The Ramsauer-Townsend Effect

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1 Abstract

In this experiment the *Ramsauer-Townsend Effect* was investigated, that is, the effect of *Resonant Quantum Tunneling*. Graphs of the Plate Current, with and without the liquid nitrogen, versus the Voltage were plotted. From these the energy of electrons for which the scattering cross section of electrons on Xenon atoms is a minimum was calculated. It was found to be 0.75±0.05eV, which corresponded to a minimum probability of $P_{min} = 0.1 \pm 0.02$.

Next, the *Contact Potential Difference* was investigated. A graph of the natural log of the Shield Current versus the Voltage was plotted. From this the Contact Potential Difference was found to be 0.34V. With this we were then able to calculate the energy of the electrons, which was found to be $198 \pm 12 \times 10^{-21}$J.

2 Introduction & Theory

2.1 The Ramsauer-Townsend Effect

From Quantum Mechanics, we know that all particles have wave-like properties. In this sense, we can observe Quantum Tunneling. Here, an electron in a potential well is able to tunnel its way out, even though its energy is much less than the height of the potential wall. Furthermore, we are able to get resonance between electrons, just as we are for classical waves. When this happens, all of the electrons and able to tunnel out of or into a Xenon atom, and we observe a minimum in the scattering cross section of the electrons.

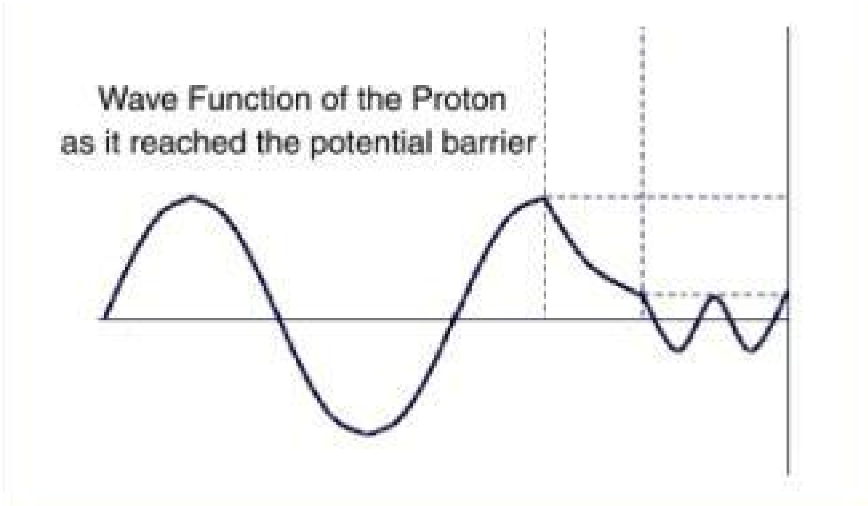

Figure 1: Quantum Tunneling

2.2 Contact Potential Difference

When two metals of different work function are placed in contact, the electrons will move from the metal with the lower work function to that with the higher work function until the maximum energy of the electrons in each metal is the same. However, this causes a positive charge to build on one of the metals, and a negative charge to build on the other. By this means, a potential difference is established between the two metals, which we call the Contact Potential Difference.

2.3 Mean Energy of the Electrons

For a given accelerating potential, V_1 say, the energy of the electrons is not simply eV_1. Rather, the electron has some energy due to it being emitted from the hot cathode, e$\bar{\mathrm{V}}$ say. Furthermore, the electron experiences an acceleration due to the contact potential difference, V_C. Thus the total energy of an electron on entering the first aperture is given by

$$E = e(V + V_C + \bar{V}) \tag{1}$$

3 Experimental Method

3.1 The Ramsauer-Townsend Effect

The circuit was set up.

The Plate Current, I_P, and the Shield Current, I_S, were measured for a range of values of Voltage, V with the Xenon gas present. The Voltage was first increased in steps of 0.1V until it reached 2V, and then steps of 1V until it reached 10V.

The pressure of the gas was then considerably reduced by inverting the tube and inserting it in the liquid nitrogen. The bottom half of the tube only was aloud to be inserted into the liquid nitrogen. The values of the Plate Current with the presence of liquid nitrogen, I_P^*, and the Shield Current with the presence of liquid nitrogen, I_S^*, were then measured again for the same range of values of V as before.

A graph of I_P and I_P^* versus the Voltage was then plotted on the same graph.

Also, a graph of the probability of an electron scattering, P, versus the Voltage was plotted using the formula

$$P = 1 - \frac{I_P I_S^*}{I_P^* I_S} \tag{2}$$

From this the value of V when P is a minimum was recorded.

Finally, the mean free path of an electron in gaseous Xenon atoms was calculated using the formula

$$P = 1 - e^{-l/\lambda} \tag{3}$$

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

3.2 Contact Potential Difference

The polarity of the power supply to the circuit was reversed.

The tube was then placed in the liquid nitrogen. The value of I_S^* was then measured for a range of values of V.

From these values a graph of the natural log of I_S^* versus V was plotted.

This graph has a curve which first increases linearly, and then levels off. By splitting the graph into two linear curves, the value of $\bar{\mathrm{V}}$ was calculated by noting that the slope of the graph is $-3/2\bar{V}$. V_C was then measured from the graph, as the x-value at the point of intersection of the two lines.

Finally, using the above values, the mean energy of the electrons was calculated using equation (1) . The wavelength of these electrons was then calculated using the formula

$$\lambda = \frac{hc}{E} \tag{4}$$

where h is Planck's constant, and c is the speed of light in a vacuum.

4 Results & Analysis

4.1 The Ramsauer-Townsend Effect

The following data was recorded when the Xenon gas was not placed in the liquid nitrogen

Voltage, V (V) ± 0.01	Shield Current, I_S (μ A) ± 1	Plate Current, I_P (μ A) ± 0.01
0.06	48.8$\pm$0.1	0.05
0.12	57.9$\pm$0.1	0.08
0.19	69.5$\pm$0.1	0.13
0.30	89.3$\pm$0.1	0.27
0.41	109.6$\pm$0.1	0.46
0.50	126.8$\pm$0.1	0.64
0.60	146.4$\pm$0.1	0.85
0.70	166.4$\pm$0.1	1.06
0.80	186.8$\pm$0.1	1.26
0.90	262	1.73
1.00	290	1.90
1.10	321	2.04
1.21	355	2.16
1.30	382	2.22
1.42	420	2.28
1.50	446	2.29
1.61	483	2.29
1.71	517	2.28
1.80	547	2.26
1.90	579	2.22
2.01	620	2.18
3.00	967	1.77
4.00	1328$\pm$10	1.58
5.00	1711$\pm$10	1.57
6.03	2210$\pm$10	1.70
7.00	2670$\pm$10	2.13
8.00	3170$\pm$10	2.55

and the following when the gas was placed in the liquid nitrogen

Voltage, V (V) ± 0.01	Shield Current, I_S^* (μ A) ± 1	Plate Current, I_P^* (μ A) ± 0.01
0.06	64.0$\pm$0.1	0.11
0.12	73.8$\pm$0.1	0.18
0.19	85.8$\pm$0.1	0.28
0.30	106.1$\pm$0.1	0.48
0.41	127.0$\pm$0.1	0.71
0.50	143.2$\pm$0.1	0.89
0.60	164.0$\pm$0.1	1.10
0.70	182.2$\pm$0.1	1.29
0.80	257	1.93
0.90	288	2.23
1.00	316	2.51
1.10	349	2.81
1.21	382	3.11
1.30	416	3.34
1.42	451	3.66
1.50	476	3.86
1.61	515	4.15
1.71	550	4.42
1.80	577	4.61
1.90	616	4.90
2.01	649	5.14
3.00	1032$\pm$10	7.99
4.00	1445$\pm$10	11.22
5.00	1907$\pm$10	14.64
6.03	2560$\pm$10	19.09
7.00	3150$\pm$10	23.29
8.00	3820$\pm$10	28.17

With these values we were able to calculate the values for the probability of scattering, P, using equation 2. We were then able to plot the following graphs of I_P and I_P^* versus the V on the same graph, and that of P versus V

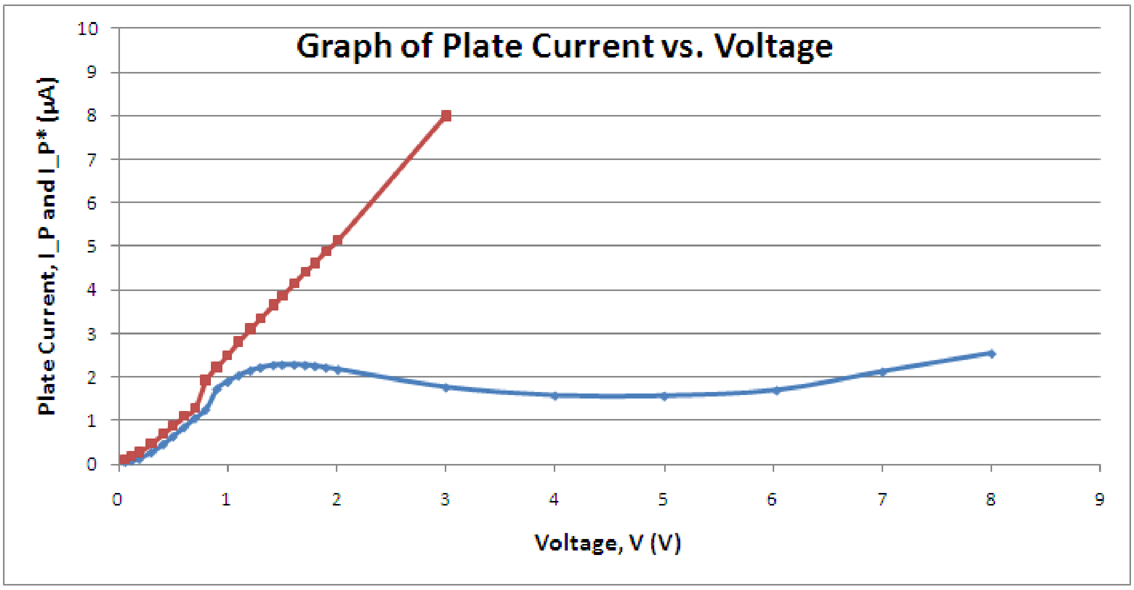

Figure 2: Graph of the Plate Currents versus the Voltage

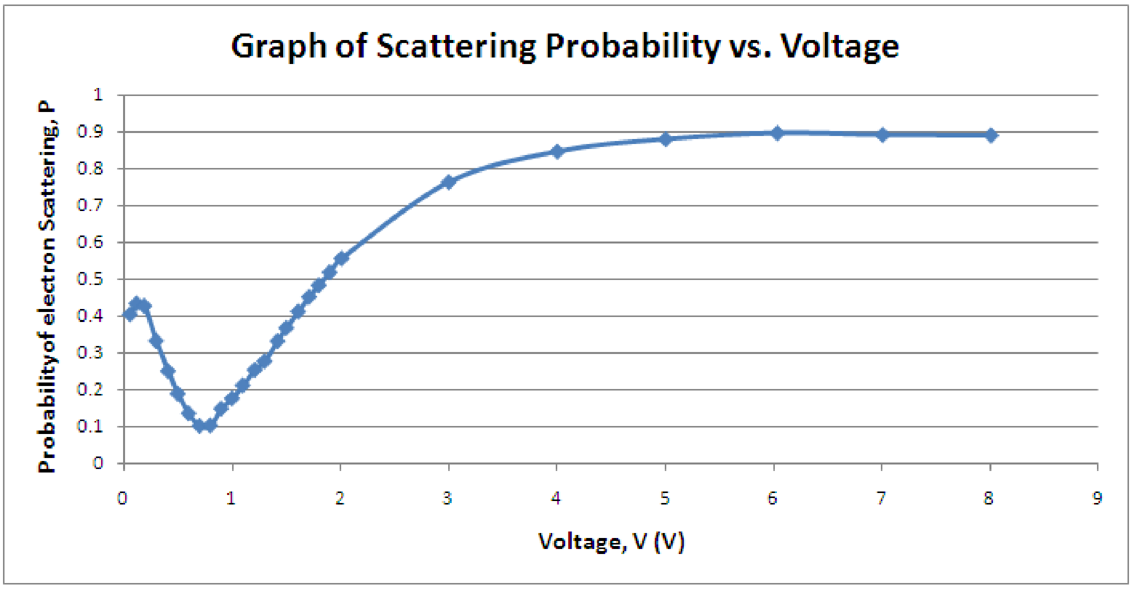

Figure 3: Graph of the Scattering Probability versus the Voltage

4.2 Contact Potential Difference

When the polarity of the power supply was reversed, the following data was recorded for V and I_S^* for the Xenon gas placed in the liquid nitrogen, and the corresponding values of $\log(I_S^*)$ calculated

Voltage, V (V) ± 0.01	Shield Current, I_S^* (μ A) ± 0.1	$\log(I_S^*)$
-0.80	0.1	-2.30±0.43
-0.76	0.2	-1.61±0.62
-0.69	0.5	-0.69±1.44
-0.65	0.6	-0.51±1.96
-0.60	1.3	0.26±3.81
-0.55	1.7	0.53±1.85
-0.50	3.3	1.19±0.84
-0.46	4.0	1.39±0.72
-0.40	8.0	2.08±0.48
-0.34	10.0	2.30±0.43
-0.31	15.4	2.73±0.37
-0.27	18.1	2.90±0.35
-0.26	16.5	2.80±0.36
-0.23	22.7	3.12±0.32
-0.22	24.3	3.19±0.31
-0.19	28.1	3.34±0.30
-0.16	28.0	3.33±0.30
-0.16	32.2	3.47±0.29
-0.12	33.7	3.52±0.28
-0.08	37.3	3.62±0.28
-0.06	48.4	3.88±0.26

Using these values we were able to plot a graph of $\log(I_S^*)$ versus V

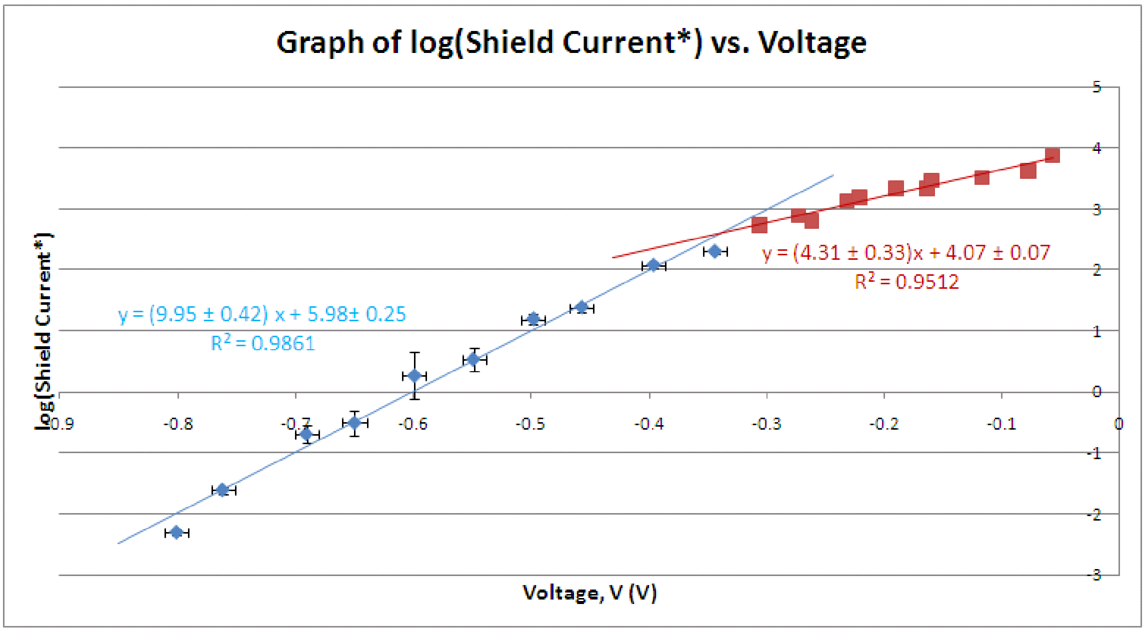

Figure 4: Graph of the natural log of the Shield Current versus the Voltage

5 Error Analysis

The errors for the values for V, I_S and I_P in the tables above were taken from the mulitmeters. The errors in P_{min}, P_{max} and the voltage for P_{min}, and that of V_C were taken from the minor bars of their respective graphs.

For the errors in the calculated values the following equations were used

$$\Delta \log(I_S^*) = \Delta I_S^* \times \frac{1}{I_S^*}$$

$$\Delta\lambda = \Delta P \times \frac{l}{(1-P)[\log(1-P)]^2}$$

$$\Delta\bar{V} = \Delta m \times \frac{-3}{2}\frac{1}{m^2}$$

$$\Delta E = e(\Delta V + \Delta V_C + \Delta\bar{V})$$

$$\Delta\text{wavelength} = \Delta E \times hc\frac{1}{E^2}$$

where λ above is the mean free path of the electron, and m is the slope of the graph for the contact potential difference.

6 Conclusions

From our results and the graphs plotted with them, we can see that the Ramsauer-Townsend Effect has occurred. That is the was a minimum in the scattering probability of the electrons in the Xenon atoms, corresponding to Resonant Quantum Tunneling. The value of the Voltage, V, corresponding to the Probability of an electron scattering, P, to be a minimum was found to be $V = 0.75 \pm 0.05$V, which is in agreement with the accepted value of 0.70V within the margins of experimental error. The maximum and minimum values of P were found to be 0.897 ± 0.020 and 0.10 ± 0.02 respectively. We were able to calculate the maximum and minimum values of the mean free path of an electron in Xenon atoms, which were found to be 66 ± 14mm and 3.08 ± 0.26mm respectively.

In the second part of the experiment we were successfully able to calculate the Contact Potential Difference between the plate and the cathode which was found to be 0.34 ± 0.02V. The emitted mean energy, $\bar{V}$, was found to be was found to be 150 ± 6mV. Finally, we were able to calculate the Energy and Wavelength of the electrons when the scattering probability was a minimum, which were found to be $E = 198 \pm 12 \times 10^{-21}$J and $\lambda = 1.00 \pm 0.61\mu$m respectively.