study paschen curve mathematically

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Abstract

By multiplying the gas pressure and the gap distance between two infinite planar electrodes, Paschen's law calculates the inception voltage for an electrical discharge. It is well known that variations from Paschen's law take place when the temperature rises. Gas breakdown voltage between two electrodes is described by Paschen's law. The Gas Breakdown Voltage (VB) is only dependent on the product of the gas pressure (p) and the electrode gap length (d), according to this law (VB=f(pd)). The theoretical and actual breakdown voltage data over various distances are presented in this research. Under the same experimental circumstances and electrode shape, it has been found that the breakdown voltage varies depending on the distance between two gas molecules of argon. This paper provides a single, comprehensive mathematical formulation of the breakdown voltage

Keywords: paschen law , theoretical breakdown , experimental breakdown voltage, electrode geometry,

دراسة منحنى باشن رياضيا

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الخلاصة :

بضرب ضغط الغاز ومسافة الفجوة بين قطبين مستويين لا حصر لهما ، يحسب قانون باشن جهد بدء التفريغ الكهربائي. من المعروف أن الاختلافات عن قانون باشن تحدث عندما ترتفع درجة الحرارة. يصف قانون باشن جهد انهيار الغاز بين قطبين. يعتمد جهد انهيار الغاز (VB) فقط على ناتج ضغط الغاز (p) وطول فجوة القطب (d) ، وفقًا لهذا القانون VB = f (pd) . تم عرض بيانات جهد الانهيار النظرية والفعلية على مسافات مختلفة في هذا البحث. في ظل نفس الظروف التجريبية وشكل القطب ، وجد أن جهد الانهيار يختلف باختلاف المسافة بين جزيئي غاز من الأرجون. يقدم هذا البحث صيغة رياضية واحدة وشاملة لجهد الانهيار.

الكلمات الرئيسية: قانون باشن ، الانهيار النظري ، جهد الانهيار التجريبي ، هندسة القطب ،

Introduction

Over many years, breakdown processes have been researched. Numerous key ideas influence how breakdown occurs in the atmosphere. Normally held in the air, primary electrons are liberated by cosmic rays and background radiation and accelerate in a strong electrical field before colliding with neutral molecules. When electrons gain sufficient energy to ionize the background gas, the cumulative ionization process encourages the creation of an avalanche of electrons. In the following section [1], further information regarding this method will be introduced.

Between two electrodes, the breakdown voltage for gaseous ionization has traditionally been expressed using Paschen's curve. Experiments have revealed that Townsend effects are the basis for Paschen's curve. , may not always be correct in explaining between-electrode breakdown located closer together than 15 m. Recently, a different mathematical explanation that takes into consideration ion- An improved field emission was suggested. to characterize the breakdown voltage in small gaps. In this domain, electron field emission contributes significantly to the breakdown event. The transition between Townsend and field emission effects, or the so-called modified Paschen's curve[2], is not predicted by either Paschen's curve or the small gap equation because they both only operate in specific regimes.

Paschen’s law

Friedrich Paschen wrote what is today referred to as Paschen Law. [3] in 1889, stating that pd is a function of the breakdown voltage VB between two electrodes, the sum of the chamber's pressure, and the distance between the electrodes. From this, he deduced the following relation :

$$V_B = \frac{Bpd}{\ln(pd) + \ln\left({Apd} \Big/ {ln\left(\frac{1}{\gamma}\right)} \right)}$$

where A, B, and γ are constants to be discussed below

Paschen's law, which is typically expressed as V= f (pd) is a nonlinear function of the sum of the gap distance (d) and gas pressure (p). Tt effectively explains the gas's tendency to disintegrate in a gap. The gas density should probably be used instead of pressure. The gas breakdown criterion has been demonstrated to be provided as γ (($e^{\alpha d}$ -1) =1 . Based on the relationship between the electric field E and the gas pressure p, the coefficients of and can be calculated. .

The formula for the typical number of electrons released by a positive ion is:

$$\frac{I}{I_0} = \frac{e^{\alpha d}}{1-\gamma(e^{\alpha d}-1)} \qquad (1)$$

Where I represent the circuit's current, I_0 represents saturation current, α represents the first Townsend coefficient, γrepresents the second Townsend ionization coefficient, and d represents the distance between the electrodes. If the internal resistance of the power supply is disregarded, the current becomes unlimited

$$\gamma(e^{\alpha d}-1) = 1 \quad (2)$$

Normally, $e^{\alpha d}$ >> 1, and Equation (2) can be written simply as

$$\gamma e^{\alpha d} = 1 \quad (3) .$$

Thus, by rewriting Equation (2) we have

$$f_1\left(\frac{V}{pd}\right)\left[e^{pd\, f_1(V/pd)} - 1\right] = 1 \quad (4)$$

It is possible to rewrite Equation (2.2), which depicts the relationship between breakdown voltage and product pd, as follows:

$$V = f(pd) \quad (5)$$

Engineering for high voltage uses this equation heavily. Experimental measurements have been made of Paschen's law. for a variety of gases. The breakdown voltage has an inverse relationship with pd value at low pd values and a direct correlation with the pd parameter at high pd values. The Paschen minimum is a range when breakdown voltage falls below a certain threshold.

Table (2.1) displays these breakdown voltages at the least for several gases

Gas	V (min)	P.d (torr.cm)
Air	327	0.567
Argon	137	0.9
H2	273	1.15
Helium	156	4
CO2	420	0.51
N2	251	0.67
N2O	418	0.5
O2	450	0.7
SO2	456	0.33
H2S	414	0.6

Air has a pd value of around 5 Torr-cm. If the pd is less than (pd)min, there were fewer collisions between electrons across the gap and a larger voltage was required to give the electrons enough energy to trigger a breakdown. When pd>(pd)min, electrons collide with gas molecules more frequently than when (pd)min, but they do so with less energy. As a result, the breakdown voltage is larger under these conditions than it is for (pd)min values.[4]

Results and Discussion:

Theoretical Calculation

Prior to this work, many experimental microscale breakdowns experiments using different electrode materials, geometries, gases, and gas pressures were carried out [5]. Although additional materials have been researched, the majority of electrode materials used in micro fabrication are silicon (Si), platinum (Pt), gold (Au), and silver (Ag). There are two common experimental setups: The two planar electrodes are either microfabricated on a substrate's surface or they are kept at a tiny gap by an external micro-positioning mechanism. Although other common gases including argon (Ar), air, carbon dioxide (Co2), and nitrogen (N2) have also been researched at pressures ranging from 0.3 torr to 7500 torr, the main air at atmospheric pressure is a gas of interest.

We can use the findings of theoretical calculations to depict the breakdown voltage curve in relation to gas pressure. Since each curve must have a unique in conjunction with the (pd)min point, the Paschen curve will serve as a guide for the actual experimental results.

Table 4.1 Numerical Townsend Coefficient Parameters A and B

Gas	A 1/cm.torr	B v/cm.torr
air	15	365
Ar	12	180
N2	10	310
He	3	34

Functions of the significant parameter pd and the breakdown voltage

$$V_B = \frac{Bpd}{\ln(pd) + \ln\left(Apd \Big/ ln\left(\frac{1}{\gamma}\right) \right)}$$

the equations can be rewritten as:

$$V_B = \frac{Bpd}{\ln(pd) + C}$$

where C is given be $C = lnA - \ln \ln (1/1 + \gamma)$

Where γ , It is simple to determine the breakdown voltage if you know the Townsend secondary ionization coefficient. The kind of gas, the composition of the cathode, and the lowered electrical field E/p all affect the Townsend secondary ionization coefficient. Although it varies for many materials and gases, this value of is quantifiable. The normal range of is 0.01 to 0.1. [6].

Figures .1, and .2, show the calculations of breakdown voltages of argon for different distances. All figures display an excellent fit with the well-known Paschen curve within the acceptable pressure range.

Table 1 Process for Calculating Argon Breakdown Voltage (A=12 1/cm Torr, B=180 V/cm Torr) for distance (1 cm)

p torr	d (cm)	pd (torr.cm)	γ	C	Argon Breakdown Voltage (V)
0.4	1	0.4	0.01	0.955569	183.34
0.5	1	0.5	0.01	0.955569	342.96
0.6	1	0.6	0.01	0.955569	242.83
0.8	1	0.8	0.01	0.955569	196.6
1	1	1	0.01	0.955569	188.36
2	1	2	0.01	0.955569	218.43
3	1	3	0.01	0.955569	262.87
4	1	4	0.01	0.955569	307.47
6	1	6	0.01	0.955569	393.1
8	1	8	0.01	0.955569	474.46
10	1	10	0.01	0.955569	552.46
15	1	15	0.01	0.955569	736.96
20	1	20	0.01	0.955569	911.09

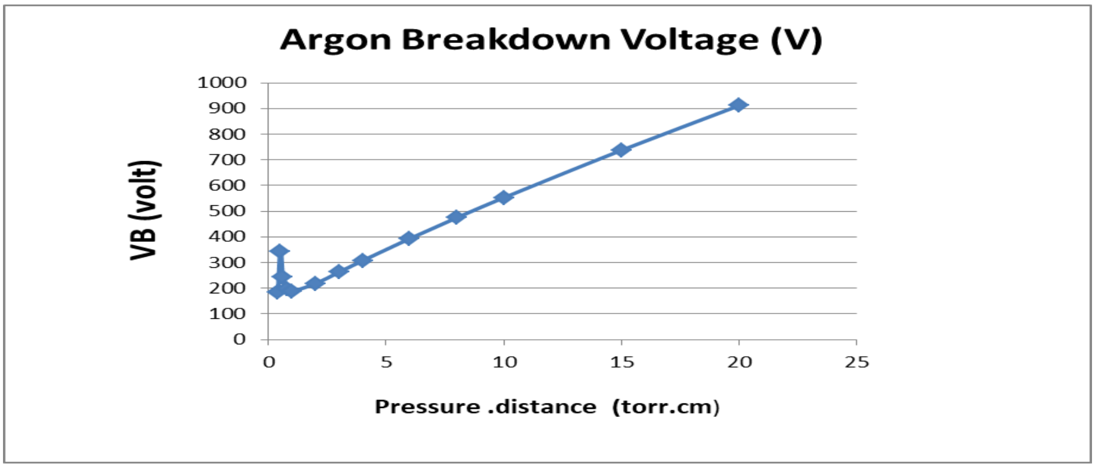

Figure (1) With theoretical data for a 1 cm spacing, Argon Breakdown Voltage as a Function of Pressure

Table 2 Process for Calculating Argon Breakdown Voltage (A=12 1/cm Torr, B=180 V/cm Torr) for distance (4 cm)

pd(torr.cm)	p(cm)	γ	C	Volut (V)
0.5	4	0.01	0.955568563	342.95
0.56	4	0.01	0.955568563	268.43
0.6	4	0.01	0.955568563	242.83
0.7	4	0.01	0.955568563	210.38
0.8	4	0.01	0.955568563	196.6
0.9	4	0.01	0.955568563	190.54
1	4	0.01	0.955568563	188.36
1.5	4	0.01	0.955568563	207
1.9	4	0.01	0.955568563	219
2	4	0.01	0.955568563	225
2.5	4	0.01	0.955568563	250
3	4	0.01	0.955568563	270
4	4	0.01	0.955568563	313

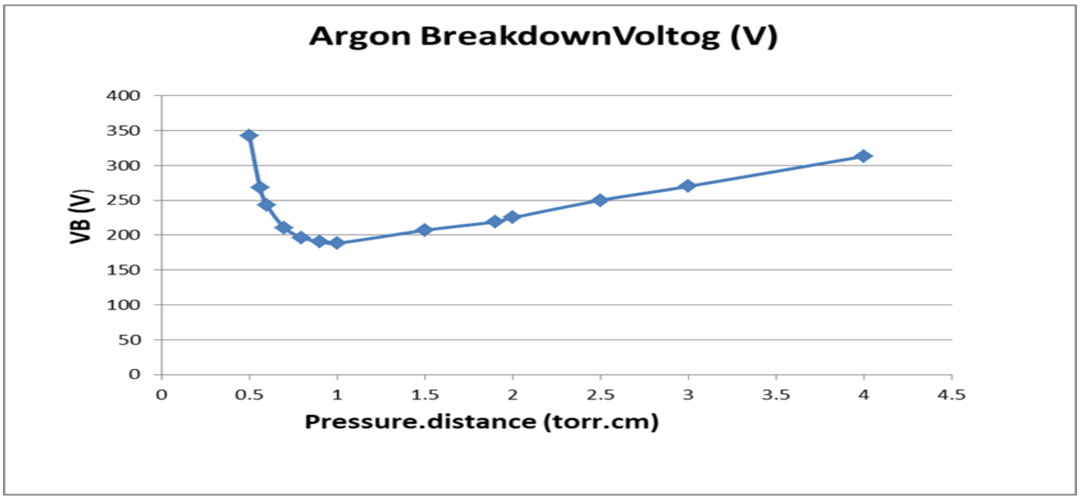

Figure (2)With theoretical data for a 4 cm spacing, Argon Breakdown Voltage as a Function of Pressure

Discussion

In this study, I described how to use Paschen's law and Townsend's theory to determine the breakdown voltages for gases. After that, experimental research is carried out to show that our calculation under a DC-applied voltage was accurate. The coefficient of secondary ionization, which is dependent on the kind of gas, the cathode material, and the electrical field E/p is lessened, was used in the theoretical calculation, which was based on Townsend breakdown theory. Negative voltage values were eliminated from the computations and erased before to drawing the breakdown voltages vs pressure curve. Under a DC voltage, the breakdown voltage depends on the pressure. , it can be seen from the theoretical calculation's numbers. When the impact of incorrect data is ignored, these numbers possess a parabolic shape similar to the Paschen curve. the same theoretical curve.

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