BS 192: Undergraduate Science Laboratory
(Physics)

A
Laboratory Report on

FRANK HERTZ EXPERIMENT

BY

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OBJECTIVE:
Determine the excitation potential of an argon atom using a Frank-Hertz tube.

THEORY:
In 1913, Niels Bohr proposed that electrons in atoms occupy discrete energy states. The Frank-Hertz experiment, conducted by James Frank and Gustav Hertz in 1914, provided empirical support for Niels Bohr's atomic theory. The experiment utilised a low-pressure mercury gas tube with three electrodes: a cathode, an accelerating mesh grid, and an anode. According to Bohr's concept, electrons have unique and discrete potential binding energies to the nucleus of an atom. The electron is released when a collision occurs at the binding energy, producing a positive ion. Although Bohr's model is not a complete current quantum model, it does describe recognised features of atomic theory. According to Bohr, the Coulomb force causes negatively charged electrons in atoms to orbit around a positively charged nucleus in circles.

Atoms in excited states release radiation at distinct frequencies, ν. The mathematical representation of the radiation frequency is given by:

$$\nu = \frac{\Delta E}{h}$$

Here, ΔE is the energy in J between two energy levels. Moreover, h is Planck's constant.

As the accelerating voltage increased, electrons collided with gas atoms in near-elastic interactions until reaching the excitation potential, leading to sudden drops in current. This phenomenon confirmed Bohr's postulate of quantised energy states for electrons within atoms. The experiment demonstrated the discrete nature of atomic energy levels and significantly contributed to the understanding of quantum mechanics.

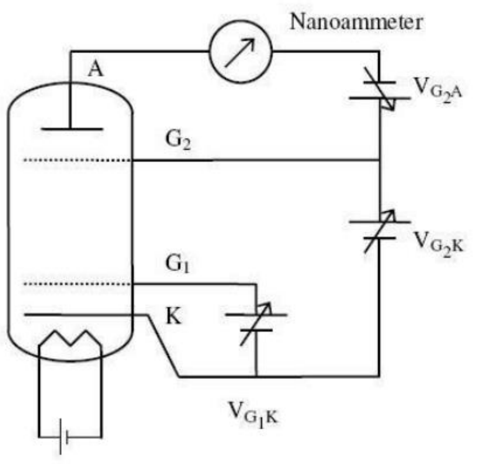


Figure 1: Schematic Diagram of Frank Hertz Experiment

The Frank Hertz Experiment schematic diagram is shown in Fig. 1. Grid G1 is utilised to lessen the impacts of space charge. Maintaining the anode at a little negative potential with respect to grid G2 makes the current dips more noticeable. In this experiment, the current is estimated with respect to VG2K.

Experimental Details:

Apparatus:

- Frank-Hertz tube
- Digital voltmeter
- Digital ammeter
- Continuously variable power supply
- Cathode ray oscilloscope

Procedure:

1. It should be noted that the control knobs are at the minimum position before the power is turned ON.
2. After switching on the machine, let the machine heat up for about 7-10 minutes.
3. Set the current multiplier knob to 10^{-9}. From the manual-auto mode, select manual mode.
4. Adjust the voltage values as, Filament = Mid position, V_{G1K} = 1.5 V, V_{G2A} = 7.5 V, VG_{2K} = 0 V.
5. Turn the V_{G2K} knob increasing the value by intervals of .5 V and noting down the value of the corresponding current. Maxima and minima to be observed and highlighted.
6. Reduce the V_{G1K}, V_{G2K}, and V_{G2A} knobs to their minimum values.
7. Plot the output current on the y-axis and the Voltage V_{G2K} on the x-axis. Find out the difference between two consecutive maxima.
8. Connect the Y, G, and X terminals of the oscilloscope to the appropriate sockets after selecting the Auto mode using the auto-manual switch. Using the x- and y-axis knobs to set up the graph, turn on the oscilloscope's x-y mode. When the scanning knob is slowly turned to the maximum, a graph with maxima and minima will be seen. To see the waveform, adjust the oscilloscope's X-gain and Y-gain. Wait 2-4 minutes for the graph to stabilise.
9. Note down the scale of the x-axis and the y-axis on the trace paper and draw the graph on the trace paper. Note down the difference between two consecutive maxima.
10. Again, Reduce the V_{G1K}, V_{G2K}, and V_{G2A} knobs to their minimum values.
11. Switch off the Power supply and the oscilloscope.

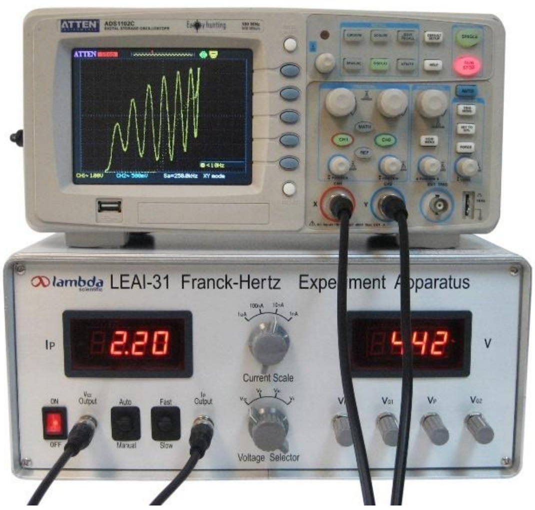


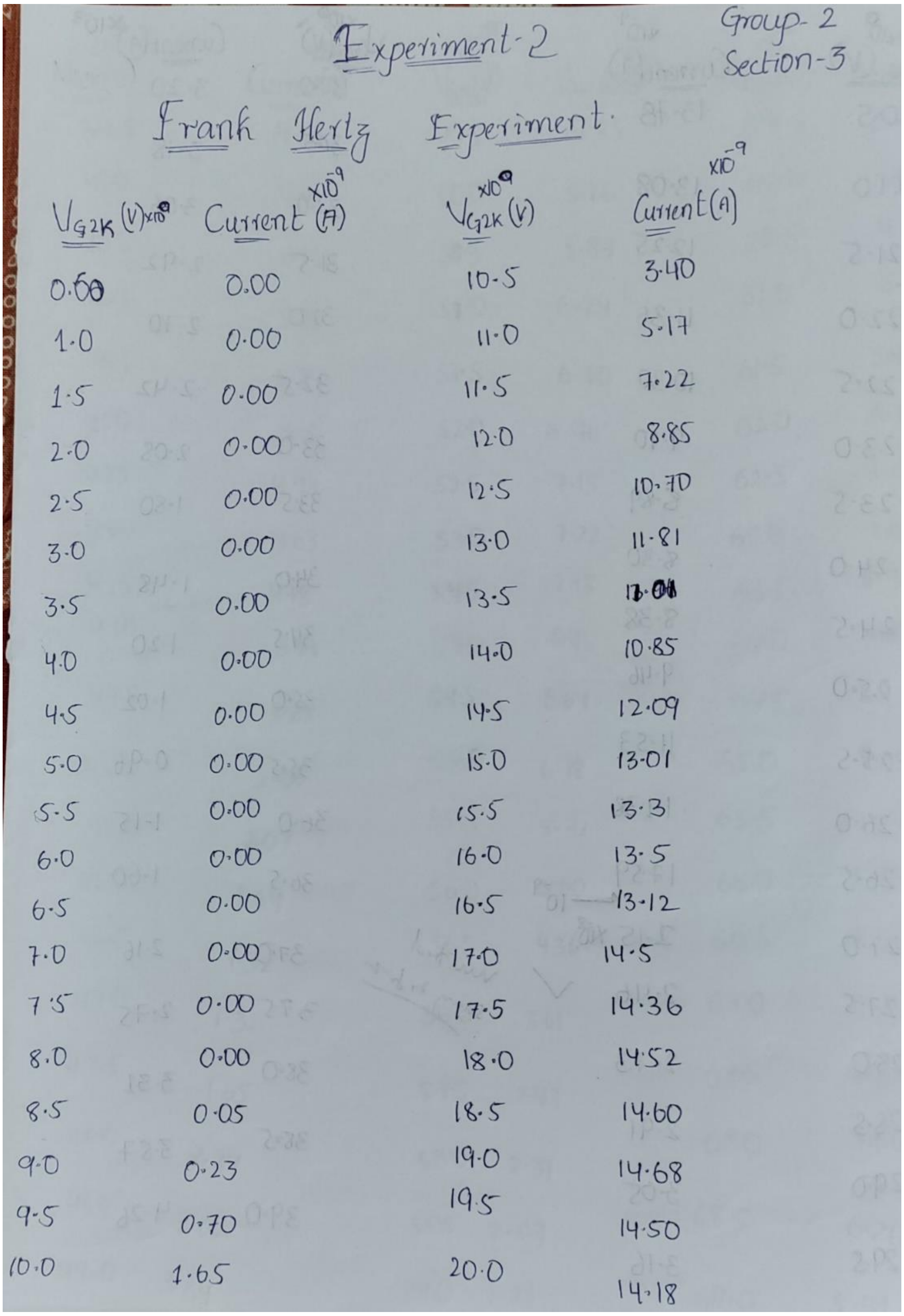
Figure 2: Experimental setup

Results and discussion

Observations:

To get accurate results, we obtained Voltages with a difference of 0.5 V between readings. For measuring current, we set our multiplier at 10^{-9} Amperes for higher precision, which was later set to 10^{-8} Amperes when readings got out of range. Before taking readings, the filament voltage was kept at mid position, V_{G1K} = 1.5 V, V_{G2A} = 7.5 V and V_{G2K} = 0 V, respectively.

Readings from Manual Mode:


Experiment-2

Group-2
Section-3

Frank Hertz Experiment.

V_{G2K} (V) $\times 10^{-9}$	Current (A) $\times 10^{-9}$	V_{G2K} (V) $\times 10^{-9}$	Current (A) $\times 10^{-9}$
0.00	0.00	10.5	3.40
1.0	0.00	11.0	5.17
1.5	0.00	11.5	7.22
2.0	0.00	12.0	8.85
2.5	0.00	12.5	10.70
3.0	0.00	13.0	11.81
3.5	0.00	13.5	[illegible]
4.0	0.00	14.0	10.85
4.5	0.00	14.5	12.09
5.0	0.00	15.0	13.01
5.5	0.00	15.5	13.3
6.0	0.00	16.0	13.5
6.5	0.00	16.5	13.12
7.0	0.00	17.0	14.5
7.5	0.00	17.5	14.36
8.0	0.00	18.0	14.52
8.5	0.05	18.5	14.60
9.0	0.23	19.0	14.68
9.5	0.70	19.5	14.50
10.0	1.65	20.0	14.18

V_{G2K} (V) $\times 10^{0}$	Current (A) $\times 10^{-9}$
20.5	13.78
21.0	13.08
21.5	12.25
22.0	11.36
22.5	10.30
23.0	9.70
23.5	8.89
24.0	8.30
24.5	8.38
25.0	9.46
25.5	11.53
26.0	14.38
26.5	17.59 10^{-9}
27.0	1.15 $\times 10^{-8}$
27.5	2.46 ✓
28.0	2.73
28.5	2.91
29.0	3.05
29.5	3.16

Verified
[signature]

V_{G2K} (V) $\times 10^{0}$	Current (A) $\times 10^{-8}$
30.0	3.20
30.5	3.18
31.0	3.06
31.5	2.92
32.0	2.70
32.5	2.42
33.0	2.08
33.5	1.80
34.0	1.48
34.5	1.20
35.0	1.02
35.5	0.96
36.0	1.15
36.5	1.60
37.0	2.16
37.5	2.75
38.0	3.31
38.5	3.87
39.0	4.26.

×10 V_{G2K}(V)	$\times 10^{-8}$ Current(A)	×10 V_{G2K}(V)	$\times 10^{-8}$ Current(A)	×10 V_{G2K}(V)	$\times 10^{-8}$ Current(A)
39.5	4.63	49.5	4.55	59.5	2.75
40.0	4.91	50.0	5.26	60.0	3.43
40.5	5.11	50.5	5.83	60.5	4.26
41.0	5.23	51.0	6.24	61.0	5.07
41.5	5.24	51.5	6.70	61.5	5.96
42.0	5.15	52.0	6.96	62.0	6.66
42.5	4.93	52.5	7.15	62.5	7.27
43.0	4.63	53.0	7.22	63.0	7.89
43.5	4.18	53.5	7.15	63.5	8.35
44.0	3.73	54.0	6.96	64.0	8.69
44.5	3.22	54.5	6.64	64.5	8.93
45.0	2.58	55.0	6.18	65.0	9.05
45.5	2.07	55.5	5.72	65.5	9.04
46.0	1.64	56.0	5.00	66.0	8.88
46.5	1.32	56.5	4.36	66.5	8.62
47.0	1.32	57.0	3.61	67.0	8.18
47.5	1.65	57.5	2.93	67.5	7.62
48.0	2.24	58.0	2.39	68.0	7.04
48.5	3.02	58.5	2.09	68.5	6.26
49.0	3.84	59.0	2.21	69.0	5.51

V_{G2K}(V)	Current(A) $\times 10^{-8}$	V_{G2K}(V)	Current(A) $\times 10^{-8}$	V_{G2K}(V)	Current(A) $\times 10^{-8}$
69.5	4.78	78.0	10.78	87.0	9.33
70.0	4.14	78.5	10.65	87.5	9.94
70.5	3.79	79.0	10.43	88.0	10.57
71.0	3.78	79.5	10.06	88.5	11.16
71.5	4.06	80.0	9.46	89.0	11.65
72.0	4.63	80.5	8.89	89.5	12.01
72.5	5.27	81.0	8.24	90.0	12.24
73.0	6.09	81.5	7.52	90.5	12.40
73.5	6.81	82.0	6.79	91.0	12.44
74.0	7.56	82.5	6.23	91.5	12.30
74.5	8.32	83.0	5.86		
75.0	8.91	83.5	5.75		
75.5	9.55	84.0	5.88		
76.0	9.98	84.5	6.20		
76.5	10.35	85.0	6.66		
77.0	10.62	85.5	7.33		
77.5	10.77	86.0	7.99		
		86.5	8.70		

Verified
Sunny [illegible]

Voltage V_{G2K} (V)	Current I ($\times 10^{-9}$ A)
0.6	0
1	0
1.5	0
2	0
2.5	0
3	0
3.5	0
4	0
4.5	0
5	0
5.5	0
6	0
6.5	0
7	0
7.5	0
8	0
8.5	0.05
9	0.23
9.5	0.7
10	1.65
10.5	3.4
11	5.17
11.5	7.22
12	8.85
12.5	10.7
13	11.81
13.5	11.01
14	10.85
14.5	12.09
15	13.2
15.5	13.3
16	13.5
16.5	13.12
17	14.5
17.5	14.31
18	14.52
18.5	14.6
19	14.68
19.5	14.4
20	14.18
20.5	13.78
21	13.08
21.5	12.25

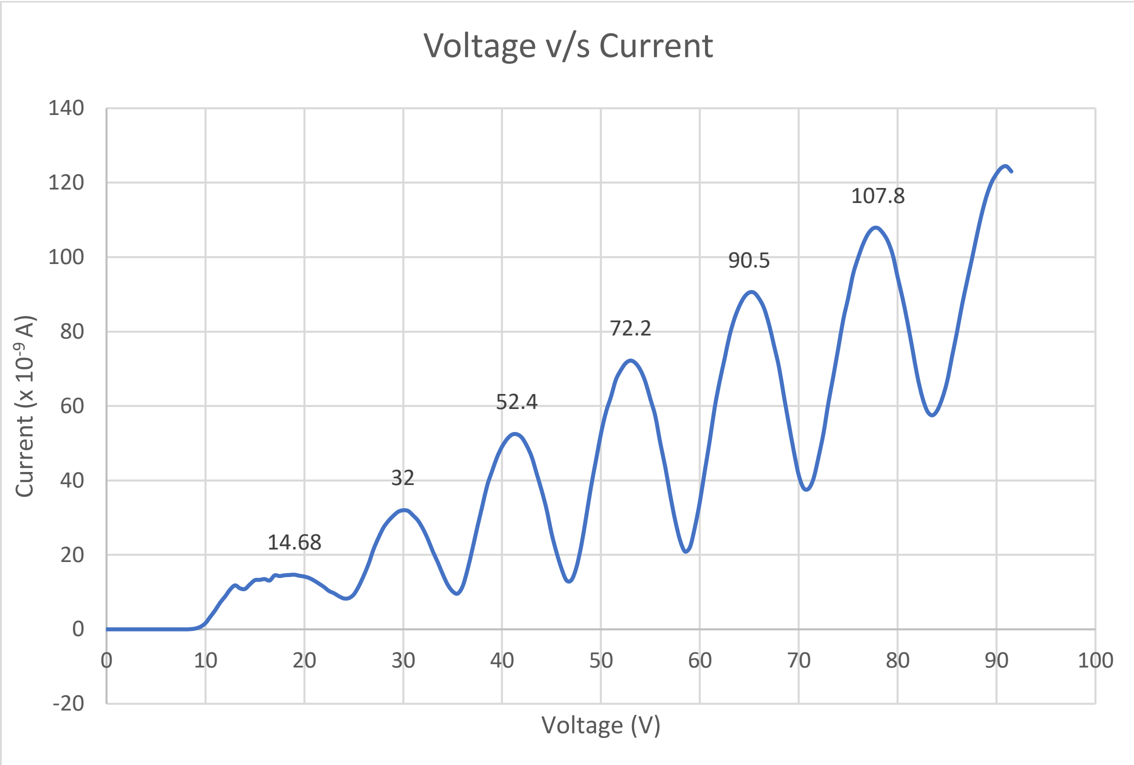
22	11.36
22.5	10.3
23	9.7
23.5	8.89
24	8.3
24.5	8.38
25	9.36
25.5	11.53
26	14.38
26.5	17.59
27	21.5
27.5	24.6
28	27.3
28.5	29.1
29	30.5
29.5	31.6
30	32
30.5	31.8
31	30.6
31.5	29.2
32	27
32.5	24.2
33	20.9
33.5	18
34	14.8
34.5	12
35	10.2
35.5	9.6
36	11.5
36.5	16
37	21.6
37.5	27.5
38	33.1
38.5	38.7
39	42.6
39.5	46.3
40	49.1
40.5	51.1
41	52.3
41.5	52.4
42	51.5
42.5	49.3
43	46.3
43.5	41.8
44	37.3
44.5	32.2

45	25.8
45.5	20.7
46	16.4
46.5	13.2
47	13.2
47.5	16.5
48	22.4
48.5	30.2
49	38.4
49.5	45.5
50	52.6
50.5	58.3
51	62.4
51.5	67
52	69.6
52.5	71.5
53	72.2
53.5	71.5
54	69.6
54.5	66.4
55	61.8
55.5	57.2
56	50
56.5	43.6
57	36.1
57.5	29.3
58	23.9
58.5	20.9
59	22.1
59.5	27.5
60	34.3
60.5	42.6
61	50.7
61.5	59.6
62	66.6
62.5	72.7
63	78.9
63.5	83.5
64	86.9
64.5	89.3
65	90.5
65.5	90.4
66	88.8
66.5	86.2
67	81.8
67.5	76.2

68	70.4
68.5	62.6
69	55.1
69.5	47.8
70	41.4
70.5	37.9
71	37.8
71.5	40.6
72	46.3
72.5	52.7
73	60.9
73.5	68.1
74	75.6
74.5	83.2
75	89.1
75.5	95.5
76	99.8
76.5	103.5
77	106.2
77.5	107.7
78	107.8
78.5	106.5
79	104.3
79.5	100.6
80	94.6
80.5	88.9
81	82.4
81.5	75.2
82	67.9
82.5	62.3
83	58.6
83.5	57.5
84	58.8
84.5	62
85	66.6
85.5	73.3
86	79.9
86.5	87
87	93.3
87.5	99.4
88	105.7
88.5	111.6
89	116.5
89.5	120.1
90	122.4
90.5	124

91	124.4
91.5	123

Voltage v/s Current Graph:



Peak Number	Voltage V_{G2K} (V)	Current I ($x10^{-9}$ A)
1	19.0	14.68
2	30.0	32.00
3	41.5	52.40
4	53.0	72.20
5	65.0	90.50
6	78.0	107.80

Peaks	Peak to Peak Voltage V_{P-P} (V)
1 and 2	11.0
2 and 3	11.5
3 and 4	12.5
4 and 5	12.0
5 and 6	13.0

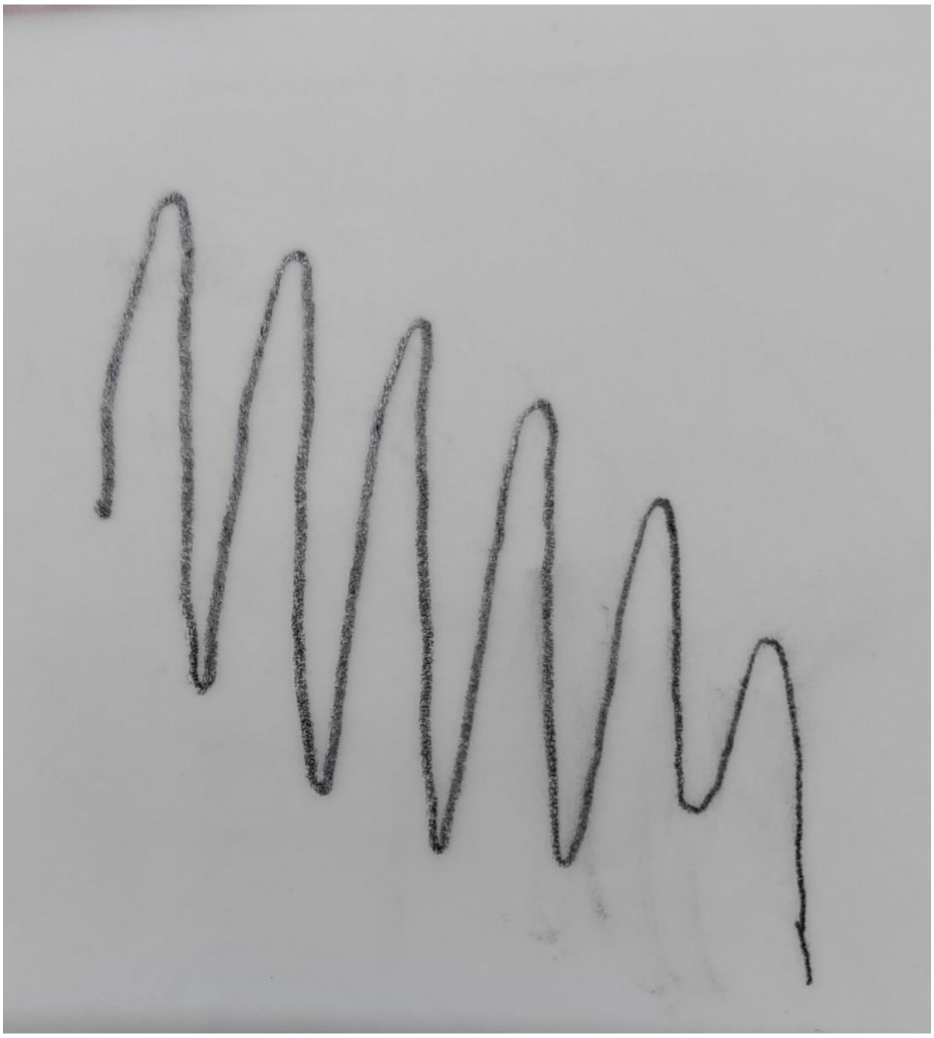
$$\text{Average } V_{P\text{-}P} = \frac{\text{Sum of VP−P for different Peaks}}{\text{Total number of Peaks}}$$

$$\text{Average } V_{P\text{-}P} = \frac{11.0 + 11.5 + 12.5 + 12.0 + 13.0}{5} \text{ V}$$

$$\text{Average } V_{P\text{-}P} = \frac{60.0}{5} \; V$$

Average $V_{P\text{-}P}$ = 12.0 V

Readings from Auto Mode:



X axis scale unit = 10 V / unit

Least count of Voltage on the oscilloscope = Volts per unit / Number of Divisions per unit

L.C. = 10 V / 10

L.C. = 1 V

Peaks	Peak to Peak Voltage $V_{P\text{-}P}$ (V)
1 and 2	9

2 and 3	10
3 and 4	10
4 and 5	9
5 and 6	9

Average $V_{P\text{-}P}$ = Sum of values of $V_{P\text{-}P}$ for different Peaks/ Total number of Peaks

Average $V_{P\text{-}P} = \frac{(9 + 10 + 10 + 9 + 9)}{5}$ V

Average $V_{P\text{-}P}$ = 9.4 V

Average $V_{P\text{-}P} \approx$ 9 V

Error Analysis

To calculate the standard deviation of the readings obtained, we will use the formula,

$$SD = \sqrt{\sum \frac{|x-\mu|^2}{N}}$$

where N is the size of our data set, and μ is the mean of our data set.

For manual data:

μ = 12 V

$SD = (\frac{|11.0-12.0|2 + |11.5-12.0|2 + |12.5-12.0|2 + |12.0-12.0|2 + |13.0-12.0|2}{5})^{1/2}$ V

$SD = (0.5)^{1/2}$ V

SD ≈ 0.7 V

Therefore, the Average Value of Argon's Excitation Potential calculated by **Manual Mode is**

<u>12.0 ± 0.7 V</u>.

For Auto Mode:

μ = 9 V

$SD = (\frac{|9-9|2 + |10-9|2 + |10-9|2 + |9-9|2 + |9-9|2)}{5})^{1/2}$ V

$SD = (0.4)^{1/2}$ V

SD ≈ 0.6 V

Therefore, the average Value of Argon's Excitation Potential calculated by **Auto Mode is**

<u>9.0 ± 0.6 V</u>.

Final Precise Results:

Average value of excitation potential of argon atom (manual mode) = 12.0 ± 0.7 V

Average value of excitation potential of argon atom (auto mode) = 9.0 ± 0.6 V

Source of Errors in the experiment:

Although this experiment is well established, there are various potential sources of errors that can affect the accuracy and reliability of our readings. Some Common sources include:

1) **Temperature Fluctuations:** The overall behaviour of the electrons can be affected due to temperature changes. It will change their properties, like the Mean Free Path, impacting the collision frequency and energy transfer.
2) **Voltage Fluctuations:** Different readings taken in this experiment from particular Voltage values are accurate only if the Voltage Fluctuations are minimal. Any uncertain Variations would not give us an accurate result.
3) **Pressure Differences:** As Argon gas is filled in a vacuum chamber, a small crack or opening would strongly affect our readings as it would change the mean free path of the electrons.
4) **Sensitivity of Measuring equipment:** If the instruments are not giving accurate readings, then this would add up to the errors we faced.
5) **Power Supply:** Our instruments operate on a desired power supply. Any fluctuations in this main supply might add up to the errors caused in the experiment.
6) **Electron-Electron Interaction:** One can't ignore these interactions as they might affect our readings at a particular stage in the experiment.

CONCLUSION:

Bohr's theory, which talks about quantifying energy levels in atoms, is proved by the Frank Hertz Experiment. In this experiment, we can determine the excitation potential of argon gas atoms by observing the output current when we change the accelerating or grid potential. In this experiment, abrupt decreases in current are noticed at specific voltage points. These declines signify inelastic collisions occurring between accelerated electrons and argon atoms. Within these collisions, electrons effectively transfer their energy to the argon atoms, inducing them to undergo excitation and ascend to higher energy states. By analysing these voltage intervals, the excitation potential of argon can be calculated. This experiment correctly validates the atom's Bohr model and provides a practical method for determining the excitation potentials of different atoms. The average excitation potential of argon atoms calculated manually is 12.0 ± 0.7 V, whereas calculated in auto mode is 9.4 ± 0.6 V respectively.

Learning Outcomes

- To Determine an Atom's excitation potential of a gas
- To find excitation Potential of any gas.
- Gained useful knowledge from analysing the circuit of this experiment.

Author Contributions

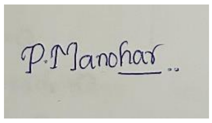
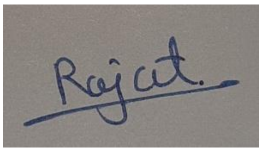
Name	Roll Number	Contribution	Signature
Prachand Aditya Prashant	23110250	• Observation Table • Results • Calculations • Graphs	
Pulakurthi Manohar	23110259	• Introduction • Mechanism • Theory	
Rajat Kabra	23110268	• Apparatus • Procedure • Safety Precautions	
Rishank Soni	23110277	• Conclusion • Learning Outcomes • Author Contributions • Editing the Report	

Image Sources

- https://lambdasys.com/uploads/20151026-081212002702.jpg
- https://drive.google.com/file/d/1Z4BSlDCCoWTCNDWzKejCTm0RmHXsO8EA/view

References

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- Class 12 Concept of Physics by HC Verma
- Understanding Physics JEE Main & Advanced Optics and Modern Physics by DC Pandey