Frank-Hertz Experiment

BS192: Undergraduate Science Laboratory (Physics)

Group 7 (Lab No. 1, Experiment No. 2)

A laboratory report by

Aksh Kishor Solanki (24110023)

Akshat Vishal Wandalkar (24110024)

Akshay (24110025)

Akshit Chhabra (24110026)

Akul Gupta (24110027)

Indian Institute of Technology, Gandhinagar

Experiment No. 2

Frank-Hertz Experiment

I. Aim

To determine the first excitation potential of the Argon atom using the Frank-Hertz tube.

II. Theory

The Frank-Hertz experiment was carried out by James Frank and Gustav Hertz in 1914. It was the first experiment that clearly showed the quantum nature of atoms. It also validated Niels Bohr's atomic model and confirmed his idea that electrons existed in quantized energy states.

The original experimental setup consisted of a glass tube filled with low-pressure mercury gas fitted with 3 electrodes: one electron-emitting cathode, a mesh grid for acceleration and an anode. The grid's voltage was kept positive with respect to the cathode, to draw the emitted electron. The current measured during the experiment is due to the electrons passing through the grid and reaching the anode.

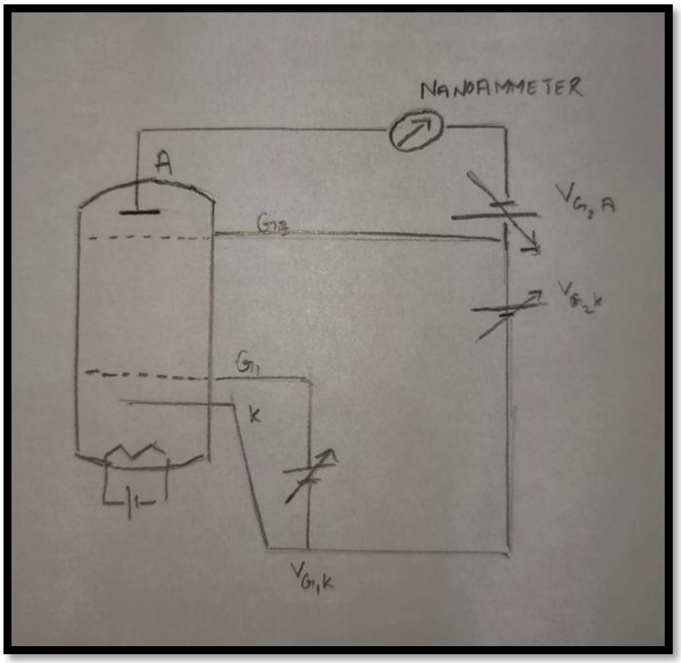
As the voltage across the electrodes is increased, the number of electrons reaching the anode increases, and hence the current increases. While the accelerating voltage is less than the excitation potential of the atom, the energized electrons are unable to transfer their energy to the atoms and merely bounce off of them after an elastic collision. When the accelerating voltage becomes equal to the excitation potential of the atom, the electrons transfer their energy to the atom and are unable to reach the anode. This results in a significant decrease in the observed current.

The sudden drop in the observed current suggests that the electrons can only accept the energy beyond the threshold for exciting them to the first excited state. Thus, Franck and Hertz observed quantization of energy states, validating Bohr's theory. Electrons with energy greater than the critical value could excite the mercury gas atoms, while the ones with lower energy just bounced around elastically. James Franck and Gustav Hertz were awarded the Nobel Prize in Physics in 1925 for their work.

III. Experimental Procedure

Apparatus Used:

- Frank-Hertz Tube
- Cathode Ray Oscilloscope
- Continuous Variable Power Supply
- Digital Voltmeter
- Digital Ammeter



Execution:

1. Before switching on, ensure that all the knobs are at their minimum position. The current multiplier can be kept at 10^{-7} but can be changed later to get readings with the desired precision. Now, turn the power ON.
2. Switch the Manual-Auto switch to the ‘Manual’ position. Set the values of
    - V_{G1K} = 1.5V
    - V_{G2K} = 0V
    - V_{G2A} = 7.5V
3. Turn the filament knob till it reaches its middle position. Wait for 5-10 minutes for the filament to heat up.
4. Increase the V_{G2K} voltage by 1V and note down the corresponding current value immediately.
5. Repeat Step 4 till the V_{G2K} voltage reaches 70V. Plot a graph with current on the Y-axis and the V_{G2K} on the X-axis.
6. Now slowly minimize all the knobs to zero again. Turn the Manual-Auto switch to the Auto position and connect the G, X and Y sockets to the corresponding terminals of the oscilloscope.
7. Put the range switch of the oscilloscope into X-Y mode. Switch on the oscilloscope and adjust the X-Y scales and X-Y shifts to make the baseline appear at the bottom of the oscilloscope screen.
8. Rotate the scanning knob to plot the waveform on the display. Adjust the X-Y gains for clarity of the waveform. Wait 1-2 minutes for the waveform to develop completely.
9. Now, use the tracing paper to trace out the shape of the waveform and mark voltage differences between consecutive peaks and valleys.
10. Turn off the oscilloscope. Now, slowly bring down all the knobs to their minimum values again and turn off the apparatus.

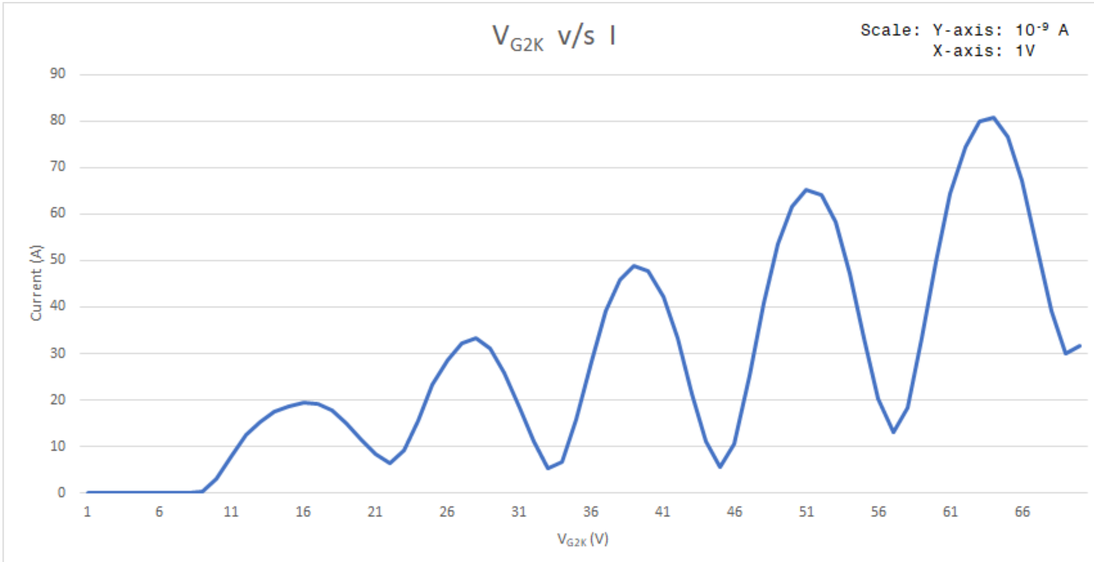
IV. Results and Discussion:

Observations:

- **Manual Mode:**

V_{G2K} (V)	Current (I x 10^{-9})	V_{G2K} (V)	Current (I x 10^{-9})	V_{G2K} (V)	Current (I x 10^{-9})
1	0.02	25	23.2	49	53.6
2	0.02	26	28.6	50	61.6
3	0.02	27	32.2	51	65.2
4	0.02	28	33.2	52	64.2
5	0.02	29	31.2	53	58.2
6	0.02	30	25.8	54	47.2
7	0.02	31	18.4	55	33.4
8	0.03	32	11.1	56	20.4
9	0.4	33	5.38	57	13.14
10	3.2	34	6.7	58	18.27
11	8.12	35	15.75	59	33.4
12	12.43	36	28.2	60	49.8
13	15.23	37	39.1	61	64.4
14	17.53	38	45.9	62	74.4
15	18.74	39	48.8	63	80
16	19.58	40	47.7	64	80.8
17	19.21	41	42.3	65	76.5
18	17.7	42	33.2	66	67.2
19	15.11	43	21.3	67	52.5
20	11.81	44	11.21	68	39.1
21	8.33	45	5.55	69	30
22	6.42	46	10.69	70	31.6
23	9.22	47	25.2		
24	15.53	48	40.8		

Plot of I v/s V_{G2K}:



1. At low values of V_{G2K}, up to 8 volts, the current in the tube was almost 0 A (0.2 x 10^{-9} A), As the voltage was further increased, the current also increased up to a certain value and then decreased. Similarly, the current rises and dips several times and we obtain peaks and valleys in the graph.
2. The peak values of the current are given below:

Current (I x 10^{-9})	V_{G2K} (V)
19.58	16
33.2	28
48.8	39
65.2	51
80.8	64

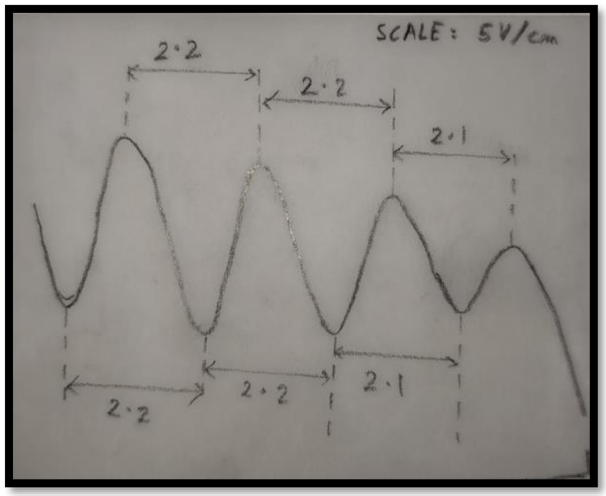
3. The dip values of the current are given below:

Current (I x 10^{-9})	V_{G2K} (V)
6.42	22
5.38	33
5.55	45
13.14	57
30.0	69

4. To obtain the first excitation potential of Argon, we will compute the difference between two consecutive values of peaks or valleys.

- **Auto Mode:**

1. On switching to auto mode and connecting the oscilloscope, we obtain a similar result to manual mode.
2. We calculate the difference between consecutive values of peaks and valleys after choosing a suitable scale.



Result and Calculation:

- **Manual Mode:**

	V_{G2K} (V)	V_i (V)	$V_i - V_0$ (V)	$(V_i - V_0)^2$ (V^2)
Peak	16	12	0.12	0.01
	28	11	-0.88	0.77
	39	12	0.12	0.01
	51	13	1.12	1.25
	64			
Dip	22	11	-0.88	0.77
	33	12	0.12	0.01
	45	12	0.12	0.01
	57	12	0.12	0.01
	69			

	Mean (V_0)	11.88		
	Standard Dev. (σ)	0.60		

1. Mark the peak points and valley points from the observed data.
2. Calculate the difference between consecutive peak and valley points.
3. Calculate the average value of the excitation potential.

$$V_0 = \frac{\sum V_i}{N}$$

4. Calculate the standard deviation using the mean.

$$\sigma = \sqrt{\frac{(V_i - V_0)^2}{N}}$$

$$V_0 = 11.88\,V,\ \ \sigma = 0.60\,V$$

- **Auto Mode:**

Scale	**X-axis**	**5 V/cm**		
	V_{G2K} (V)	**V_i (V)**	**V_i - V_0 (V)**	**$(V_i - V_0)^2$ (V^2)**
Peak	2.1	10.5	-0.33	0.11
	2.2	11	0.17	0.03
	2.2	11	0.17	0.03
Dip	2.1	10.5	-0.33	0.11
	2.2	11	0.17	0.03
	2.2	11	0.17	0.03
	Mean (V_0)	10.83		
	Standard Dev. (σ)	0.24		

1. Get the distance between the consecutive peak and valley points on the oscilloscope with a suitable scale.
2. Multiply that distance by the scale for x-axis.
3. Calculate the average value for the excitation potential.

$$V_0 = \frac{\sum V_i}{N}$$

4. Calculate the standard deviation using the mean.

$$\sigma = \sqrt{\frac{(V_i - V_0)^2}{N}}$$

$$V_0 = 10.83\ V,\ \ \sigma = 0.24\ V$$

V. Error Analysis:

The absolute error with the true value of the excitation potential of Argon:

- **Manual Mode:**

$V_0 = 11.88 \pm 0.60\ V$

$$Error = \frac{|V_0 - V_{actual}|}{V_{actual}} \times 100\%$$

Error = 9.31%

- **Auto Mode:**

$V_0 = 10.83 \pm 0.24\ V$

$$Error = \frac{|V_0 - V_{actual}|}{V_{actual}} \times 100\%$$

Error = 17.33%

The possible source of errors:

- The initial value of the V_{G2K} voltage was supposed to be 0 V, but we could not get it below 0.08 V in manual mode, and 0.06 V in auto mode. Similarly, even after minimizing all the voltages, the current value did not go below 0.02 x 10^{-9} A. (Zero Error)
- Lack of enough points (low resolution of data) due to a large interval value of 1 V and only taking the average value of 3-4 peak/valley points. Reducing the interval of V_{G2K} or using more peak/valley points could lead to more accurate values.
- On changing the V_{G2K} value, the current value fluctuates heavily. We noted down the immediate value of the current on changing the voltage. Waiting for the current to stabilize and averaging over the fluctuations could have resulted in more accurate results.
- The variation in temperature (Thermal Instability) of the Frank-Hertz tube could have introduced errors as the lower the temperature, the greater the distance between the peak and valley points.
- The scale and resolution of the oscilloscope may lead to some error in the distance measured between peak and valley points
- Improper experimental setup such as misaligned anode and cathode, faulty or miscalibrated sensors, gas pressure, mechanical vibration and electrical interference etc. can all introduce various errors to our data.
- Human error while tracing the graph from oscilloscope to a trace paper as estimating where along the x-axis the peaks and valleys lied was difficult due to the distortion or gain of plotted data.

VI. Precautions:

1. During the experiment, when V_{G2K} is around 70 V, be careful and pay attention to the current indicator. If the ammeter reading shoots up suddenly, decrease the voltage at once to prevent damaging the tube.
2. When the filament voltage is changed, wait 5-10 minutes to let the filament heat up and stabilize.
3. When the Frank-Hertz tube is already connected, make sure that the manual-auto switch is in manual mode, the Filament Voltage, V_{G1K}, V_{G2K}, V_{G2A} are all at their minimum position to avoid damage to the tube.
4. Use a stable power supply and increase the voltage V_{G2K} gradually to avoid sudden fluctuations in the readings.
5. Make sure that the instruments such as voltmeter, ammeter and are properly calibrated before use.
6. Ensure proper connection between the G, X and Y sockets to the corresponding terminals of the oscilloscope.

VII. Author Contributions:

Name	Roll number	Contribution	Signature
Aksh Kishor Solanki	24110023	Operating the equipment during the experiment, Introduction, Theory	
Akshat Vishal Wandalkar	24110024	Reading and noting down data during experiment, Conclusion	
Akshay	24110025	Proofreading of reports and elimination of errors, drawing diagrams	
Akshit Chhabra	24110026	Tracing of the waveform, analysis of data, Result, Error Analysis and Precautions in the lab report	
Akul Gupta	24110027	Experimental Procedure, loading data from written format into a spreadsheet, graphing of data	