Franck-Hertz experiment using Neon tube

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The Franck–Hertz experiment was performed using a Neon-filled tetrode tube to investigate quantized atomic excitation. Electrons emitted from a heated cathode were accelerated through Neon gas, and the resulting periodic modulation of collector current with accelerating voltage directly demonstrated inelastic collisions at discrete threshold energies. From the separation of successive current maxima, the excitation energy of Neon was calculated to be $E_{ext} = (18.7 \pm 0.1)$eV. The results validate Bohr's quantum theory and provide direct experimental evidence for quantized energy levels.

I. OBJECTIVE

Study of quantized excitation of Neon atoms by inelastic scattering and determine the excitation energy.

II. THEORY

The Franck-Hertz experiment[1] demonstrates the quantized nature of atomic energy levels through the inelastic scattering of electrons in a gas-filled tube. In this experiment, Neon atoms are excited by accelerated electrons, and the resulting periodic changes in current provide direct evidence of discrete energy levels. The theoretical aspects are discussed below.

A. Quantized Energy Transfer

Electrons are emitted from a heated cathode via thermionic emission and accelerated toward the anode under an applied accelerating potential U_A. The kinetic energy of an electron just before anode A is

$$E_k = eU_A, \tag{1}$$

where e is the electronic charge. If $E_k < E_{\text{ex}}$, the excitation energy of neon, electrons collide elastically, and the collector current increases with U_A. When $E_k \geq E_{\text{ex}}$, inelastic collisions occur, and electrons lose energy to excite the atom:

$$E_{\text{ex}} = e\Delta U, \tag{2}$$

where ΔU is the voltage difference between two consecutive maxima in the current-voltage characteristic curve.

As shown in Figure 1, for neon, the strongest excitations correspond to transitions from the ground state to the $3p$ levels between 18.4 eV and 19.0 eV. De-excitation occurs via the $3s$ states, emitting photons in the visible region.

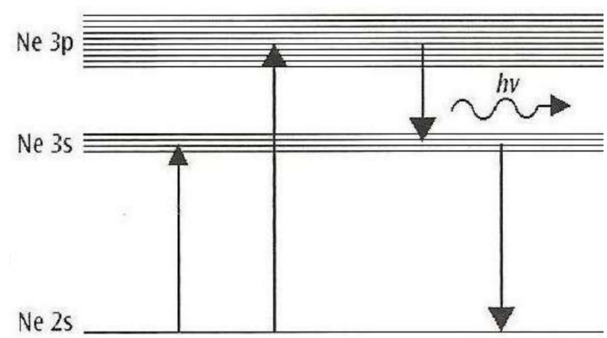

FIG. 1: Energy levels of Neon

B. Characteristic Curve

When the accelerating voltage is increased, the collector current initially rises, reaching a maximum when electrons gain just enough energy to excite Neon atoms. After inelastic collisions, the electrons lose energy and are unable to overcome the braking potential U_{AE}, resulting in a decrease in collector current. As the voltage increases further, electrons again gain sufficient energy, causing another rise in current. This process repeats, producing a periodic current-voltage characteristic known as the Franck-Hertz curve.

C. Significance

The periodic variation of collector current with accelerating voltage provides strong experimental evidence for quantized atomic energy levels. The measured spacing ΔU allows direct determination of the excitation energy of neon atoms. This experiment thus serves as a direct validation of Bohr's quantum theory and the quantization of atomic states.

III. EXPERIMENTAL CIRCUIT

The Franck-Hertz tube is a tetrode filled with neon gas at low pressure. It consists of:

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1. A cathode (K) coated with barium oxide, heated indirectly to emit electrons.
2. A control grid (G), which accelerates electrons.
3. An anode (A), which allows accelerated electrons to pass.
4. A collector electrode (E), which measures the transmitted electrons after passing the anode.

A small braking potential U_{AE} is applied between the anode and collector so that only electrons with sufficient kinetic energy reach the collector.

As shown in Figure 2, the tube is connected to a base unit that provides voltages to the cathode heater, control grid, and anode. The accelerating voltage U_A is varied, while the filament voltage U_F, grid voltage U_{KG}, and retarding potential U_{AE} are kept fixed.

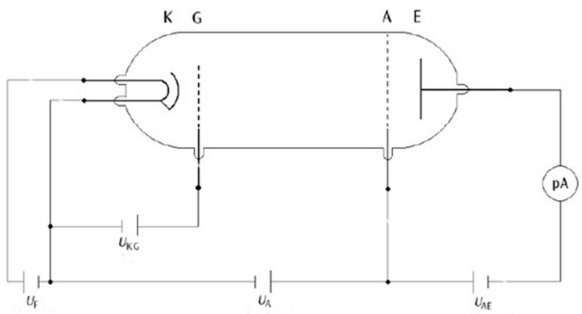

FIG. 2: Circuit diagram of the Franck-Hertz experiment.

IV. OBSERVATION

The complete set of tables are provided in the supplementary material. Each table contains 81 readings, including accelerating voltage (U_A) (in V) and collector current I (in nA). The three tables correspond to the following voltage value configurations.

TABLE I: Circuit configurations in the 3 datasets

Dataset	U_f(V)	U_{AG} (V)	U_{KG} (V)
Table 1	8	5	6
Table 2	8.5	7	5
Table 3	8.8	6	4

V. DATA ANALYSIS

A. Characteristic curve plots

The plots 3, 4, 5 are obtained from the data provided in the supplementary material (full code at [2]). The first

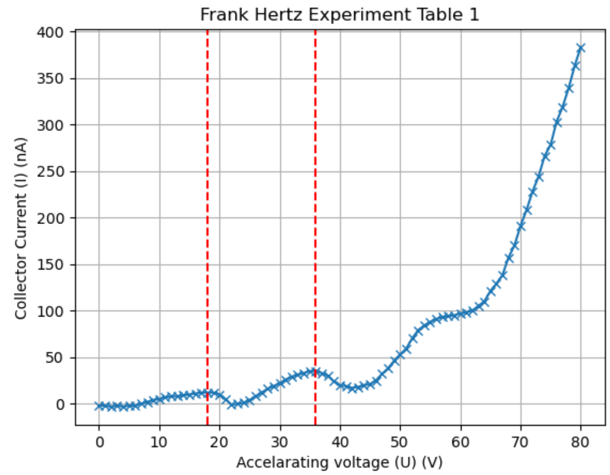

FIG. 3: Table 1 plot

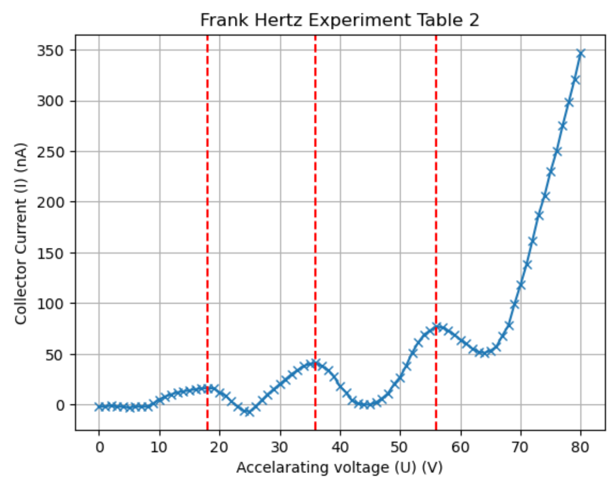

FIG. 4: Table 2 plot

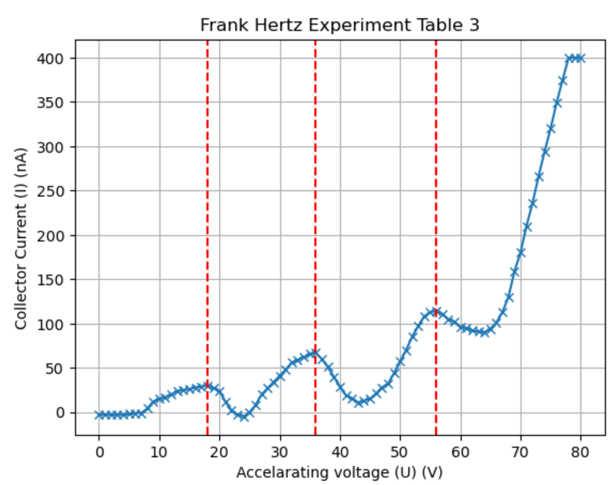

FIG. 5: Table 3 plot

one has 2 maxima, while second and third have 3 maxima each. The position of these maxima are mentioned in the table below.

TABLE II: Positon of maxima in characteristic curves

Dataset	First	Second	Third
Table 1	18	36	–
Table 2	18	36	56
Table 3	18	36	56

B. Calculation of Excitation energy

The excitation energy E_{ex} of neon is obtained from the spacing between two consecutive maxima:

$$E_{\mathrm{ex}} = e\,\Delta U$$

where ΔU is the voltage difference between maxima.
For Table 1:

$$\Delta U = 36 - 18 = 18\,\mathrm{V} \quad \Rightarrow \quad E_{\mathrm{ex}} = 18\,\mathrm{eV}$$

For Table 2:

$$\Delta U_1 = 36 - 18 = 18\,\mathrm{V}, \quad \Delta U_2 = 56 - 36 = 20\,\mathrm{V}$$

$$E_{\mathrm{ex}} = \frac{18 + 20}{2} = 19\,\mathrm{eV}$$

For Table 3:

$$\Delta U_1 = 36 - 18 = 18\,\mathrm{V}, \quad \Delta U_2 = 56 - 36 = 20\,\mathrm{V}$$

$$E_{\mathrm{ex}} = 19\,\mathrm{eV}$$

Thus, the average excitation energy from all tables is:

$$\langle E_{\mathrm{ex}} \rangle \approx 18.7\,\mathrm{eV}$$

C. Error Analysis

Each accelerating voltage reading carries an uncertainty equal to the least count of the instrument, i.e 0.1 V. Since the excitation energy is obtained from the difference between two voltages corresponding to successive maxima, the uncertainty in ΔU is obtained by standard error propagation [3]:

$$\delta(\Delta U) = \sqrt{(\delta U_1)^2 + (\delta U_2)^2} = 0.14\,\mathrm{V}$$

The excitation energy is calculated using

$$E_{\mathrm{ex}} = e\,\Delta U$$

hence the propagated uncertainty in energy is

$$\delta E = e\,\delta(\Delta U) \approx 0.1 \text{ eV}$$

VI. RESULTS

The average excitation energy of neon atoms calculated in the Frank Hertz experiment is:

$$E_{\mathrm{ex}} = (18.7 \pm 0.1)\,\mathrm{eV}$$

The literature value for this excitation energy is in the range 18.4 - 19 eV. Therefore, the observed energy lies within the range of literature values.

VII. CONCLUSION

The Franck-Hertz experiment with a neon-filled tetrode tube successfully demonstrated the quantized nature of atomic energy levels. The periodic variation of collector current with accelerating voltage confirmed that electrons undergo inelastic collisions, losing discrete quanta of energy to excite neon atoms. The measured excitation energy was found to be 18.7 ± 1.0 eV, which is in good agreement with the accepted values for the excitation of neon to the $3p$ states. The experiment thus validates Bohr's quantum theory and provides direct evidence for quantized atomic transitions.

VIII. SUPPLEMENTARY MATERIAL

[1] National Institute of Science Education and Research. *Franck-Hertz experiment using Neon tube*. NISER, 2024. Laboratory Manual for Modern Physics Experiments.

[2] Aryan Shrivastava. P343—modern-physics-lab. `https://github.com/crimsonpane23/P343---Modern-Physics-lab.git`, 2025.

[3] John R. Taylor. *An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements*. University Science Books, Sausalito, CA, 2nd edition, 1997.

TABLE III: Table 1

Accelerating Voltage	Collector Current
0	−2
1	−2
2	−3
3	−2
4	−3
5	−2
6	−2
7	0
8	2
9	4
10	5
11	7
12	8
13	8
14	9
15	10
16	11
17	12
18	12
19	12
20	10
21	5
22	−1
23	0
24	1
25	4
26	8
27	12
28	16
29	19
30	22
31	26
32	29
33	31
34	33
35	35
36	35
37	33
38	30
39	24
40	20
41	19
42	17
43	18
44	20
45	21
46	25
47	32
48	38
49	46
50	53
51	59
52	70
53	79
54	84
55	88
56	91
57	93
58	94
59	95
60	97
61	98
62	100
63	105
64	110
65	121
66	129
67	138
68	157
69	170
70	191
71	208
72	228
73	244
74	266
75	278
76	303
77	319
78	339
79	363
80	383

TABLE IV: Table 2

Accelerating Voltage	Collector Current
0	−2
1	−2
2	−1
3	−2
4	−2
5	−3
6	−2
7	−2
8	−2
9	1
10	5
11	8
12	10
13	12
14	13
15	14
16	15
17	16
18	16
19	16
20	12
21	9
22	3
23	−2
24	−6
25	−7
26	−2
27	4
28	10
29	15
30	20
31	25
32	30
33	34
34	38
35	40
36	41
37	38
38	34
39	28
40	18
41	12
42	4
43	1
44	0
45	0
46	2
47	6
48	11
49	20
50	27
51	38
52	51
53	61
54	69
55	73
56	77
57	76
58	73
59	69
60	64
61	60
62	55
63	52
64	51
65	53
66	57
67	68
68	78
69	99
70	118
71	138
72	162
73	187
74	206
75	230
76	250
77	275
78	298
79	321
80	347

TABLE V: Table 3

Accelerating Voltage	Collector Current
0	−3
1	−3
2	−3
3	−3
4	−3
5	−2
6	−1
7	−1
8	4
9	12
10	15
11	17
12	20
13	24
14	25
15	26
16	28
17	29
18	30
19	27
20	24
21	12
22	2
23	−3
24	−5
25	0
26	8
27	20
28	27
29	34
30	41
31	48
32	56
33	59
34	62
35	66
36	67
37	60
38	51
39	40
40	29
41	19
42	16
43	11
44	13
45	15
46	21
47	28
48	32
49	44
50	57
51	70
52	85
53	97
54	108
55	113
56	114
57	111
58	105
59	102
60	96
61	95
62	92
63	91
64	90
65	94
66	101
67	113
68	130
69	159
70	180
71	210
72	236
73	266
74	294
75	320
76	349
77	375
78	400
79	400
80	400