Measurement of the first Townsend coefficient

Contents

1 Introduction

The avalanche theory, originally proposed by J.S.Townsend, explains the fundamentals of the ionization mechanism, necessary for the existence of the self-sustained electric discharge. Let us have two parallel metal plates and a homogeneous electric field E in the gap between them. The free electrons in the gap are accelerated by this electric field and even at low pressures there is a high probability that they will collide a collision with neutral atoms and molecules of the gas during the flight. In the case of inelastic collisions this neutral species may be ionized or excited.

Given that n is the number of electrons located at x, moving in the x-axis direction, then there will be $\mathrm{d}n$ new electrons produced from their collisions over the distance $\mathrm{d}x$. It can be written

$$\mathrm{d}n = n\alpha \, \mathrm{d}x \tag{1}$$

where the linear coefficient α is known as the first first Townsend ionization coefficient. It is the number of ionizing collisions one electron executes over the unit of distance. Integration of (1) yields $\ln n = \alpha x + \mathrm{const.}$, which can be rewritten as $n = n_0 \exp(\alpha x)$, where n_0 is the number of electrons at $x = 0$.

The Townsend coefficient α depends on the electric field intensity E and the gas pressure p. The electric field intensity determines the acceleration of an electron between collisions, therefore E is the measure of the electron mean energy gain along its mean free path. The pressure p corresponds to the particle concentration and effectively the length of the mean free path.

Naturally the ionization by the accelerated electron will happen only if the energy of this electron is larger than the ionization potential of gas molecules/atoms. The ratio E/p is therefore decisive, whether the collisions will be ionizing. Furthermore, with the E/p fixed, the coefficient α is proportional to the number of collisions per unit length. It can be written as:

$$\alpha = pf\left(\frac{E}{p}\right) \tag{2}$$

The solution for number of ionizing collisions was simplified by Townsend, assuming that each collision is ionizing, provided that the mean free path of the electron (λ_e) is larger than the mean free path between two ionizing collisions (λ_i): $\lambda_\mathrm{e} > \lambda_\mathrm{i}$. Defining N as the number of collisions over unit distance, the electron that travels the unit distance λ ($\lambda > \lambda_\mathrm{i}$) will perform $N \exp(-\lambda_\mathrm{i}/\lambda_\mathrm{e})$ ionizations. Since the first Townsend coefficient is defined as the number of ionizing collisions per unit length, it can be written as

$$\alpha = N \exp\left(-\frac{\lambda_\mathrm{i}}{\lambda_\mathrm{e}}\right) \tag{3}$$

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From its definition, λ_i is the distance, that the electron must travel in order to reach the ionization energy threshold of the surrounding gas U_i and the electron energy is equal to the electric field intensity multiplied by the distance travelled by the electron. This means that λ_i can be replaced as $\lambda_\mathrm{i} = U_\mathrm{i}/E$. Furthermore the mean free path of an electron is equal to the inverse of N (number of collisions per unit length) $\lambda_\mathrm{e} = 1/N$. The equation (3) then yields.

$$\alpha = N \exp\left(-\frac{N\,U_\mathrm{i}}{E}\right) \tag{4}$$

The collision number is linearly proportional to the pressure. In can be used to express the number of collisions per unit length N as $N = N_0 \cdot p$, where the number of collisions per unit length per unit pressure N_0 is defined. Substituting the term in (4) leads to:

$$\frac{\alpha}{p} = N_0 \exp\left(-\frac{N_0\,U_\mathrm{i}}{E}\,p\right) \tag{5}$$

The experimental results show, that even in the general case, the first Townsend coefficient α (as a function of E) has the form:

$$\frac{\alpha}{p} = A \exp\left(-\frac{B\,p}{E}\right) \tag{6}$$

where A a B are certain constants, that satisfy $U_\mathrm{i} = B/A$. Their values can be determined experimentally and in effect also the function $\alpha = f(E/p)$.

2 Experimental set-up

A sketch of the experimental setup is shown in Figure 1. The planar aluminum cathode is illuminated by the mercury lamp. Photoelectrons are accelerated by the homogeneous electric field and the resulting current is collected at the grating of the anode. The position of the cathode can be adjusted, changing the distance travelled by electrons (along which the ionization occurs).

The discharge tube is pumped by the rotary oil vane, while the argon is continuously admitted to the system. Setting the argon flow will therefore set the pressure in the discharge tube. The pressure is monitored by the Pirani gauge. A DC voltage is applied across the electrode gap. It must be set appropriately, not allowing the formation of an self-sustaining discharge

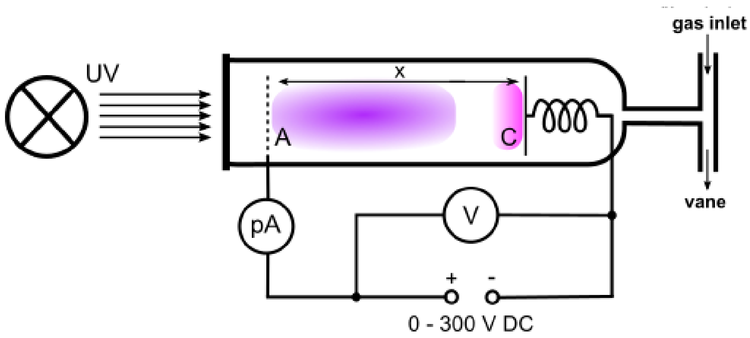

Figure 1: Diagram of the experimental set-up.

(maximum intensity of the electric field 80-120 V/cm). The photo of the actual experimental set-up is presented in Figure 2.

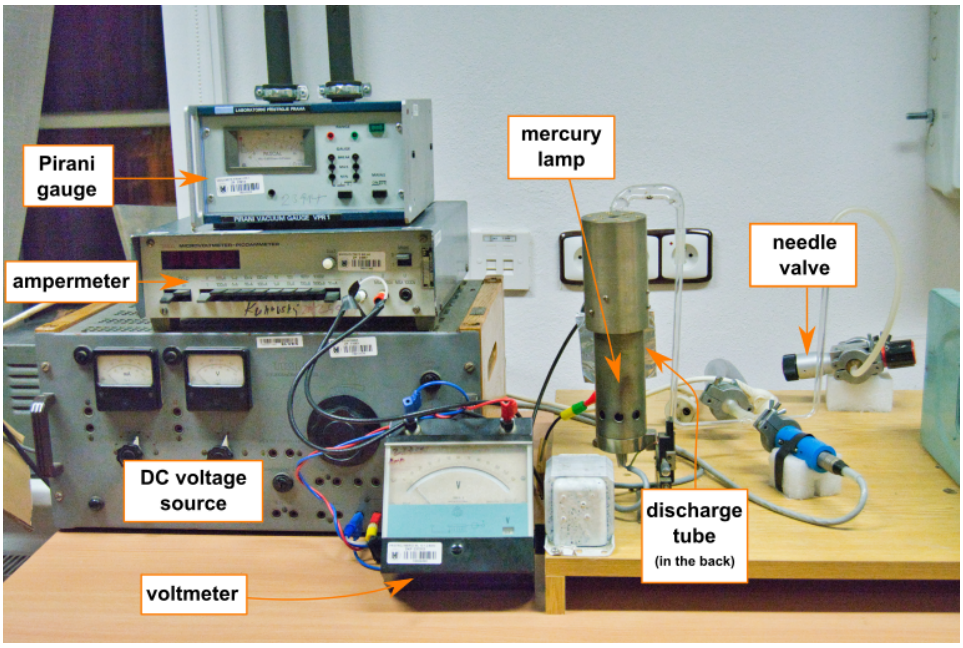

Figure 2: Photo of the experimental set-up.

3 Measurement

The electron beam is emitted from the cathode by the photoemission (UV radiation) and accelerated by the homogeneous electric field. The electrons passing through the gas ionize the neutrals. The coefficient α is measured from the total current in the circuit as the function of the distance between electrodes at constant electric field intensity E and pressure p. The total current is related to the electrode distance as follows:

$$i = i_0 \exp(\alpha\, x) \tag{7}$$

Plotting the functions $i = i_0\, f(x)$ and $\ln i = \ln i_0 + \alpha\, x$ in graphs enables the determination ofi_0 and α. A typical behaviour of $i = f(x)$ is presented in Figure 3.

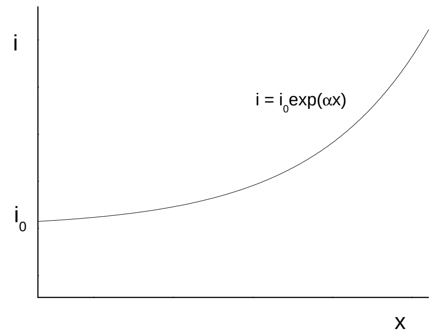

Figure 3: Total current i as the function of the electrode distance x.

This measurement is repeated for different values E/p, which enables the construction of the graph for $\ln \alpha/p = f(p/E)$. This function has to be linear according to (6), meaning both constants A and B can be determined. Finally, the ionization potential of argon is calculated from these constants.

4 Assignments

1. Perform the measurement of $i = f(x)$ at given gas pressure in the discharge tube and 5 values of the electric field intensity between the electrodes from the interval $E \in [30\ \mathrm{V/cm};\ 200\ \mathrm{V/cm}]$.

2. Plot the graphs for:
   - $i = f(x)$
   - $\ln i = g(x)$
   - $\ln \alpha/p = f(p/E)$

3. Determine the coefficients α, i_0, A, B and U_i from the graphs.

4. Discuss the results and compare the measured value of U_i with literature.