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Effect of the Longitudinal Magnetic Field on the Electrical Breakdown in Argon and Nitrogen Plasma Discharges

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ABSTRACT

The electrical breakdown has been studied for low-pressure argon and nitrogen discharges under the influence of a longitudinal magnetic field. Plane-parallel stainless steel electrodes (7.25 cm diameter) separated at the distance d (2.0 cm) were sustained with a dc voltage (0 - 700 V). Permanent magnets was used to produce an uniform magnetic field (B = 855G) parallel to the discharge axis. Paschen curves are obtained and the first Paschen curves, these curves are plotted for fixed values of B = 0 and B = 855 Gauss. The effect of longitudinal magnetic field becomes more significanor to obtain values of η, but it is less for the values of γ, separations (2cm) and different working pressure contributes Townsend discharge regime at a new range of plane-parallel electrode. The results show that by increasing of magnetic field Townsend coefficient and the ionization efficiency of the system significantly enhances.

***Keywords*:** Paschen curves; Minimum breakdown voltage; Townsend coefficient; Ionization efficiency; Permanent Magnet

1. INTRODUCTION

Generally speaking Gas discharge breakdown is a complex process which begins at electronic avalanche. Primary electronic ionization occurs prior to cascade ionization. Which in introduced a Townsend coefficient α known as Townsend's first ionization coefficient which is introduced by defined as the number of electrons produced by an electron per unit length of path in the direction of field. The Townsend ionization coefficient becomes onlyonec sufficiently high along with the intensification of electric field. This will be current transfer from non-self-maintained to self-maintained process that cause electric breakdown.

Let n_0 to the number of electrons leaving the cathode and these become n when these have moved through a distance x from the cathode. Now the production will be additition dn electrons which due to collision when distance dx produce additional dn electrons due to collision.

Therefore, [1].

$$dn = an\,dx \qquad (1)$$

$$\ln n = ax + A \qquad (2)$$

Now at x = 0, n = n_0.
Therefore,

$$\ln n_0 = A$$

$$ln\,n = \alpha x + ln\,n_0 \qquad (3)$$

At x = d

$$n = n_0 e^{\alpha x} \qquad (4)$$

The term ($e^{\alpha x}$) is called the electron avalanche which it represents the number of electrons produced by one electron in travelling from cathode to anode. [1] The first Townsend's coefficient, which depends on the gas type and gas pressure, and on the electric field E in the inter-electrode space. Can be expressed following Townsend theory as:

$$\frac{\alpha}{P} = A\exp[-\frac{BP}{E}] \qquad (5)$$

A and B are constants for a particular gas. It is more convenient to use the ionization coefficient η [2]:

$$\eta = \alpha / E \qquad (6)$$

Only this quantity depends on the reduced electric field E/P. Usually the experimental data are presented either in the form η(E/P) or as α/P (E/P).The production of the number of secondary electrons detached from the cathode by impact of the various particles which produced in the gas (positive ions, photons, excited atoms. . .) is known as the effective second Townsend coefficient γ. It is important to say that in additionally to α parameter in the Townsend regime which depends on the electrode material and on the nature of the filling gas used. By using eq. (6) the secondary ionization coefficient is related to that of Townsend's first ionization coefficient α, and which can by expressed can be expressed in terms of the ionization coefficient η [2,3]:

$$V_b = \frac{Bpd}{\ln\left[\frac{Apd}{\ln\left(1+\frac{1}{\gamma}\right)}\right]} \tag{7}$$

Thus, γ *depends* on the cathode material and gas type, as well as on the ratio *E/P* [4].

The minimum voltage gas discharge breakdown voltage V_B is required for initial breakdown of discharge. Paschen has found through experiment the function between gas discharge breakdown voltage and the product of gas pressure（P）and cathode-anode distance (d), Townsend proposed the gas discharge breakdown theory, Before i.e.:

$$VB = \mathrm{f}\,(Pd) \tag{8}$$

This functional relationship is called Paschen Law. Following is the Paschen Law expression of Townsend discharge [5]:

$$\gamma = \frac{1}{e^{\eta V_B}} \overline{-1} \tag{9}$$

A Paschen curve can also be created according to formula (9) to express the functional relationship between gas discharge breakdown voltage and the product Pd of discharge gas pressure p and cathode-anode distance d.

In Paschen's curve the existence of a minimum breakdown voltage may be explained as follows:

Electrons crossing the gap make more repeated collisions with gas molecules than at $(pd)_{min}$, but the energy gained between collisions is lower, for values of pd > $(pd)_{min}$,. Subsequently, to maintain the desired ionization more voltage has to be applied. Electron may cross the gap without even making a collision or making only less number of collisions to get it Pd < (Pd) min, more voltage has to be applied for. The occur of breakdown more voltage has to be applied to maintain the desired ionization [2,6].

The characteristics of electrical breakdown and the properties of a Townsend discharge may be effected through the study of the magnetic field which in turn is motivated is motivated by a necessity of gaining a better understanding of the complex mechanisms of gas discharge phenomena and also by the B-field which favorably may contribute to deal with practical problems that associated with the use of this kind of discharge for plasma processing technologies [5,6]. In this work, the measurement of breakdown potentials in Ar and N_2 under the presence of an longitudinal magnetic field were presented in the Townsend discharge regime. The electrons in the tail of the energy distribution function have enough energy to ionize the gas atoms in this regime the production of the secondary electrons can also obtain a sufficient amount of energy from the electric field to ionize atoms and produce new electrons. An avalanche-like growth gives rise to of the degree of ionization. And occur this loss of electrons should be rather small. The losses of electron will occur By recombination with ions as a result of diffusion toward the walls and also, as in the case of electronegative gases as a consequence of the formation of negative ions, the losses of the electrons will occur.

Consequently the lateral diffusion of electrons to be hindered by the magnetic field which reducing losses and enhancing the ionization efficiency in the Townsend regime. Will be expected. This phenomenon is confirmed by the reduction of the breakdown voltage when a magnetic field was applied. Which is shown by the experimental results?

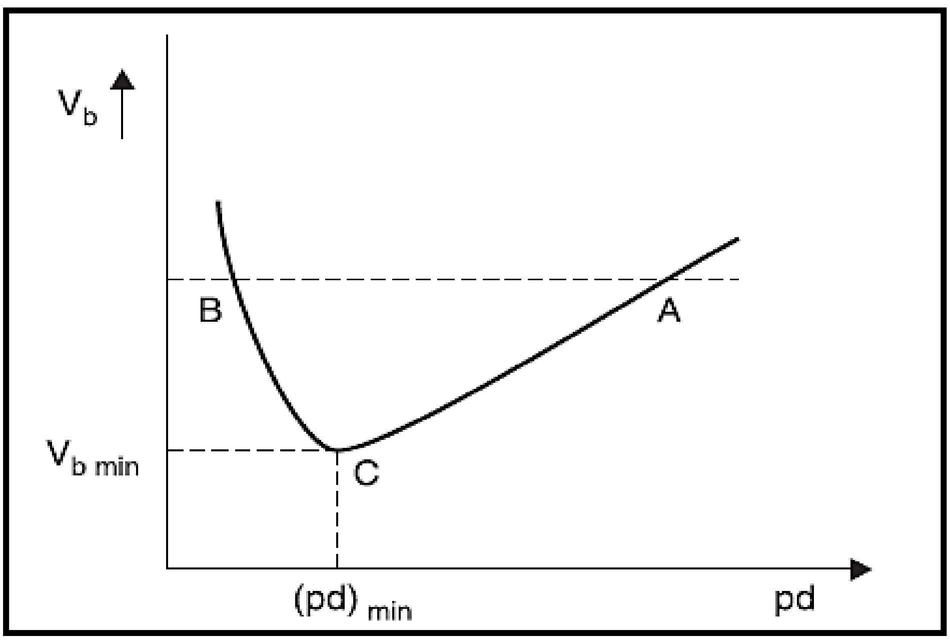


Fig. 1. Paschen's law curve [6].

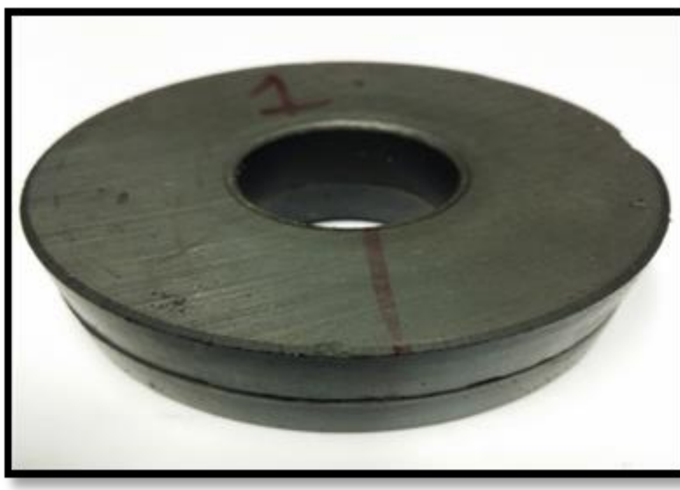
2. EXPERIMENTAL SETUP

Fig. 3 shows Schematic diagram of the system experimental set-up used in this work. A Pyrex glass cylindrical vacuum chamber with length and diameter of 35 cm and 14.5 cm respectively has been used for plasma discharge. Basically, the breakdown - discharge is formed inside of the chamber which consists of two electrodes between which the electrodes are made of 99% pure stainless steel material and each of them was 7.25 cm diameter and thickness (3 mm).

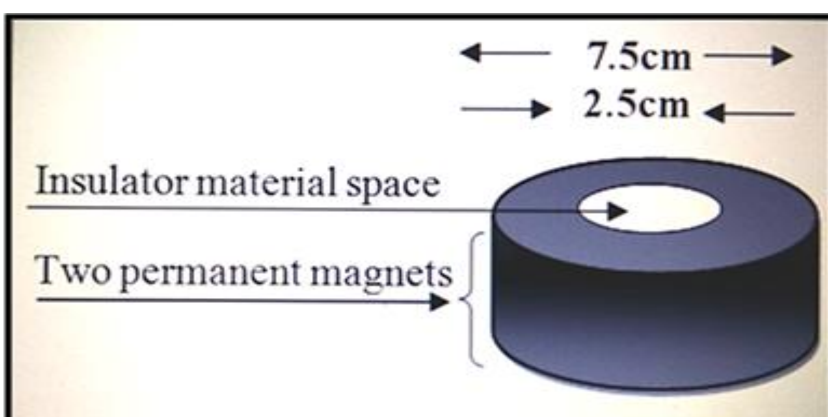
Concentric magnets were placed behind each electrode. To from the magnetically Two annular configuration. These chambers were filled with (N_2, Ar). And gas supply feed through were inserted into the chamber, also the chamber included one side four feed through for vacuum.

The discharge chamber was evacuated by a two-stage Edward rotary pump and the vacuum inside chamber is measured by Pirani gauge which is to a vacuum controller from Balzers VWS 120. Argon gas was supplied to the chamber through a fine-controlled needle valve (0-160 sccm) to control the gas pressure inside the chamber. The longitudinal magnetic field generated by pair of permanent magnets which produces a high flux density (B = 855 Gauss) at the electrode surface, the combination of the two magnets allows for lower pressure operation than either magnet alone**.** The magnetic lines of force run from one pole to the other, and the poles are positioned such that any flaws present run normal to theses lines of force.

Tow permanent circular magnets are placed behind the electrode surface to produce the magnetic field. The geometry and the dimension of the magnet are shown in Fig. (2).



(a)



(b)

Fig. 2. (a) hotograph magnets **(b)** the geometry and the dimension of the magnet

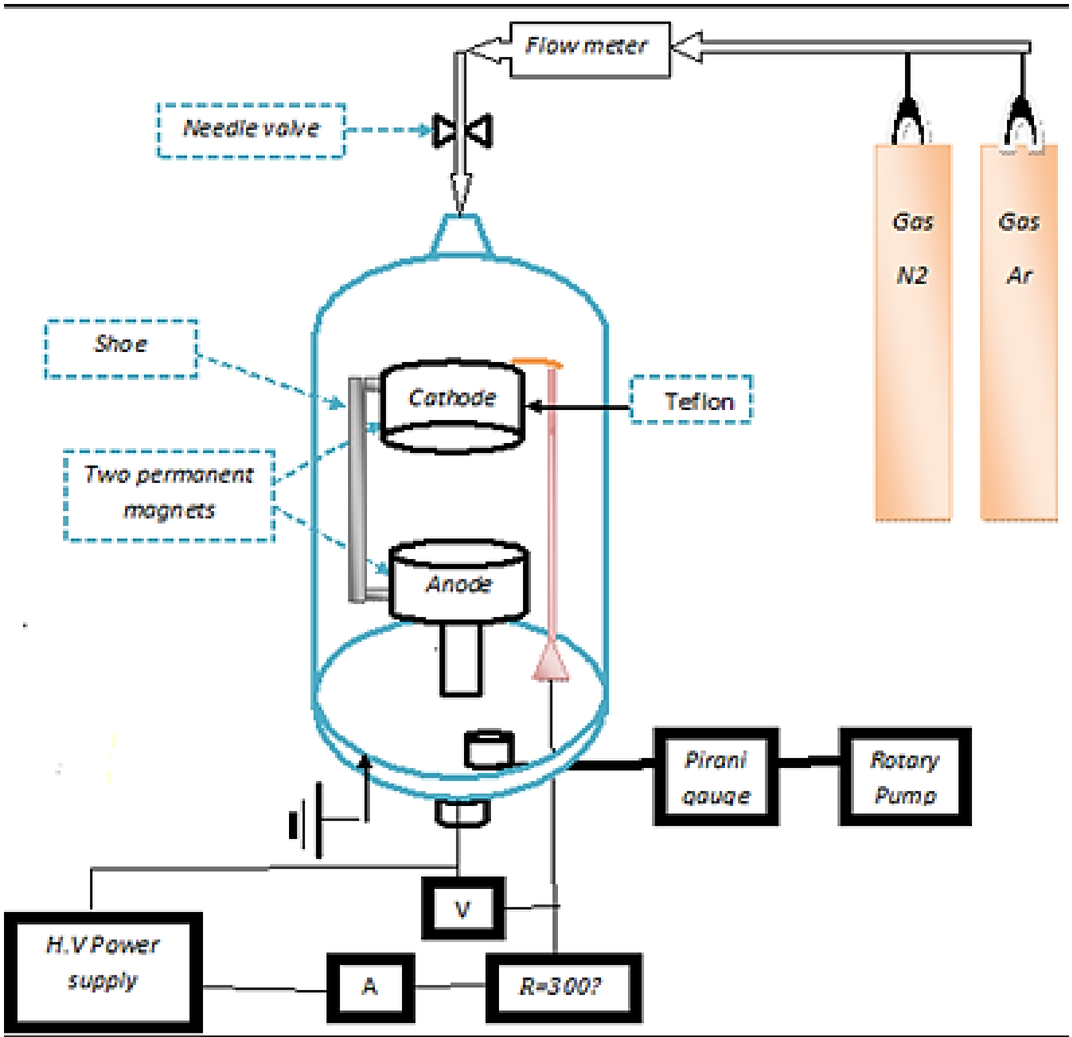


Fig. 3. Schematic diagram of the plasma system.

3. RESULTS AND DISCUSSION

3. 1. Breakdown Voltage and Paschen Curves

The measurement of breakdown voltage of the (Ar and N_2) plasma discharge is acquired at pressure range of 0.05 mbar to 1.4 mbar with the inter-electrode distance varying between 2.0 cm respectively. In these operational ranges. The magnetic field an induction application of with intensity of the order of 855G. The confinement of electrons rather than ions is performed at magnetic field intensity of (0-855) Gauss. Will happened in this way, a magnetic field of 855 G promotes. An efficient plasma confinement once the electrons which keep frozen to the B-field lines will be promoted by magnetic field of 855G [7]. To occur breakdown there must be sufficient number of collisions between electrons and the gas particles in order to enable the required amount of ionization in the inter-electrode space. If pressure is too low then the inter-electrode distance must be correspondingly the pressure must be increased if the inter-electrode distance is small.

Alternatively, if the inter-electrode distance is small then the pressure must be correspondingly increased. The magnetic field acts more efficiently for lower pressures, at higher inter-electrodes distances because the collisionality decreases by decreasing the pressure thus enhancing the effectiveness of the magnetic confinement.

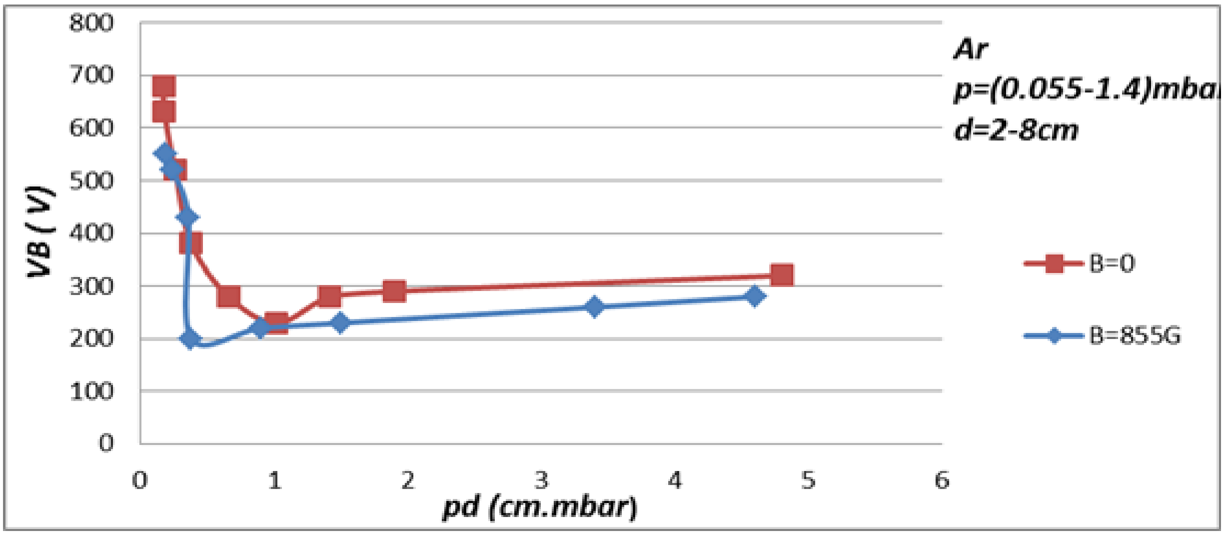


Fig. 4. Breakdown voltage (V_B) for Ar as a function of Pd (Paschen curves) within and without of magnetic field.

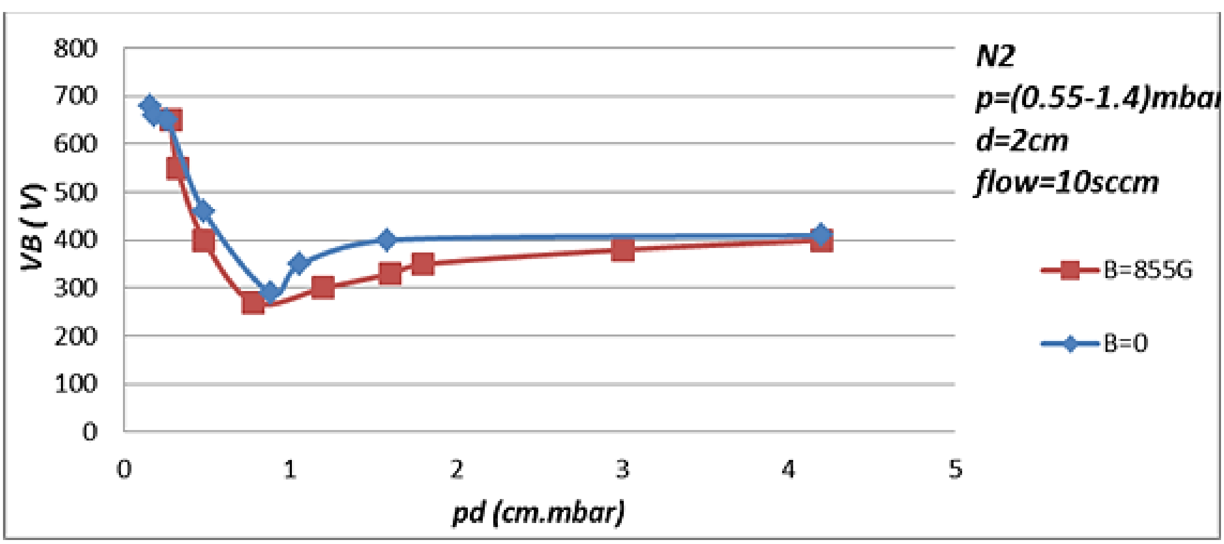


Fig. 5. Breakdown voltage (V_B) for N_2 as a function of Pd (Paschen curves) for two values of magnetic field.

The breakdown voltage values are almost invariable for values of the gas pressures above 0.1 Torr and for induction magnetic field values below 855 Gauss are observed also. For the consequences of the action of the magnetic field are observe that the electron free paths across the residual gas are lengthened and also that the lateral diffusion of the electrons can be reduced. These combined effects imply that the losses of electrons are reduced and they can now make more collisions with the gas molecules than they could do in the absence of the magnetic field. In effect, the breakdown voltage is reduced, as shown in (Figs. 4 and 5) respectively for argon and nitrogen.

On the right side of the minimum, the breakdown voltage increases gradually when increasing *Pd*, which can be attributed to the decrease in the ionization cross-section, making the electrons to require more energy in order to achieve the breakdown of the discharge gap while, On the left side of the minimum Paschen curves, V_B decreases fast when increasing *Pd* which can be attributed to the increase in the collision frequency between electrons and neutral atoms or molecules [8].

The results show that the

1. Effect of the magnetic field on the Paschen curves is to reduce the breakdown voltage, especially on the region of Pashen's minimum. This effect is more pronounced for nitrogen than for argon.
2. Which can be attributed to the higher efficiency of the secondary ionization processes in N_2 discharge as compared with Ar discharge under the conditions of the pressure and reduced field investigated.
3. Effect of the B-field is reduced because in this region the breakdown is governed primarily by the electrode material properties rather than by ionization process in the bulk of the gas. At lower values of Pd and on the left side of the minimum.

3. 2. Ionization efficiency

Figures 6 and 7 show the variation of the ionization efficiency with E/P for argon and nitrogen.

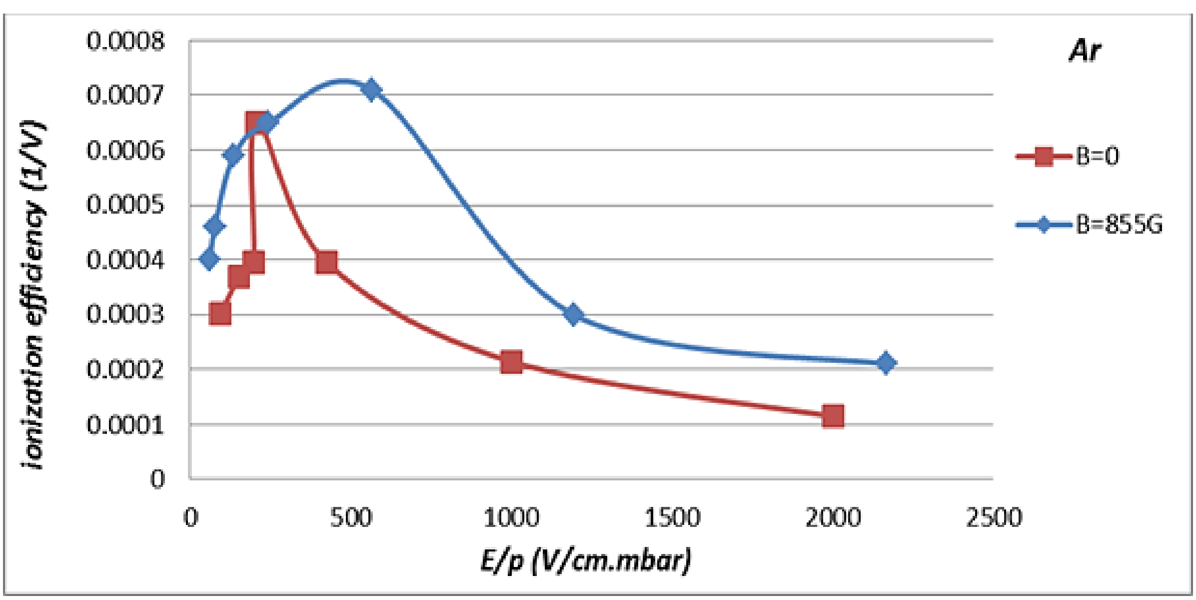


Fig. 6. Ionization efficiency (η) as a function of E/p for Ar using the data of Fig. 5

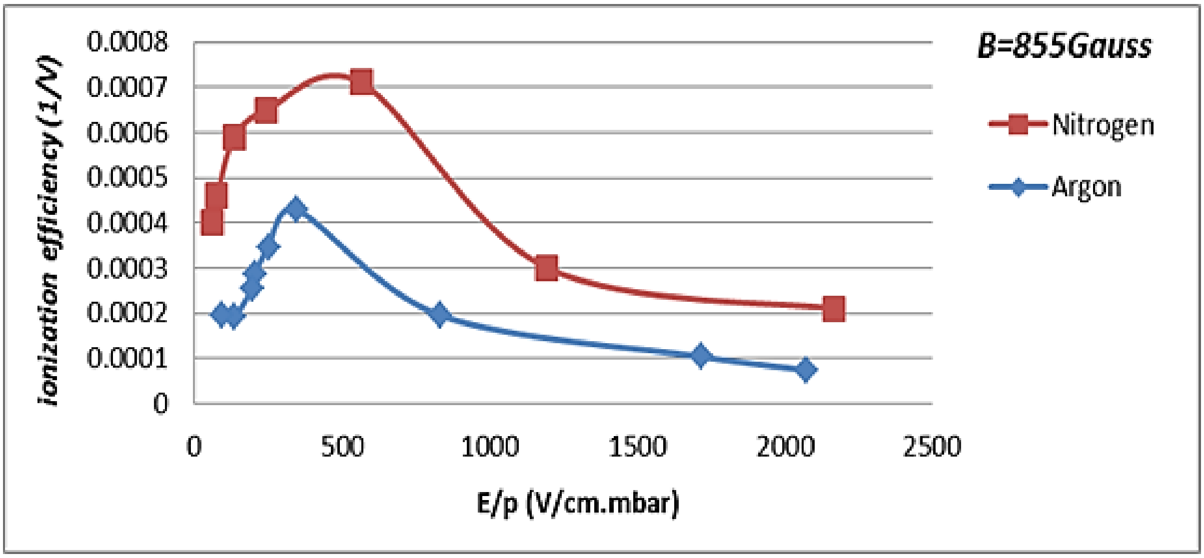


Fig. 7. Ionization efficiency (η) as a function of E/p for argon and nitrogen (B = 855 Gauss).

From these figures I observe that η(E/P), at small *E*/*P*, increases sharplyat small E/p, then reaches a maximum and falls off on further increase of *E*/*P*. This point of maximum is obtained by differentiating η (eq. 6) with respect to *E*/*P* and setting the derivative equal to zero. This maximum of η has a value of η_{max} = A $B^{-1}e^{-1}$ which is in turn proportional to the inverse of the ionization potential of the gas (Vi = B/A). The effect of the magnetic field corresponds to a lowering of the ionization potential of the gas. For the nitrogen discharge only the descending branch of the curve was obtained, as shown in fig. 7 but the qualitative effect of the B-field on the ionization efficiency in nitrogen is similar to that in argon. In the absence of magnetic field, the required voltage for maintaining the breakdown discharge depends on the work function of cathode material for which a high voltage should be supplied if the cathode is made of high material work function. The present of magnetic field lengthens the trajectory of free electrons (i.e. Larmor frequency) in ionization region and decreased the mean energy of released electrons to reach anode which in turn increases the number of collisions [1].

3. 3. Secondary emission coefficient

The variation of the effective secondary electron emission coefficient γ with the reduced field E/P is shown in Figs. 8 and 9 for Ar and N_2, respectively. Variation of γ with E/P. The values of secondary electron emission coefficients γ are calculated from the mean Paschen curves and represented in fig. 4. It is reported that the curves of γ versus E/P has a minimum value of γ for several gases such as N_2, Ar, it is usually observed that the curve of γ(E/P) has a minimum [10] but only in the experimental range of reduced field investigated only the ascending branches of the curves are obtained. I observe that γ rises faster for nitrogen than for argon and that it increases with the magnetic field, which especially for argon, becomes less effective as the reduced field is decreased. The secondary emission of electrons can be due to any combination of effects of impacts of positive ions, photons, excited atoms on the aluminum electrode which depends on the state of the cathode surface.

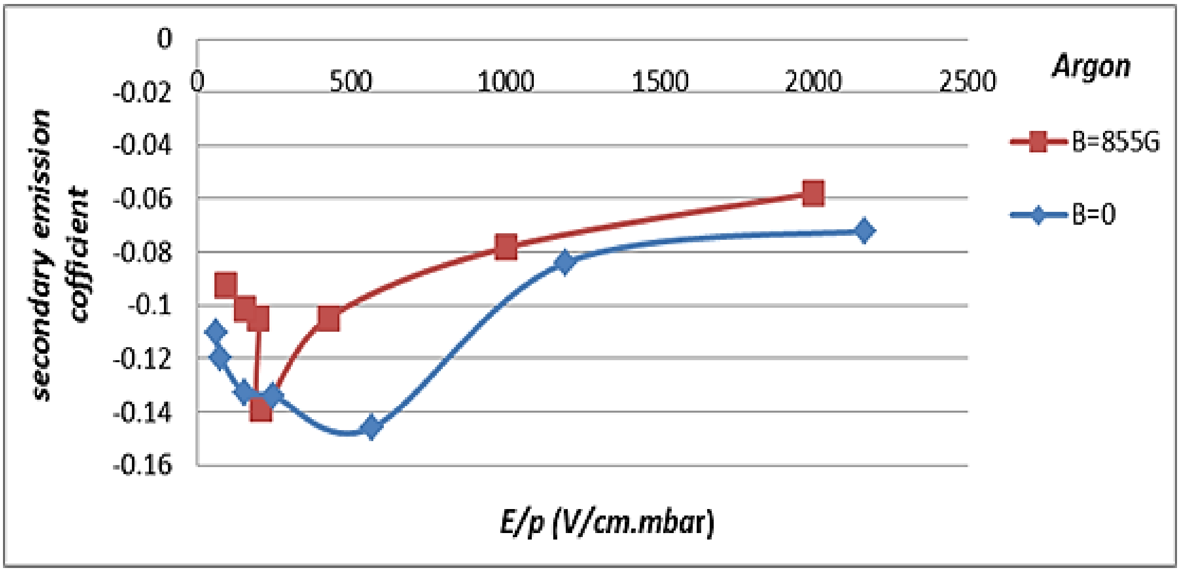


Fig. 8. Variation of the secondary Ionization coefficiency (γ) with E/p for Ar gas.

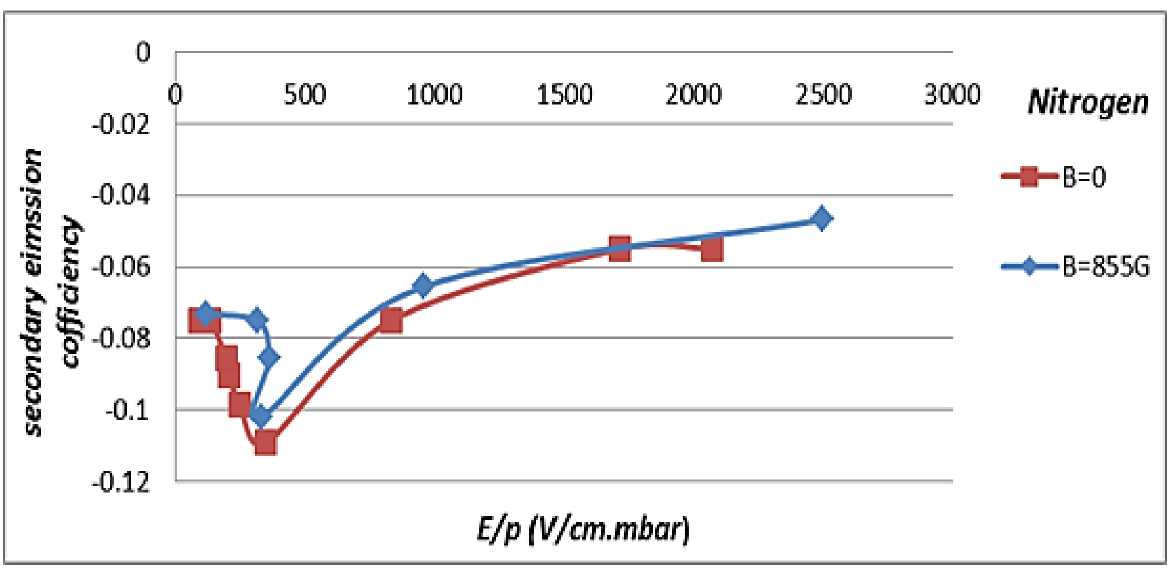


Fig. 9. Variation of the secondary Ionization coefficiency (γ) with E/p for N_2 gas.

The mean electron energy is low and the excitation within the gas becomes more important than ionization for weak reduced fields. Then Secondary electrons are ejected from the cathode mainly by photon impact (photoelectric effect) and a mechanism become less sensitive to the magnetic field. On the other hand. The secondary electron emission is governed by impact of ions on the cathode and even at higher values by the impact of neutral rapid species at high values of E/p [10]. These mechanisms are dependent on the dynamics of the charged particles and the emission of secondary electrons is enhanced by the confinement effect which is promoted by the application of a magnetic field. At given value of E/p, the magnetic field effect is associated with the increase of γ is equivalent to a decrease in the work function of the cathode material becauses a lower voltage would be required to maintain the discharge in the presence of a B-field for the case of field-free discharge with a cathode of lower work function. The efficiency of electron emission increases by the incidence of the ions onto the cathode.

Especially when using a smaller ion mass, I. e. γ (N_2) > γ (Ar) at a given *E*/*P* value [9] a behavior that is demonstrated by comparing the curves in Figs. 8 and 9.

4. CONCLUSIONS

In the present paper, the experimental results of the electrical breakdown and secondary electron emission coefficient under the influence of longitudinal magnetic field are compared with the literature of previous works and showed a good agreement. The breakdown voltages in low pressure gases have been measured for argon and nitrogen discharges using plane-parallel stainless steel electrodes. We have investigated the influence of a longitudinal magnetic field on the Paschen curves and on the Townsend parameters. We observed that the longitudinal magnetic field applied along the discharge axis promoted a reduction of the breakdown voltage. The breakdown is facilitated by the magnetic confinement of electrons which reduces the electron losses and effectively increases the collision frequency between electrons and the gas particles at a given reduced field, thus increasing the ionization efficiency. This effect is equivalent to a change of the operating gas by another of lower ionization potential. The presence of the magnetic field enhances the secondary ionization coefficient at a given *E*/*P* value.

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