The Franck-Hertz Experiment

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1 Abstract

In this experiment the first excitation potential of gaseous mercury and neon atoms was investigated using the Franck-Hertz partial current method. The values of the potential found were 5.1 ± 0.4eV and 19.2 ± 0.5eV respectively. These agree with the accepted values of 4.9eV and 18.4-19.0eV respectively. A graph of the Accelerator Voltage versus the Current (in the form of the Stopping Voltage) was plotted for each gas.

2 Introduction & Theory

2.1 The Franck-Hertz Experiment

The *Franck-Hertz experiment*, preformed in 1914, is an experiment for confirming the *Bohr Model* of that atom. It was found that when electrons in a potential field were passed through mercury vapour they experienced an energy loss in *disinct steps*, and that that the mercury gave an emission line at $\lambda = 254$nm. This was due to collisions between the electrons and the mercury atoms.

2.2 Energy Levels

If the Franck-Hertz Experiment is carried out using neon gas the emission spectrum is in the visible range of the electromagnetic spectrum. The neon atoms can be excited to only a speific number of *sub-energy levels.* There are ten *3p-states*, which are between 18.4eV and 19eV from the *ground state*, and four *3s-states* at 16.6eV to 16.9eV from the ground state. When an atom is excited its electrons can only move to speific energy levels depending on the *selection cretiera* of the atoms *quantum numbers* n, l, m_l and m_s.

$$\Delta l = \pm 1 \tag{1}$$

$$\Delta m_l = \pm 1, 0 \tag{2}$$

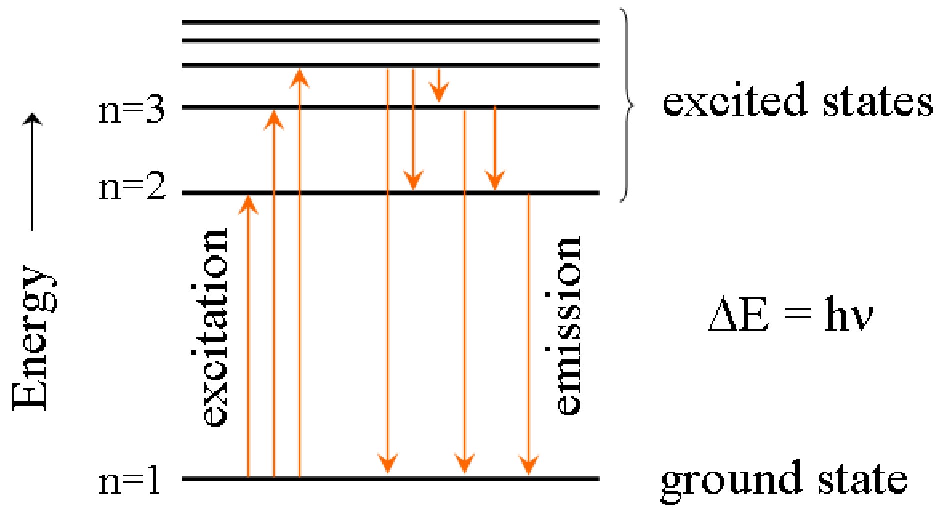

Figure 1: Energy level transitions

2.3 The Franck-Hertz Circuit

The apparatus consists of glass tube containing the circuitry. An electrode emits electrons when heated, which are attracted to a grid system by a driving potential across the glass tube of U_1. The grid consists of two layers, G_1 and G_2 between which is the accelerating potential U_2. Finally, there is a collector A outside of G_2 with a breaking voltage U_3 between them.

As the accelerating potential U_2 is increased the collector current I_A increases to a maximum until the electrons have enough energy to transfer to and excite the mercury atoms through collisions, which is $E = 4.9$eV. As such the collector current then drops off, as after collision less electrons are able to overcome the breaking voltage U_3. As U_2 is increased further the electrons can again excite the mercury atoms, and another maximum is found. This process is repeated.

3 Experimental Method

3.1 Equipment setup

With the power supply unit turned off, the oven and the oscilloscope were connected.

The variables U_1, U_2 and U_3 were all set to zero, and the power supply was turned on.

The operating mode was set to MAN.

Finally, the heater was set to $\vartheta = 175^oC$ and allowed to heat up for 15mins.

The oscilloscope was set to XY-mode and the infinite option was selected to retain the plot of the curve.

3.2 Graph Optimization

The Franck-Hertz tube was first set up to give an optimal graph. That is one of the form

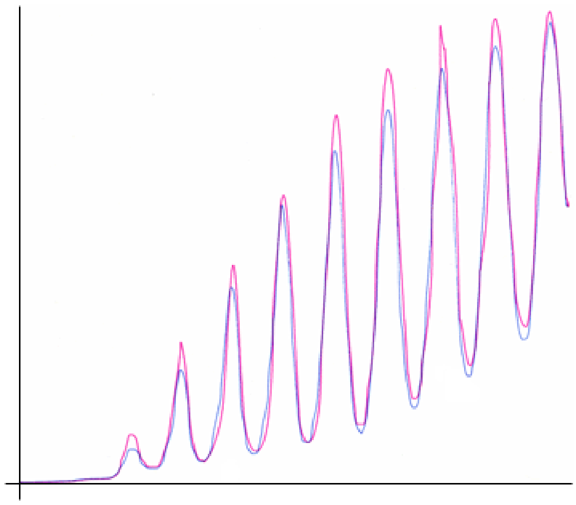

Figure 2: A typical Franck-Hertz curve

which does not rise too steeply, is not too flat, and which has well defined maxima and minima which are not cut off at the bottom. This is done by adjusting the values of the driving potential U_1, which should be around 1.5V, and breaking voltage U_3 which should be around 1.5V.

3.3 The Franck-Hertz Curve for Mercury

A multimeter was connected to measure the Collector Voltage V in place of the Collector Current I_A.

The Accelerating Voltage U_2 was slowly increased from 0 to 30V to produce a curve on the oscilloscope.

The value of the accelerating voltage U_2 and collector voltage V were recorded for a range of values of accelerating voltage, with a number of measurements taken around the maxima and minima of the curve.

A graph of the collector voltage V versus accelerating voltage U_2 was plotted. From this the first excitation energy of mercury ΔU_2 was calculated by measuring the separation between the successive maxima.

The value of the contact potential was calculated using the formula

$$G = U_1 + U_2 - \Delta U_2 \tag{3}$$

Finally, the mean free path of an electron in mercury vapour at a temperature of 160^o was calculated using the equation

$$\mu = \frac{k_B T}{\sqrt{2}\pi d^2 P} \tag{4}$$

where k_B is Boltzmann's constant, T is the temperature, d is the diameter of the mercury molecules and P is the pressure.

3.4 The Franck-Hertz Curve for Neon

The apparatus was turned off and allowed to cool down. The mercury source was disconnected, and the neon gas tube was connected instead.

Each of U_1, U_2 and U_3 were all set to zero and the power supply unit was turned on, with the operating mode still set to MAN.

Once on, U_1 was set to 1.53V and U_3 to 10.25V.

The Accelerating Voltage U_2 was then slowly increased from 0 to 80V, again to produce a curve on the oscilloscope, and the value of the accelerating voltage U_2 and collector voltage V were recorded for a range of values of accelerating voltage, with a number of measurements taken around the maxima and minima of the curve.

The voltages that caused luminance bands to appear in the neon tube were recorded for one, two and three luminance bands respectively.

Again, a graph of the collector voltage V versus accelerating voltage U_2 was plotted, and from this the first excitation energy of neon ΔU_2 was calculated by measuring the separation between successive maxima.

4 Results & Analysis

4.1 The Franck-Hertz Curve for Mercury

The variables U_1 and U_3 were set to 3.8V and 1.6V respectively to optimize the curve on the oscilloscope. The following data was recorded for the Mercury Frank-Hertz curve

Accelerating Voltage, $U_2(V) \pm 0.1$	Collector Voltage, $V(V) \pm 0.03$		
0	0.00		
0.4	0.00	26.7	4.64
1.4	0.02	27.5	7.95
2.4	0.16	28.1	10.6±0.05
3.4	0.58	28.6	11.15±0.3
4.4	0.26	29.1	9.90±0.1
5.4	0.10	29.5	7.95
6.4	0.37	30.3	6.93
7.4	1.28	30.8	6.71±0.1
7.9	1.83	31.3	7.40±0.1
8.4	2.12		
8.9	1.49		
9.6	0.54		
10.1	0.30		
10.6	0.38		
11.3	0.86		
12	1.72		
12.8	3.82		
13.3	4.39		
13.8	3.12		
14.1	1.99		
14.4	1.17		
14.7	0.86		
15.2	0.63		
15.7	0.86		
16.3	1.43		
17	2.88		
17.6	5.05		
18.1	6.17		
18.6	5.38±0.1		
19	3.75		
19.4	2.48		
19.8	1.78		
20.3	1.47		
20.8	1.73		
21.5	2.56		
22.1	4.29		
22.8	7.40		
23.3	8.31		
23.8	7.21±0.05		
24.2	5.13		
24.6	4.03		
25.1	3.33		
25.6	3.28		
26.1	3.50		

With this the following graph was plotted

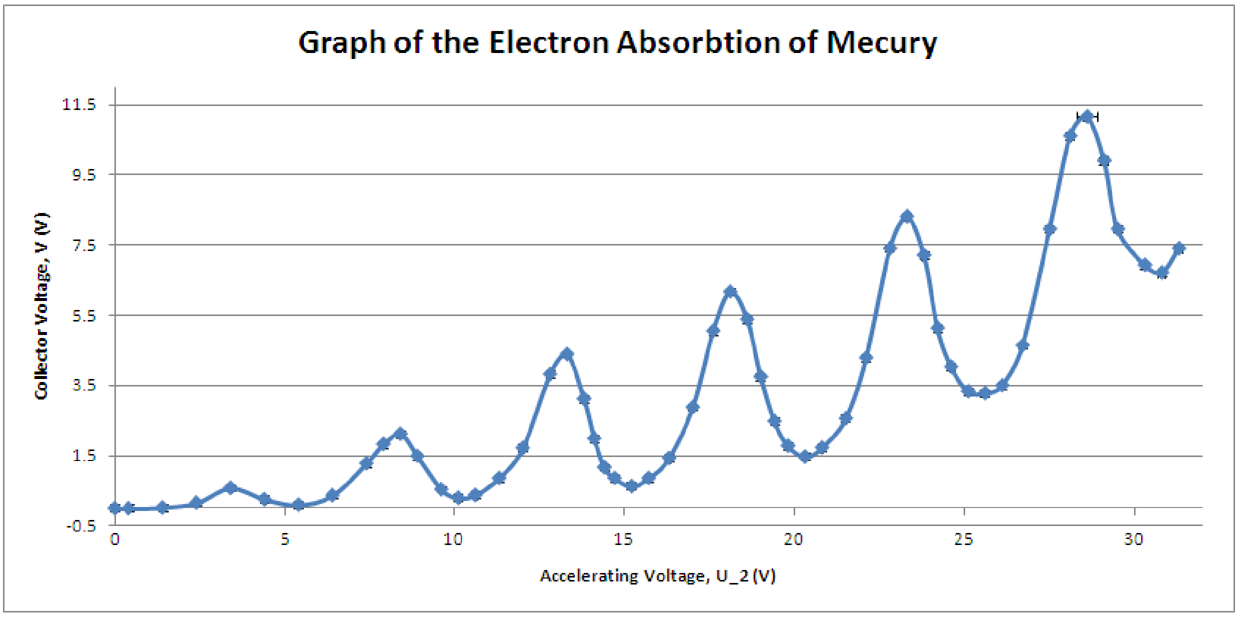

Figure 3: The Frank-Hertz Curve for Mercury

The Mean free path was calculated to be 37.18μm using equation 4, where $k_B = 1.3 \times 10^{-23}$, $P = 11.28$mm Hg $\equiv$ 1495Pa, $\vartheta = 160 + 273.15 = 433.15$K and $d = 151 \times 10^{-12}$m.

4.2 The Franck-Hertz Curve for Neon

The following data was recorded for the Frank-Hertz curve for Neon

Accelerating Voltage, $U_2(V) \pm 0.2$	Collector Voltage, $V(V) \pm 0.03$		
0	0.03		
3.3	0.04		
6.7	0.04	58.5	2.23
10.4	0.04	60.2	0.67
12.7	0.97	61.9	0.01
14	1.35	62.9	-0.03
17.3	2.06	63.9	0.07
18.3	2.14	65.6	0.72
19.3	1.50	67.3	2.08
20.4	0.61	69	3.84
21.6	0.03	70.6	5.55
22.6	-0.04	72.3	6.77
23.6	-0.06	74	7.42
27	-0.06	75	7.41
28	-0.01	76	7.32
29	1.17	76.3	7.28
30.8	2.43	77.6	6.73
31.5	2.81	78.9	6.37
34.3	3.97	79.9	5.93
35.3	4.17		
36.3	3.66		
37.5	2.61		
38.7	1.43		
39.9	0.43		
40.9	-0.03		
41.9	-0.06		
45	-0.07		
46	-0.04		
47	0.56		
48.3	1.57		
49.7	2.81		
50.8	3.76		
51.7	4.49		
52.6	5.06		
53.6	5.10		
54.6	4.98		
56	4.20		
57.3	3.28		

and again the following graph was plotted using the data

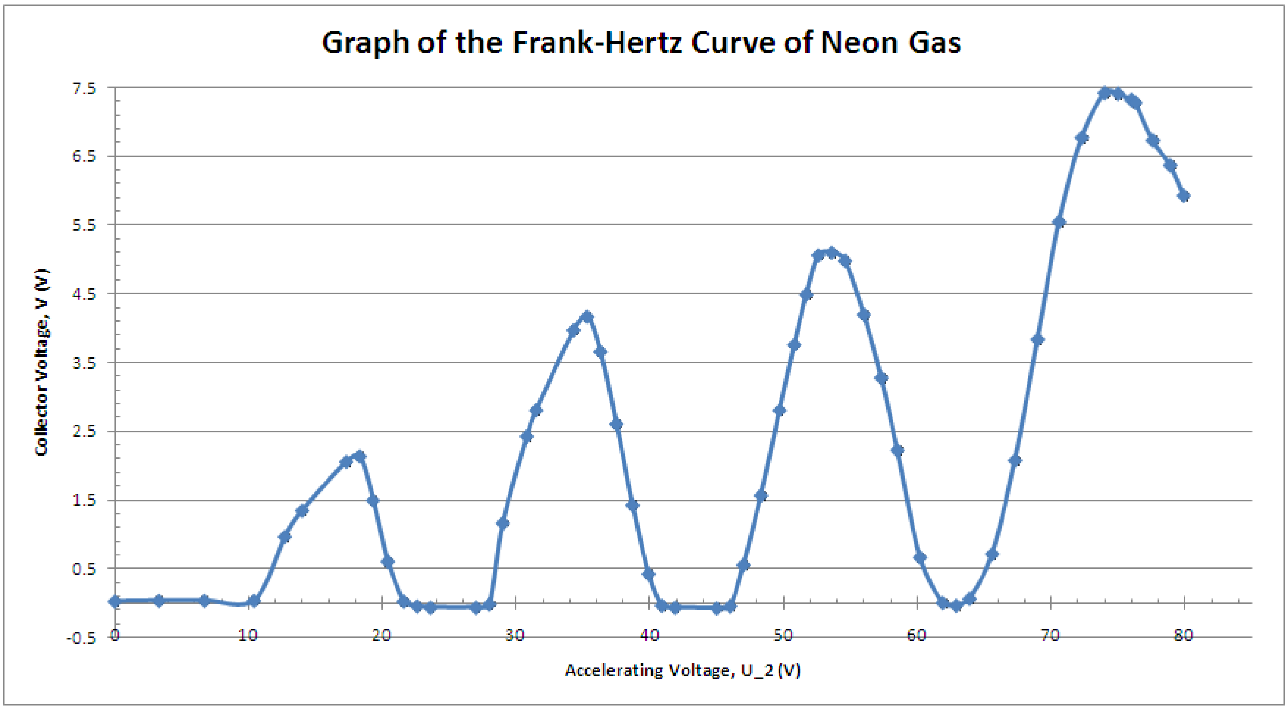

Figure 4: The Frank-Hertz Curve for Neon

The red-orange luminance bands were seen at equal intervals of accelerating potential as follows

Number of Luminance Bands	Accelerating Potential, U_2 (V)
1	35.3
2	53.6
3	75.0

5 Error Analysis

The error on the measurements for the accelerating potential U_2 was taken to be ± 0.1 for the Mercury experiment as this was the machine gave a reading to the first decimal place. For the Neon experiment the error was taken to ± 0.2, as the larger range in the potential had a larger uncertainty.

For the error in the collector voltages V, an uncertainty of ± 0.03 was taken due to the slight fluciations that occurred when reading the mulitmeter. There was a larger uncertainty given to some of the values for a high accelerating potential during the mercury experiment due to larger fluciations on the multimeter.

Finally, for calculating the error in ΔU for both mercury and neon the following relation was used.

$$\Delta U = U \times \sqrt{\sum_{1}^{n} \frac{\Delta U_{2,n}}{U_{2,n}}}$$

where n was the index of the peek differences.

6 Conclusions

In this experiment we calculated the the first excitation potential of mercury atoms, which was found to be 5.1 ± 0.4eV. This agrees with the accepted value of 4.9eV within the limits of experimental error. The contact potential was found to be 7.1 ± 0.4eV. The mean free path of an electron in mercury vapor was found to be 37.18μm using the above equation. We conclude that electrons excite mercury atoms to descret energy levels, and the excited mercury atoms can then loose this energy by emitting photons in the ultraviolet light range.

Secondly, we calculated the the first excitation potential of neon atoms, which was found to be 19.2 ± 0.5eV. Again, this agrees with the accepted value of 18.4 to 19.0eV within the limits of experimental accuracy. This corresponds to the neon atoms being excited to the 3p energy levels. This excitation is clearly more probable, since it was recorded to occur for every excitation, and we can determine that this was the only excitation to occur. From our table for the number of luminance bands, we can see that the luminance bands correspond to the peeks of the Franck-Hertz curve. Thus we expect the next band, that is the fourth, to occur at 94.2 ± 0.5eV.