THE FIRST TOWNSEND COEFFICIENT FOR
ARGON-ISOBUTANE MIXTURES

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ABSTRACT — Using the Korff approximation for the first Townsend coefficient and the evolution of the charge with the anode voltage for a proportional counter geometry, effective molecular parameters were calculated for argon-isobutane mixtures with the following isobutane concentrations: 32, 39, 44, 48, 51, 56 and 60 percent.

1 — INTRODUCTION

Data are available on the first Townsend coefficient α, the mean number of ion-pairs produced per unit length of drift, for noble gases, hydrocarbon gases and a wide variety of mixtures [1].

Argon-isobutane mixtures have been widely used in detectors, an important characteristic of isobutane being its low optical transmission cut-off at ~ 7.3 eV [2], helping to prevent spurious effects due to photon feedback. Together with its widespread use in multiwire proportional chambers, multiwire drift chambers and more recently, time projection chambers, a reasonable knowledge of the basic mechanisms is now available, useful from the point of view of gaseous electronics and of better understanding and predicting the detectors intrinsic properties. Most theoretical interpretations rely on the Boltzman transport equations and are directed towards the transport coefficients, both with and without magnetic fields, computing drift velocities ω and diffusion

coefficients D. The interpretation of these parameters corresponds essentially, from an instrumental point of view, to the problem of positioning by drift techniques. Using experimental data on D and ω from [3] for mixtures of argon and isobutane (from 7 % up to 38 % isobutane) good fits have been obtained [4] that enabled to guess the behaviour of the total and excitation cross-sections of isobutane with energy [5].

Recently, research in a new mode of charge multiplication in gaseous detectors is being pursued: the formation of narrow streamers ~ 150 μm wide, orthogonally to thick anode wires, that quench themselves under a continuously applied high voltage. Large currents, approaching 1 mA are produced in less than ~ 100 ns, allowing for good localization properties with simple electronics. Again, and essentially for the optical transmission properties of isobutane, argon-isobutane mixtures are being used in the self-quenching streamer mode, SQS [6 , 7], and efforts are being made towards understanding the basic mechanisms involved. It is known that the process is strongly photon mediated and space charge conditioned [8] and based on a mechanism of self-breeding by photoelectrons of the avalanche; quantitative estimations have been made of the photon flux as a function of its wavelength [9]. The first Townsend coefficient is a determinant parameter both for itself and for the calculation of the photon fluxes, essential to a quantitative interpretation of the SQS mode, and in this work experimental data for α over a wide range of isobutane concentrations (large concentrations are a necessary condition to obtain good efficiency plateaux) is presented.

2 — EXPERIMENTAL TECHNIQUE

The experimental system used in this work is essentially the one described in [7]. The gaseous mixture, argon-isobutane, in different proportions, flows through a cylindrical proportional detector under a continuous flow regimen at atmospheric pressure. For the determination of the gaseous composition, calibration curves of the flowmeters were obtained for both gases used. The

detector has an aluminium cathode 13 cm long and 14 mm internal diameter. The anode is a nichrome wire 60 μm thick stretched along the detector axis.

The measurements of the charge characteristics of the chamber were made using a conventional charge amplifier electronic system and multichannel analyzer. The calibration of this system was made by using a Si-semiconductor detector. The bombarding radiation, X-rays from a ^{55}Fe source, enters the detector through an aluminium (0.025 mg/cm^2) window.

3 – EXPERIMENTAL RESULTS AND DATA ANALYSIS

The experimental data obtained in this work are displayed in Fig. 1. The behaviour of the results is similar to that observed in multiwire chambers for the same mixtures [1] and proportional counters used for SQS filled with argon-methane and methylal [10]. It reflects the general behaviour of the first Townsend coefficient in mixtures of noble gases and polyatomic gases namely that, for increasing concentrations of this last component, higher fields are needed to obtain the same α.

Data analysis must consider carefully space-charge distortion of the field, otherwise the molecular properties of the gas are obscured. Provided that this effect is taken into account determination of α for such different techniques as sparking potentials and conduction measurements [11] lead to the same results for the same regions of E/p.

Space-charge effects are well defined in Fig. 1 for charges $\gtrsim$ 1.5 pC. This detector was provided with better insulators (^{1}) than a counter used previously for SQS studies [7]; the spread of pulse-heights for higher voltages was small so that reliable data, with clear space-charge effects, could be collected. These data were used for the analysis reported in this work.

The usual Korff approximation [12] $\alpha = pA \exp(-B\, p/E)$ was used, where A and B are constants for a certain mixture, p is the pressure and E the electric field. From the field confi-

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(^{1}) Kindly made for us by Dr. Rob Hollander, of IRI-ISO group, Delft Technical University, Holland.

guration, the charge gain of the counter is given, with a very good approximation, by

$$Q(V) = (E_{RX} \, e/W) \, \exp \, [\, AV'/B \, \exp \, (-Ba/V') \,]$$

where E_{RX} is the X-ray energy, e the electron charge, W the energy needed to produce an ion pair and $V' = V/\ln(b/a)$, V being the applied voltage, b and a the cathode and anode radius

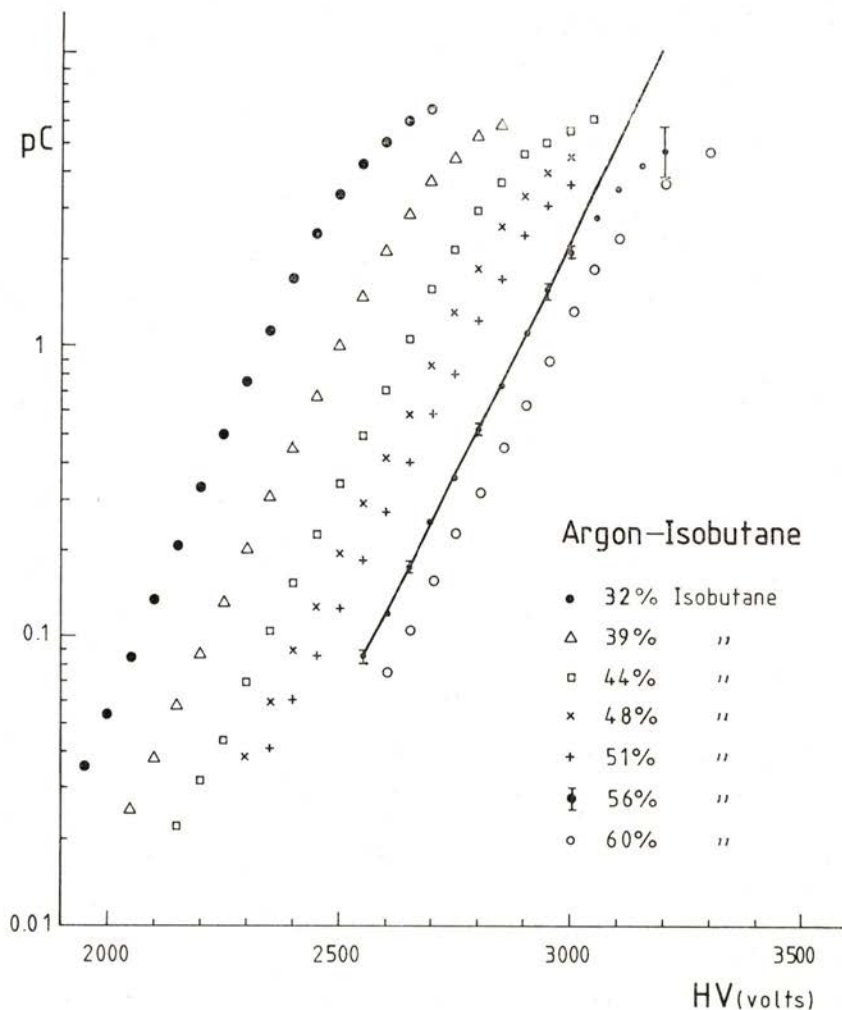Fig. 1 — The average measured charge against applied anode voltage for different argon-isobutane mixtures. The isobutane concentration is quoted for each mixture. A least squares fit is shown.

respectively. The number of primary ion pairs was calculated using the formula given in [13]. Weighted non-linear least square fits to the experimental data, using the expression above for the gain, were made for the several concentrations of isobutane. As an example Fig. 2 shows the evolution of x^2, by varying the number of experimental data points used (successively supressing data corresponding to higher anode voltages) with the highest charge, Q_{max}, included in the fit. The same Fig. 2 shows also a detected correlation between A and B, that was taken into account,
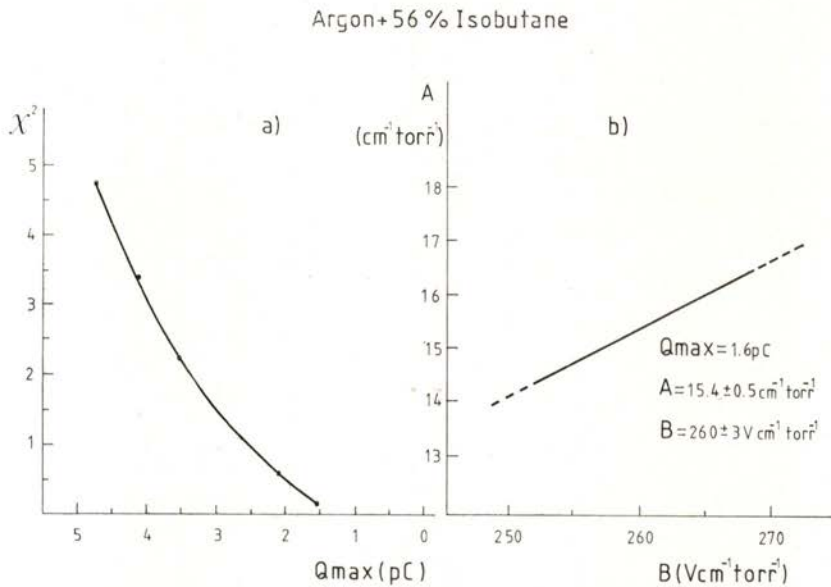
Argon + 56 % Isobutane

Fig. 2 — a) The evolution of the x^2 as a function of maximum charge included in the fit (Q_{max}) ; b) The detected correlation between parameters A and B for the argon + 56 % isobutane mixture; full line corresponds to good fits.

at this stage, simply by the uncertainties quoted for A and B. As an example, a best fit for the argon + 56 % isobutane is shown in Fig. 1, deviations at large charges being attributed to space-charge effects, although the question of the validity of the expression used for α should not be completely disregarded. The data obtained are summarized in Table I. Uncertainties in A are $\sigma_A \simeq 0.5$, and in B, $\sigma_B \simeq 3$.

TABLE I — Derived molecular constants according to $\alpha = pA \exp(-Bp/E)$

% isobutane	32	39	44	48	51	56	60
A (cm^{-1} $torr^{-1}$)	13.1	14.6	15.8	16.6	15.5	15.4	17.9
B (V cm^{-1} $torr^{-1}$)	195	220	240	255	251	260	286
E/p max (V cm^{-1} $torr^{-1}$)	185	205	213	221	225	237	241

The corresponding effective mean free path length at atmospheric pressure $\lambda_{mo} = 1/A$ (λ_m at pressure p is given by λ_{mo}/p) and the effective ionization potential $V_i = B \lambda_{mo}$ [14], are presented in Table II.

TABLE II — Effective molecular parameters

% isobutane	32	39	44	48	51	56	60
λ_{mo} (μm)	1.00	0.90	0.83	0.79	0.85	0.85	0.74
V_i (eV)	14.87	15.08	15.23	15.37	16.14	16.91	15.98

4 — DISCUSSION

The main source of uncertainty associated with the data obtained in this work may be related to space-charge effects: positive ions produced in the early avalanches give rise to modifications of the local electric field and therefore reduce the gain

associated to electrons, from the same track, arriving later to the high field region.

Experimental data available now for this effect concern both proportional counter and multiwire chambers [15, 16, 17] and the space charge reduction is of course dependent on the track geometry and diffusion. Data using X-rays leading to energy deposits varying by an order of magnitude (Mn K and Mn L) show space-charge gain effects starting at about 1 pC (0.3 pC from [16] and 2.4 pC from [15]) if the criterion of negligible field distortion for the lower energy deposit is used. Although the main experimental parameters used by these authors that can affect the space-charge are similar to those of this work (X-ray energy, diffusion, wire thickness) another relevant one, the spatial distribution of the avalanche, is unknown. Nevertheless the threshold for field distortion obtained in this work by the use of Korff's approximation can be considered quite reasonable implying the validity of that approximation for the argon-isobutane mixtures studied, up to the E/p values quoted.

The value of the effective ionization potential V_i is also natural: indeed the thresholds for ionization for argon and isobutane are respectively 15.77 eV and 10.57 eV, and the mean energy to make an ion-pair is about 25 eV. No considerations can be made concerning λ_{mo} due to lack of information on cross-section for ionization: for processes induced by electron impact there is data up to 8 eV only.

In the same way that experimental data on drift velocities and diffusion parameters allowed the determination of total and excitations cross-sections for mixtures of argon and isobutane, the data presented here may lead to the calculation of ionization cross-sections.

As a general indication and to be compared with the data of this work effective molecular parameters for several hydrocarbons are calculated from [11] and shown in Table III.

TABLE III — Effective molecular parameters [11]

Hydrocarbon	Methane	Ethane	Ethylene	Acetylene
λ_{mo}	1.8	1.3	1.4	0.88
(μm)	1.5	1.1	1.2	0.87
V_i	27.1	23.2	32.0	22.2
(eV)	23.8	19.4	29.4	22.5
E/p range ($V\ cm^{-1}\ torr^{-1}$)	33-165	50-190	43-154	47-285

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