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Franck Hertz Experiment

Determining the excitation potential of Argon atom using Franck Hertz tube.

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***Abstract*—In 1913, Niels Bohr introduced the concept that the electrons in an atom can only exist in a discrete-bound quantized energy state. Subsequently, in 1914, James Franck and Gustav Hertz performed an experiment showing the existence of excited states in mercury atoms, confirming Bohr's hypothesis. Their experimental setup included a tube filled with mercury gas and fitted with three electrodes: One of them being a cathode, the other anode and the third one being a mesh grid for acceleration. In this session, we are calculating the excitation state of the Argon atom using both auto and manual modes.**

***Index Terms*—Argon atom, Quantized energy state, electron emission and acceleration, etc.**

I. OBJECTIVE

The aim of this experiment is:

a. To determine the value of excitation potential for Argon atom using auto and manual mode
b. To find the mean distance between the consecutive peaks and their standard deviation.

II. MATERIALS AND METHODS

A. Materials

The materials that were used are:- continuously variable power supply (V_{G1k}(1.3-5 V), V_{G2A}(1.3-12 V), V_{G2K}(0-95 V)), Franck-Hertz tube, multi-range digital voltmeter, multi-range digital ammeter, cathode ray oscilloscope,

B. Methods

The original Franck-Hertz experiment used mercury atoms. However, the underlying principles apply to any atom with discrete energy levels. In this experiment, we find the excitation energy of the Argon atom. For this purpose, the vacuum tube is filled with argon gas. When a potential difference between the cathode and grid is applied, initially, electrons emitted from the cathode undergo elastic collisions with argon atoms in the vapor. When electrons acquire enough energy to overcome the threshold energy required to excite an argon atom, inelastic collisions start to occur. When the accelerating voltage equals the excitation potential of the gas atom, the energy of electrons is given completely to the gas atoms and there is a sudden drop in the current. This drop is attributed to inelastic collisions between accelerated and atomic electrons. This sudden onset suggests that the gas electrons cannot accept energy until they reach the threshold for elevating them to an excited state.
The schematic of the Franck-hertz experiment is as follows:

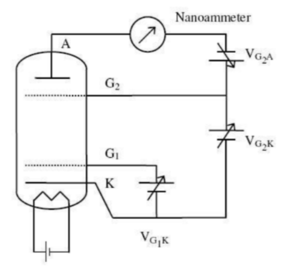


Fig. 1. Schematic of Franck Hertz Experiment

As shown in Fig. 1 above, the Grid G_1 helps minimise the space charge effect (accumulation of charges). This is done by placing the grid between the cathode and anode to act as a barrier for the electrons by limiting the speed of electrons and preventing them from forming a high-density, high-speed beam. Thus, preventing the space charge effect. If this is not done, then the electrons could accumulate and repel each other, leading to distortions in the experimental results.
The anode is maintained at a potential slightly negative with respect to the grid G_2, which creates an energy barrier that filters out electrons with insufficient energy, allowing only those with specific energies related to the quantized energy levels of the atoms to reach the anode. This helps in making the dips in the current more prominent.

III. PROCEDURE

A. Determination of the distance between two consecutive peaks by manual mode

1) Before switching ON the instrument, it is necessary to ensure that all the knobs are turned down to the minimum value
2) Turn the manual-auto switch to manual and adjust the voltage parameters as follows:
   a) Filament voltage = mid-position
   b) $V_{G1K} = 1.5V$
   c) $V_{G2A} = 7.5V$
   d) $V_{G2K} = 0V$
   e) Current Multiplier:10^{-7}
3) Now vary V_{G2K} and increase it by 1 V by and note down the changes in corresponding current.
4) Plot a graph for Current vs V_{G2K}
5) Find the voltage difference between two consecutive peaks or valleys and tabulate them against the multiplicity order.

B. Determination of the distance between two consecutive peaks by auto mode

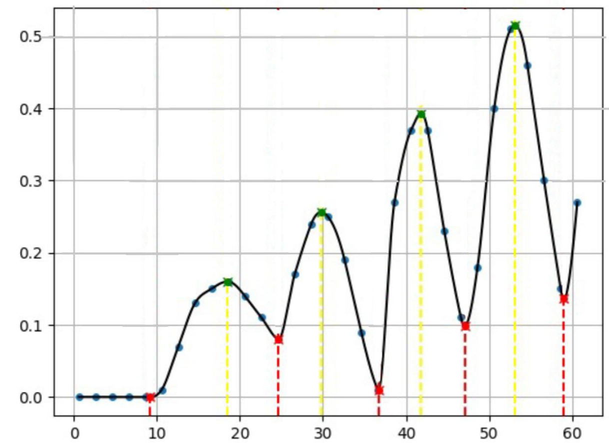
6) Now slowly bring V_{G2K} and all the other knobs to minimum position and switch the Manual-Auto to auto mode
7) Now switch on the oscilloscope. Ensure that the scanning range switch is on X-Y mode. Adjust the Y and X shifts to make the scan baseline on the bottom of the screen. Adjust the voltage parameters to the values mentioned in step 2
8) Now adjust the X gain and Y gain to make the graph visible.
9) Wait for 2-4 minutes till the waveform develops completely. Note the Scale on the x-axis knob on Cathode Ray Oscilloscope
10) Take a tracing paper and trace the graph so obtained and measure the difference between to consecutive peaks or valleys

IV. OBSERVATION AND GRAPHS

A. Determining excitation potential of argon gas by Manual mode

V_{G2K} (in V)	Current ($I \times 10^{-7}$ A)
0.6	0
1.6	0
2.6	0
4.6	0
6.6	0
8.6	0
10.6	0.01
12.6	0.07
14.6	0.13
16.6	0.15
18.6	0.16
20.6	0.14
22.6	0.11
24.6	0.08
26.6	0.17
28.6	0.24
30.6	0.25
32.6	0.19
34.6	0.09
36.6	0.1
38.6	0.27
40.6	0.37
42.6	0.37
44.6	0.23
46.6	0.11
48.6	0.18
50.6	0.40
52.6	0.51
54.6	0.46
56.6	0.30
58.6	0.15
60.6	0.27

TABLE I
CURRENT READINGS FOR VARYING V_{G2K}



1) At a very low voltage value of up to 10.6V, there was no current observed. As the voltage increased, the current also increased, and after a certain voltage value, it dipped down. Thus, we obtained a number of peaks and valleys.
2) The graph was then plotted using the Lagrange interpolation method in order to get a smooth curve. This method fits a polynomial curve through n points.
3) After the curve fitting, local maximums and local minimums were obtained
4) The peak values of the current were as follows;

Current($I \times 10^{-7}$)	VG2K
0.16	18.53
0.26	29.77
0.39	41.78
0.51	53.11

TABLE II
PEAK VALUES

5) The valleys are as follows:

Current($I \times 10^{-7}$)	VG2K
0.08	24.65
0.01	36.67
0.10	47.06
0.14	59.00

TABLE III
VALLEYS

6) In order to obtain excitation potential difference between consecutive peak or valley potentials is calculated

B. Determining excitation potential of argon gas by Auto mode

1) on the oscilloscope, we obtain a similar graph. Here the multiplier is 10^{-9}
2) By adjusting the scale difference between peaks and valleys is calculated

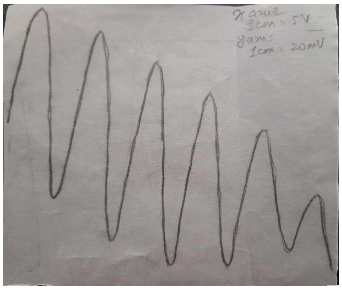


Fig. 2. Graph obtained in auto mode

V. Results and Analyses

A. Results

- Results for manual mode

	V_{G2K}	$V_{G2K} - V_o(V_i)$	$V_i - V_o$	$(V_i - V_o)^2$
Peaks	18.53	11.24	-0.24	0.06
	29.77	12.01	0.52	0.28
	41.78	11.32	-0.17	0.03
	53.11			
Valleys	24.65	12.01	0.53	0.28
	36.67	10.39	-1.10	1.20
	47.06	11.94	0.45	0.20
	59.00			
Mean(V_o)		11.49		
Standard deviation(σ)		0.34		

1) Calculate the difference between two consecutive peaks and valleys
2) Find the average given by the formula

$$V_o = \frac{\Sigma V_i}{N} \tag{1}$$

Where.
V_o is mean voltage
V_i is the difference between peaks and valleys
N is the number of readings
Hence, the Average Excitation potential comes out to be 11.49V

3) The formula for the standard deviation is given by:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \tag{2}$$

Where:

σ is the standard deviation,

n is the number of data points,

x_i represents each individual data point,

$\bar{x}$ is the mean of the data set.

The standard deviation comes out to be 0.34V//

4) Error percentage comes out to be:

$$\frac{\sigma}{V_o} \times 100 = \frac{0.34}{11.49} \times 100 = 2.95\% \tag{3}$$

- Results for auto mode

	Distance(in cm)	V_i	$V_i - V_o$	$(V_i - V_o)^2$
Peaks	2.3	11.50	0.35	0.12
	2.3	11.50	0.35	0.12
	2.2	11.00	-0.15	0.02
	2.1	10.50	-0.65	0.42
	2.2	11.00	-0.15	0.02
Valleys	2.3	11.50	0.35	0.12
	2.3	11.50	0.35	0.12
	2.1	10.50	-0.65	0.42
	2.2	11.00	-0.15	0.02
	2.3	11.50	0.35	0.12
Mean		11.15		
Standard		0.15		

1) After tracing the graph on tracing paper mark the valley and the peak points
2) measure the distance between consecutive peak and valley points
3) Convert it to actual voltage value
4) Thus the mean value by above stated formula comes out to be 11.15V
5) the standard deviation comes out to be 0.15V
6) Error percentage is:

$$\frac{\sigma}{V_o} \times 100 = \frac{0.15}{11.15} \times 100 = 1.34\% \tag{4}$$

B. Discussions

The Franck-Hertz experiment was successfully adapted to determine the excitation potential of argon gas.

Observations in Manual Mode: The manual mode involved adjusting parameters like filament voltage and grid potentials to vary the accelerating voltage (VG2K). The observed current readings for varying VG2K were tabulated and graphed. The sudden drops in current corresponded to inelastic collisions, indicating the excitation of argon atoms.

Observations in Auto Mode: The auto mode utilized the oscilloscope to visualise the current-voltage relationship dynamically. This method allowed for tracing and direct measurement of the distance between consecutive peaks or valleys.

C. Error analysis

- Possible factors that caused errors in both the experiments

1) One of the major errors in this experiment is the setting of the multiplier. During the manual mode it 10^{-7} where as during auto mode it was 10^{-9}.Ideally, both readings should have been taken at the same multiplier.
2) According to the procedure we should have started varying V_{G2K} from 0.00V but the least we could get was 0.06V
3) There can be a human error while tracing the graph from the oscilloscope. This can be due to irregularity of the curve.
4) Also, there can be an error while measuring the distance between the peaks as the least count of the scale is 0,1cm
5) There could have been uncertainties in the maximum and minimum value of the curve as it uses the interpolation method

6) The varying temperature of surrounding could have induced an error because if the temperature increases, the atoms gain energy, and thus the excitation potential decreases.

VI. Conclusion and Future Prospects

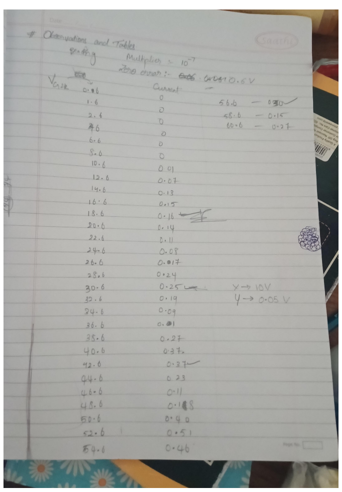
Hence, after the completion of the experiment, the excitation potential of argon was found to be (11.49±0.34)V with a percentage error of 2.95% for manual mode, which is reasonable within experimental constraints. The standard deviation of the excitation potential is found to be 0.34V.

For auto mode, the excitation potential of argon was found to be (11.15±0.15)V with a percentage error of 1.34% The standard deviation of the excitation potential is found to be 0.15V.

For future prospects, we can use an enhanced version of the setup so that we can take readings up to five peaks instead of four. We can also conduct the same experiments for different temperatures. This is because as the temperature increases, the energy of atoms will increase; as a result, the energy required to excite the electrons should decrease.

VII. Reading images

The following are the images of the observations taken in the lab.



VIII. Author Contributions

Name	Roll number	Contribution	Signature
Faayza Vora	23110109	Abstract, Objective, Material and Methods, Conclusion,	Faayza
Goraksh Bendale	23110118	Lab readings/equipment handling, Error analysis ,Discussion,Compilation	Goraksh Bendale
Dishant Tanmay	23110100	Observation tables, Result and calculation, Taking Readings in the lab, Graph plotting	Dishant
Haravath Saroja	23110127	Taking readings in the lab,proceedure	Saroja

TABLE IV
Author's Contribution