# The Ramsauer-Townsend Effect

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# Abstract

The Ramsauer-Townsend effect was observed for electron scattering in a Xenon thyratron. The electron energy for which the probability of scattering was minimum was found to be$1.4884x10^{-18}J$.

# Introduction and Theory

The Ramsauer-Townsend effect is the observable minimum in probability of scattering of low energy electrons by a noble gas, due to the implications of wave-particle duality on the collision. The probability of an electron colliding with a Xenon atom obtains a minimum for a value of the electrons energy in the region of 1eV. This experiment aims to demonstrate deviation from the behaviour predicted by a classical collision by finding the value of electron energy for which the scattering cross section is minimum.

The classical model of the interactions of the electrons with the xenon atoms is of elastic collisions between hard spheres. The experiment aims to demonstrate that this does not accurately describe their behaviour.

 The interaction is accurately described by the three dimensional Schrödinger equation for the electron incident on an attractive potential, three dimensional, square well.

The setup consists of a thermionic cathode in a chamber filled with xenon gas, as shown below.



Electrons flow through the xenon gas towards the anode, a plate which is held at a positive voltage relative to the cathode. The electrons can be scattered from their path between cathode and anode by collisions or interactions with the gaseous xenon atoms. On collision with an atom, electrons can either continue to the plate or be scattered and travel to the shield. The shield is a box like structure which encases the plate and cathode.

The gaseous xenon molecules can be “frozen out” by inserting the vacuum tube in liquid nitrogen. This reduces the amount of gaseous molecules for the electrons to interact with to insignificant amounts for this experiment.

The current to the plate is $I\_{p}$ with the xenon gas present and$I\_{p}^{\*}$ when it has been frozen out. The current to the shield is $I\_{s}$ with the xenon gas present and $I\_{s}^{\*}$ when it has been frozen out.

The ratio of the currents to the plate and shield (due to the flow of thermionically emitted electrons) when the xenon molecules have been effectively removed is:

$f\left(V\right)=\frac{I\_{p}^{\*}}{I\_{s}^{\*}}$ It is written as f(V) because the ratio is dependent on the number of scattered electrons, which is in turn dependent on the voltage (the speed given to the freed electrons).

$I\_{p}^{\*}$is therefore equal to$ I\_{s}^{\*}f\left(V\right)$. When the xenon gas is present the plate current is given by

$$I\_{p}=I\_{s}f\left(V\right)(1-P)$$

P is the probability of scattering an electron. This is given by $P=1-e^{-\frac{I}{λ}}$, where I is the distance between the plate and the aperture and $λ$ is the mean free path of the electron.

The probability of scattering can be given by:

$$P=1-\left(\frac{I\_{p}}{I\_{s}}\right)\left(\frac{1}{f\left(V\right)}\right)=1-\left(\frac{I\_{p}xI\_{s}^{\*}}{I\_{s}xI\_{p}^{\*} }\right)$$

The experiment will demonstrate that the probability of scattering, P, is minimum for a specific value of the voltage applied,$ V\_{minimum}$. The total energy of the electron is equal to $e(V=V\_{c}+\overline{V})$, where $V\_{c}$­ is the contact potential difference between the plate and the cathode and $\overline{V}$ is the voltage each electron is emitted with due to the heating of the cathode.

Electrons on the surface of a metal have a maximum energy less that those just outside the metal. This difference in energy is called the work function of the metal. When two metals of different work functions are put into contact electrons will flow from the metal of lower work potential to the metal of higher work potential until the maximum energy of the electrons in both metals are the same. Due to the flow of electrons in this process the metals will experience a difference in charge. This will generate a potential difference between the metals, the contact potential difference. The cathode and plate in this experiment will have a contact potential difference despite the fact that they are not in physical contact. This effective contact potential difference is due to the xenon gas facilitating electron flow between the two metals.

# Experimental method

# Part 1

The circuit was set up as shown in figure 1. The ammeters across placed in series with the plate and shield were set to the microamp scale. The respective currents across the plate and shield were recorded as a function of the voltage applied across the cathode and plate. This was carried out for a range of values form 0.05V to 8V. The vacuum tube was then partially submerged in liquid nitrogen, liquefying the xenon gas and reducing the gas pressure inside the tube from approximately 0.05torr to approximately$10^{-3}torr$. The measurements of shield and plate currents were recorded for the same values of voltage as previously.

To demonstrate the effect of the xenon gas both $I\_{p}$and $I\_{p}^{\*}$ were plotted as a function of V.

P was plotted as a function of V using the relation$P=1-\left(\frac{I\_{p}xI\_{s}^{\*}}{I\_{s}xI\_{p}^{\*} }\right)$.

# Part 2

The polarity of the power supply across the cathode and plate was reversed. The vacuum tube was again submerged in the nitrogen. And a range of values of $I\_{s}^{\*}$ for the new circuit arrangement was plotted with respect to voltage. Then ln($I\_{s}^{\*}$) was plotted as a function of voltage.

# Results and Analysis

The data obtained for current values in amps and probabilities of scattering with respect to voltage is tabulated below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Voltage | Is(A) with xenon | Ip(A) with xenon | Is\*(A) | Ip\*(A) | Probability |
| 0.05 | 0.0000461 | 0.00000019 | 0.000064 | 0.00000047 | 0.43877786 |
| 0.11 | 0.0000551 | 0.00000026 | 0.000005 | 0.00000056 | 0.95786881 |
| 0.19 | 0.0000673 | 0.00000036 | 0.0000882 | 0.00000067 | 0.295824 |
| 0.3 | 0.0000883 | 0.00000056 | 0.0001113 | 0.00000087 | 0.18865935 |
| 0.4 | 0.0001065 | 0.00000073 | 0.0001292 | 0.00000103 | 0.14019782 |
| 0.5 | 0.0001254 | 0.00000092 | 0.0001491 | 0.00000119 | 0.08077681 |
| 0.6 | 0.0001475 | 0.00000112 | 0.0001708 | 0.00000138 | 0.06020142 |
| 0.7 | 0.0001676 | 0.00000129 | 0.000193 | 0.00000156 | 0.04775565 |
| 0.81 | 0.0001918 | 0.00000146 | 0.000273 | 0.00000217 | 0.04234922 |
| 0.91 | 0.000273 | 0.0000019 | 0.000306 | 0.00000243 | 0.12359246 |
| 1 | 0.000303 | 0.00000201 | 0.00034 | 0.00000268 | 0.15841584 |
| 1.11 | 0.000337 | 0.00000211 | 0.000371 | 0.0000029 | 0.19900747 |
| 1.19 | 0.000366 | 0.00000216 | 0.000408 | 0.00000315 | 0.23559719 |
| 1.31 | 0.000405 | 0.0000022 | 0.000441 | 0.00000338 | 0.29125575 |
| 1.4 | 0.000435 | 0.00000222 | 0.000475 | 0.00000361 | 0.32849365 |
| 1.51 | 0.000475 | 0.00000222 | 0.000514 | 0.00000386 | 0.3776493 |
| 1.61 | 0.000508 | 0.00000221 | 0.000553 | 0.00000412 | 0.4160758 |
| 1.69 | 0.000538 | 0.00000219 | 0.000584 | 0.00000432 | 0.44971086 |
| 1.79 | 0.000572 | 0.00000216 | 0.000624 | 0.00000459 | 0.48663102 |
| 1.91 | 0.000616 | 0.00000211 | 0.00066 | 0.00000483 | 0.53194321 |
| 2 | 0.000651 | 0.00000207 | 0.000701 | 0.00000509 | 0.56208523 |
| 3.01 | 0.001036 | 0.00000163 | 0.001109 | 0.00000778 | 0.77572555 |
| 4.01 | 0.001436 | 0.00000139 | 0.00156 | 0.00001072 | 0.85913919 |
| 4.99 | 0.001852 | 0.00000137 | 0.00218 | 0.00001454 | 0.88908975 |
| 5.99 | 0.002401 | 0.00000148 | 0.0028 | 0.00001845 | 0.90645271 |
| 7.01 | 0.00294 | 0.0000018 | 0.00344 | 0.00002275 | 0.90742319 |
| 8.03 | 0.00353 | 0.00000233 | 0.00418 | 0.00002772 | 0.90046765 |

The probability of electron scattering was plotted as follows:

In the plot of the Probability of scattering with voltage, a minimum in probability was observed for a fixed value of voltage, approximately 0.81V±0.02V.

The maximum probability for an electron to be scattered was approximately 0.907 and the minimum probability for scattering was approximately 0.042.

From these maximum and minimum values of probability the maximum and minimum mean free path of an electron was calculated using the equation:

$$λ=-\frac{I}{ln⁡(P)}$$

The maximum and minimum values of $λ$ were found to be 0.0717m and 0.0022m respectively.

The data acquired in the second part of the experiment is tabulated below.

|  |  |  |
| --- | --- | --- |
| Voltage  | Is\*(amps) | ln(Is\*) |
| -0.06 | 0.00000034 | -14.89432022 |
| -0.11 | 0.00000029 | -15.05338491 |
| -0.19 | 0.00000022 | -15.32963829 |
| -0.3 | 0.00000013 | -15.85573139 |
| -0.4 | 0.00000008 | -16.3412392 |
| -0.5 | 0.00000004 | -17.03438638 |
| -0.6 | 0.00000002 | -17.72753356 |
| -0.7 | 0.00000001 | -18.42068074 |

Then ln($I\_{s}^{\*}$) was plotted as a function of voltage, having reversed polarity of the voltage.

The plot of ln($I\_{s}^{\*}$) with voltage was observed to consists of data points forming a straight line of a certain gradient up to a specific negative voltage, at which point the subsequent data points formed a line of significantly smaller slope.

 The electrons are collected at the electrode under a retarding potential with respect to the electron source. In this scenario, the electron current across the shield is given by:

$$i=i\_{0}e^{\frac{-3V\_{r}}{2\overline{V}}}$$

Rearranging the above equation above and substituting variables from our measurements gives us the relation:

$$\overline{V}=-\frac{3V\_{r}}{2ln⁡(\frac{i}{i\_{0}})}=-\frac{3}{2}x\frac{1}{m}$$

Where m is the slope of the line formed on the left side of the break between lines. $\overline{V}$ was found to be approximately -10.39725V.

 This break in the curve coincides with the removal of any potential barrier between the cathode and shield. The magnitude of this negative voltage equates to the contact potential difference between the plate and the cathode, |$V\_{c}|$. This value was found to be approximately 0.3V.

Using the values obtained for $\overline{V}$, $V\_{c}$ and V when the probability of scattering is minimum the minimum energy of an electron was calculated:

$$E=eV=\left(-1.602176565\left(35\right)×10-19 \right)\left(0.81+0.3-10.4\right)=1.4884x10^{-18}J$$

The above value for the total energy of the electron can be related to the velocity of the electron according to the equation:

$$eV=\frac{1}{2}m\_{e}v^{2}$$

where eV has been illustrated previously, $m\_{e}$ is the rest mass of the electron and *v* is the velocity of the electron.

The velocity of the electron can be calculated as follows:

$$v=\sqrt{\frac{2eV}{m\_{e}}}=\sqrt{\frac{2(1.4884x10^{-18})}{9.109 382 15×10^{-31}}}=1807716.69m/s$$

The wavelength of the electron was calculated according to the equation:

$$λ=\frac{h}{p}=\frac{6.626068 × 10-34}{\left(9.109 382 15×10^{-31}\right)(1807716.69)}=4.023801972x10^{-10}m$$

Where $λ$ is the wavelength of the electron, h is is Planck’s constant 6.626068 × 10-34 m2 kg / s and P is its relativistic momentum.

As the velocity of the electron is related to its de Broglie wavelength, the probability of scattering is also dependant on the wavelength.

# Discussion and Conclusions

The Ramsauer-Townsend effect was observed and the De Broglie wavelength of the electron was shown to relate to its probability of scattering. The kinetic energy of an electron in the field which minimised the probability of scattering was calculated to be $1.4884x10^{-18}J$ which corresponded to a De Broglie wavelength of$4.023801972x10^{-10}m$.