The Franck-Hertz Experiment for Mercury and Neon

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Abstract:

In this experiment an attempt was made to produce Franck-Hertz curves for both mercury and neon, and to examine some of their properties. Although it was not possible to produce a Franck-Hertz curve for mercury due to issues with the equipment, one was produced for neon. The first excitation potential of mercury was found to be 4.92V±0.04V, and that of neon was found to be 19.3V±0.1V. It was found that the neon atoms were being excited to the 3p-levels. No relationship was found between the luminance bands in the neon tube and the Franck-Hertz curve, however it is possible that this is due to the difficulty in accurately determining the appearance of these bands.

Aims:

Our aims in this experiment were;

- To record a Franck-Hertz curve for mercury
- To estimate the first excitation potential of mercury
- To estimate the mean free path of an electron in mercury vapour
- To record a Franck-Hertz curve for neon
- To calculate the first excitation potential of neon
- To identify which energy level contribute to its Franck-Hertz curve
- To investigate the relationship of the luminance bands in the neon tube to the characteristic Franck-Hertz curve of neon

Introduction and Theory:

In 1913 Niels Bohr proposed his model of the atom, along with this he also speculated that atoms have discrete energy levels which electrons can occupy(orbitals). The evidence for this was discovered soon after when, in 1914, James Franck and Gustav Hertz reported an energy loss occurring in distinct "steps" for electrons passing through mercury vapour, and a corresponding emission at the ultraviolet line of mercury. The results of their experiment confirmed Bohr's quantised model of the atom by demonstrating that atoms could indeed only absorb or be excited by discrete amounts of energy (quanta).

In this experiment, a glass tube is evacuated, and mercury atoms are kept at a constant vapour pressure of 1500Pa, see Fig. 1 below. In the centre of the glass tube is a cathode, K, from which electrons are emitted via thermionic emission (the cathode is heated indirectly to prevent a potential difference along K). The glass tube is surrounded by a grid-type control electrode, G_1, at a distance of a few millimetres. This in turn is surrounded an acceleration grid, G_2, at a slightly larger distance, and an outermost collector electrode, A.

Electrons are emitted from the centre cathode, K, and attracted by the driving potential U_1between K and G_1. The electrons are also attracted through the mercury vapour by the grid G_2, because of the accelerating potential U_2. The emission current is practically independent of this acceleration voltage between the two grids. The anode, A, is then held at a slightly lower electric potential than the grid G_2, (i.e. a braking voltage, U_3, is applied). This ensures that only electrons with sufficient kinetic energy can reach the anode and contribute to the collector current, I.

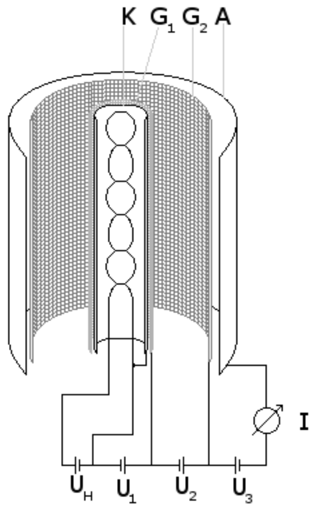

Fig. 1

According to Bohr's theory, an atom cannot absorb any energy until the collision energy between the atom and an electron exceeds that which is required to lift the atom to a higher energy state. Therefore when U_2 is low, the accelerated electrons only acquire a small amount of kinetic energy, not enough to excited the mercury atoms, thus only inelastic collisions occur. As U_2 is increased, the electrons gain more kinetic energy, more electrons are attracted by the grid, and the collector current I increases. This continues until the electrons have enough kinetic energy to excite the mercury atoms, and inelastic collisions occur, causing the energy to be transferred to the mercury atoms, exciting them to a higher state. The electrons are left with very little kinetic energy, meaning few can overcome the braking potential U_3 to reach the anode, A, and so we see a sharp drop in the collector current I as this happens. This kinetic energy is known at the first excitation potential for the mercury atoms. This process occurs again and again, with the electrons gathering kinetic energy until once again they have sufficient energy to excite the atoms to an even higher energy state.

The mean free path of a particle can be given by the equation

$$\lambda_{mfp} = \frac{kT}{4\sqrt{2}\pi a^2 p}$$

Where k is the Boltzmann constant, T is the temperature of the system in Kelvin, a is the diameter of the atom, and p is the pressure of the system in Pascals.

Experimental Method:

Mercury:

- The apparatus was set up as shown below in Fig. 2, and the equipment calibrated according to the parameters given.
- It was ensured that all voltages U_1, U_2, U_3 were set to zero. The heater was allowed to heat up for 15 minutes to raise the temperature of the cathode to approximately 175°C.
- The driving potential U_1 and braking voltage U_3 were adjusted so as to optimise the Franck-hertz curve obtained, and then held constant.
- The acceleration voltage U_2 was slowly increased from 0 – 30V, while taking recordings of its value, along with that of the collector current I. More data points were taken around each peak in order to correctly identify each maximum.
- An I-V curve was plotted from the data obtained.

Neon:

- The apparatus was set up before, with the exception of a glass tube filled with neon gas in place of the one filled with mercury vapour. In this case no heating is required to keep the atoms in a vapour. The equipment was calibrated as before.
- The driving potential U_1 and braking voltage U_3 are once again held constant.
- The acceleration voltage U_2 was slowly increased from 0 – 80V, and measurements taken as before.
- Luminance bands were observed for increasing acceleration voltages, and the voltage required to see 1, 2, and 3 bands recorded.
- Once again an I-V curve was plotted from the data obtained.

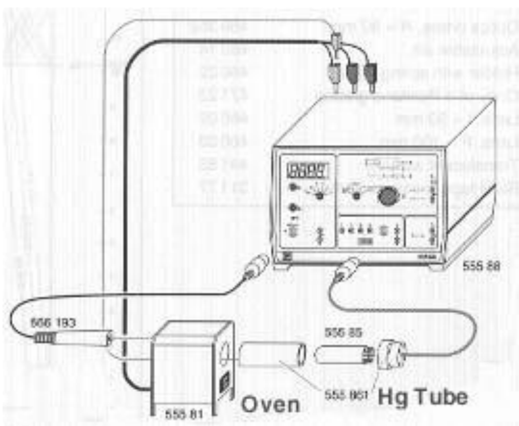

Fig. 2

Results and Analysis:

Mercury:

Unfortunately, due to the mercury bulb overheating caused by a fault with the devices thermostat, it was almost impossible to record usable results. The only results that could be recorded were the positions of the peak currents. However, despite the lack of tangible results, what was clear from the results we obtained was that the maxima were approximately 4.9V apart, as expected, as can be seen below in Fig. 3 and Table 1 below. Our average difference between maxima was found to be 4.92V±0.04V, which agrees very well with the accepted excitation energy of mercury of 4.9V. Our first maximum appeared at approximately 4V±0.1V, which is reasonably near the expected value of 4.9V.

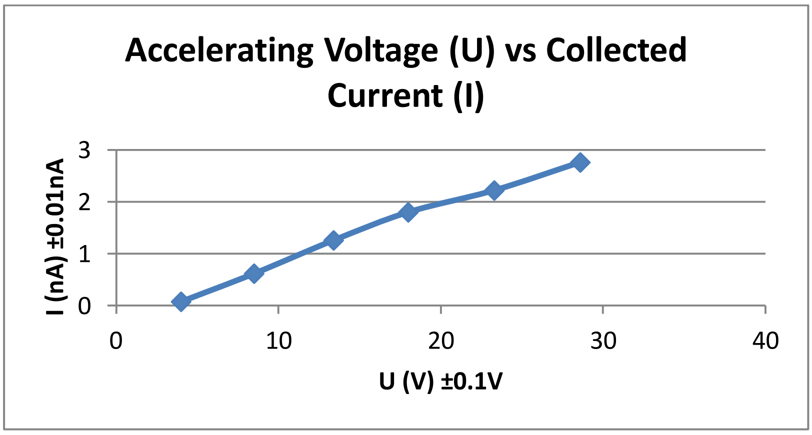

Fig 3. I-V graph for Mercury

Table 1

Value at max (V)	Difference from preceding max (V)
4	—
8.5	4.5
13.4	4.9
18	4.6
23.3	5.3
28.6	5.3

Average difference = 4.92V±0.04V

To find the mean free path of an electron in mercury we use the equation from above

$$\lambda_{mfp} = \frac{kT}{4\sqrt{2}\pi a^2 p}$$

By conversion we know that p=1503.9Pa, T=433.15K, and we know that a is the diameter of the mercury atom $a = 0.314 \times 10^{-9}$ and Boltzmann's constant $k = 1.38 \times 10^{-23}$. We then obtain the result $\lambda_{mfp} = 2.27 \times 10^{-6}$ and this measurement has no errors.

Neon:

This part of the experiment was far more successful, an I-V graph quite similar to the expected one was obtained, see Fig. 4 and Fig 5 below.

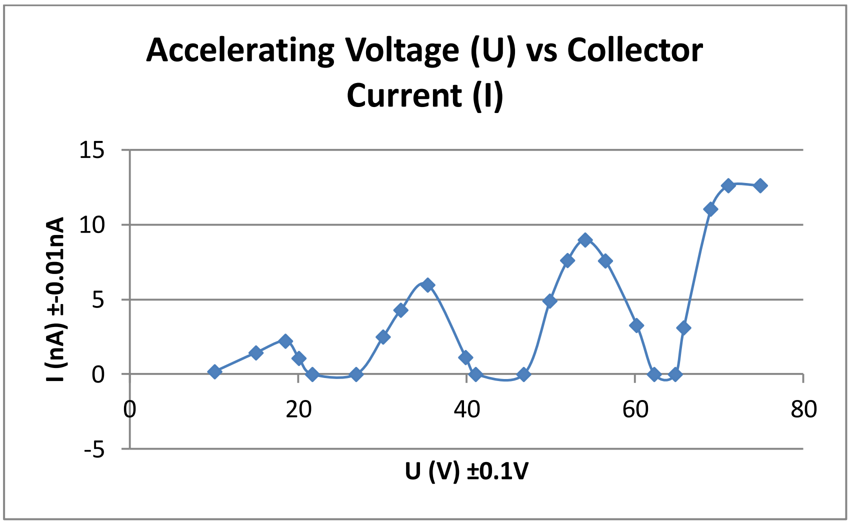

Fig. 4 I-V graph for neon

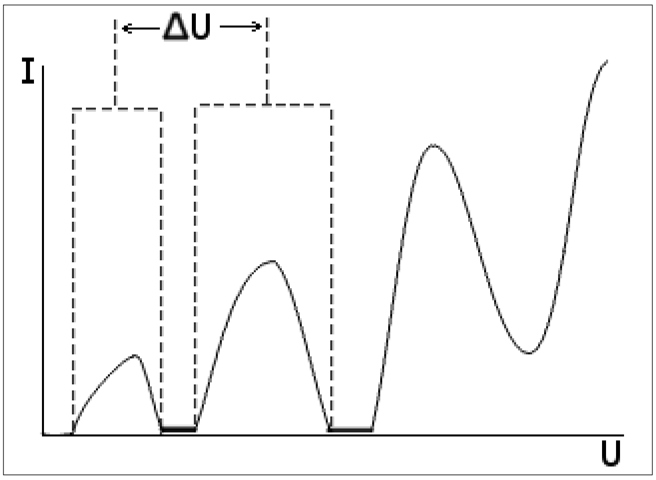

Fig. 5 Expected I-V graph for neon

The voltages at which the luminance bands were observed were recorded, as shown in Table 2 below, however there seemed to be no relation between their positions and the I-V graph. We suspect it is possible that this is due to the difficulty in accurately determining the appearance of these bands. It was estimated that a fourth band would be visible at approximately 70-80V.

Table 2

Band No.	Voltage (V)
1	21.9
2	53.9
3	66.1

To find the excitation potential the average distance between the centre of successive peaks needed to be found. The centres of peaks 1, 2, and 3 were located at 15.9V, 34V, and 54.6V respectively each with an error of ±0.1V. Therefore the average distance between centre of peaks was found to be 19.3V±0.1V. This implies that the neon atoms are being excited to the 3p-levels, which is also the more probable excitation since atoms can be excited to the 3p level from both the ground state and the 3s level.

Discussions and Conclusions:

- Due to issues with the thermostat at the beginning of the experiment our results were difficult to obtain and at times illogical. The thermostat malfunctioned causing the heater to greatly exceed its upper threshold, and possibly damaging the mercury bulb.
- The first part of this experiment was almost a complete failure, and we did not manage to produce a Franck-Hertz curve for mercury. Although we did observe a partial Franck-Hertz curve it was lost before we could take sufficient measurements. However some measurements were obtained which allowed us to estimate the first excitation potential of mercury as 4.92V±0.04V which is within experimental error of the accepted value of 4.9V.
- The mean free path for an electron in mercury was found to be $\lambda_{mfp} = 2.27 \times 10^{-6}$.
- The second half of the experiment involving neon was far more successful. A Franck-Hertz curve was obtained that was quite similar to a typical curve for neon.
- The first excitation potential of neon was calculated as 19.3V±0.1V which was very close to the range of 18.4-19V for 3p-level excitation.
- The first, second, and third luminance bands for neon excitation were observed and their voltages recorded, with a fourth being predicted in the range of 70-80V.