Frank Hertz Experiment

Aritra Mukhopadhyay
(Roll. No.: 2011030)

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1 Abstract

For the historical validation of Bohr's theory based on Planck's quantum theory, the Frank Hertz Experiment was essential. The quantization of energy states for a neon atom excited in a frank Hertz tube will be confirmed in this experiment. The graph between the collector current and accelerating voltage of the electrons from thermionic emission used to excite the Neon atoms shows the corresponding excitation energy for the most likely excitation state (10 3-p states). Maxima and minima in the curve's shape provide proof that discrete energy states corresponding to discrete excitation energy exist (accelerating voltage).

2 Theory

By using the excitation of neon atoms in a cathode tube and recording the excitation energy necessary for the transition between the states, the Frank Hertz experiment confirms the quantization of energy states. Thus, using Plank's (Blackbody radiation) and Einstein's new quantum theory, Frank Hertz was used as a verification for Bohr's atomic model for the hydrogen spectrum (Photoelectric effect).

The thermionic emission process, which is heated by a filament in the tube's cathode to emit electrons, is used to excite the neon atoms through inelastic collisions. A knob is used to regulate the heating voltage. Electrons in Ne atoms are excited and then de-excited to produce a direct-observable glow in the gas after absorbing energy from collisions. The ten 3p-states, which are between 18.4 eV and 19.0 eV above the ground state, are where the most likely excitation through inelastic electron collision occurs, as shown in the following figure. The probability of excitation is lower for the four lower 3s-states between 16.6 eV and 16.9 eV. Only through the 3s-states are the 3p states able to be de-excited to the ground. An photon is released as a result of the 3p-3s transition. This process emits light that is visible to the human eye and falls in the region between red and green.

Between the cathode K and the anode A is the accelerating voltage UA. Through an inelastic collision, the emitted electrons excite the neon atoms, and depending on their kinetic energy, they then fall on electrode E and contribute to the collector current. As the accelerating potential rises, the collector current also rises while the other voltages (UF, UKG, and UAE) remain constant. When the electrons are moving closely in front of Anode A and have just enough kinetic energy to transfer the energy needed to excite the neon atoms through collisions, the collector current is at its highest. Because the electrons after a collision can no longer overcome the braking voltage UAE present between anode A and collector electrode E, the collector current drops off dramatically. The luminous zones that are observed at the distances where the atoms are excited are the minima. The electrons reach the energy level necessary for exciting the neon atoms at ever-greater distances from anode A as the acceleration voltage UA rises.

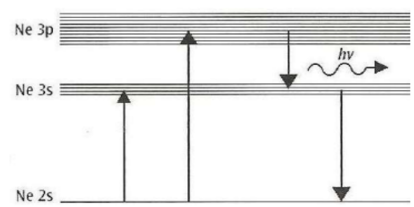

Figure 1: **Energy level diagram for Neon**

As a result, the emission line is already obtained. After colliding, they are once again accelerated, and when the acceleration voltage is enough, they once more absorb enough energy from the electrical field to excite a neon atom, resulting in the formation of more than one maximum. As shown in the figure below, at higher acceleration voltages, we can see distinct red/orange luminance layers between grid G and anode A. The distance between the equidistant maxima of the electron current in a variable opposing electric field is used to calculate the excitation energy of neon.

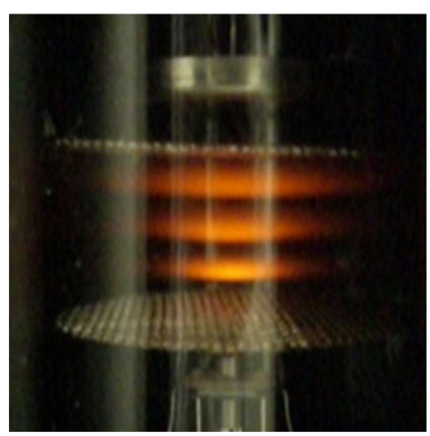

Figure 2: **Visible luminescence layers between grids**

3 Experimental Setup

As shown in figure below, the Franck-Hertz tube is a tetrode with an indirectly heated barium oxide cathode K, a meshtype control grid G, a mesh-type anode A, and a collector electrode E. The electrodes are in a planeparallel configuration and the tube is fileld with neon gas at a pressure appropriate for the characteristic curve (several hundred Pascal). The distance between the control grid and the anode grid is about 5 mm, and the distances between the cathode and the control grid and between the anode and the collector electrode are both about 2 mm.

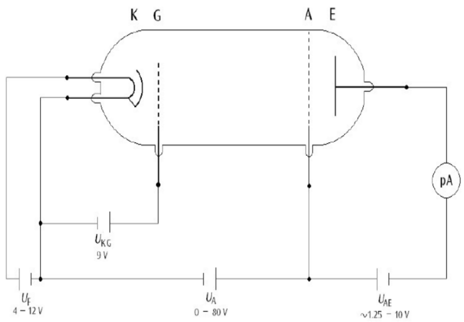

Figure 3: **Frank-Hertz tube setup and circuit diagram**

The connecting sockets for the heater (Filament voltage: 4 - 12 V), control grid (Control voltage: 9 V) and anode grid voltages are on the base of the instrument. The collector current is taken off through the BNC socket at the top end of the screening cylinder. An internal $10k\Omega$ limiting resistor is permanently built in between the connector sockets for the accelerator (control grid) voltage and the anode voltage. This protects the tube in case there is a spark discharge caused by applying too high a voltage. The voltage loss in this resistor when making measurements is negligible, as the anode current in the tube is smaller than 5 pA. (Thus the voltage loss in the protecting resistor is 0.05 V.)

4 Observations and Calculations

4.1 Dataset I:

$U_F = 10.0V$ $\quad U_E = 6.2V$ $\quad U_G = 5.3V$

Sl. No.	Accelerating Voltage (U_A) V	Collector Current (I_E) nA
1	0	0
2	7	0
3	8	1
4	8.5	2
5	9	2
6	9.5	3
7	10	4
8	10.5	4
9	11	4
10	12	5
11	13	5
12	15	5
13	16	6
14	18	6
15	18.5	7
16	19	4
17	19.5	3
18	20	2
19	21	0
20	22	-1
21	23	-3
22	24	-1
23	25	0
24	26	2
25	28	8

Sl. No.	Accelerating Voltage (U_A) V	Collector Current (I_E) nA
26	30.5	15
27	32	19
28	33	20
29	34	22
30	35	23
31	36	22
32	37	18
33	39	9
34	40	5
35	41	4
36	42	2
37	44	10
38	46	25
39	50	69
40	52	87
41	54	97
42	55.5	100
43	56	100
44	57.5	101
45	58	104
46	60	109
47	62	119
48	65	145
49	67	171

Table 1: Dataset I

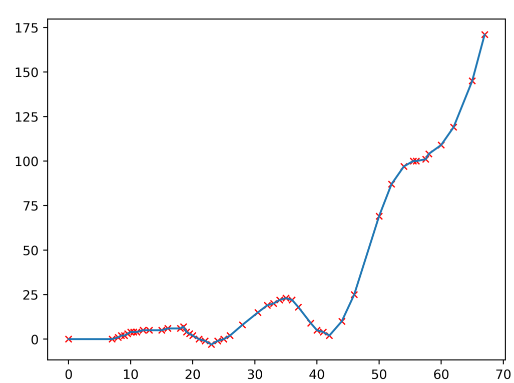

Figure 4: **Graph for First dataset**

4.2 Dataset II:

$U_F = 9.2V$ $\quad U_E = 6.2V$ $\quad U_G = 6.5V$

Sl. No.	Accelerating Voltage (U_A) V	Collector Current (I_E) nA
1	0	0
2	7.5	0
3	8	1
4	8.5	3
5	9	4
6	9.5	5
7	10	5
8	10.5	6
9	11	7
10	11.5	8
11	12	8
12	12.5	9
13	13	9
14	14	9
15	15	10
16	16	11
17	17	11
18	17.5	12
19	18	11
20	18.5	10
21	19	9
22	20	7
23	21	1
24	22	0
25	23	-3
26	24	-3
27	25	0
28	26	4
29	28	12
30	29	15
31	30	20
32	32	26

Sl. No.	Accelerating Voltage (U_A) V	Collector Current (I_E) nA
33	34	32
34	35	33
35	36	32
36	38	23
37	39	18
38	40	12
39	41	6
40	43	3
41	44	4
42	45	9
43	46	15
44	47	24
45	48	35
46	49	48
47	50	55
48	52	76
49	54	88
50	54.5	90
51	55	91
52	55.5	91
53	56	90
54	56.5	88
55	57	88
56	58	85
57	59	82
58	60	81
59	62	85
60	64	100
61	65	109
62	66	118
63	68	152
64	70	181

Table 2: dataset II

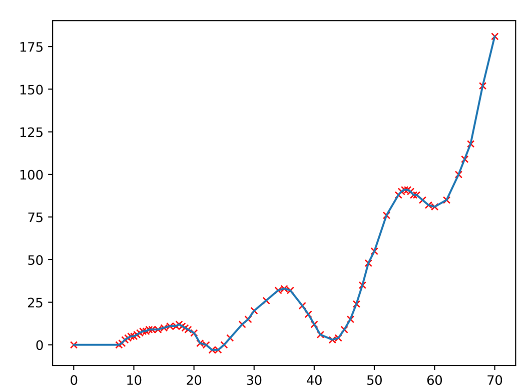

Figure 5: **Graph for Second dataset**

5 Calculations

Dataset	U_a at maxima (V)	Excitation Energy ΔU (eV)
1	18.5	
	35	16.5
	56	21
2	17.5	
	35	17.5
	55	20

Table 3: For Average Excitation Energy

Average Excitation Energy $= \left(\frac{16.5+21+17.5+20}{4}\right) = 18.75eV$

6 Error Analysis

Sl. No.	$\Delta U_i (eV)$	$(\Delta\bar{U} - \Delta\bar{U}_i)^2$ (eV^2)
1	16.5	5.06
2	21	5.06
3	17.5	1.56
4	20	1.56

Table 4: Error Analysis for ΔU

$$\Delta\bar{U} = 18.75eV$$

$$\delta\Delta U(S.D.) = \sqrt{\frac{(\Delta\bar{U} - \Delta\bar{U}_i)^2}{n-1}} = 3.31eV$$

7 Results & Conclusions

Average Excitation energy $(\Delta U = 18.75pm3.31eV)$

- The observed value 18.8 eV is much closer to the 3p excited states range (18.4-19.0 eV) than the 3s states range (16.6-16.9 eV), thereby proving that the probability of transition from ground state to 3-p state is more than the 3-s states. There is a 0.26% error between the experiment value 18.75 and average 18.7 eV energy of the 3p states.

- However presence of values such as 16.5 eV shows that the excitation to the 3s states cannot be ignored completely. And the actual transitions are a combination of the two types of transition.

- The luminous zones correlate with the minimas of the curve as it is there almost whole of the energy is utilized in exciting the electrons.

- The negative values of current occurs when U_{AG} is greater than the anode voltage and the incoming electrons do not sufficient leftover kinetic energy to pass through the braking voltage, thereby leading to a reverse current.

References

[SPS, 2022] SPS (2022). Lab manual. *Website*. https://www.niser.ac.in/sps/sites/default/files/basic_page/Franck-Hertz%20experiment_NISER.pdf.

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	A	B	D	G	H	K	L	M
1	Ua	Ie	Uf = 10.0V	ua	ie	Uf	ug	ue
2	0	0	Ue = 6.2V	0	0	9.2	6.5	6.2
3	7	0	Ug = 5.3V	7.5	0			
4	8	1		8	1			
5	8.5	2		8.5	3			
6	9	2		9	4			
7	9.5	3		9.5	5			
8	10	4		10	5			
9	10.5	4		10.5	6			
10	11	4		11	7			
11	12	5		11.5	8			
12	13	5		12	8			
13	15	5		12.5	9			
14	16	6		13	9			
15	18	6		14	9			
16	18.5	7		15	10			
17	19	4		16	11			
18	19.5	3		17	11			
19	20	2		17.5	12			
20	21	0		18	11			
21	22	-1		18.5	10			
22	23	-3		19	9			
23	24	-1		20	7			
24	25	0		21	1			
25	26	2		22	0			
26	28	8		23	-3			
27	30.5	15		24	-3			
28	32	19		25	0			
29	33	20		26	4			
30	34	22		28	12			
31	35	23		29	15			
32	36	22		30	20			
33	37	18		32	26			
34	39	9		34	32			
35	40	5		35	33			
36	41	4		36	32			
37	42	2		38	23			
38	44	10		39	18			
39	46	25		40	12			
40	50	69		41	6			
41	52	87		43	3			
42	54	97		44	4			
43	55.5	100		45	9			
44	56	100		46	15			
45	57.5	101		47	24			
46	58	104		48	35			
47	60	109		49	48			
48	62	119		50	55			
49	65	145		52	76			
50	67	171		54	88			
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62				65	109			
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64				68	152			
65				70	181			
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