

## Quadrant II – Transcript and Related Materials

**Programme:** Bachelor of Science (Second Year)

**Subject:** Physics

**Paper Code:** PYC104

**Paper Title:** Section 2 – Modern Physics

**Unit:** 1- Motion of charged particles in electric and magnetic fields

**Module Name:** Electric discharge through gases

**Module No:** 4

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### Notes

The passage of electricity through gases gives rise to different types of results and are chiefly dependent on two factors:

- the pressure of the gas
- the strength of the electric field.

At ordinary pressures most gases are found to be good insulators i.e., they do not conduct electricity at all. Normal air is almost a perfect insulator. All gases, however, become conductors allowing the passage of electricity under certain conditions.

The cause of this induced conductivity is due to the presence of charged particles called ions. Under ordinary circumstances gases contain very few free ions and hence are excellent non-conductors; but when they are subjected to the influence of a suitable agent, a large number of free ions are produced and they acquire conductivity. The process of producing these ions is called the **ionization** of gases. It consists in the detachment of one or more electrons from the neutral atom or molecule of the gas.

- The residue of the atom (positively charged) consists practically of the whole mass of the original atom or molecule constitutes the **positive ion**.
- The detached electron soon attached itself to a neutral atom or molecule and constitutes the **negative ion**.

As the two kinds of ions are formed from an electrically neutral atom or molecule, the charge on the negative ion must be numerically equal to that on the positive ion.

Under the action of the electric field the positive ions will be drawn towards the negative terminal and the negative ions towards the positive terminal. Such a movement constitutes a current through the gas which is known as the ionisation current. At ordinary pressures, the mobility and diffusion coefficients of the positive and negative ions are of the same order. But as the pressure is reduced the negative ion throws off its attendant atom or molecule and the resultant negatively charged light particle, the bare electron travels free and faster than the positive ion. Electric discharge at low pressures give rise to new and interesting phenomena that reveal the **properties of individual atoms** and of **electricity**.

The simple experimental arrangement required to observe the effects at low pressure is called a **discharge tube**.

- It consists of a strong closed glass tube about 30cms long and 4cms in diameter provided with two metal electrodes *C* and *A* and a side tap *P* meant for connecting the tube with a high vacuum pump and a low pressure gauge. [To obtain very low pressures a molecular pump and charcoal cooled by liquid air that has the property of absorbing most of the residual gas are used.]
- The two electrodes are connected to the secondary of a powerful induction coil capable of giving a high P.D. of the order of 50,000 volts and more.
- The electrode connected to the negative terminal of the secondary is the **cathode C** while the one connected to the positive is the **anode A**.

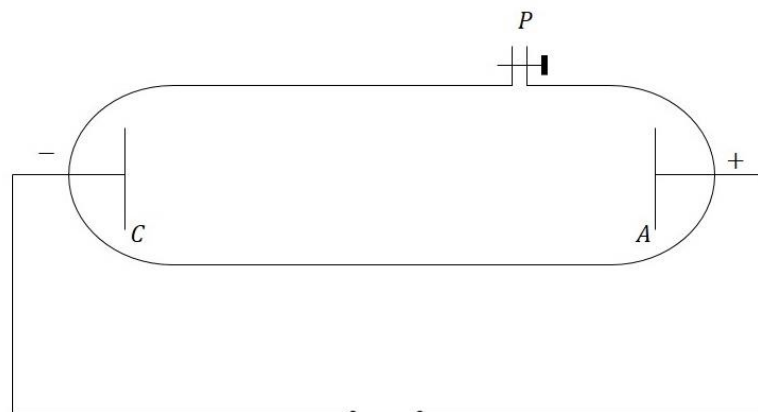


Figure 1: Discharge Tube

### General description of the phenomena observed

The following series of phenomenon is found to take place in succession.

| Pressure         | Observation   |
|------------------|---|
| 10 cm of mercury | Irregular streaks of light appear accompanied by a crackling noise  |
| 1 cm of mercury  | Crackling streaks broaden into a luminous column with a continuous buzzing sound, extending from anode to |

cathode. This luminous column is known as the **positive column**.

3 – 4 mm of mercury

A difference between the two ends of the discharge becomes visible, with a blue luminosity around the cathode and a discontinuity near it from the positive column.

The glow on the cathode is called the **negative or cathode glow**.

The discontinuous dark space between the cathode glow and the positive column is called **Faraday dark space**.

1 mm of mercury

Positive column gets shortened, the Faraday dark space extending to a greater length

< 1mm of mercury

The cathode glow gets detached from the cathode and a second dark space called **Crookes dark space** is formed between the cathode glow and the cathode

0.1 mm of mercury

Crookes dark space increases in length and the positive column is split up into bright and dark bands called striations.

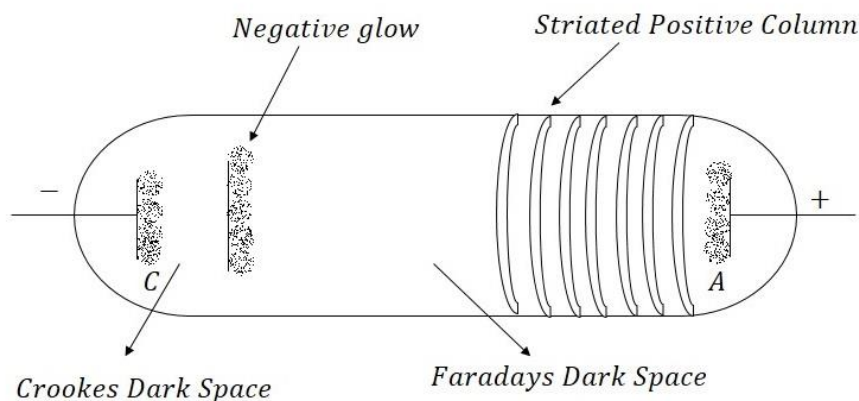


Figure 2: Appearance of a discharge tube at about 0.1mm

On further reduction of pressure the tube begins to decrease in brilliancy, the striations recede towards the anode and finally disappear. The Crookes dark space and the cathode glow expand. Then the cathode glow becomes ill defined and finally vanishes. At a pressure of about 0.01mm, the Crookes dark space practically fills the whole tube when a new phenomenon gradually comes into existence. The walls of the tube begin to glow with a bluish or greenish light depending on the nature of the composition of glass of which the tube is made. This is known as **fluorescence** caused by X rays resulting from the impact of some invisible agent in Crookes dark space. If the exhaustion is continued further the discharge has an increasing difficulty in passing until finally the tube refuses to conduct.

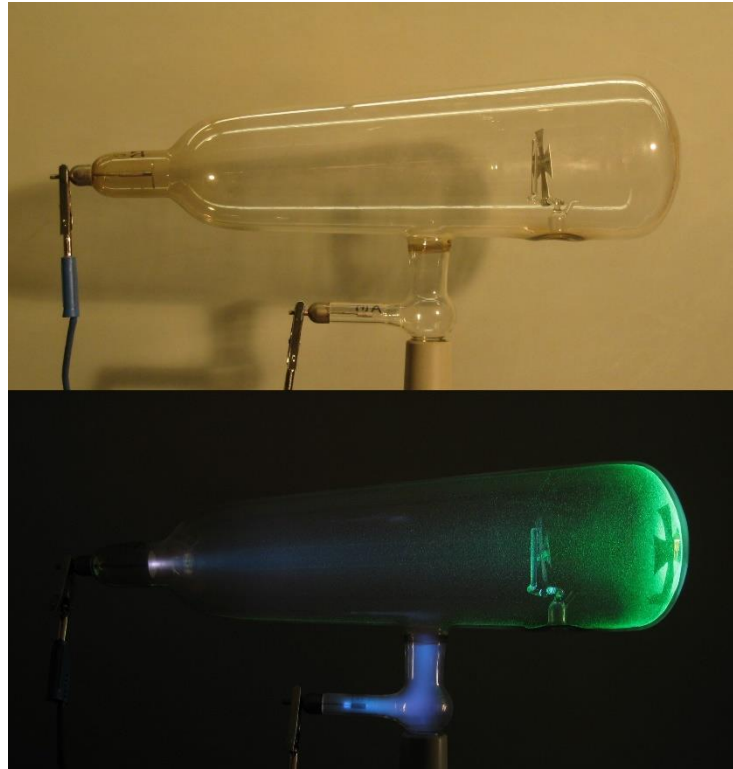


Figure 3: Two photos of a Crookes tube; one by ordinary light and one showing it in operation lit by its own fluorescence.  
[https://upload.wikimedia.org/wikipedia/commons/thumb/b/bf/Crookes\\_tube\\_two\\_views.jpg/573px-Crookes\\_tube\\_two\\_views.jpg](https://upload.wikimedia.org/wikipedia/commons/thumb/b/bf/Crookes_tube_two_views.jpg/573px-Crookes_tube_two_views.jpg)  
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### **Explanation**

The variation in the appearance of the discharge with pressure indicates that the distribution of electric field along the tube must be greatly affected by changes in pressure of the gas. The field distribution may be determined by using an insulated exploring electrode. The results, when the discharge tube presents the appearance shown in Figure 2 is shown below.

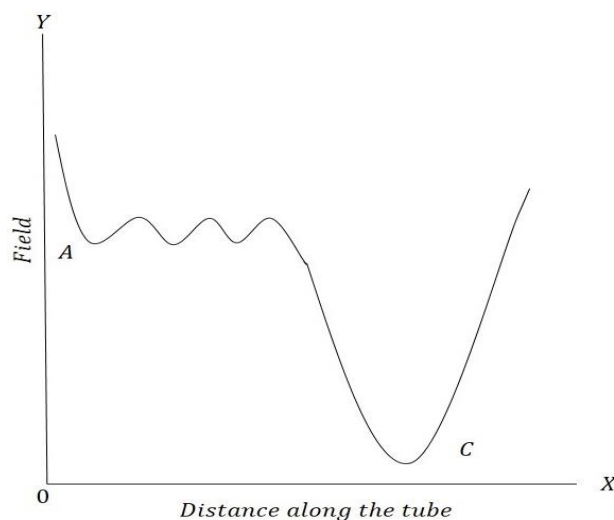


Figure 4: Field distribution in the discharge tube at about 0.1mm pressure

The main potential fall is across Crookes dark space. The flat portion with small dips represents the uniform potential gradient in the positive column with a fall in the field at each striation dark band. The normal cathode fall of potential is approximately equal to the minimum sparking potential of about 300 – 400 volts.

The different type of phenomena that appear in the discharge tube can be attributed to

- ionization by collision
- excited atoms or molecules alone are capable of emitting light whereas moving electrons are not.

Under the influence of electric field, some of the gas molecules in the tube will be ionized, forming positive and negative ions. At the instant of ionization, the free electrons expelled from the neutral molecules will possess a relatively higher mobility than the positive ions and will be repelled from the vicinity of the cathode rapidly. This results in the accumulation of positive ions near the cathode which accounts for the **intense field gradient** and a **large potential drop**.

The accelerated positive ions strike the cathode and cause it to liberate a great number of electrons. These electrons travel some distance accelerated through the strong electric field near the cathode before they acquire sufficient energy to ionize gas molecules by collision. The space they travel before colliding with molecules will be dark constituting the **Crookes dark space**.

After traversing the Crookes dark space the accelerated ions strike the molecules and ionize them giving rise to the **cathode glow**.

The positive ions resulting from the collision process tend to slow down the electrons which in consequence lose their power to ionize molecules temporarily. Emission of light ceases, resulting in the **Faraday dark space**.

Electrons continue to be accelerated although they have to move much farther to acquire the energy necessary for ionising molecules as the intensity in the Faraday dark space is lower. Once again the electrons are capable of ionizing molecules by collision with the corresponding appearance of glow in the gas. This constitutes the beginning of the **positive column**, with the production of both positive and negative ions. The electrons thus created move rapidly towards the anode while the heavier positive ions accumulate, once again retard the progress of the electrons and render them incapable of ionising molecules. Hence once more a **dark space (striation)** is produced in the positive column. The formation of alternate bright and dark bands in the positive column extending up to the anode is due to the repetition of the above process.

**NOTE:** The extent of the dark space depends on the distance the electron can travel without collision i.e. the mean free path of the electron. This mean free path increases as the pressure of the gas is decreased.