

Measuring the mobilities of the ions formed in P-10 mixtures

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Abstract—We measured the reduced mobilities (k_0 in $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$) of the ions that are formed in P-10 mixtures under different pressures and various reduced electric fields. Two types of ions were identified. We then used the extrapolated values of k_0 when $E/N \rightarrow 0$ (2.41 and $2.76 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$), the Langevin formula and the Blanc's law, to calculate the masses of these ions. Calculations indicate that the two ions have masses of 41 a.u. and 25 a.u., respectively. We propose hypothesis to explain the nature and origin of those ions.

I. INTRODUCTION

KNOWING the mobilities of ions in gases is a matter of great importance for gaseous radiation detectors. In radiation detectors based on avalanche processes the drift of positive ions near the anode plays a significant role in the pulse formation [1]. Therefore, in order to fully understand these detectors it is important to have detailed information on the transport properties of ions in the detector gases.

The P-10 mixture (90% Ar + 10% CH₄) is commonly used as a filling gas in gaseous detectors [2]. Due to the Penning effect and given that the argon ionization energy (15.7596 eV [3]) is greater than that of methane (CH₄/CH₄⁺: 12.65±0.4 eV [4]), a greater number of ion pairs are formed as a result of the interaction of the radiation with the gaseous medium. Methane is also a quench gas thus suppressing photon-induced effects that may lead to the loss of proportionality in gaseous radiation detectors [2].

Let's consider a swarm of ions moving in a gas of uniform temperature and constant pressure. If a uniform electric field is applied, after a number of ion-neutral collisions, a steady state is attained where the velocity of the centre of charge of the ion cloud, v_d , is directly proportional to the electric field intensity E . Thus $v_d = kE$, where k is the mobility of the ions. To facilitate the comparison and use of data, the mobility is usually converted into a reduced mobility, k_0 , defined by the equation $k_0 = kN/N_0$ where N is the gas number density and N_0 its value at 273 K and 1 atm ($N_0 = 2.687 \times 10^{19} \text{ cm}^{-3}$).

The scope of this work is to measure the reduced mobilities of the ions that are formed in P-10 mixtures under different pressures and E/N values.

II. EXPERIMENTAL SETUP

The measurements were carried out using a set up that will be described in detail in an article to be published later. It consists on a vessel filled with P-10, containing a xenon UV flash lamp (Hamamatsu L2439), a standard CERN Gaseous Electron Multiplier (GEM [5]) covered with a 200 nm thick CsI photocathode and two closely spaced grids (0.5 mm apart).

Pulsed photons from the UV flash lamp (repetition rate of 10 Hz) cause the release of photoelectrons from the CsI photocathode which enter the GEM holes where, due to the intense electric field, they ionize the surrounding gas atoms. The ions that are produced, mostly atomic ions, are extracted from the GEM holes and made to drift along a 21.7 mm long region under the influence of an uniform electric field. The grid which is closest to the GEM acts as a Frisch grid [2] shielding the other grid which collects the ions producing a voltage pulse.

The pulse is fed to a voltage pre-amplifier before being recorded in a digital oscilloscope (Tektronix TDS 1012) that enables the continuous calculation of the average of up to 128 pulses. This information is transmitted to a computer where it is further processed.

Measuring the time that the ions take to travel the distance between the GEM and the Frisch grid allows for the calculation of their drift velocities.

III. RESULTS

We measured the mobilities of the ions that are formed in P-10 mixtures for different reduced electric fields E/N (from 7.9 up to 28 Td) and for different pressures (in the 5.5-10.2 Torr range). Two types of ions were identified (Fig. 1).

We then calculated by extrapolation the reduced mobilities of these two ions when $E/N \rightarrow 0$, the ions' Langevin limits, and obtained the following values, 2.41 and $2.76 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ (Fig.2).

We also varied the voltage across the GEM, VGEM, and registered the evolution of the ions' induced signal (Fig.3).

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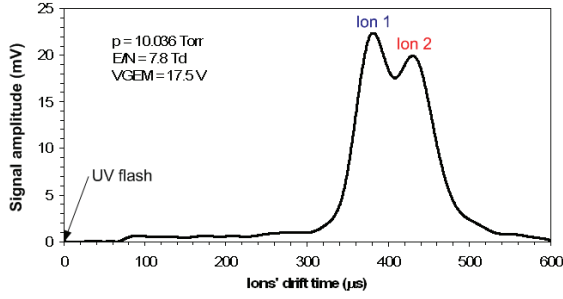


Fig. 1. Typical average of 128 digitalized ion induced pulses recorded in a P-10 mixture at 10.036 Torr, for a reduced electric field, E/N , of 7.8 Td and for a voltage across the GEM, VGEM, of 17.5 V. The signal induced by the UV flash has been subtracted from the original spectrum.

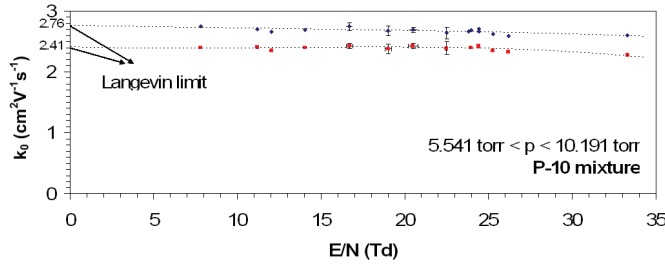


Fig. 2. Reduced mobilities of the two ions formed in P-10 mixtures. Measurements were carried out for pressures between 5.5 and 10.2 Torr and for E/N values in the 7.9–28 Td range. For each ion, the value of k_0 when $E/N \rightarrow 0$ (Langevin limit), was extrapolated.

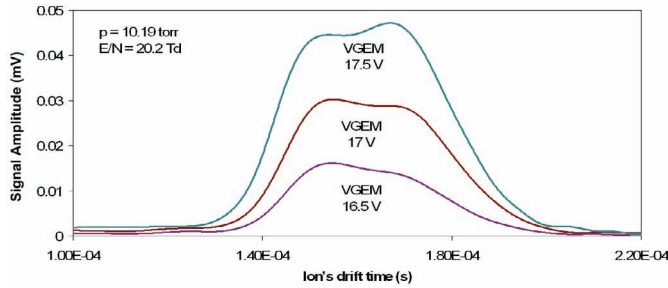


Fig. 3. Variation of the ions' induced pulse with the voltage across the GEM, VGEM. Measurements carried out at 10.19 Torr and for a E/N of 20.2 Td.

IV. DISCUSSION

In the absence of charge exchange effects and ion or atom exchange or interchange upon collision, the Langevin polarization limit, represents a limit for k_0 [6]. According to the Langevin's theory, published in 1905 [7], the limiting value of the mobility is reached when the repulsion cross section becomes negligible compared with the polarization effect. Assuming the predominance of the polarization interaction, the Langevin limit reads [8], $k_0 = 13.88/\sqrt{\alpha\mu}$, where α is the neutral polarizability in cubic angstroms and μ is the ion-neutral reduced mass in atomic mass units.

The Blanc's law uses the mobility of a charged particle in two or more gases to calculate the mobility of that same particle in the gas mixture, for which data may not be available [9]. The basic form of the Blanc's law for an ion moving in a two gas mixture is, $1/k_{0m} = \beta_1/k_{01} + \beta_2/k_{02}$, where k_{0m} is the ion reduced mobility in the gas mixture, β_1 is the

fractional concentration of the gas in which the reduced mobility is k_{01} and β_2 the fractional concentration of the a gas in which the reduced mobility is k_{02} .

Applying both the Blanc's law and the Langevin formula we obtained the following formula for the ion reduced mobility in a P-10 mixture,

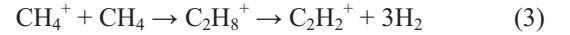
$$1/k_{0m} = 0.1/(13.88/\sqrt{\alpha_1\mu_1}) + 0.9/(13.88/\sqrt{\alpha_2\mu_2}) \quad (1)$$

where α_1 and α_2 , are the CH_4 and Ar polarizabilities ($\alpha_1 = 2.62 \times 10^{-24} \text{ cm}^3$ [10] and $\alpha_2 = 1.64 \times 10^{-24} \text{ cm}^3$ [11]), and μ_1 and μ_2 are the ion- CH_4 and the ion-Ar, reduced masses, respectively. For each of the two observed ions, we substituted k_{0m} by the extrapolated value of k_0 (when $E/N \rightarrow 0$ Td), and then solved equation (1) numerically in order to determine the mass of the ion.

The slower ion, for which $k_{0m} = 2.41 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$, has a mass of 41 a.u. We looked in the literature for ions with similar masses that could result from reactions involving Ar and/or CH_4 neutrals and/or ions. In this case, the strongest candidate is the ArH^+ ion, with a mass of 41 a.u., which may be formed in a collision involving an Ar^+ ion and a CH_4 molecule [12]:



The faster ion, with an extrapolated reduced mobility of $2.76 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$, has a mass of 25 a.u. In this case, the most likely candidate is the C_2H_2^+ ion, with a mass of 26 a.u., which could be formed through reaction:



The results presented in Fig. 3 regarding the variation of the ions' induced pulse with the voltage across the GEM, reveal that not only does the overall peak intensity increases with VGEM (as VGEM increases so does the number of ions produced in the GEM holes) but also the relation between the amplitudes of the two observed peaks is altered. As VGEM increases, so does the amplitude of the 2nd peak corresponding to the slower ion. This could corroborate the choice of reactions (2) and (3).

As VGEM is raised, the photoelectrons acquire more and more energy as they drift inside the GEM holes. This means that for low values of VGEM, photoelectrons may only have enough energy to ionize the CH_4 molecules. However, if we raise VGEM we give photoelectrons the energy to ionize Ar atoms. So, for low VGEM voltages mostly CH_4^+ ions are formed, which then result in C_2H_2^+ ions through reaction (3). That's why the 1st peak, corresponding to the faster ion, is more prominent for low VGEM values. For higher VGEM voltages, Ar ionization is more significant and the Ar^+ ions then form the observed ArH^+ ions through reaction (2).

V. CONCLUSIONS

We have measured the mobilities of the ions that are formed in P-10 mixtures under different pressures and different

reduced electric field values. Two ions were identified and their masses were calculated combining the Blanc's law and the Langevin formula. We suggest hypothesis to explain the nature and origin of each of the ions. We're already studying the behavior of the ions' time arrival spectra for different Ar-CH₄ concentrations to further support our explanations.

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