**A MEASUREMENT OF THE FIRST TOWNSEND COEFFICIENT
IN ARGON BASED MIXTURES AT HIGH FIELDS**

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ABSTRACT

We have measured the first Townsend Coefficient α at high fields, in pure hydrocarbons and carbon dioxide, and their mixtures with Argon using a parallel plate chamber at various pressures. This is in order to understand the operating characteristics for high localization accuracy drift chambers operating in proportional and streamer regimes.

Presented by A. Sharma at the sixth International Wire Chamber
Conference Vienna, February 17-21, 1992

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Introduction

Gas amplification at high electric fields is exploited for ionizing 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].

Performance of chambers can be optimized by playing with a number of factors, the most important of them being gas mixtures, geometry, readout electronics, materials used, etc. It is desirable not to use a too low gas gain (and neither too high as that may lead to sparks!) in order to get a detectable signal in a small gas volume. Chambers operating in the high gain mode have some advantages like cheap 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.

In order to understand the operating characteristics of drift chambers operating in proportional and streamer regimes, and to aim at better localization accuracy we have measured the first Townsend Coefficient in various widely used gas mixtures.

Theory

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 α , the first Townsend coefficient. This is a fundamental parameter, which determines the gas gain. It is easily seen [2] that if n_0 is the number of primary electrons without amplification in a uniform electric field, the number of electrons after distance x , under avalanche conditions, is given by $n = n_0 e^{\alpha x}$ implying that the current $i = i_0 e^{\alpha x}$, where i_0 is the current with n_0 primary electrons. 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 varied for best chamber performances.

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

Much effort has gone into the determination of α , and a lot of data exist for a wide variety of pure gases and at low values of electric field [4-6]. In practice, however, mixtures of noble gases with quenchers are used in drift and proportional chambers, and the fields in high gain chambers are close to $\sim 10^4$ - 10^5 volts/cm while most of the data exist in the region of $\sim 10^2$ - 10^3 volts/cm. On the other hand, the little data that exist for high fields [7-8] have been obtained with chambers of non-uniform geometries. This is due to the experimental limitation of working at high voltages. To access high values of α/p experimentally, and avoid having excessively high working voltages, we carried out the measurements at high field but low pressures as α/p scales with E/p . An approximated expression [2,3] that we use to describe our data is

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

Experimental Set Up and Procedure

The measurements of α presented here have been realized using a parallel plate chamber which has the advantage of uniform field for amplification and thus not requiring interpolations and fitting algorithms. Furthermore, 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 100μ thin 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 produce enough primary ionization, and is separated from the multiplication region by a stainless steel grid of 50μ ϕ and 500μ 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 rounded edges 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. The calibration curves of the gas flowmeters are made to determine the percentage of each gas in a mixture.

The current in the chamber under radiation is measured with a current meter with a sensitivity of the order of 10^{-12} amp, and is typically $\sim 10^{-10}$ amp without gain; this is consistent with calculations from the source activity and simple assumptions on geometry and solid angle. The anode is kept at ground potential while the amplification field is provided by HV on the grid, the drift field being kept constant in all the measurements. Figure 2 shows a typical raw measurement; the anodic current is measured and the plateau of the current at no gain (I_0) determined. Continuing the measurement at higher fields, one gets into the multiplication region, the ratio of the two 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 is well known [9] breakdown appears at a certain amount of charge; hence we have lowered the source intensity and measured the current again at the same field for normalization; then the field is raised again. 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 (voltage) are obtained. The pressure is kept almost constant for one set of gas mixture; wherever this was not possible due to practical reasons, the data were normalized.

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 information on the ionic mobility.

Results

Figures 4(a-c) show the measured α/p vs. E/p curve for the various gas mixtures of Argon with isobutane, dimethyl ether (DME) and carbon-dioxide. The solid lines are the exponential fits to the data. A two parameter exponential fit according to Equation (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 reduced electric field E/p are given in table I.

The chamber could withstand just a little higher (10 or 20 volts in most cases) voltage without the source but with the source the breakdown voltage was lower. This confirms that breakdown was indeed due to discharge in the gas. Our data agree with an extrapolation at higher fields of previous measurements of DME from ref. 4; and lower fields, although obtained from a slightly different gas mixture of Argon carbon-dioxide derived from proportional chamber measurements, from ref. 8 (see figure 5).

Discussion

As expected when increasing the quencher fraction one has to go to 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.

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. One observation that was made from the current measurements is that the breakdown charge is nearly the same, namely a few pC at various gains in agreement with observations of ref. [9].

From table 1 it is seen that both parameters A and B, for the various gases and their mixtures increase with quencher fraction. The χ^2 of the fit depends on the number of experimental points taken into consideration. Due to the reason given in the preceding paragraph the charging up of insulators in the chamber may lead to the erroneous reconstruction of points at high gains.

Consequently when the α/p values at high gains are suppressed from the data, the fits are better, suggesting space charge effects.

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Figure Captions

- 1. Geometrical description of the chamber used for measurements of the Townsend coefficient, α .
- 2. Procedure of the measurements.
- 3. An example of the output signal.
- 4. a) α/p vs. E/p for Argon-Isobutane mixtures
b) α/p vs. E/p for Argon-DME mixtures
c) α/p vs. E/p for Argon-Carbon dioxide mixtures
- 5. Comparison of our data with other work.

Table I

Parmaters A and B from the fit of the data to the Townsend Equation.

EXPERIMENTAL SET-UP

Fig. 1

Fig. 2

Fig. 3

Fig. 4a

Fig. 4b

Fig. 4c

Fig. 5

Table-I Parameters derived from the fit of the data to the
Townsend Equation

(Argon-Isobutane)

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
Parameter A $\text{cm}^{-1}\text{Torr}^{-1}$	22.45	70.7	108.5	133.3	144.7	100.5	147.1	176.3	200.1
Parameter B $\text{Vcm}^{-1}\text{Torr}^{-1}$	94.5	143.1	165.4	167.4	178.6	206.2	248.0	266.7	232.8
Upper limit of E/p $\text{Vcm}^{-1}\text{Torr}^{-1}$	20.1	25.5	28.7	29.3	31.5	35.1	36.5	40.5	41.8

(Argon-DME)

Data set	1	2	3
Percentage of DME	9.0	18.1	100
Parameter A $\text{cm}^{-1}\text{Torr}^{-1}$	4.3	7.9	8.0
Parameter B $\text{Vcm}^{-1}\text{Torr}^{-1}$	57.6	107.5	213.1
Upper limit of E/p $\text{Vcm}^{-1}\text{Torr}^{-1}$	10.4	13.5	31.0

(Argon-Carbon Dioxide)

Data set	1	2	3	4
Percentage of Carbon dioxide	3.7	22.8	87.2	100
Parameter A $\text{cm}^{-1}\text{Torr}^{-1}$	5.0	58.8	47.8	44.5
Parameter B $\text{Vcm}^{-1}\text{Torr}^{-1}$	90.82	182.9	257.8	280.7
Upper limit of E/p $\text{Vcm}^{-1}\text{Torr}^{-1}$	16.2	21.6	32.9	36.4