BIRZEIT UNIVERSITY

Faculty of Science

Physics Department

Physics 212

Frank-Hertz

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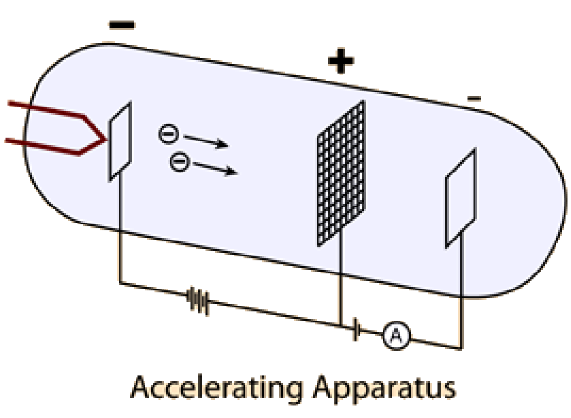
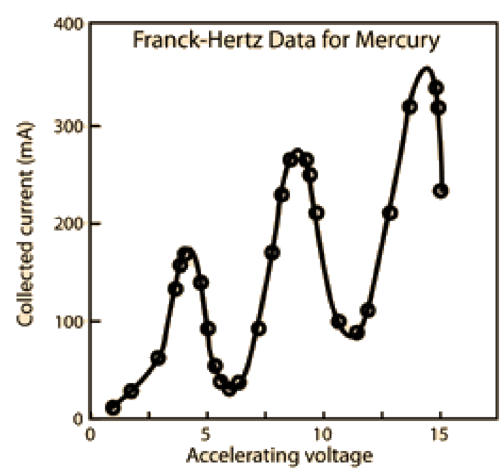
– Abstract:

The aim of this experiment is to verify the quantization of energy levels in atoms. By using Franck-Hertz Apparatus with mercury-filled tube in the laboratory, the curve of current vs voltage was potting at mercury's temperature of 178°C. The experimental value of $\Delta E = 4.9eV$, and this value is same as original Franck-Hertz Experiment. Mercury atoms emit radiation at wavelength of $253nm$ in this experiment, and this value is near to $254nm$ which is the original value in Franck-Hertz Experiment.

– Theory:

In 1914, James Franck and Gustav Hertz performed an experiment which demonstrated the existence of excited states in mercury atoms, helping to confirm the quantum theory which predicted that electrons occupied only discrete, quantized energy states. Electrons were accelerated by a voltage toward a positively charged grid in a glass envelope filled with mercury vapor. Past the grid was a collection plate held at a small negative voltage with respect to the grid. The values of accelerating voltage where the current dropped gave a measure of the energy necessary to force an electron to an excited state.





Electrons are accelerated in the Franck-Hertz apparatus and the collected current rises with accelerated voltage. As the Franck-Hertz data shows, when the accelerating voltage reaches 4.9 volts, the current sharply drops, indicating the sharp onset of a new phenomenon which takes enough energy away from the electrons that they cannot reach the collector. This drop is attributed to inelastic collisions between the accelerated electrons and atomic electrons in the mercury atoms. The sudden onset suggests that the mercury electrons cannot accept energy until it reaches the threshold for elevating them to an excited state. This 4.9 volt excited state corresponds to a strong line in the ultraviolet emission spectrum of mercury at 254 nm (a 4.9eV photon). Drops in the collected current occur at multiples of 4.9 volts since an accelerated electron which has 4.9 eV of energy removed in a collision can be re-accelerated to produce other such collisions at multiples of 4.9 volts. This experiment was strong confirmation of the idea of quantized atomic energy levels.

Graph I vs V:

The differences between successive peaks are about 4.9V. The average value is:

$$\overline{\Delta V_P} = \frac{\sum_{i=n}^{N} \Delta V_{Pn}}{N}$$

And the energy difference would be:

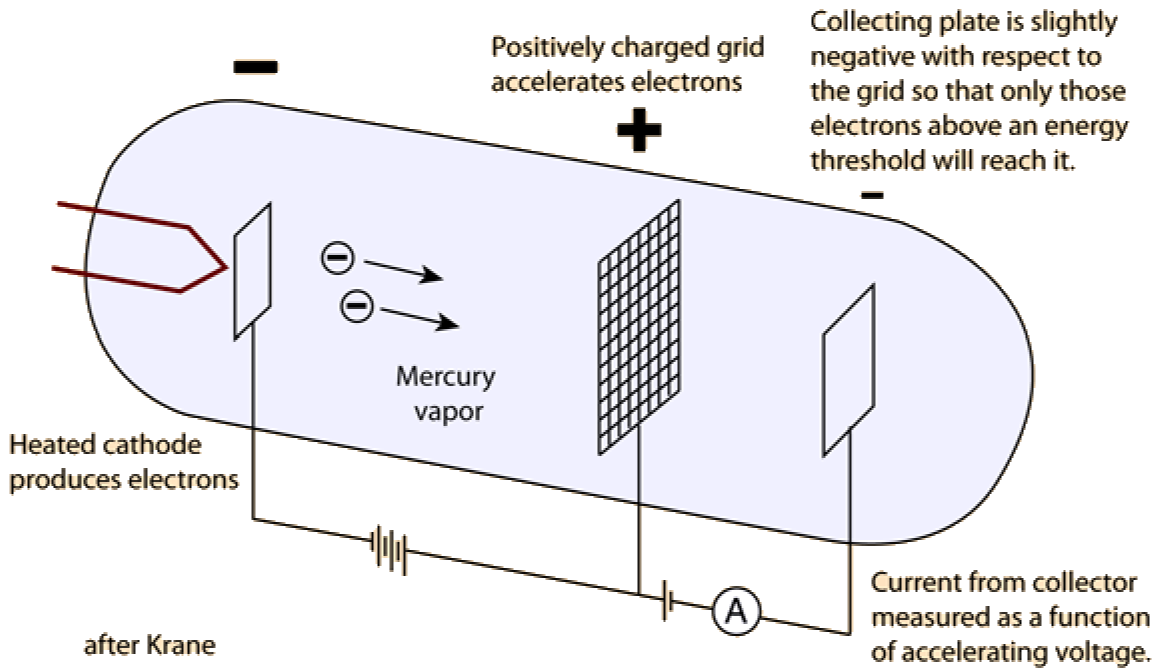
$$\Delta E = e\overline{\Delta \mathrm{V_P}}$$

The wavelength of the radiation which mercury atoms emit is:

$$\lambda = \frac{hc}{\Delta E}$$

– Procedure:

Prepare the apparatus: A mercury-filled Franck-Hertz tube, an oven, a control unit for power supply, and a DC current amplifier.



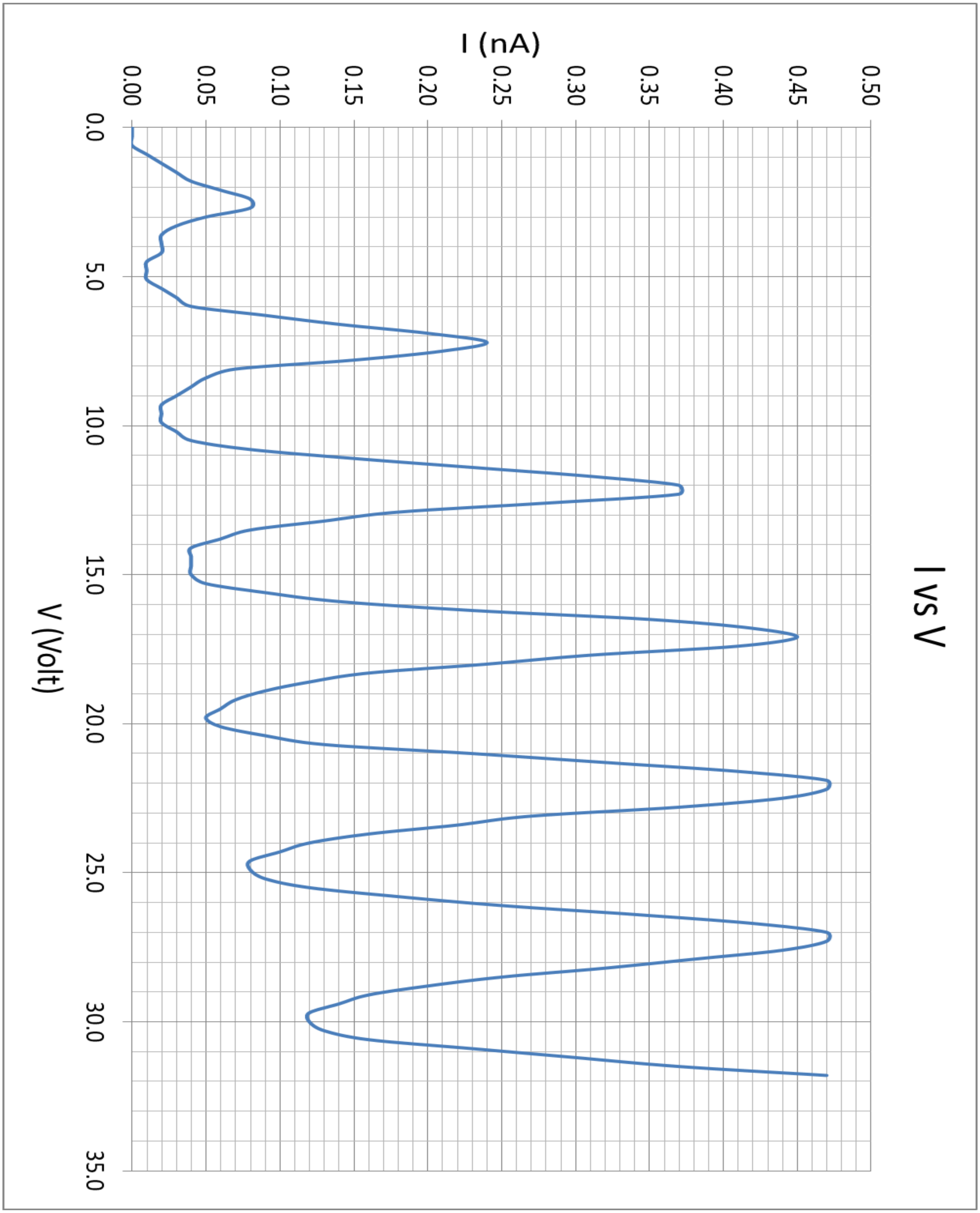
1. Turn on the Franck-Hertz Apparatus.
2. Wait until the temperature reach (178-180)°C.
3. Record the values of the current in nanoampares when the values of the voltage is (0.0+0.3n)Volt , n = 0,1,2,…,106.

– Data:

V(Volt)	I(nA)
0.0	0.00
0.3	0.00
0.6	0.00
0.9	0.01
1.2	0.02
1.5	0.03
1.8	0.04
2.1	0.06
2.4	0.08
2.7	0.08
3.0	0.05
3.3	0.03
3.6	0.02
3.9	0.02
4.2	0.02
4.5	0.01
4.8	0.01
5.1	0.01
5.4	0.02
5.7	0.03
6.0	0.04
6.3	0.09
6.6	0.14
6.9	0.20
7.2	0.24
7.5	0.21
7.8	0.15
8.1	0.07
8.4	0.05
8.7	0.04
9.0	0.03
9.3	0.02
9.6	0.02
9.9	0.02
10.2	0.03
10.5	0.04

V(Volt)	I(nA)
10.8	0.08
11.1	0.15
11.4	0.23
11.7	0.31
12.0	0.37
12.3	0.37
12.6	0.28
12.9	0.18
13.2	0.13
13.5	0.08
13.8	0.06
14.1	0.04
14.4	0.04
14.7	0.04
15.0	0.04
15.3	0.05
15.6	0.09
15.9	0.14
16.2	0.23
16.5	0.35
16.8	0.42
17.1	0.45
17.4	0.41
17.7	0.31
18.0	0.24
18.3	0.16
18.6	0.12
18.9	0.09
19.2	0.07
19.5	0.06
19.8	0.05
20.1	0.06
20.4	0.09
20.7	0.13
21.0	0.23
21.3	0.32

V(Volt)	I(nA)
21.6	0.41
21.9	0.47
22.2	0.47
22.5	0.44
22.8	0.37
23.1	0.27
23.4	0.22
23.7	0.16
24.0	0.12
24.3	0.10
24.6	0.08
24.9	0.08
25.2	0.09
25.5	0.12
25.8	0.18
26.1	0.25
26.4	0.34
26.7	0.42
27.0	0.47
27.3	0.47
27.6	0.44
27.9	0.38
28.2	0.32
28.5	0.25
28.8	0.20
29.1	0.16
29.4	0.14
29.7	0.12
30.0	0.12
30.3	0.13
30.6	0.16
30.9	0.23
31.2	0.30
31.5	0.37
31.8	0.47


I vs V
I (nA)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
V (Volt)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0

– Calculations:

Voltage Peaks (Volt):

V_{P1}	V_{P2}	V_{P3}	V_{P4}	V_{P5}	V_{P6}
2.4	7.2	12.0	17.1	21.9	27.0

$\Delta V_{Pn} = \left(V_{P(n+1)} - V_{Pn}\right)$ (Volt):

ΔV_{P1}	ΔV_{P2}	ΔV_{P3}	ΔV_{P4}	ΔV_{P5}
4.8	4.8	5.1	4.8	5.1

$$\overline{\Delta V_P} = \frac{\sum_{i=1}^{5} \Delta V_{Pi}}{5} = 4.9V$$

$$\Delta E = e\overline{\Delta V_P} = e \times 4.9V = 4.9eV$$

$$\lambda = \frac{hc}{\Delta E} = \frac{1240eV.nm}{4.9eV} \approx 253nm$$

– Results:

$\Delta E = 4.9eV$

$\lambda = 253nm$

– Discussion:

The experimental value of ΔE in this experiment was 4.9eV. This value in the original Franck-Hertz Experiment is the same. So, this result is acceptable.

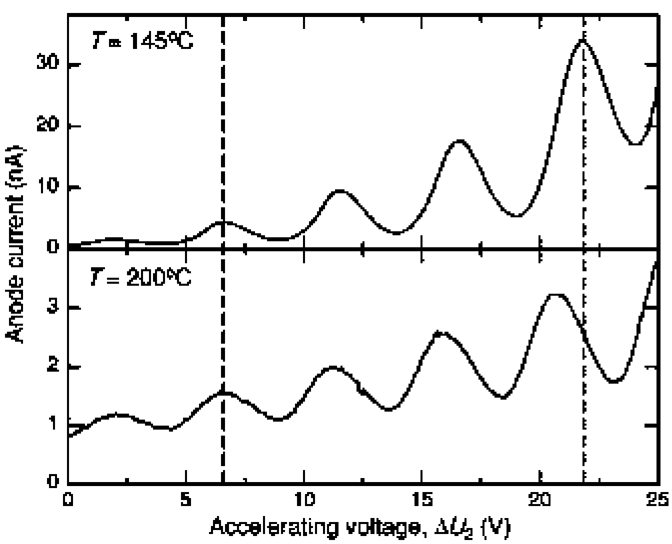
In graph I vs V, the peaks voltage were (2.4, 7.2, 12.0, 17.1, 1.9 ,27.0) Volts. The differences between one peak and which followed were (4.8, 4.8, 5.1, 4.8, 5.1). These values seem to be the same. So, when measuring the plate current versus the accelerating voltage, periodic maxima and minima are observed.

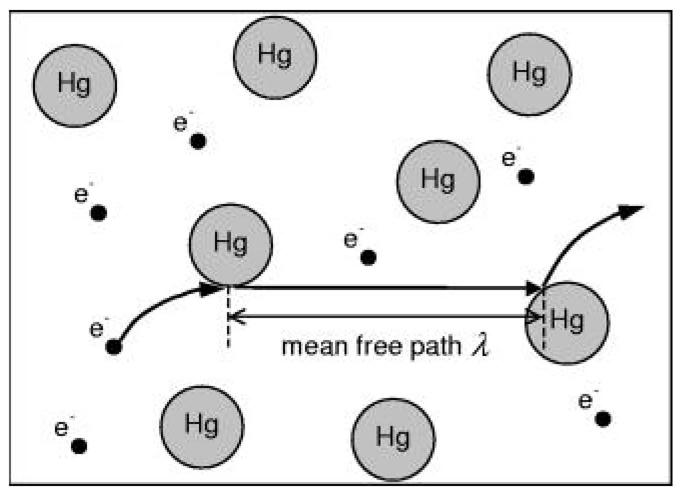
The values you obtained for the peak do not correspond accurately to the excitation energy ΔE of mercury. This is because these voltages should be corrected against the contact potential between the anode and cathode, and against the initial thermal energy of the electrons. However, since this correction remains constant shift of the actual values. The excitation energy should then be taken as the difference between the successive peaks.

Mercury atoms emit radiation at wavelength of 253nm in this experiment, and this value is near to 254nm which is the original value in Franck-Hertz Experiment.

In Graph I vs V, the value of minimums seem to increase with the value of voltage. For example, the first minimum was I(0.3V)=0.00nA, the second minimum was I(4.8V)=0.01nA, the third minimum was I(9.6V)=0.02nA, the forth minimum was I(14.4V)=0.004nA, the fifth minimum was I(19.8V)=0.05nA, the sixth minimum was I(24.6V)=0.08nA, the seventh minimum was I(29.7V)=0.12nA. This is also for maximums.

The energy levels and cross-sections are, of course, temperature independent, but the number density of Hg atoms increases rapidly with temperature because the gas is in equilibrium with a droplet of liquid mercury. This means that the distance the electrons can travel between inelastic collisions, the mean free path λ, becomes shorter as temperature increases.





The experiment must be performed with a monatomic gas; since if a molecular vapor is bombarded, it is possible for the electrons to transfer energy to the molecular energy levels which form almost a continuum. So, some of the preferred elements for the Frank-Hertz experiment are mercury, neon, and argon.

There were some systematic errors in this experiment. For example, some values of the current were oscillating between two readings. The value of voltage was not exactly as the reading on the screen of the experiment apparatus. A small rotation in the voltage wheel makes a big jump on the value of voltage. More thermal energy means more entropy in the medium. The high temperature of mercury made some perturbations in data. And many other factors from the environment and the quantum nature of the experiment would change these results.

– References:

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