SENIOR FRESH EXPERIMENTAL PHYSICS LABORATORY REPORT

# Laboratory 5: The Ramsauer-Townsend Effect

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# Contents

# 1 ABSTRACT

In this experiment we attempt to observe the Ramsauer-Townsend effect. The scattering cross section of electrons by noble gasses, Xenon in our case, exhibits a minimum at certain energies. Using a thyratron we shoot electrons through this Xenon gas and determine it's effect on the scattering of electrons by measuring the current of the plate and the current of the shield for a series of voltages. This is done with the Xenon present (at room temperature) and when the Xenon is evacuated to the walls (when the tube is immersed in liquid nitrogen).

The experiment was successful and it can be seen that when the scattering probability takes a maximum the mean free path of the electron takes a minimum. And visa versa for the minimum of the scattering probability. Figure 5.1 shows that the absence of the Xenon gas has an immense effect on the scattering of electrons as the current continuously increases as the voltage increases.

By reversing the polarity of the circuit, it was found that the scattering probability of the electrons attained a minimum when the energy of the electrons were $E = 1.4574 \pm 0.01 eV$.

# 2 INTRODUCTION & THEORY

## 2.1 THE RAMSAUER-TOWNSEND EFFECT

The Ramsauer-Townsend Effect provides many insights into the scattering processes of electrons. The scattering cross section of electrons by noble gasses, Xenon in our case, exhibits a minimum at certain energies. So what's the use? Well the Ramsauer-Townsend Effect provides insights into electron scattering processes, which are fundamental to various fields like plasma physics, gas discharge studies, and semiconductor device fabrication. Why noble gasses? Well noble gases have high first ionization energy. Hence electrons do not carry enough energy to cause excited electronic states. This is convenient for analysing collisions because the probability of elastic scattering is equal to the probablility of collision.

## 2.2 WAVE NATURE OF ELECTRONS

In quantum mechanics, electrons can be thought of as both particles and waves... wave-particle duality. This is described by the wave function, $\psi$, which characterizes the probability amplitude of finding the particle at different positions. At low-energys, electrons scatter off noble gas atoms, Xenon in our case. This scattering process involves the interaction between the electron waves and the potential field of the atom. The wave nature of electrons becomes crucial because the interference between the incident electron wave and the scattered wave affects the scattering cross-section. At certain energies, the electron waves interfere destructively, leading to a minimum in the scattering cross-section, as observed in the Ramsauer-Townsend effect.

### 2.3 Mean free path of an electron

Simply put, the mean free path of an electron is the average distance in which an electron can travel before colliding with other particles or defects in materials and substantially changing it's direction or energy.

Speed of molecule Volume of gas

Mean free path of a gas molecule

$$\lambda = v t_{\text{mean}} = \frac{V}{4\pi\sqrt{2}r^2 N} \qquad (18.21)$$

Mean free time between collisions Radius of a molecule Number of molecules in gas

Figure 2.1: Mean free path of a gas molecule [1]

This influences the probability of electron scattering. At low energies where the Ramsauer-Townsend effect is observes, the mean free path becomes comparable to the characteristic dimensions of the atom or the interatomic space. Then the wave-like nature of electrons becomes significant to describe scattering.

### 2.4 Contact potential difference

To understand contact potential difference we must first understand the *work function* of metals. The work function is the amount of energy required to release an electron from the surface of a metal. When the maximum energy of electrons inside a metal is less than that of an electron just outside, the difference in energy is the work function.
When two metals are put in contact electrons will transfer from one to the other because of the difference in work functions. The electrons will move from the one with the lower work function into the other until the maximum energy of the electrons in each is the same. The transfer in electrons cause the metal to become charged and this gives rise to a potential difference between them. This is called the *contact potential difference*.

## 3 Experimental Setup

The apparatus in this experiment consists of a EM91 thyratron vacuum tube where the RT effect will occur, a 10 V DC power supply used to accelerate electrons, a 4 V DC power supply used to heat the cathode filament and produce electrons, 2 x Keithley 2110 multimeters to measure electrical current at the plate and shield electrodes, a digital multimeter (DMM) to measure voltage, and a liquid nitrogen flask. Ensure that the heater voltage must not be less than 4 volts and the inter-electrode voltage must be kept below 10 volts.

Set up the circuit as shown in figure 3.1

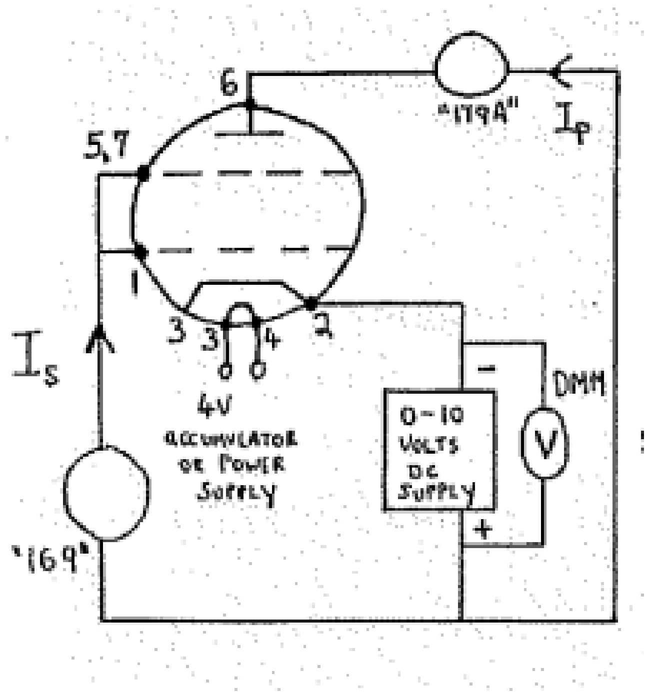


Figure 3.1: Circuit diagram [2]

There are two situations we are investigating in relation to the xenon gas. When the gas is present we follow the methodology, noting down voltages and corresponding currents accordingly. However to understand the operation of the thyratron in the experiment in more detail, we must consider the case when no xenon gas is present as shown in figure 3.2.

# 4 Methodology

Set up the apparatus as it is in figure 3.1. When the xenon gas is present (no liquid nitrogen and at room temperature) $I_p$ and $I_s$ are measured for a series of voltages from 0-10 V.

Now to reduce the pressure of the Xenon gas the tube is inverted and placed in liquid nitrogen. Now a series of values will be obtained for $I_p*$ and $I_s*$ for a series of voltages from 0-10V. The same increments are used as before.

To determine the *contact potential* and *mean thermionic emission*, the polarity of the plate/shield to cathode connection is reversed.
Plot Ip and Ip* to attempt to see the effect on the gas and the scattering of the electrons. Then calculate $P_s$ using:

$$P_s = 1 - \frac{I_p}{I_s}\frac{I_s*}{I_p*} \tag{4.1}$$

and plot Ps vs V.and use the plot to observe when the probability scattering attains a maximum

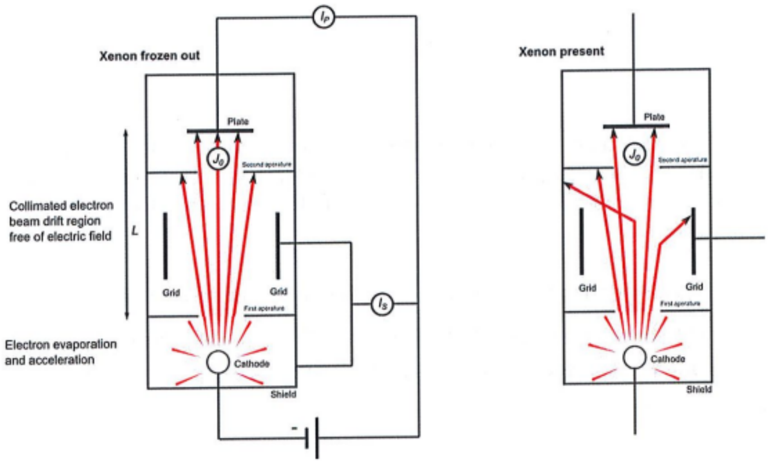


Figure 3.2: Schematic of the thyratron operation. (Left, no xenon present) Electrons emitted from the cathode in chamber 1 of the shield are accelerated by the voltage V and impinge mostly on the shield. Some electrons make it through the first aperture and into the field-free region where they drift in straight lines hitting either other regions of the common shield-grid electrodes, or hitting the isolated plate electrode located in the third chamber. (Right, xenon present) Electrons are scattered by xenon atoms reducing the chance of reaching the plate electrode and increasing the shield electrode current. [2]

and a minimum, and note the values of Ps and V in each case. Calculate the mean free electron path $\lambda$ using:

$$P = 1 - e^{-\frac{l}{\lambda}} \tag{4.2}$$

where l in this experiment the path length which is the field free region from the 1st aperture to the plate electrode is 0.7cm.

Another important outcome to determine in this experiment is the current at the shield electrode as a function of the escaping thermionic current $I_0$, the contact potential $V_c$ and the energy acquired from the heating of the cathode $\bar{V}$.

$$I(V_r) = I_0 e^{-\frac{3V_r}{2\bar{V}}} \tag{4.3}$$

$$\log I_s^* = \log I_0 - \frac{3V_r}{2\bar{V}} \tag{4.4}$$

We can use a plot of logIs* vs V to obtain values of $V_c$ (the point of intersection) and $\bar{V}$ (the slope)

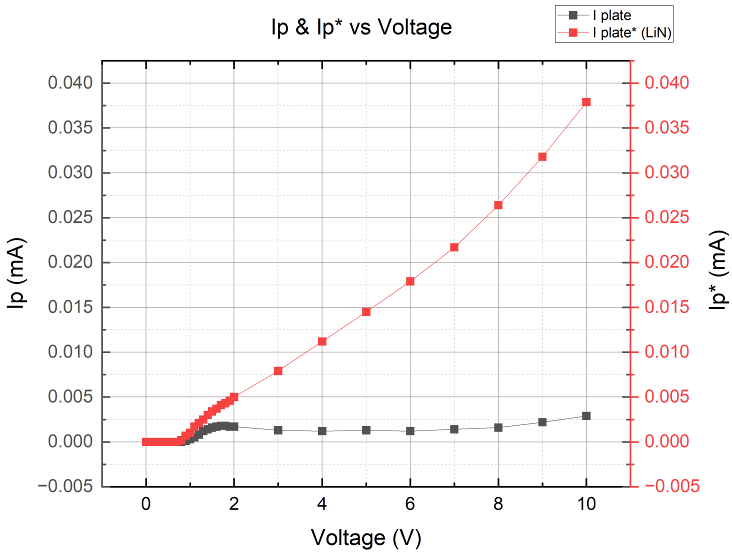


Figure 5.1: Plate current at room temperature $I_p$ and plate current in liquid nitrogen $I_p*$ vs Voltage

# 5 Results and Discussions

It can be seen from figure 5.1 that $I_p*$ rises continually almost linearly with increase in voltage. The effect of the Xenon gas is clear from this figure. When the gas is present the current is much less as there is more electron scattering due to the gas.

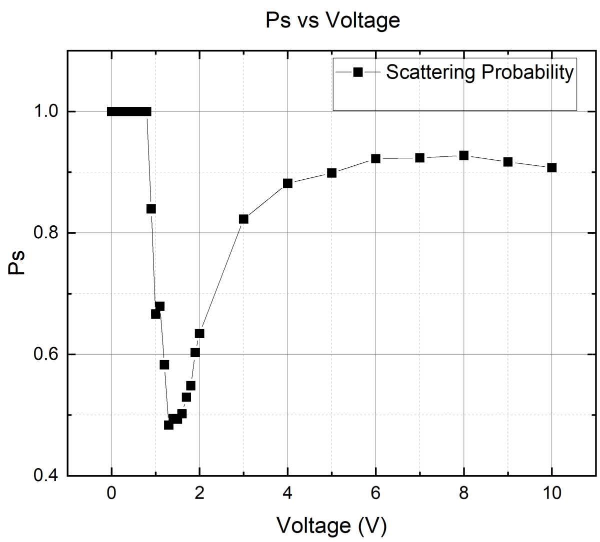


Figure 5.2: Scattering Probability vs Voltage

Figure 5.2 shows the scattering probability of the electrons. When $P_s$ reaches a minimum it attains a value of $P_s = 0.4836 \pm 0.01$ and $V = 1.3 \pm 0.01V$. A maximum attains a value of $P_s = 0.9275 \pm 0.01$ and $V = 8 \pm 0.01V$.
Using equation 4.2, the mean free path of the minimum is calculated to be $\lambda_1 = (0.01059 \pm 0.00696)m$. The mean free path of the maximum is calculated to be $\lambda_2 = (2.6675x10^{-3} \pm 0.00736)m$. These values have clear indications for the scattering of electrons. Simply, if the probability of scattering is higher that means the electron is more likely to collide with particles and atoms. The corresponding mean free path is short because the electron can only travel a short distance before being scattered. The opposite is true for the minimum scattering probability, the electron has a relatively larger mean free path before being scattered.

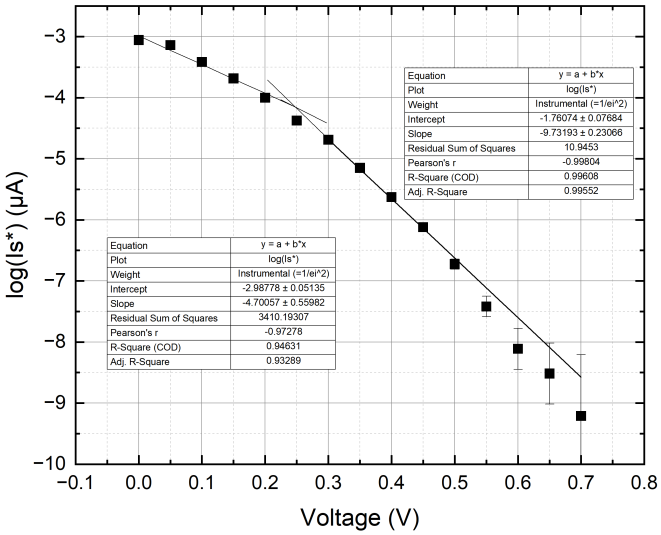


Figure 5.3: Reversing the polarity and plotting log(Is*) vs V

The equation of the red line is y = $(-4.701 \pm 0.55)x + (-2.988 \pm 0.05)$ and the blue line is y = $(-9.732 \pm 0.231) + (-1.761 \pm 0.0768)$
Using figure 5.3 $V_c$ (the point of intersection) was determined to be 0.248 ± 0.01V. $\bar{V}$ was found to be $0.9732 \pm 0.231$. Hence $V_{eff} = 1.4574 \pm 0.01V$ which corresponds to an energy of $1.4574 \pm 0.01eV$.

# 6 CONCLUSIONS

The Ramsauer-Townsend effect was successfully observed. The effect of the Xenon gas was clear when looking at the current with the gas (at room temperature) and without the gas (in liquid nitrogen). When the gas is present and the scattering probability reaches a minimum at $P_s = 0.4836 \pm 0.01$ the mean free path reaches a maximum at $\lambda_{max} = (0.01059 \pm 0.00696)m$. When the scattering probability is at a maximum at $P_s = 0.9275 \pm 0.01$ the mean free electron path reaches a minimum of $\lambda_{min} = (2.6675x10^{-3} \pm 0.00736)m$.

By reversing the polarity of the circuit, it was found that the scattering probability of the electrons attained a minimum when the energy of the electrons were $E = 1.4574 \pm 0.01eV$.

It is clear from this experiment that we cannot fully trust classical mechanics. The wave-nature of the electron plays a big part in its scattering probabilities. Quantum mechanic provides a new, deeper, and in depth meaning to collisions and scatterings of elementary particles.

# REFERENCES


[1] Roger Freedman Hugh Young. *University Physics with Modern Physics*. 2023-24.

[2] *Trinity Lab Manual*. 2024.


"I have read and I understand the plagiarism provisions in the General Regulations of the University Calendar for the current year, found at `http://www.tcd.ie/calendar`.

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# 7 APPENDIX

## 7.1 ERROR PROPAGATION

The voltages have constant error: $\pm 0.01V$

Current - constant error: $0.0.0000001A$

$$\begin{aligned} Q &= a + b + \ldots + c - (\delta x + \delta y + \ldots + \delta z) \\ \delta Q &= \sqrt{(\delta a)^2 + (\delta b)^2 + \ldots + (\delta c)^2 + (\delta x)^2 + (\delta y)^2 + \ldots + (\delta z)^2} \end{aligned} \tag{7.1}$$

$$\frac{\partial z}{z} = \sqrt{\left(\frac{\partial x}{x}\right)^2 + \left(\frac{\partial y}{y}\right)^2}$$

When x and y are the same (ie. $x^2$) we get:

$$\delta x^2 = x^2\sqrt{2}\delta x$$

$$\frac{\Delta z}{z} = \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2}$$

$$\Delta \log x = |\frac{1}{x}|\Delta x$$

## 7.2 Data

| V | Is reverse | $\log Is*$ | $\Delta \log Is*$ |
|---|---|---|---|
| 0 | 0.0471 | -3.05548 | 0.002123142 |
| 0.05 | 0.0433 | -3.1396 | 0.002309469 |
| 0.1 | 0.0329 | -3.41428 | 0.003039514 |
| 0.15 | 0.0251 | -3.68489 | 0.003984064 |
| 0.2 | 0.0183 | -4.00085 | 0.005464481 |
| 0.25 | 0.0126 | -4.37406 | 0.007936508 |
| 0.3 | 0.0092 | -4.68855 | 0.010869565 |
| 0.35 | 0.0058 | -5.1499 | 0.017241379 |
| 0.4 | 0.0036 | -5.62682 | 0.027777778 |
| 0.45 | 0.0022 | -6.1193 | 0.045454545 |
| 0.5 | 0.0012 | -6.72543 | 0.083333333 |
| 0.55 | 0.0006 | -7.41858 | 0.166666667 |
| 0.6 | 0.0003 | -8.11173 | 0.333333333 |
| 0.65 | 0.0002 | -8.51719 | 0.5 |
| 0.7 | 0.0001 | -9.21034 | 1 |

| Voltage (V) | $I_p$ A | $I_s$ A | $I_p *$ A | $I_s *$ A | $P_s$ |
|---|---|---|---|---|---|
| 0 | 0 | 0.0552 | 0.0000001 | 0.0497 | 1 |
| 0.1 | 0 | 0.0658 | 0.0000001 | 0.0955 | 1 |
| 0.2 | 0 | 0.0966 | 0.0000001 | 0.1328 | 1 |
| 0.3 | 0 | 0.1335 | 0.0000001 | 0.1714 | 1 |
| 0.4 | 0 | 0.1745 | 0.0000001 | 0.2151 | 1 |
| 0.5 | 0 | 0.2155 | 0.0000001 | 0.2581 | 1 |
| 0.6 | 0 | 0.2644 | 0.0000001 | 0.3073 | 1 |
| 0.7 | 0 | 0.3157 | 0.0000001 | 0.3601 | 1 |
| 0.8 | 0 | 0.3637 | 2.00E-04 | 0.4095 | 1 |
| 0.9 | 1.00E-04 | 4.17E-01 | 7.00E-04 | 0.4674 | 0.839684 |
| 1 | 3.00E-04 | 4.73E-01 | 0.001 | 0.526 | 0.666526 |
| 1.1 | 5.00E-04 | 5.31E-01 | 0.0017 | 0.5791 | 0.6793 |
| 1.2 | 8.00E-04 | 5.88E-01 | 0.0021 | 0.6438 | 0.582896 |
| 1.3 | 0.0012 | 0.6503 | 0.0025 | 0.6996 | 0.483611 |
| 1.4 | 0.0014 | 0.7055 | 0.003 | 0.7644 | 0.494373 |
| 1.5 | 0.0016 | 0.7696 | 0.0034 | 0.8289 | 0.493152 |
| 1.6 | 0.0017 | 0.8292 | 0.0037 | 0.8984 | 0.502197 |
| 1.7 | 0.0018 | 0.8971 | 0.0041 | 0.9612 | 0.529606 |
| 1.8 | 0.0018 | 0.9614 | 0.0043 | 1.0371 | 0.548435 |
| 1.9 | 0.0017 | 1.0231 | 0.0046 | 1.0991 | 0.602982 |
| 2 | 0.0017 | 1.0893 | 0.005 | 1.1721 | 0.634156 |
| 3 | 0.0013 | 1.7623 | 0.0079 | 1.8981 | 0.822763 |
| 4 | 0.0012 | 2.4392 | 0.0112 | 2.6943 | 0.881652 |
| 5 | 0.0013 | 3.1673 | 0.0145 | 3.5791 | 0.898688 |
| 6 | 0.0012 | 3.9407 | 0.0179 | 4.5637 | 0.922362 |
| 7 | 0.0014 | 4.7975 | 0.0217 | 5.6696 | 0.923756 |
| 8 | 0.0016 | 5.7704 | 0.0264 | 6.8987 | 0.927543 |
| 9 | 0.0022 | 6.8673 | 0.0318 | 8.2382 | 0.917007 |
| 10 | 0.0029 | 7.9864 | 0.0379 | 9.6627 | 0.907422 |