# PHYC30300- Advanced Laboratory I

# Demonstration of the Ramsauer Townsend Effect in Xenon Thyratron

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# Abstract

In this experiment the Ramsauer-Townsend Effect was investigated, using a thyratron, electrons were fired through xenon gas. By graphing the Plate Current versus the Voltage, with and without liquid nitrogen, It was found that the probability of electron scattering was a minimum when the energy of the electrons were E = 1.06 ± 0.125 eV at V= 1.06 ± 0.125 V, which is in agreement with the accepted value of 1eV within the margins of experimental error .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 0.3 ± 0.025 V. These results contradict classical theory which leads to the conclusion that electrons must have a wave nature which is responsible for the scattering phenomenon.

# 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. The Ramsauer-Townsend experiment shows that the probability of scattering electrons moving through a noble gas experiences a minimum at around 1eV. This contradicts the classical view and it is clear from this that another theory is required to explain this. From Quantum Mechanics, we know that all particles have wave-like properties. In this sense, we can observe a phenomenon known as Quantum Tunneling. [5] 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. When this happens, all of the electrons are able to tunnel out of or into a Xenon atom, and we observe a minimum in the scattering cross section of the electrons.

# Theory

## The Ramsauer-Townsend Effect

To observe the effect, the experiment will be set up such that a cathode will fire electrons through a thyratron filled with xenon gas.[1] It will then either go towards a shield indicating scattering or to the plate when it goes straight through the tube. 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 freezing the thyratron using liquid nitrogen to measure the current of the shield($I_s$*) and the plate($I_p$*). The pressure of the gas is considerably reduced, this reduces the probability of a collision to approximately zero.
To observe the minimum in the scattering cross section of the electrons, the probability of scattering must be calculated using; $P = 1 - (\frac{I_s * I_p}{I_s * I_p})$

## Contact Potential Difference

However, when the minimum is observed in the probability of electron scattering, it is often found that there is a discrepancy in the results. This is due to the contact potential difference in the cathode and the shield of the thyratron and the emission energy of the thermionic electrons from the cathode. [2] When two metals of different work function are placed in close contact, electrons will move from the metal with the lower work function to the higher work function until the maximum energy of the electrons in each metal is the same. This creates a positive charge to build on one of the metals, and a negative charge to build on the other. By this means there is a potential difference between the two metals which we refer to as the Contact Potential Difference.

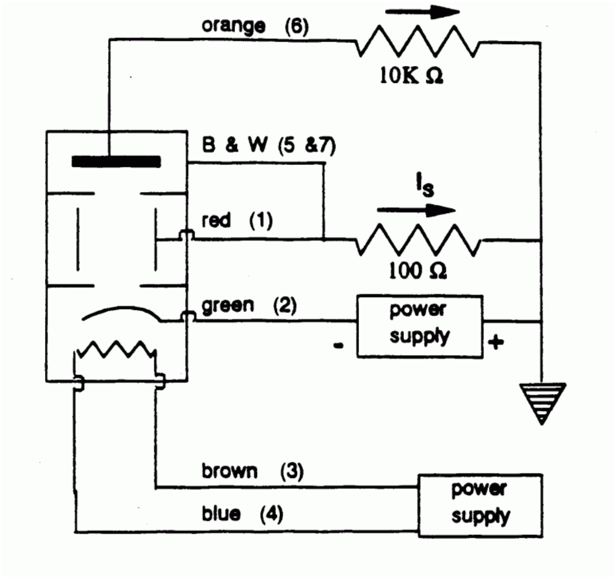
## True Energy of the Electrons

To account for this discrepancy, the additional energy and acceleration given to the electrons must be accounted for to find their true kinetic energy. This is given as;

$$E = e(V + V_c + \overline{V})$$

V is the applied accelerating voltage, $V_c$ is the contact potential difference,and $\overline{V}$ 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. Plotting log($I_s$*) vs V will find $V_c$ and $\overline{V}$ . $V_c$ corresponds to the point of intersection and $\overline{V}$ corresponds to the slope. [2]

# Experimental Procedure



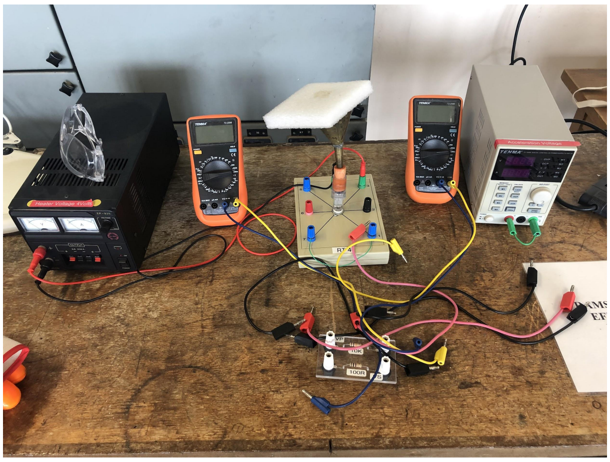



Fig.1 Diagram of Circuit [4]

Fig. 2 Experiment Apparatus

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 0.5V until it reached 12.5V. The pressure of the gas was then considerably reduced by inverting the tube and inserting it in the liquid nitrogen, thereby reducing the probability of a collision to approximately zero

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. The plate potential was a measure of how many electrons made it through the cloud of xenon gas without suffering a collision. The shield potential was a measure of the electrons that were scattered by the xenon atoms.

As the accelerating potential was increased, the scattering cross-section increased up to a point. Then it dropped sharply, and resumed climbing shortly after. The reason it drops is due to the Ramsauer-Townsend effect described in the theory section above.

Also, a graph of the probability of an electron scattering, P, versus the Voltage was plotted From this the value of V when P is a minimum was recorded.

# Results and Data Analysis

## The Ramsauer-Townsend Effect

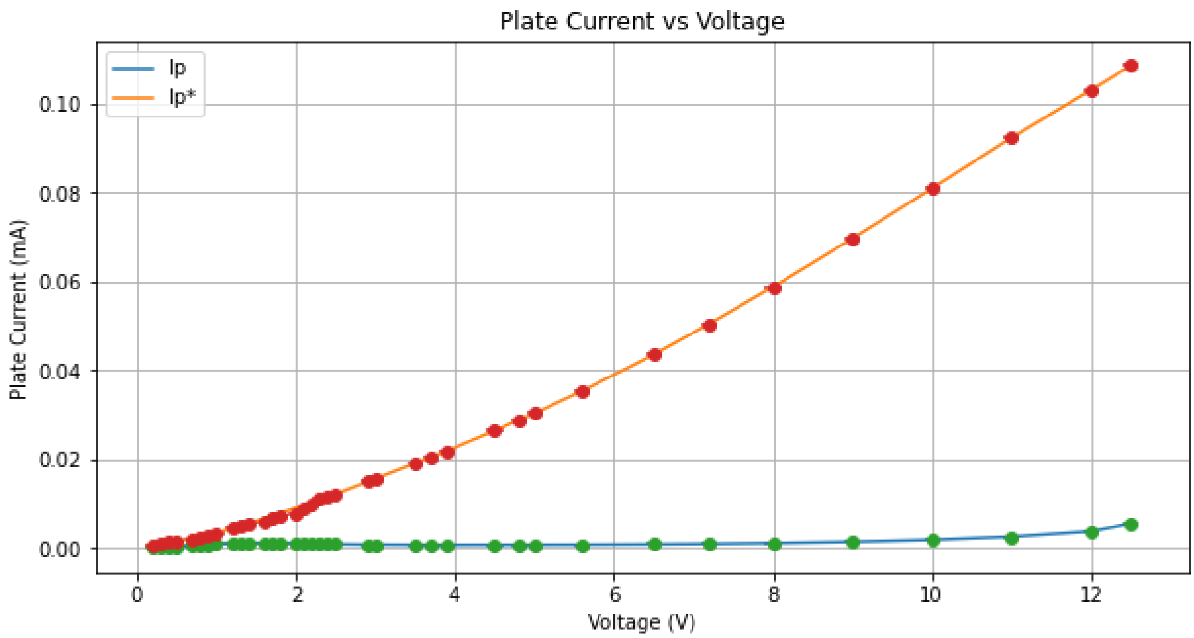



Fig.3 Graph showing Plate Current (mA) vs Voltage (V)

This plot clearly shows the difference the liquid nitrogen makes to the scattering of electrons by the Xenon gas. The presence of the gas had a huge effect on the amount of electrons that were able to reach the plate.

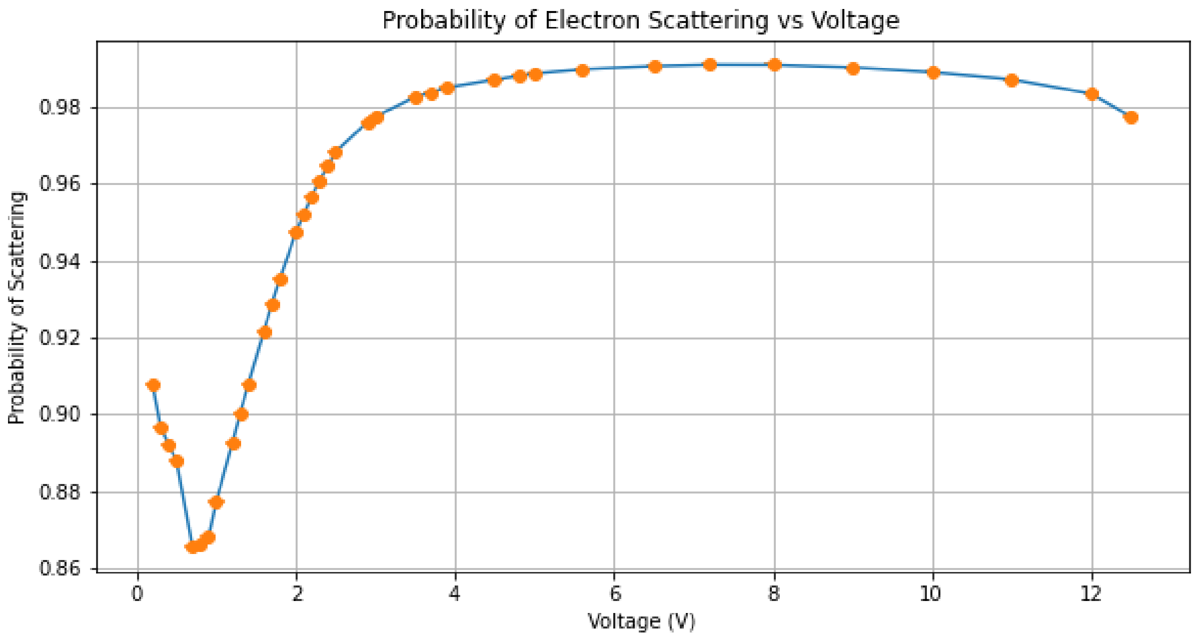



Fig.4 Graph showing Probability of Scattering vs Voltage (V)

As you can see from the graph, a clear minimum can be found in the probability of scattering around 1ev. This is a clear example of the Ramsauer-Townsend Effect. As expected, a minimum occurs at V = 0.865 ± 0.01 V and a maximum at V= 7.2 ± 0.01 V.

## Contact Potential Difference

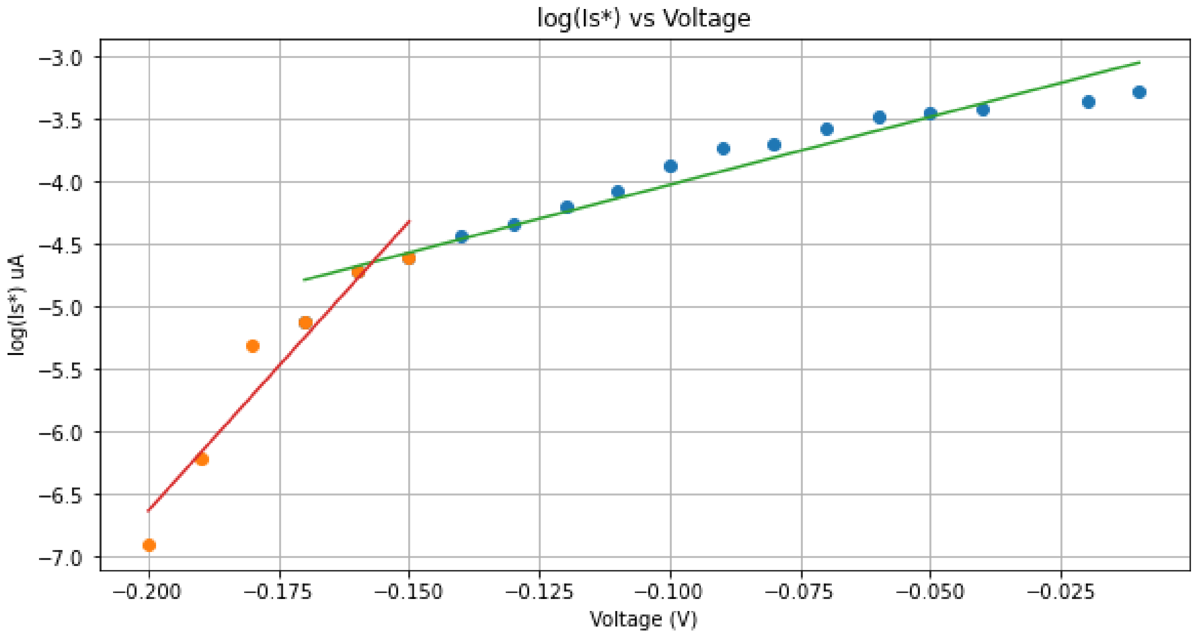



Fig.5 Graph showing log($I_s$*) vs Voltage (V)

This graph has a curve which first increases linearly, and then levels off. By splitting the graph into two linear curves, the value of V was calculated by noting that the slope of the graph is −3/2 $\bar{V}$ .$V_c$ is found where the two lines intersect.

Vc and $\bar{V}$ were found to be 0.16 ± 0.025 V and 0.3 ± 0.025 V respectively.

## True Energy of the Electrons

Now using the formula;

$$T = V + V_c + \bar{V}$$

We can calculate the true kinetic energy of the electrons at the minimum point found above in Fig.4. This was found to be at V= 1.06 ± 0.125 V and E = 1.06 ± 0.125 eV

## Error Analysis

The errors for the values for V ,$I_s$*, $I_s$ ,$I_p$* and $I_p$ were taken from the multimeters.

The error for Δlog($I_s$*) = Δ*($I_s$*) x 1/($I_s$*). For ΔV = (Δ$V_c$ +ΔV+ Δ $\bar{V}$) and ΔE = e(Δ$V_c$ + ΔV+ Δ $\bar{V}$)

# Discussion and Conclusion

From our results, it can be clearly seen that the Ramsauer-Townsend Effect has occurred. This is evidence for the failure of the classical model which predicts a monotonically decreasing scattering cross-section for an increasing acceleration potential.
It was found that the probability of electron scattering was a minimum when the energy of the electrons were $E = 1.06 \pm 0.125$ eV at $V = 1.06 \pm 0.125$ V, which is in agreement with the accepted value of 1eV within the margins of experimental error.
The Contact Potential Difference was found to be $0.3 \pm 0.025$ V. These results contradict classical theory which leads to the conclusion that electrons must have a wave nature which is responsible for this scattering phenomenon.

# References

[1]Kukolich, S.G., 1968. Demonstration of the ramsauer-townsend effect in a xenon thyratron. *American Journal of Physics*, *36*(8), pp.701-703.
[2]Woolsey, G.A., 1971. An Extension of the Ramsauer-Townsend Experiment in a Xenon Thyratron. *American Journal of Physics*, *39*(5), pp.558-560.
[3]RAMSAUER - TOWNSEND EFFECT Advanced Laboratory, Physics 407, University of Wisconsin Madison, Wisconsin 53706
[4] Ramsauer-Townsend Effect,PhysicsOpenLab, PhysicsOpenLab
[5] University Physics Volume 3,7.6 The Quantum Tunneling of Particles through Potential Barriers

In [1]:
```
import numpy as np
V,Vs,Vp = np.loadtxt("Townsend Effect Data 3.txt", unpack=True) #import data
```

In [2]:
```
V2,Vs2,Vp2 = np.loadtxt("Townsend Effect Data 2.txt", unpack=True) #import second data
```

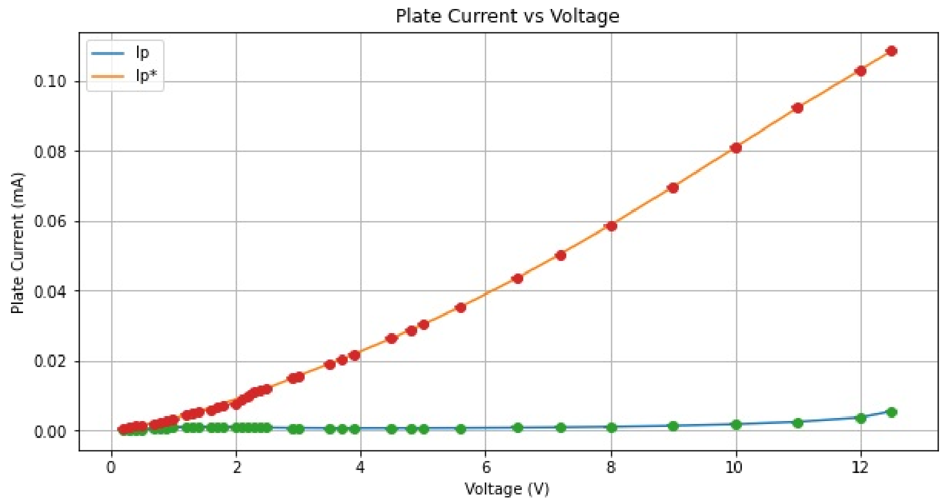
In [ ]:
```

```

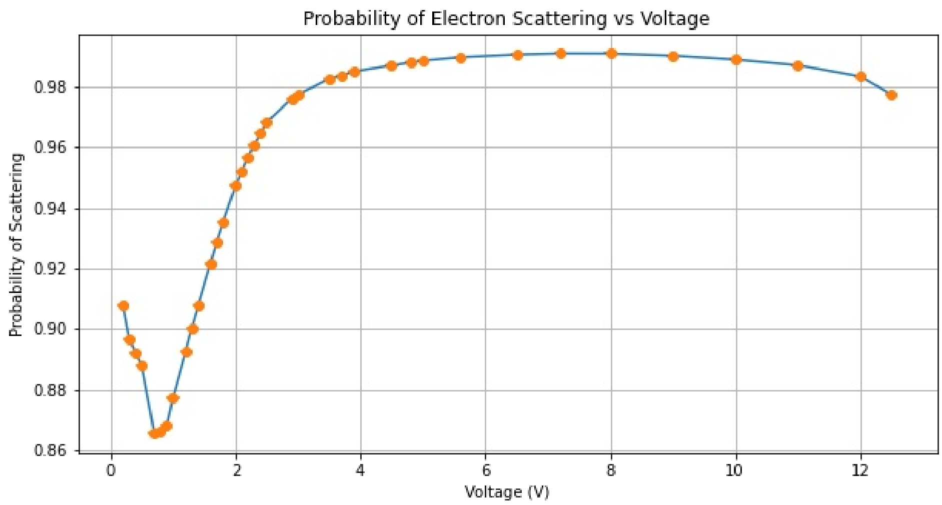
In [3]:
```
import matplotlib.pyplot as plt
import numpy as np
plt.rcParams['figure.figsize'] = (10, 5)
plt.rcParams.update({'font.size': 10})
```

In [4]:
```
Ip=(Vp/10000) # calculate currents
Is=(Vs/100)
Ip2=(Vp2/10000)
Is2=(Vs2/100)
```

In [5]:
```
plt.plot(V,Ip)
plt.plot(V2,Ip2)
plt.title("Plate Current vs Voltage")
plt.xlabel("Voltage (V)")
plt.ylabel("Plate Current (mA)")
plt.legend(["Ip","Ip*"])
plt.errorbar(V, Ip, xerr=0.1, yerr=0.1/10000,fmt="o")
plt.errorbar(V, Ip2, xerr=0.1, yerr=0.1/10000,fmt="o")
plt.grid(True); #graph of plate current vs voltage
```




In [13]:
```
P = 1-((Ip*Is2)/(Ip2*Is)) #plotting prob vs voltage
plt.plot(V,P)
plt.title("Probability of Electron Scattering vs Voltage")
plt.xlabel("Voltage (V)")
plt.ylabel("Probability of Scattering")
plt.grid(True)
plt.errorbar(V, P, xerr=0.1, yerr=0.1/10000,fmt="o");
```



In [7]:

```
V3,Vs3 = np.loadtxt("Townsend Effect Data 14.txt", unpack=True)
```

In [8]:

```
V4,Vs4 = np.loadtxt("Townsend Effect Data 5.txt", unpack=True)
```

In [9]:

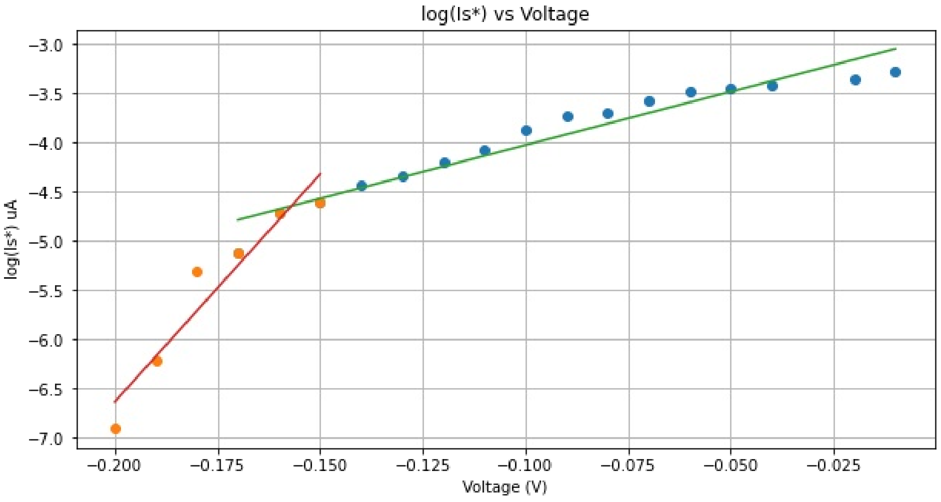
```
Is3= Vs3/(10)
Is4= Vs4/(10)
```

In [10]:

```
log_Is3=np.log(Is3)
log_Is4=np.log(Is4)
```

In [11]:

```
plt.plot(V3,log_Is3, "o") #plot log(i*s) vs voltage
plt.plot(V4,log_Is4, "o")
m, b = np.polyfit(V3,log_Is3 , 1)
plt.plot(V3, m*V3 + b)
z, r = np.polyfit(V4,log_Is4 , 1)
plt.plot(V4, z*V4+ r)
plt.title("log(Is*) vs Voltage")
plt.xlabel("Voltage (V)")
plt.ylabel("log(Is*) uA")
plt.grid(True);
```

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