Plasma

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Abstract

Plasmas have some unique properties compared to other states of matter. Using an argon filled tube along with the Child-Langmuir Law, the electron charge-to-mass ratio was found. It was found to be $\frac{e}{m} = (1.323 \pm 0.005) \times 10^{12}$ C/kg which does not agree with the accepted value of 1.75×10^{11} C/kg. This suggests that the setup of the experiment may not agree with the assumptions of the Child-Langmuir Law. However, it was found that the ionisation potential of argon was 15 ± 1 V compared to the accepeted value of 15.7 V. A plasma was then created in a triode tube and a Langmuir probe was used to investigate its properties. The electron temperature of the plasma was found to be 0.7262 ± 0.002 eV agreeing with a result of Alexeff, Pytlinski and Olsen, 0.9 eV. The electron density was found to be $n_e = 1.347 \pm 0.002 \times 10^8$ cm^{-3}.

⋆ Introduction

Experiment 1: Measurement of $\frac{e}{m}$ and the ionisation potential of argon

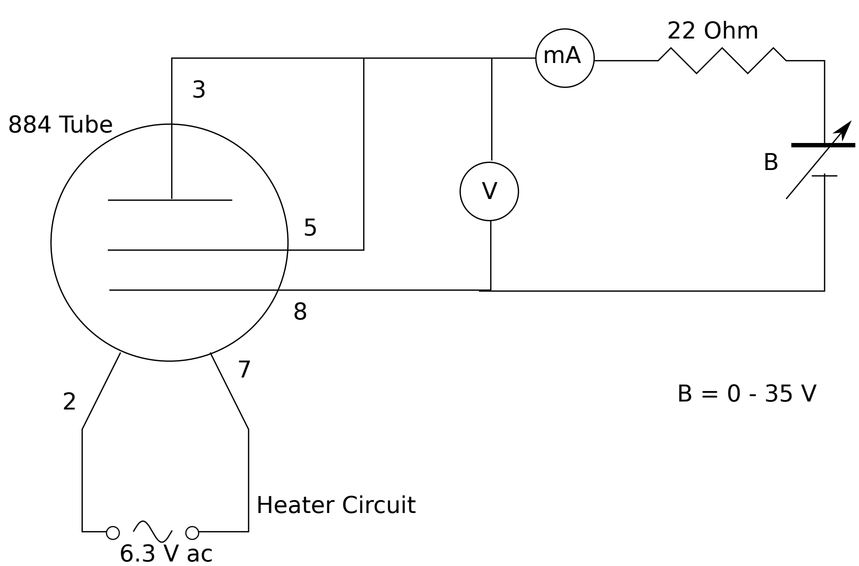

Figure 1: Diagram of Circuit

A gas filled tube is a good way of creating a plasma. Consider a tube filled with argon with a cylindrical electrode structure as shown in figure 1. Consider a potential V across the plates. Due to cylindrical symmetry, Poisson's equation is

$$\frac{1}{r}\frac{d}{dr}\left(\frac{1}{r}\frac{d}{dr}V\right) = -\frac{\rho}{\epsilon_0}$$

where ρ is the charge density. Cylindrical symmetry also gives the current density to be $J = 2\pi r\rho v$. If we assume that the electron's energy is initially zero, then $\frac{1}{2}mv^2 = eV$. Combining these equations gives,

$$r\frac{d^2V}{dr^2} + \frac{dV}{dr} = J\sqrt{\frac{2m}{eV}}$$

It is found that this has solution

$$I = \left(2\pi\epsilon_0(\frac{4L}{9R})\sqrt{\frac{2e}{m}}\right)V^{\frac{3}{2}}$$

where L is the anode length (2.24cm) and R is the anode radius (0.15cm). This is the Child-Langmuir Law. It is easy to see that the electron charge-to-mass ratio can be found from this.

However, for large voltages, the electrons have enough energy to ionise the argon and we can no longer assume the electrons do not interact with the gas. The current will deviate from the Child-Langmuir Law. Hence, it is possible to find the ionisation potential of argon by finding the difference between the breakdown voltage and the voltage at $I = 0$.

Experiment 2: Measurement of the plasma electron density and electron temperature

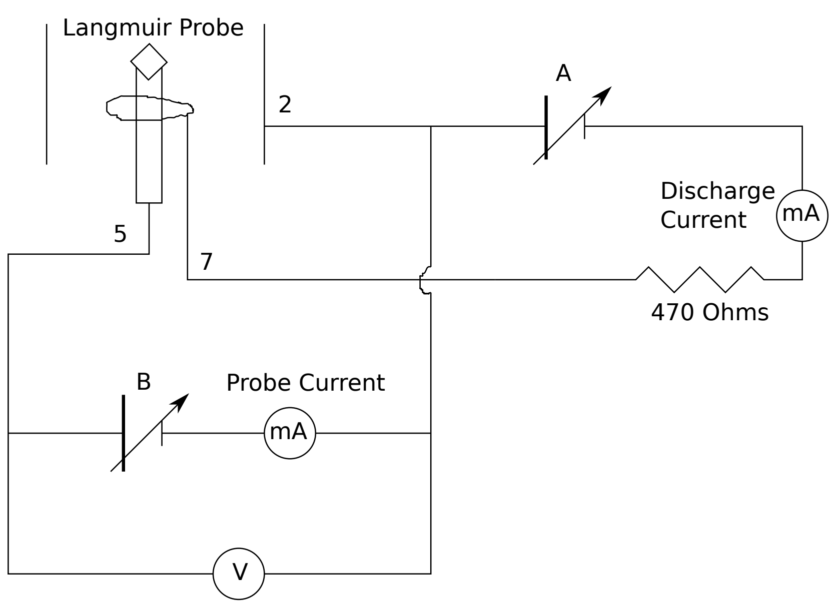

Figure 2: Diagram of Circuit: A = 35 – 350V, B = 0 – 35V

Consider now a gas triode as shown in figure 2. We create a plasma by applying a DC voltage between the cylindrical anode and ring cathode. The Langmuir probe is used to examine the properties of the plasma. Assuming that the electrons of the plasma have a Maxwell-Boltzmann distribution, then it is found that the current and voltage of the probe has the relation

$$I \propto \exp\left(\frac{eV}{kT_e}\right)$$

where k is Boltzmann's constant and T_e is the electron's temperature. At higher voltages, the current will saturate at the point

$$I = An_e e\sqrt{\frac{kT_e}{2\pi m}} \tag{1}$$

where A is the surface area of the probe. In this experiment, the length is 5mm and the diameter is 0.7mm. n_e is the electron density. Our aim in this experiment is to find the electron temperature and the density of electrons.

⋆ Experimental Method

Experiment 1

Set up the circuit as shown in figure 1. Allow the circuit to warm up. Measure the current whilst varying the voltage from 0 to 14V.

Experiment 2

Set up the circuit as shown in figure 2. Raise the discharge voltage until a purple glow is observed. Set the discharge voltage to some value such that the discharge current is about 10mA. Measure the probe current whilst varying the probe voltage from -4 to 15V.

⋆ Results and Analysis

Experiment 1

From figure 3, the slope of the graph is $m = 2.135 \pm 0.008$ V/mA$^{2/3}$. Using the Child-Langmuir Law, it was found that $\frac{e}{m} = (1.323 \pm 0.005) \times 10^{12}$ C/kg. The accepted value is 1.75×10^{11} C/kg. This is out by an order of magnitude suggesting that there may be some unaccountable experimental error. It is also possible that the assumptions of the Child-Langmuir Law were not valid while this experiment was running such as the electrons having initial kinetic energy or the structure of the tube may not be perfectly cylindrical. It was also found that the ionisation potential of argon was 15 ± 1 V from reading the graph which agrees with the accepted value of 15.7 V.

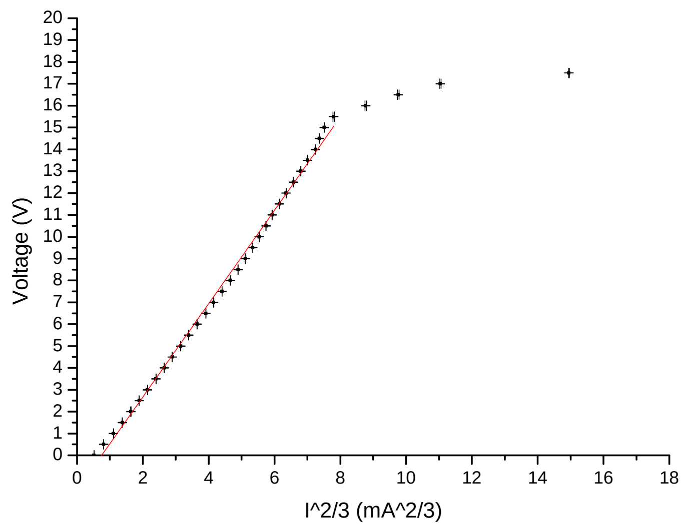

Figure 3: Graph of $I^{\frac{2}{3}}$ vs V with $m = 2.135 \pm 0.008$ V/mA$^{2/3}$

Experiment 2

The electron temperature is $kT_e = \frac{e}{d}$. From figure 4, the slope is $d = 1.377 \pm 0.005$ so the energy of the electrons is $kT_e = 0.7262 \pm 0.002$ eV. This is close to the experiment done by Alexeff, Pytlinski and Olsen who got a value of 0.9 eV. The discrepancy is most likely because their setup was slightly different from our experiment. T_e is found to be around 8000K. This may sound like a ridiculously high temperature. However, this is a unique consequence of plasma physics. The saturation current was found to be 5.92 ± 0.01 mA. Hence, it was found from equation (1) that $n_e = 1.347 \pm 0.002 \times 10^8$ cm^{-3}. Comparing to Alexeff et al., their result was 2.7×10^9 cm^{-3}. Taking into account that our setup was different, this is a reasonable result.

⋆ Conclusion

The electron charge-to-mass ratio was found to be $\frac{e}{m} = (1.323 \pm 0.005) \times 10^{12}$ C/kg which unfortunately does not agree with the accepted value of 1.75×10^{11} C/kg implying there has been some unknown error in the experiment or our initial assumptions are invalid. It was found that the ionisation potential of argon was 15 ± 1 which agrees with the accepted value of 15.7 V.

In the triode tube, the electron temperature was found to be 0.7262 ± 0.002 eV similar to a result of Alexeff, Pytlinski and Olsen. The electron density was found to be $n_e = 1.347 \pm 0.002 \times 10^8$ cm^{-3}.

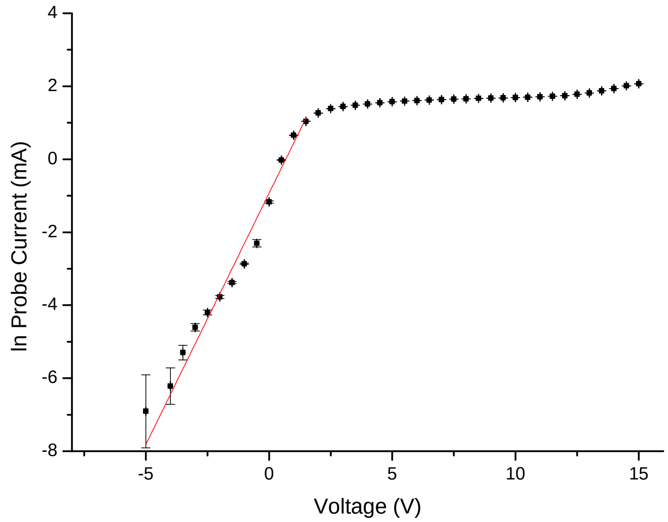

Figure 4: Graph of V vs $\ln I$ with $d = 1.377 \pm 0.005$mA

⋆ References

Phys. Rev. 2, 450486 (1913); Irving Langmuir
New elementary experiments in plasma physics; I. Alexeff, J. T. Pytlinski, N. L. Oleson