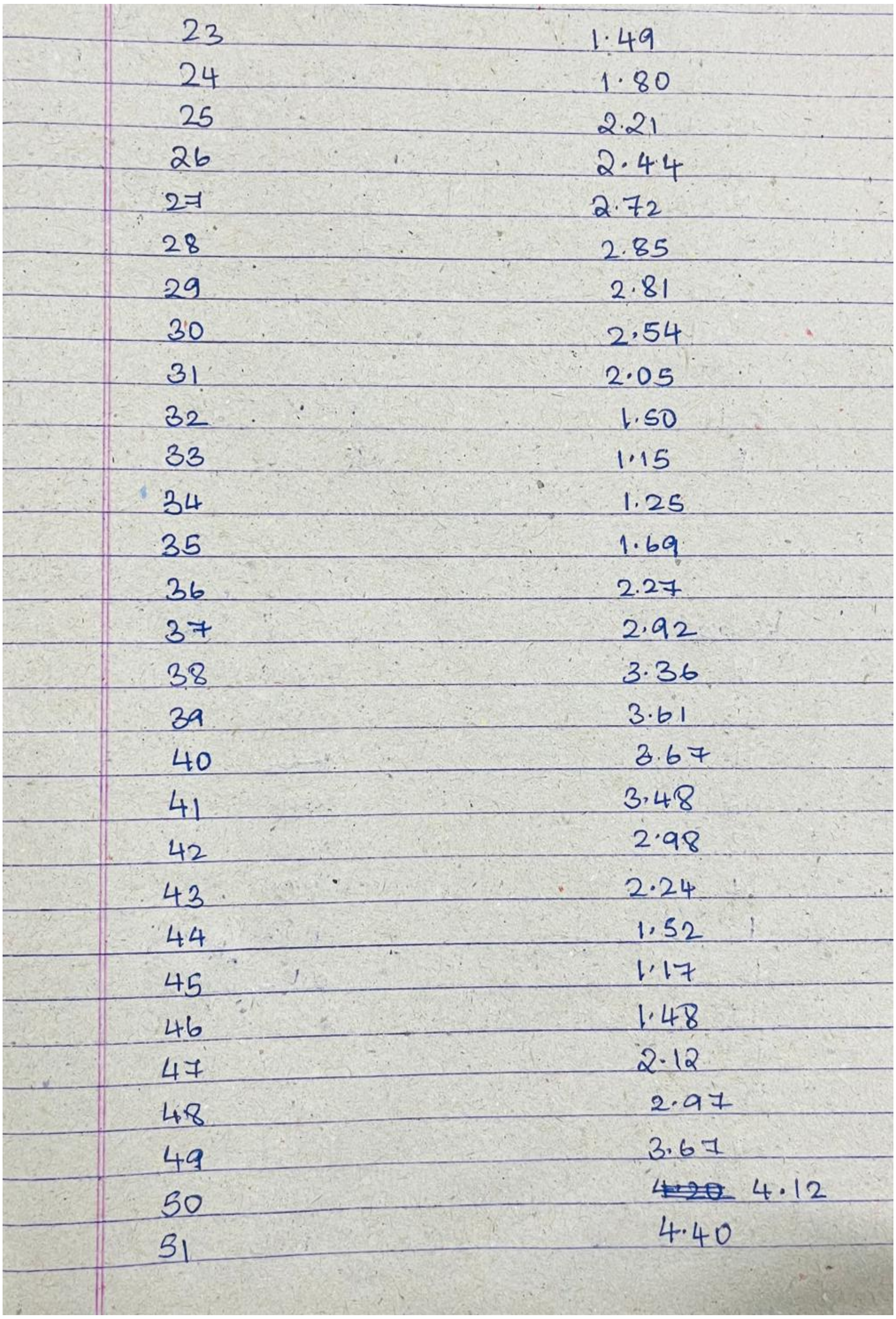
Current	Voltage
−0.29	0.8
−0.24	1
−1.0	2
−0.07	3
−0.05	4
−0.02	5
−0.01	6
1.89	7
15.11	8
~~1~~	~~9~~

$\times 10^{-9}$

$\times 10^{-7}$

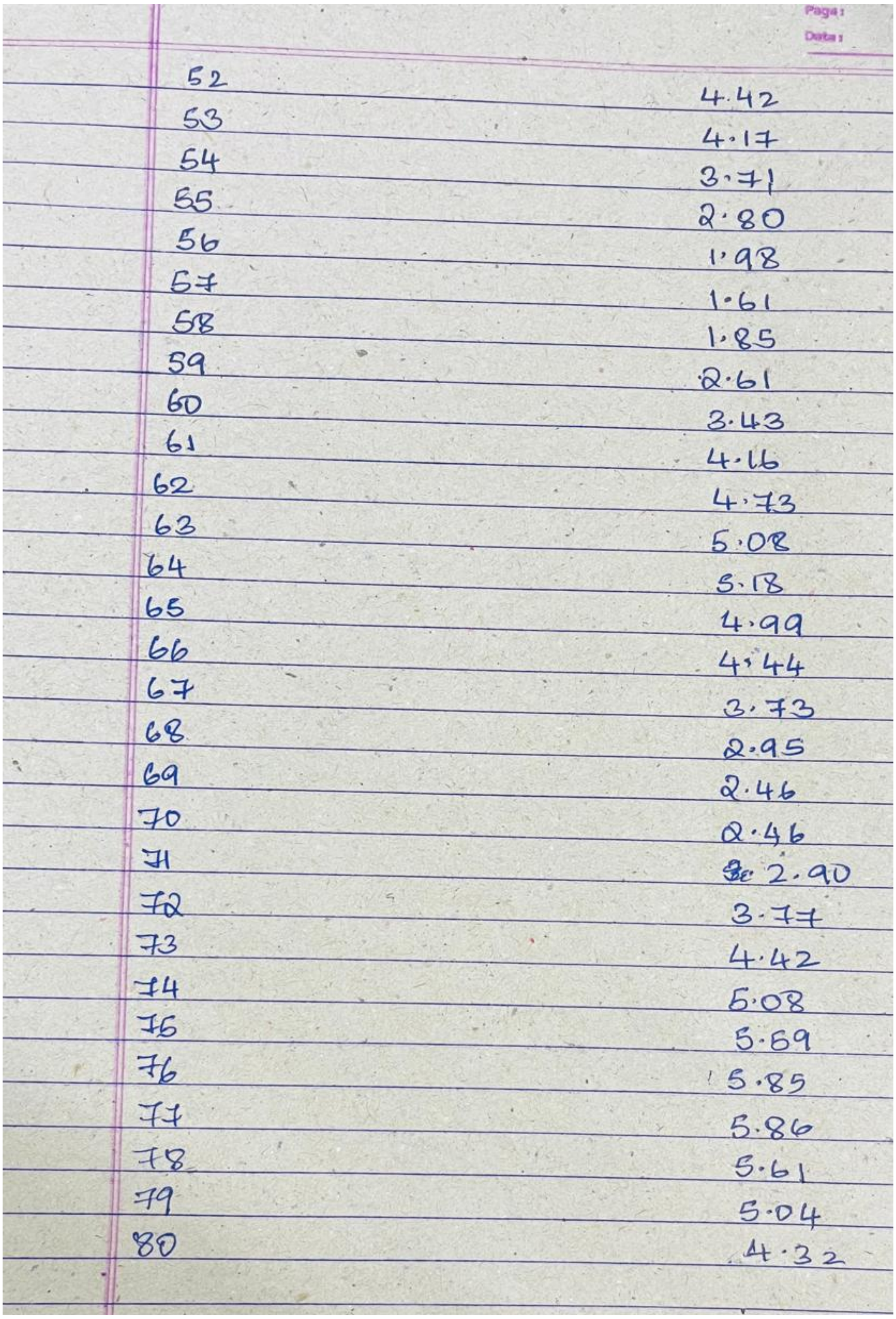
Voltage	Current
9	0.44
10	0.85
11	~~1.22~~ 1.16
12	1.46
13	1.66
14	1.80
15	1.93
16	2.02
17	2.05
18	1.99
19	1.83
20	1.58
21	1.37
22	1.33

Figure 6: Lab Recordings



23	1.49
24	1.80
25	2.21
26	2.44
27	2.72
28	2.85
29	2.81
30	2.54
31	2.05
32	1.50
33	1.15
34	1.25
35	1.69
36	2.27
37	2.92
38	3.36
39	3.61
40	3.67
41	3.48
42	2.98
43	2.24
44	1.52
45	1.17
46	1.48
47	2.12
48	2.97
49	3.67
50	~~4.20~~ 4.12
51	4.40

Figure 7: Lab Recordings



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52	4.42
53	4.17
54	3.71
55	2.80
56	1.98
57	1.61
58	1.85
59	2.61
60	3.43
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62	4.73
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64	5.18
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66	4.44
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68	2.95
69	2.46
70	2.46
71	2.90
72	3.77
73	4.42
74	5.08
75	5.69
76	5.85
77	5.86
78	5.61
79	5.04
80	4.32

Figure 8: Lab Recordings