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Effective Ionization Coefficients, Electron Drift Velocities, and Limiting Breakdown Fields for Gas Mixtures of Possible Interest to Particle Detectors[1]

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ABSTRACT

We have measured the gas-density, N, normalized effective ionization coefficient, $\bar{\alpha}/N$, and the electron drift velocity, w, as a function of the density-reduced electric field, E/N, and obtained the limiting, $(E/N)_{lim}$, value of E/N for the unitary gases Ar, CO_2, and CF_4, the binary gas mixtures CO_2:Ar (20:80), CO_2:CH_4 (20:80), and CF_4:Ar (20:80), and the ternary gas mixtures CO_2:CF_4:Ar (10:10:80) and H_2O:CF_4:Ar (2:18:80). Addition of the strongly electron thermalizing gas CO_2 or H_2O to the binary mixture CF_4:Ar (i) "cools" the mixture (i.e., lowers the electron energies), (ii) has only a small effect on the magnitude of w(E/N) in the E/N range employed in the particle detectors, and (iii) increases $\bar{\alpha}/N$ for $E/N \geq 50 \times 10^{-17}$ V cm^2. The increase in $\bar{\alpha}/N$, even though the electron energies are lower in the ternary mixture, is due to the Penning ionization of CO_2 (or H_2O) in collisions with excited Ar^* atoms. The ternary mixtures -- being fast, cool, and efficient -- have potential for advanced gas-filled particle detectors such as those for the SCC muon chambers.

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INTRODUCTION

Considerable efforts have recently been made to explore and develop appropriate gas mixtures for use in particle detectors in general and in the Superconducting Super Collider (SCC) muon detectors in particular [1-4]. Gaseous media for precise particle detectors must possess good chemical properties (e.g., low flammability and toxicity; be nonexplosive), high electron drift velocity, w, ("fast" gas), high gain ("efficient" gas), low electron diffusion ("cool" gas), and high corona inception and breakdown voltages; they also must be nonelectron attaching.

A measure of the efficiency of the detector gas mixture is the magnitude of the gas-density normalized effective ionization coefficient $\bar{\alpha}/N$. We define $\bar{\alpha}/N$ as the difference between the gas-density normalized ionization coefficient α/N and the gas-density normalized electron attachment coefficient η/N. Also, from the values of the $(E/N)_{lim}$ we can determine which gas mixtures possess better breakdown strengths.

In this paper we report our measurements on w(E/N), $\bar{\alpha}/N(E/N)$ and $(E/N)_{lim}$ for various unitary, binary, and ternary gas mixtures of possible interest to SSC muon detectors.

EXPERIMENTAL TECHNIQUE

The technique used has been described earlier [4]. The experimental set up is shown in Fig.1. The cell used consists of six-way 10.2 cm wide stainless steel cube with a sapphire window to allow a laser beam to enter the cell. The two parallel stainless steel electrodes were circular disks of 3.8 cm diameter and were held at a distance of 1.01 cm. The photons strike the cathode through a hole (~0.1 cm diameter) in the anode electrode; a converging lens was used to pass the laser light through the hole. The induced signal due to the motion of the photoelectrons in the drift gap was detected and recorded with a Tektronix 7912AD digitizer through a 50Ω resistor to ground; this signal is proportional to the induced electron current in the gap. From the recorded electron current waveforms we determined the electron drift velocity and the effective ionization coefficient as a function of E/N.

The gases used Ar (99.999%), CO_2 (99.995%), CF_4 (99.9%) and CH_4 (99.99%) were obtained from Matheson Gas Products and the H_2O (99.9%) was purchased from Aldrich Chemical Company. All the samples were subjected to several vacuum distillation cycles prior to any measurements in order to remove air from the samples. All the measurements were made at T ~ 300 K and the total gas number density was varied from 6.48 x 10^{16} to 2.43 x 10^{19} molecules cm^{-3}.

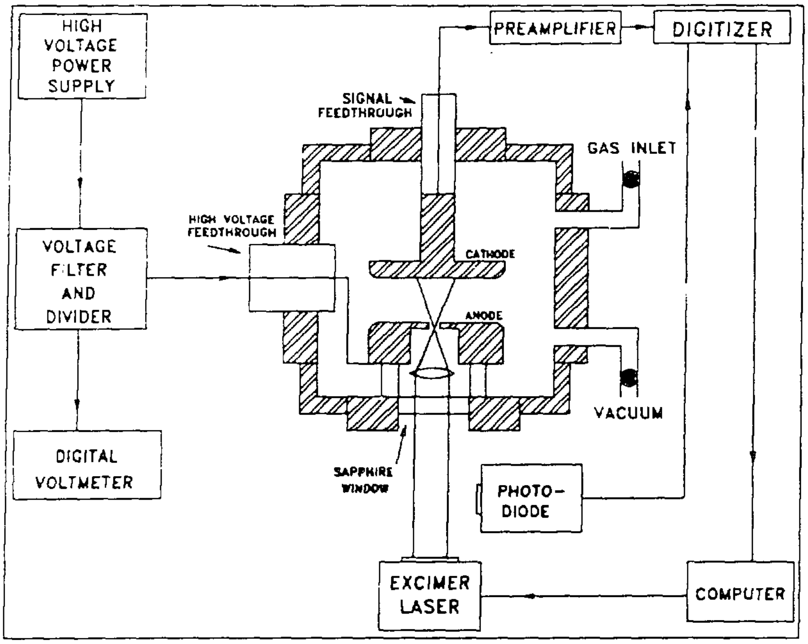

Fig. 1. Schematic diagram of the experimental set up.

RESULTS

A. Unitary Gases

In Fig. 2 we present our measurements of $\bar{\alpha}/N(E/N)$ for Ar, CO_2 and CF_4. The agreement between the measured $\bar{\alpha}/N(E/N)$ for CO_2 and the earlier reported experimental values [5] is good while the reported calculated results [6] are higher than both the present and earlier experimental results. The $\bar{\alpha}/N(E/N)$ for CF_4 are in excellent agreement with previous measurements [7]. The $\bar{\alpha}/N(E/N)$ for Ar becomes positive at $E/N \sim 25 \times 10^{-17}$ V cm^2 and rapidly exceeds that of either CO_2 or CF_4. This reflects the fact that for a fixed E/N the mean electron energies in Ar are much higher than for the other two gases. The electrons are slowed-down more efficiently in CO_2 and CF_4 principally because of the low-lying negative ion states for CO_2 and because of both the low vibrational thresholds and negative ion states for CF_4.

In Fig. 3 are presented our measurements of w(E/N) for Ar, CO_2, and CF_4. For CO_2 the measured w(E/N) are in excellent agreement with data found in the literature [8-10] for $E/N < 200 \times 10^{-17}$ V cm^2

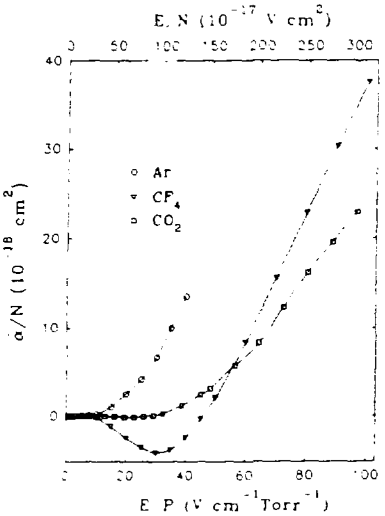

Fig. 2. Measured $\bar{\alpha}$/N vs E/N (or E/P) for Ar, CF_4, and CO_2.

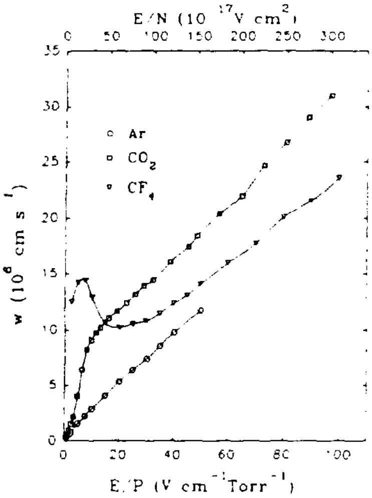

Fig. 3. Measured w vs E/N (or E/P) for Ar, CF_4, and CO_2.

while for higher E/N values the measured w(E/N) are higher than those reported [10]. The measured w(E/N) for CF_4 compare well with earlier work [11]. Figure 3 shows the superior properties of CF_4 in terms of electron drift [3,4,11-13]. In the E/N range in which the particle detector would normally operate (E/N < 10 x 10^{-17} V cm^2) CF_4 possesses the highest electron drift velocity from all the three systems studied.

B. Binary Gas Mixtures

In Fig. 4 we summarize our measurements of $\bar{\alpha}$/N(E/N) for the binary mixtures CF_4:Ar (20:80), CO_2:Ar (20:80) and CO_2:CH_4 (20:80). At E/N > 150 x 10^{-17} V cm^2, the CF_4:Ar mixture exhibits the highest $\bar{\alpha}$/N values, but $\bar{\alpha}$/N becomes negative below ~72 x 10^{-17} V cm^2 attaining its lowest value at ~50 x 10^{-17} V cm^2. This indicates that in the E/N range from ~15 x 10^{-17} to ~ 72 x 10^{-17} V cm^2 electron attachment exceeds ionization. The CO_2:Ar mixture has a somewhat lower $\bar{\alpha}$/N than the CF_4:Ar binary mixture for E/N >150 x 10^{-17} V cm^2. However, for the CO_2:Ar gas mixture $\bar{\alpha}$/N remains always positive. The third binary gas mixture CO_2:CH_4 exhibits the lowest $\bar{\alpha}$/N(E/N) values of the three binary systems studied for E/N > 72 x 10^{-17} V cm^2. Below this E/N

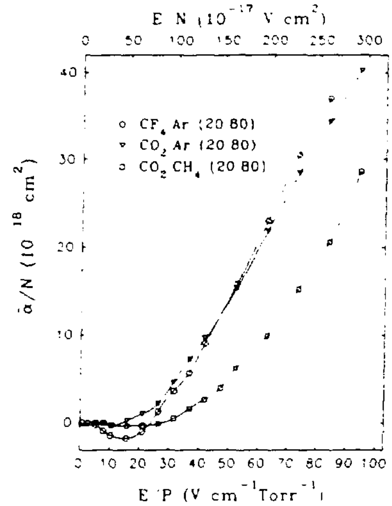

Fig. 4. Measured $\bar{\alpha}/N$ vs E/N for CF_4:Ar, CO_2:Ar CO_2:CH_4 binary gas mixtures.

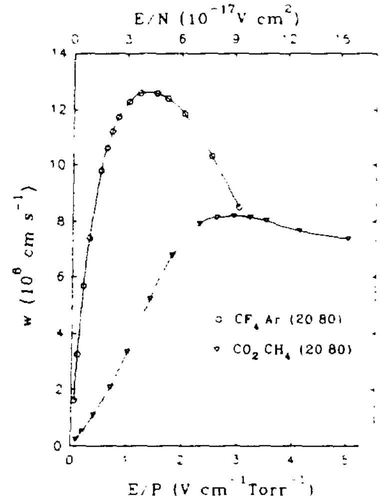

Fig. 5. Measured w vs E/N (or E/P) for CF_4:Ar (20:80) and CO_2:CH_4 (20:80) gas mixtures.

value, the $\bar{\alpha}/N(E/N)$ for CO_2:CH_4 is smaller than that of CO_2:Ar, but larger than the $\bar{\alpha}/N$ for CF_4:Ar. In Figures 5 and 6 we summarize our measurements on w(E/N) for the binary mixtures we studied. In Fig. 5 we compare the w for CF_4:Ar (20:80) and CO_2:CH_4 (20:80) and in Fig. 6 that for CF_4:Ar (20:80) and CO_2:Ar (20:80).

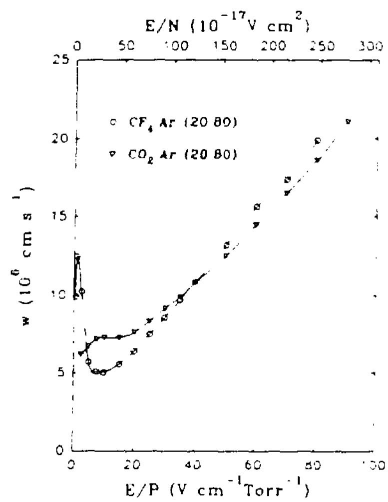

Fig. 6. Measured w vs E/N (or E/P) for CF_4:Ar (20:80) and CO_2:Ar (20:80) gas mixtures.

C. Ternary Gas Mixtures

Because of the favorable transport properties of the CF_4:Ar mixtures we selected the CF_4:Ar (20:80) gas mixture for possible enhancement of its electron yield. This we attempted by addition of a third additive which also shifts the electron energies to lower values (making it "cooler"). We used two known good electron thermalizing molecules [13,14] CO_2 and H_2O. We measured $\bar{\alpha}$/N and w as a function of E/N for the ternary mixtures CO_2:CF_4:Ar (10:10:80) and H_2O:CF_4:Ar (2:18:80). The measured $\bar{\alpha}$/N(E/N) and w(E/N) are plotted in Figs. 7 and 8, respectively along with the $\bar{\alpha}$/N(E/N) and w(E/N) for CF_4:Ar (20:80) for comparison. We found that $\bar{\alpha}$/N(E/N) for CO_2:CF_4:Ar (10:10:80) is always ≥ 0 over the entire E/N range studied and that it is also somewhat higher than that for CF_4:Ar (20:80) in spite of the fact that the electron energies shift towards lower values for a given E/N value [3]. For the H_2O:CF_4:Ar (2:18:80), $\bar{\alpha}$/N(E/N) becomes negative for values of E/N below $< 73 \times 10^{-17}$ V cm^2. However, when E/N $\geq 100 \times 10^{-17}$ V cm^2, $\bar{\alpha}$/N(E/N) attains values which are larger than those in either CF_4:Ar (20:80) or CO_2:CF_4:Ar (10:10:80); this is due to the Penning ionization of H_2O molecules by the excited Ar^* atoms.

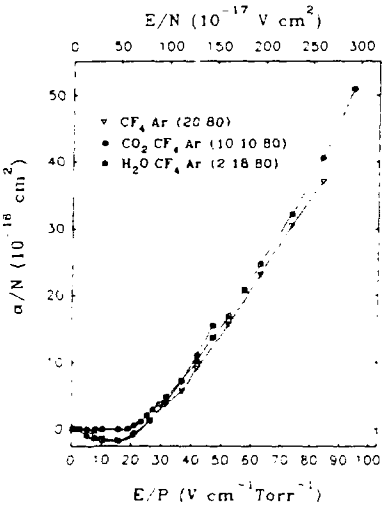

Fig. 7. Measured $\bar{\alpha}$/N vs E/N (or E/P) for CF_4:Ar (20:80), CO_2:CF_4:Ar (10:10:80) and H_2O:CF_4:Ar (2:18:80) gas mixtures.

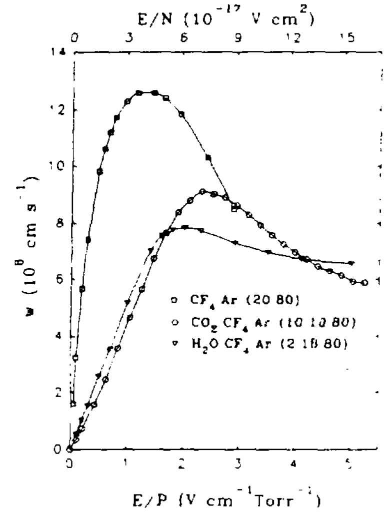

Fig. 8. Measured w vs E/N (or E/P) for CF_4:Ar (20:80), CO_2:CF_4:Ar (10:10:80) and H_2O:CF_4:Ar (2:18:80) gas mixtures.

D. Limiting Electric Field Strengths

The limiting electric field strength, $(E/N)_{lim}$, of a gas is defined [7,14] as the maximum E/N value for which $\bar{\alpha}/N$ [$= (\alpha/N - \eta/N)$] is still ≤ 0. Under certain conditions (e.g., absence of significant secondary electron loss or gain processes such as secondary ionization, electron detachment, etc.) $(E/N)_{lim}$ can be identified with the uniform breakdown field strength of the gaseous medium. We determined approximate values of $(E/N)_{lim}$ for the gas mixtures we studied. These are summarized in Table I along with earlier experimental values for the unitary gases.

TABLE I. Approximate Values of the Electric Field Strength, $(E/N)_{lim}$.

Gas/Mixture	$(E/N)_{lim}$ (10^{-17} V cm^2)	
	Present values	Previous values
Ar	25	25.2[13]
CF_4	142	140[7],143[15],[16]
CO_2	93	108[17],87[5]
CF_4:Ar (20:80)	72	
CO_2:Ar (20:80)	42	
CO_2:CH_4 (20:80)	85	
CO_2:CF_4:Ar (10:10:80)	55	
H_2O:CF_4:Ar (2:18:80)	73	

CONCLUSIONS

The results presented in this paper show that it is possible to develop multicomponent gas mixtures that are both fast ($w \sim 10^7$ cm s^{-1}) and cool [$\langle\varepsilon\rangle < 1$ eV at convenient operating E/N values (less than 10×10^{-17} V cm^2)] as well as efficient ($\bar{\alpha}/N \sim 10^{-17}$ cm^2) and with reasonably high $(E/N)_{lim}$ values. While a number of binary gas mixtures appear to be suitable for muon and other high-energy particle detectors, ternary gas mixtures such as CO_2:CF_4:Ar or H_2O:CF_4:Ar in approximate ratios of 10:10:80 and 2:18:80, respectively, seem to be promising based on the present measurements of their electron drift velocities, effective ionization coefficients, and $(E/N)_{lim}$ and mean electron energies reported earlier [3].

REFERENCES

[1] U. Becker, M. Carrel, M. Chen, M. White, C. H. YE, K. YEE, J. Fehlmann, and P. G. Seiler, *Nucl. Instr. Meth.*, 214, 525 (1983).

[2] R. Donaldson and M. G. D. Gilchriese (Eds.), in *Experiments, Detectors, and Experimental Areas for the Supercollider* , World Scientific Publishing Company, Singapore (1988).

[3] L. G. Christophorou, P. G. Datskos, and J. G. Carter, *Nucl. Instr. Meth. Phys. Res.* (in Press).

[4] P. G. Datskos, J. G. Carter, and L. G. Christophorou, *J. Chem. Phys.* (submitted).

[5] M. S. Bhalla and T. D. Craggs, *Proc. Phys. Soc.* 76, 369 (1960).

[6] H. N. Kucukarpaci and J. Lucas, *J. Phys. D* 12, 2123 (1979).

[7] S. R Hunter, J. G. Carter, and L. G. Christophorou, *J. Chem. Phys.* 86, 693 (1987).

[8] M. T. Elford and G. N. Haddad, *Austr. J. Phys.*, 33, 517 (1980).

[9] R. A. Sierra, H. L. Brooks, A. J. Sommever, S. R. Foltyn, and K. T. Nygaard, *J. Phys. D* 14, 1791 (1981).

[10] H. T. Saellee, J. Lucas, and T. W. Limbeek, *IEE Solid State Electron. Dev.* 1, 111 (1979).

[11] L. G. Christophorou, D. L. McCorkle, D. V. Maxey, and J. G. Carter, *Nucl. Instr. Meth.* 163 141 (1979).

[12] L. G. Christophorou, *Atomic and Molecular Radiation Physics*, Wiley, New York (1971).

[13] L. G. Christophorou and S. R. Hunter, in *Electron Molecule Interactions and Their Applications*, (Ed. L. G. Christophorou) Academic Press, New York (1984).

[14] L. G. Christophorou and L. A. Pinnaduwage, *IEEE Trans. Elect. Insul.* 25, 55 (1990).

[15] C. S. Lakshminarasimha, J. Lucas, and D. A. Price, *Proc. Inst. Electr. Eng.* 120, 1044 (1973).

[16] C. S. Lakshminarasimha, J. Lucas, and R. A. Snelson, *Proc. Inst. Electr. Eng.* 122, 1162 (1975).

[17] L. G. Christophorou, D. R. James, and R. Y. Pai, in *Applied Atomic Collision Physics* (Eds. H. S. W. Massey, E. W. McDaniel, and B. Bederson), Academic Press, New York (1982).