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Paschen law for argon glow discharge

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Abstract. Electric discharge between two electrically charged surfaces occurs at a well-defined, gas-dependent combination of atmospheric pressure and the distance between those surfaces, as described by Paschen's law. The understanding of when the discharge will occur in an Ar discharge is essential basic knowledge. A glow discharge apparatus was used in this experiment of Ar discharge at a pressure range between 2.0 Torr and 12 Torr, a power of 20 W and 40 l/min flow rate of gases. The optical emission spectroscopy was carried out in the wavelength range of 200 to 1100 nm. Here, we present experimentally measured plasma Paschen curves for Ar gas and compare our results of breakdown voltages with the literature. The minimum voltage measured for a discharge in Ar atmosphere was 215 ± 2.2 at 0.7 Torr-cm, which agree with previous measurements.

1. Introduction

Friedrich Paschen developed a law in 1889, which is known as the Paschen's curve describing the breakdown voltage as a function of the electrode spacing or gap (d), operating pressure (p), and gas composition [1]. The breakdown voltage is a function of the product of the pressure p and the inter-electrode distance d: $V_{rup} = f(p \times d)$. The mathematical formulation of Paschen's curve is derived from Townsend's description of the basic charge generation processes including electron impact ionization (α process) and secondary electron emission from the cathode due primarily to ion bombardment (the γ process), though other bombardment processes may play a role [2]. Historically, Paschen's curve has proved to be accurate for large gaps and at low pressures [3], but it is often acknowledged that it fails to describe behavior at extremely low or high *pd* values [4].

2. Experimental details

The experiments were carried out with a discharge chamber of the Laboratorio de Física Avanzada, Facultad de Ciencias, UAEM. The apparatus to measure the plasma emission spectrum is similar to that described elsewhere [5-7]. The discharge cell consists of two movable parallel electrodes enclosed in a stainless steel vacuum chamber. The two electrodes were made of copper disc, with 2.5 cm in diameter. The electrodes are positioned at the centre of the reaction chamber with 20 mm of gap spacing. The cell was pumped down by a vacuum system (Turbomolecular pump Alcatel and ATP80 Varian D5302) to a base pressure of 10^{-6} Torr. A continuous dynamic flow of Ar gas (ultra-pure, Praxair 99.99%) was let in the system through a needle valve at the desired pressures. A DC glow discharge was activated between the two electrodes at a pressure of 2.0 Torr. The discharge power supply (Spellman SA4) was maintained at an output of 0.5kV and a current of 40mA (20 W), which was measured using a digital Fluke multimeter model 8846A.The other lateral flange was a quartz window, used to monitor the active species generated in the glow discharge by plasma emission spectroscopy; the spectrum of the emission (200-1100 nm) was obtained using a spectrometer Ocean Optics HR4000CG-UV-NIR and an optical fiber P600-2-SR. The wavelengths interval was 0.75 nm and the well time of 500ms. The data were obtained in a single accumulation with a 5.0 s integration time. The DC source was connected to the electrodes and an oscilloscope, in order to measure the breakdown voltage. To measure the breakdown voltage the chamber was first filled to a certain pressure; then the voltage on upper electrode was slowly, manually increased until breakdown was indicated by an increase in current on the ammeter and a spike in the voltage displayed on the scope. This breakdown voltage was recorded, after which the voltage on the electrode was increased further to ensure that a discharge was occurring. Then, the electrode voltage was reduced to 0 V, the pressure was increased (or decreased) and the procedure was repeated. Measurements were taken from 2.0 to 12.0 Torr, which was sufficient to obtain a curve, to determine the lowest breakdown point.

3. Results

A typical emission spectroscopy measurement of Ar glow discharge plasma at a pressure of 2.0 Torr is displayed in figure 1.

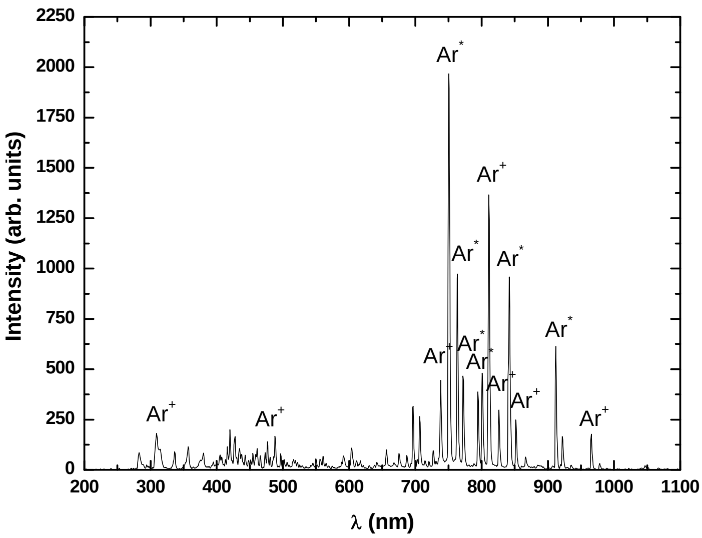

Figure 1. Emission spectra measurements of Ar at pressure of 2.0 Torr.

All lines appearing in the spectrum have been identified as Ar* and Ar^+ species.

For discharges containing argon, models have been built and are considered to be valid over a wide range of conditions [8]. More accurately measured cross sections have been used in the models in recent years [8-9]. According to those models, the most important processes involved with high-lying (3p, 4p, and 5p) excited levels are the electron impact excitation and ionization from the ground state,

$$e + Ar_g \rightarrow e + Ar_i, \quad (1)$$

$$e + Ar \rightarrow 2e + Ar^+,$$

the electron impact transition between excited levels,

$$e + Ar_i \rightarrow e + Ar_j,$$

$$e + Ar_j \rightarrow e + Ar_i, \quad (2)$$

and spontaneous radiation,

$$Ar_j \rightarrow Ar_i + h\nu \quad (3)$$

Here Ar_g are atoms in the ground state. Ar_i and Ar_j are atoms in metastable states or excited levels.

Figure 2 shows the breakdown voltage in a d-c discharge at a pressure of 2.0 Torr with an electrode separation of 2.0 cm. It can be observed the step in voltage caused by the generation of the glow discharge.

The Paschen curve was built by varying the distance between electrodes for a given pressure. In this case the curve shows a decreasing behavior of the voltage as function of the product between the distance and the pressure up to the point *pd*= 0.8 Torr cm, after which the voltage has a nearly linear increase (figure 3).

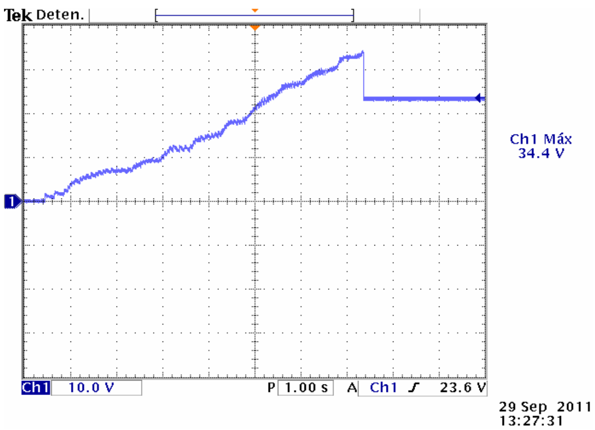

Figure 2. Breakdown voltage.

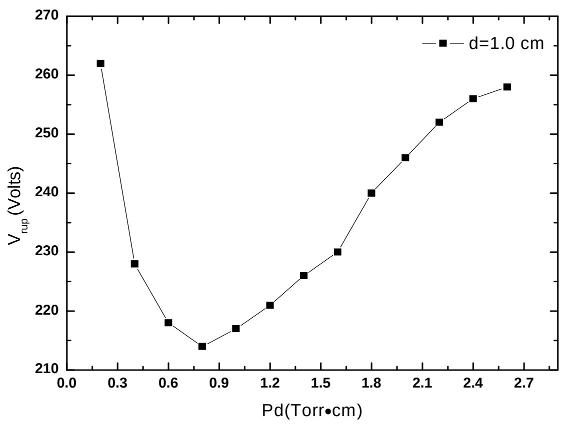

Figure 3. Paschen´s curve obtained varying the distance between cooper electrodes.

Figure 4 illustrates Paschen curves for four different inter-electrode distances (0.5 cm to 2.0 cm) and reflects the Townsend breakdown mechanism in gases, that is, it related to the non-spatial uniformity of the electric field.

We measured the minimum voltage for discharge in Ar atmosphere of (215 ± 2.2) V at 0.7 Torr-cm, which agree with previous measurements. However, at the same pd value, the breakdown voltage differs depending on the inter-electrode distance d.

From figure 4, it observed that the four curves have similar behavior between 0.1 Torr-cm and 0.3 Torr-cm, and at pd values much bigger than 0.3 Torr-cm the curves are separated in two groups, at the inter-electrode distances of 0.5 Torr-cm and 2.0 Torr-cm has almost the same behavior and their absolute values of the voltage are much bigger than the curves at inter-electrode distances of 1.0 Torr-cm and 1.5 Torr-cm, which have the same behavior.

4. Conclusions

We obtained experimentally Paschen's curves for an Ar glow discharge. Also, it found that the breakdown voltage depends on a function between the product of the pressure and electrode distance, like Paschen’s law established.

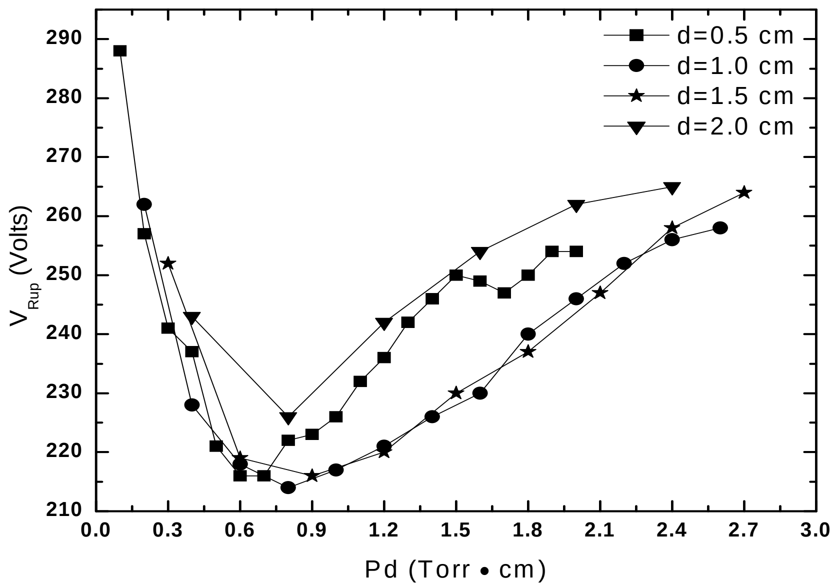

Figure 4. Paschen´s curve obtained varying the Ar gas pressure and distance between cooper electrodes.

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