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**FIRST TOWNSEND COEFFICIENT MEASURED IN ARGON BASED
MIXTURES AT HIGH FIELDS**

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ABSTRACT

The first Townsend coefficient α is measured at high fields, in pure hydrocarbons and carbon dioxide, and in their mixtures with argon, using a parallel plate chamber at various pressures. From a fit to the Townsend relation $\alpha/p = A \exp(-Bp/E)$ the gas constants A and B are derived. Space charge effects are observed at high fields.

1. Introduction

High accuracy detectors operating in proportional and streamer mode exploit gas amplification at high electric fields for radiation detection. Event reconstruction at the SSC and LHC is a challenge requiring an understanding of the performance as well as an optimization of the present generation of gaseous detectors [1].

A number of factors influence the performance of chambers which may be optimized; the most important of them being gas mixtures, geometry, readout electronics, materials used. It is desirable that the gas gain not be too low (and neither too high as that may lead to sparks!) so that we have a detectable signal in a small gas volume. Chambers operating in the high gain mode have some advantages like cheaper amplification electronics and relative ease of production. This optimization requires a knowledge of distortions due to space charge effects which can be estimated by modelling the avalanche in a gas for which the Townsend coefficient as a function of field must be known. We have measured the first Townsend coefficient in various widely used gas mixtures. The measurements for some gas mixtures have been presented in ref. [2].

2. Experimental Procedure

The average distance an electron travels between ionizing collisions is called the mean free path for ionization; its inverse, the number of ionizing collisions per cm, is the first Townsend coefficient α . This is a fundamental parameter, which determines the gas gain. If n_0 is the number of primary electrons in a uniform electric field, the number of electrons after distance x , under avalanche conditions, is given by $n = n_0 e^{\alpha x}$; in presence of a continuous source of ionisation, the current $i = i_0 e^{\alpha x}$, where i_0 is the current produced by n_0 primary electrons produced per unit time. The multiplication factor or gain G is given by $G = n/n_0 = i/i_0 = e^{\alpha x}$. The first Townsend coefficient α depends upon many parameters, the main ones being nature of the gas, field and pressure. Addition to noble gases of polyatomic molecules, which have a number of low lying excitation, vibrational and rotational levels increases the field required to reach similar gains, hence this is a useful parameter to be played with for best chamber performances.

The Townsend coefficient α smoothly increases with E , but depends on the pressure p . It can be demonstrated [3,4] that in a wide range of E and p the ratio α/p is a unique function of E/p .

Many efforts have been done for the determination of α and a lot of data exist for a wide variety of gases and mixtures [5]. Unfortunately, the fields in high gain chambers are in the range of 10^4 - 10^5 volts/cm while most of the data exist in the range of 10^2 - 10^3 volts/cm. The data that exist for high fields [6,7] have been obtained with chambers having non-uniform electric field. We have made our measurements in a parallel plate chamber having a uniform electric field. To access high values of α/p experimentally, and avoid having excessively high working voltages, we make the measurements at high field but low pressures, as α/p scales with E/p . To describe our data we use the approximated expression:

$$\alpha/p = A e^{-Bp/E} \quad (1)$$

The measurements of α presented here have been realized using a parallel plate chamber which has the advantage that it uses uniform field for amplification without resort to interpolations and fitting algorithms. Further, these measurements extend to a high reduced field (E/p) employing low pressure.

Figure 1 shows a geometric description of the parallel plate chamber used for the measurements. It consists of a cylindrical teflon box of outer diameter 14 cm and inner diameter of 10 cm. The copper cathode is glued to the lid with a 1.4 cm hole having a 100 μ thin mylar window which allows to illuminate the chamber with an x-ray source. The chamber is divided into two regions - drift and amplification. The drift region is 9 cm thick to allow production and collection of enough primary ionization, and is separated from the multiplication region by a stainless steel grid

with wires of 50 μ diameter and 500 μ pitch. Two stainless steel concentric rings are placed at appropriate potentials equidistant from the cathode and the grid in order to keep the drift field uniform. The grid is soldered onto a circular steel frame with edges covered with insulating paint to avoid edge effects like corona discharges. The anode is a circular aluminium plate with edges rounded for the same reason. High voltage feed throughs for the grid and the cathode are engrooved in the lid while that for the anode is at the bottom. The chamber is connected to a pump which enables us to work at low pressure. An electronic valve is connected at the inlet to allow control of pressure. Calibration gas flowmeters are used to determine the percentage of each gas in a mixture.

The current in the chamber under radiation is measured with a meter having a sensitivity of the order of 10^{-12} A, and is typically $\sim 10^{-10}$ A without gain. The anode is kept at ground potential while the amplification field is provided by HV on the grid, the drift field is kept constant in all the measurements. Figure 2 shows a typical raw measurement ; the anodic current is measured and after subtraction of the leakage current (anodic current without the source) we determine the value of the current at no gain (i_0). Continuing the measurement at higher fields, one gets into the multiplication region, the ratio of the two currents is the absolute gain. A practical limitation of the method appears when, at a given source intensity, the gain is large enough to induce breakdown. As well known [9] breakdown appears at a certain amount of charge, hence when reaching this point, we lower the source intensity, the current is measured again at the same field for normalization and the measurement is continued. This procedure enables us to go to higher gains by measuring the current at higher fields, which is in fact renormalized. In this way ionization curves ie current versus the field are made. It may be noted that after removing the source while working at high gains, it takes a long time (> 30 mins) for the current to come back to its original value at a given point of reference possibly due to the local charging up of insulators in the chamber. For measurements at high gains, the leakage current i.e., the current without the source is measured and subtracted from the current measured with the source.

On the same setup, the signal is seen on a scope using a fast charge amplifier . With a proper choice of timing constant of the amplifier, the electronic and ionic component of the signal can be seen (see figure 3); this provides informations on the ionic mobility.

3. Results and Discussion

Figures 4(a-e) show the measured α/p vs. E/p curves for various gas mixtures of argon with methane, ethane, isobutane, dimethyl ether (DME), and carbon dioxide. A two parameter exponential fit according to expression (1) is done and the constants A and B are derived. The values of the parameters for the various cases with the upper limit of the range of the reduced electric field E/p are given in table I.

The chamber could withstand just a little higher voltage (10 or 20 volts in most cases) without the source. This confirms that breakdown was indeed due to discharge in the gas. Fig 5 shows the breakdown charge for the data at various gains for the various mixtures. One can see that the charge at breakdown is almost independent of gas mixture and gain, as already observed [9]. Extrapolations of our data agree with previous measurements at higher fields in argon/carbon-dioxide obtained in a proportional chamber with a slightly different gas mixture [7] and with measurements in DME at lower fields [8], as may be derived from fig. 6.

As expected, increased quencher concentration requires higher fields for the same gain. This is because the large cross-sections for excitation and vibration states in the quencher molecule cool the electrons as energy is absorbed in these non-ionizing modes.

From table I it is seen that the values of both parameters A and B, for the gases studied increase with quencher fraction. Note that at high E/p values expression (1) does not reproduce well the data, probably because of the appearance of space charge field distortion.

TABLE I Experimentally determined parameters A and B derived from a fit to $\alpha/p = A e^{-Bp/E}$

Argon-Methane mixtures:

Data Set [@]	1	2	3	4	5	6	7	8	9	10	11
Percentage of Methane	0	1.96	16.6	32.4	44.8	55.6	65.4	74.0	82.2	93.3	100
A (cm ⁻¹ Torr ⁻¹)	2.8	3.1	2.7	2.3	5.8	38.3	68.0	111.4	237.3	244.7	436.1
B (Vcm ⁻¹ Torr ⁻¹)	60.6	65.5	81.7	88.4	130.1	230.1	265.6	298.5	342.5	347.8	388.3
E/p [#] (Vcm ⁻¹ Torr ⁻¹)	11.8	15.8	19.7	22.1	26.8	32.8	35.5	36.8	38.4	38.9	40.8

Argon-Isobutane mixtures:

Data Set	1	2	3	4	5	6	7	8	9
Percentage of Isobutane	8.21	20.7	41.33	47.0	52.7	74.3	79.4	90.7	100
A (cm ⁻¹ Torr ⁻¹)	22.45	70.7	133.3	108.5	144.7	100.5	200.1	147.1	176.3
B (Vcm ⁻¹ Torr ⁻¹)	127.6	193.2	225.6	223.3	241.1	278.3	314.2	334.8	360.0
E/p [#] (Vcm ⁻¹ Torr ⁻¹)	20.1	25.5	28.7	29.3	31.5	35.1	36.5	40.5	41.8

Argon-Ethane mixtures:

Data Set	1	2	3	4	5
Percentage of Ethane	31.7	33.1	54.8	72.1	100
A (cm ⁻¹ Torr ⁻¹)	24.6	26.8	40.0	164.1	242.6
B (Vcm ⁻¹ Torr ⁻¹)	154.8	192.5	237.1	301.9	340.8
E/p [#] (Vcm ⁻¹ Torr ⁻¹)	21.6	27.0	29.7	31.7	34.4

Argon-DME mixtures:

Data set	1	2	3
Percentage of DME	9.0	18.1	100
A (cm ⁻¹ Torr ⁻¹)	4.3	7.9	8.0
B (Vcm ⁻¹ Torr ⁻¹)	57.6	107.5	213.1
E/p [#] (Vcm ⁻¹ Torr ⁻¹)	10.4	13.5	31.0

Argon-Carbon Dioxide mixtures:

Data set	1	2	3	4
Percentage of Carbon dioxide	3.7	22.8	87.2	100
A (cm ⁻¹ Torr ⁻¹)	5.04	221.2	158.3	145.1
B (Vcm ⁻¹ Torr ⁻¹)	90.82	207.6	291.8	318.2
E/p [#] (Vcm ⁻¹ Torr ⁻¹)	16.2	21.6	32.9	36.4

[@] The data set numbers correspond to the curves in the respective figs.

[#] This is the upper limit of the reduced electric field E/p up to which relation (1) fits well.

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Figure Captions

- 1. Schematics of the chamber used for measurements of the Townsend Coefficient α .
- 2. Procedure of the measurements.
- 3. An example of the output signal as seen on a fast charge amplifier.
- 4. α/p vs. E/p for a) argon-methane mixtures b) argon-ethane mixtures c) argon-isobutane mixtures d) argon-DME mixtures and e) argon-carbon dioxide mixtures
- 5. Breakdown charge at various gains for all gas mixtures measured.
- 6. Comparison of our data for the Townsend coefficient with other work.

EXPERIMENTAL SET-UP

Fig. 1

Fig. 2

Fig. 3

Fig. 4(e)

Fig. 5

Fig. 6