The Ramsauer-Townsend Effect

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Abstract

Using a thyratron, the Ramsauer-Townsend effect was observed by firing electrons through xenon gas. It was found that the probability of the electrons scattering was a minimum when the energy of the electrons were 1.1 ± 0.1 eV confirming the need for a quantum treatment of the phenomenon. It was then found that the De Broglie wavelength of the electrons at this energy were 1.1 ± 0.2nm.

⋆ Introduction

When particles move through a gas, the gas may scatter the particles. Classically, the probability of scattering depends on the energy of the particle. If the particle does not have enough energy, it will be scattered by the interacting potential. Else, it will have enough energy to overcome the potential. Essentially, the probability of scattering decreases monotonically with increasing energy.

However, experiments show that the probability of scattering electrons moving through a noble gas will experience a minimum at unexpected energies; in particular, 1eV. This contradicts the classical view and it is clear from this that another theory is required to explain this.

In quantum mechanics, the interaction can be modelled as a step potential. Schrodinger's equation predicts that some of the wave will be reflected twice. Once when it steps up and once when it steps down. It is then possible that if the two reflected waves are out of phase, destructive interference occurs and there is no scattering. Hence, there is a certain energy value such that the scattering will be a minimum.

To observe the effect, the experiment will be set up such that a cathode will fire electrons through a tube(thyratron) filled with xenon gas. It will then either go towards a shield indicating scattering or to the plate when it goes straight through. The current of the shield(I_s) and the plate(I_p) will then be measured to determine whether an electron is present or not. The experiment is then repeated with the gas absent by inverting and freezing the thyratron to measure the current of the shield(I_s^*) and the plate(I_p^*).

The ratio of the currents in the absence of xenon can be expressed as

$$f(V) = \frac{I_p^*}{I_s^*} \Rightarrow I_p^* = I_s^* f(V)$$

With gas present, we get

$$I_p = I_s f(V)(1-P)$$

where P is the probability of scattering. This gives,

$$P = 1 - \frac{I_p I_s^*}{I_p^* I_s}$$

P can also be expressed as

$$P = 1 - e^{\frac{l}{\lambda}} \tag{1}$$

where l is the distance between the plate and aperture and λ is the mean free path of the electron.

Now, it is necessary to determine the kinetic energy of the electron. This is given as $T = eV_{eff}$ where $V_{eff} = V + V_c + \bar{V}$. V is the applied accelerating voltage, V_c is the contact potential difference which arises from two different metals in contact and $\bar{V}$ is the energy acquired from the heating of the cathode. These values can be found by reversing the polarity and measuring I_s^* and V. It can then be shown that,

$$\log I_s^* = \log I_0 - \frac{3V}{2\bar{V}} \tag{2}$$

so a plot of $\log I_s^*$ vs V will give V_c and $\bar{V}$. V_c corresponds to the point of intersection and $\bar{V}$ corresponds to the slope on the left side.

⋆ Experimental Method

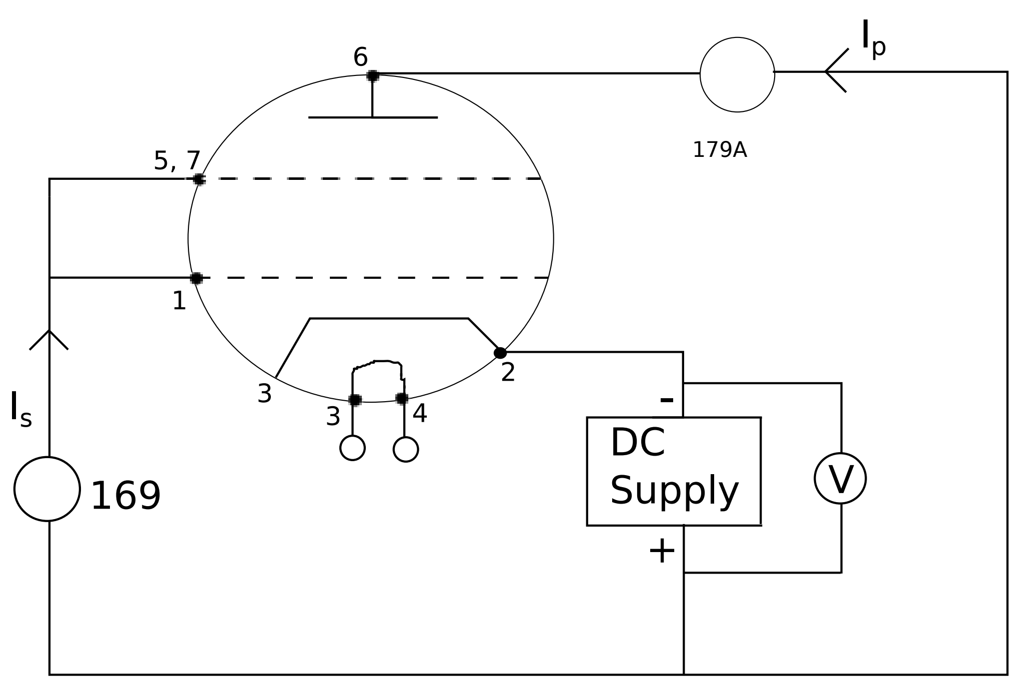

Figure 1: Diagram of Circuit

The circuit is set up as shown in figure 1. I_p and I_s are measured while varying the voltage with gas present. The thyraton is then inverted and submerged in liquid nitrogen and I_p^* and I_s^* are measured. Finally, the polarity of the circuit is reversed and I_s^* is measured whilst varying voltage and still submerged in liquid nitrogen.

⋆ Results and Analysis

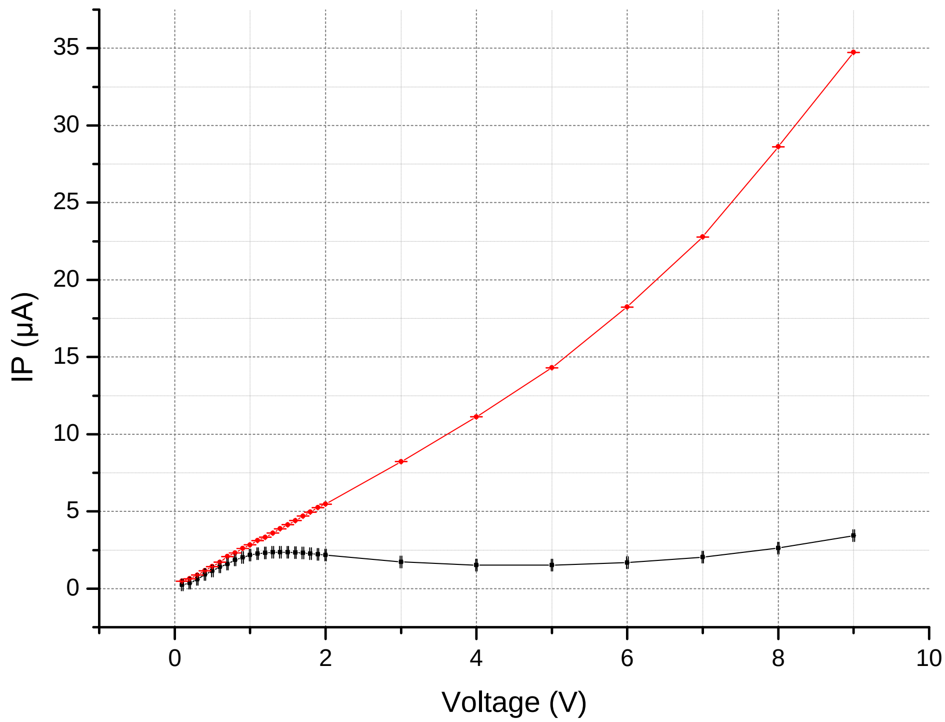

Figure 2: Graph of I_p(black) and I_p^*(red) against V

Figure 2 shows the differences with the presence and absence of gas. Clearly, the gas has a huge effect as it is scattering the electrons such that they are unable to reach the plate.

Figure 3 shows the plot of the probability of scattering against the voltage. This is a clear example of the Ramsauer-Townsend effect. As expected, a minimum occurs and this occurs for $P = 0.05 \pm 0.01$ and $V = 0.6 \pm 0.1$. A maximum occurs for $P = 0.88 \pm 0.01$ and $V = 6.5 \pm 0.1$. Hence, from equation (1), the mean free path for the minimum was found to be 0.14 ± 0.02m and the mean free path for the maximum was found to be 0.0033 ± 0.0001m.

Using Equation (2) and figure 4, $\bar{V}$ was found to be 0.16 ± 0.05V. By finding the point of intersection of the two lines, V_c was found to be 0.33 ± 0.06V. Hence, $V_{eff} = 1.1 \pm 0.1$V so the energy is $E = 1.1 \pm 0.1$eV which is close to the 1eV mark that was expected. Using the De Broglie relation, the wavelength of the electron was found to be $(1.1 \pm 0.2) \times 10^{-9}$m.

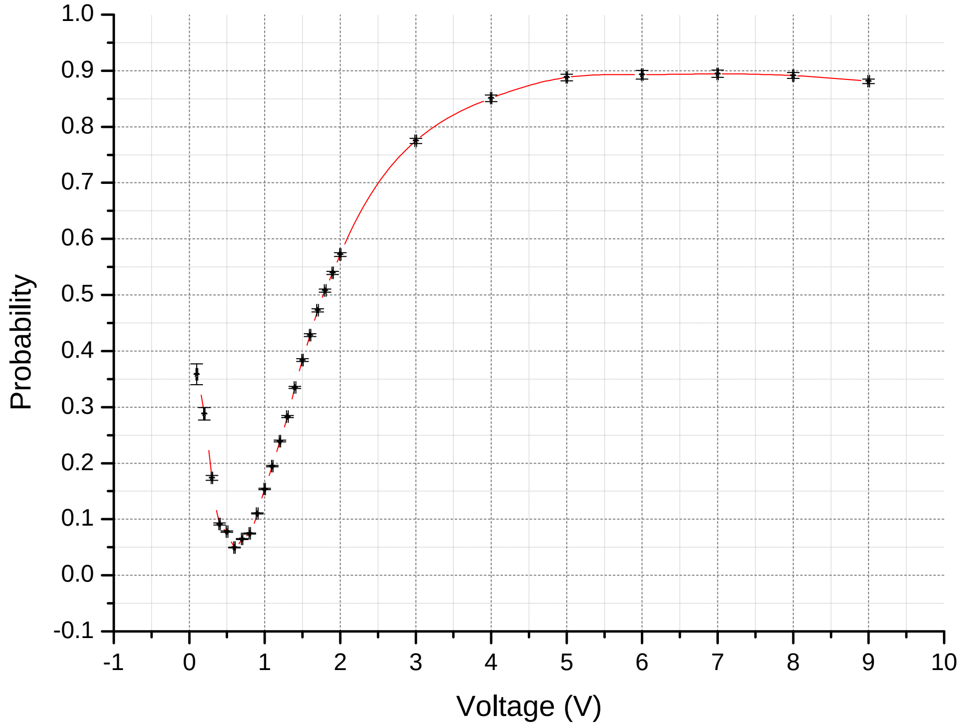

Figure 3: Graph of P against V

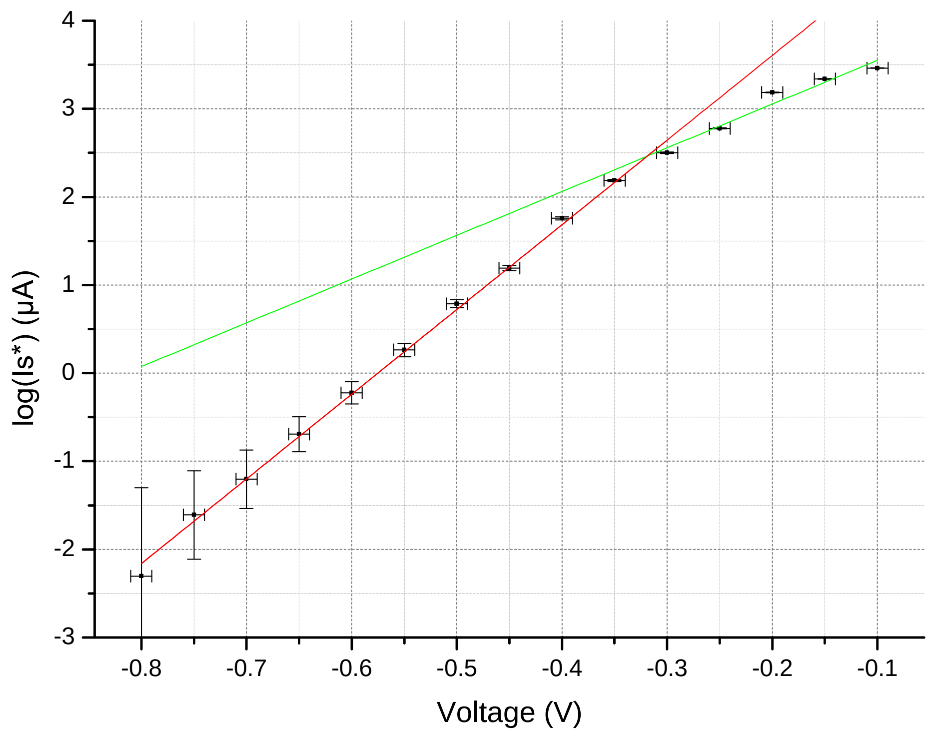

Figure 4: Graph of $\log I_s^*$ against V; Red: $y = (9.6 \pm 0.2)x + 5.5 \pm 0.1$; Green: $y = (5.0 \pm 0.6)x + 4.0 \pm 0.1$

⋆ Conclusion

Qualitatively, the Ramsauer-Townsend effect was observed with the probability reaching a minimum for $V = 1.1 \pm 0.1$ V and $E = 1.1 \pm 0.1$eV. It was found that the mean free path of the electrons for the minimum and maximum were 0.14 ± 0.02m and 0.0033 ± 0.0001m respectively.

After finding the contact potential and mean potential, the De Broglie relation was used to find that the wavelength of the electron was 1.1 ± 0.2nm.

To conclude, it was important to observe a phenomenon that contradicts classical mechanics calling for the need of a better theory. Quantum mechanics steps in and delivers showing the necessity for a quantum view of the world.