Experimental ion mobility measurements for the LCTPC Collaboration

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LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTICULAS

Abstract

Measuring the mobility of ions in gases is relevant in several areas, from physics to chemistry, e.g. in gaseous radiation detectors modelling and in the understanding of the pulse shape formation. One of these examples is the upcoming LCTPC (Linear Collider TPC) for the International Linear Collider (ILC), where a gating device will be installed at a certain distance from the gas amplification stage to neutralize the ions produced. Knowing the ion mobility will allow to define this distance and to ensure a high ion reduction while minimizing the thickness of the end plate (LCTPC Collaboration, 2017).

This work focuses on measurements of positive ion mobility for mixtures of interest for the LCTPC, more specifically Ar-CF_4-iC_4H_{10} (95-3-2). The results are grouped in 3 different mixtures: Ar-CF_4 (Cortez et at. 2017, Santos et al. 2018), CF_4-iC_4H_{10} and Ar-iC_4H_{10} for low reduced electric fields (from 15 Td to 25 Td), at low pressures and at room temperature are here presented.

Introduction

Ion mobility – Fundamental concepts

- A group of ions moving in a weakly ionized gas under a uniform electric field will reach a steady state and the resulting average speed of this group of ions, v_d, is directly proportional to the electric field intensity (E), where K is the ion mobility.
- According to Langevin's theory, there are two limits: one for the elastic scattering (typically for large organic molecules) and one where the polarization dominates. The elastic is not really observed and so in these mixtures the Langevin formula used is the one corresponding to the polarization limit.
- Using Blanc's law the reduced mobility of the binary and tertiary gas mixtures can be determined and compared with the experimental values obtained.
- Ions react and transfer their charge, the resulting drifting ions are mostly ions with the lowest ionization potential: 15.70 eV for Ar, 15.69 eV for CF_4 and 10.7 eV for iC_4H_{10}.

Mobility

$$v_{drift} = KE$$

Reduced Mobility

$$K_0 = KN/N_0$$

Blanc's law

$$\frac{1}{K_{0,\,mix}} = \frac{f_1}{K_{0,\,gas\,1}} + \frac{f_2}{K_{0,\,gas\,2}}$$

Langevin Limit

$$K_0 = 13.88\left(\frac{1}{\alpha\mu}\right)^{\frac{1}{2}}$$

N_0: Loschmidt number
N: gas number density
μ: ion neutral-reduced mass mixture

α: neutral polarizability
f_n: molar fraction of the gas n in the binary

Experimental Set-up & Working Principle

To perform these measurements a drift chamber was developed, that uses a gaseous electron multiplier (GEM) covered with a 250 nm thick CsI film as the photocathode, a UV flash lamp with a frequency of 10 Hz and with pulse duration shorter than 0.5 µs, and two grids separated by 0.5 mm .

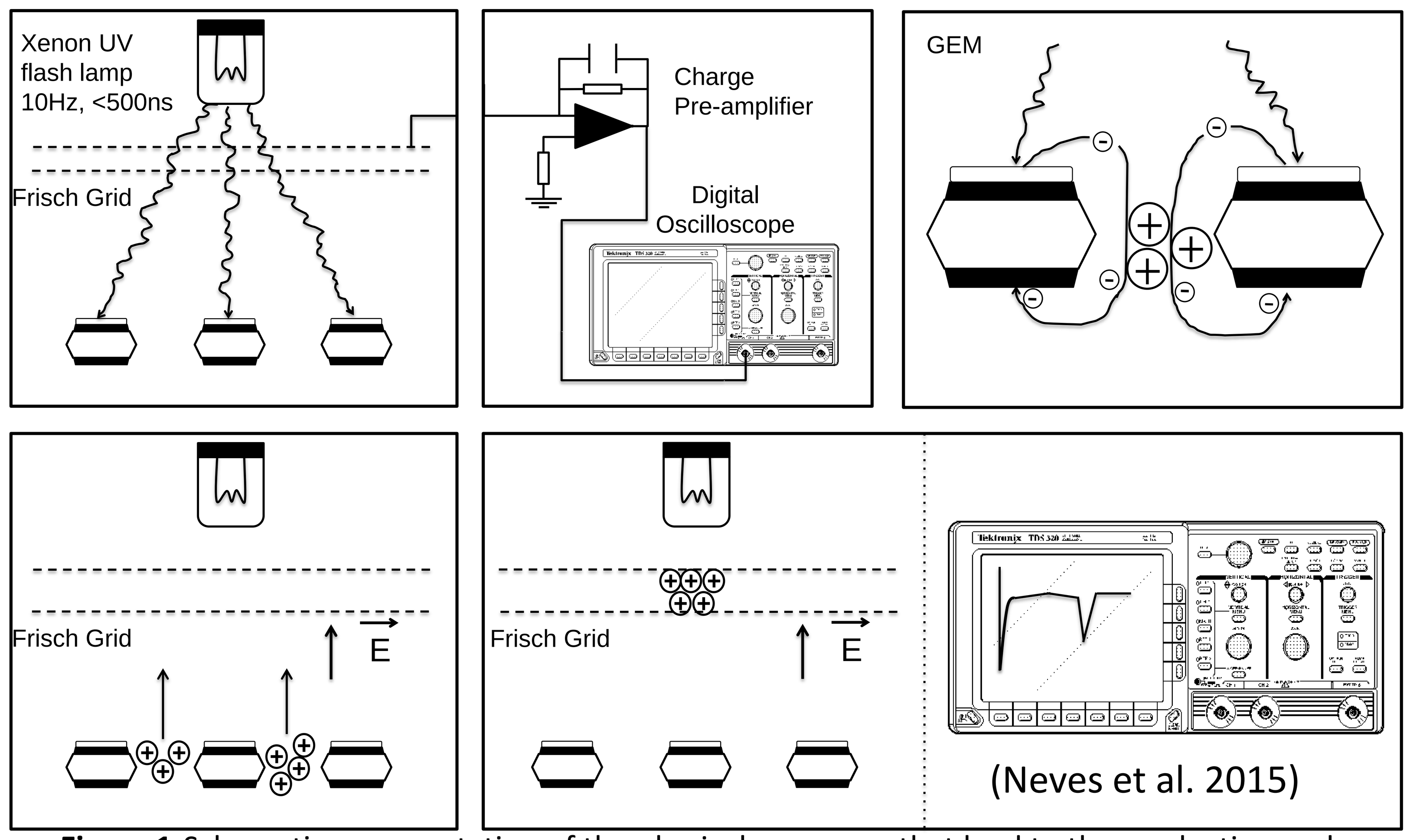


Figure 1-Schematic representation of the physical processes that lead to the production and detection of ions

Results and Discussion

The first step for the understanding of the Ar-CF_4-iC_4H_{10} mixture was to study the ion mobility of Ar-CF_4 (Santos et al. 2018). In this mixture only one peak was observed in the entire range of mixtures studied, with the mobility increasing with Ar concentration, as can be seen in figure 2.

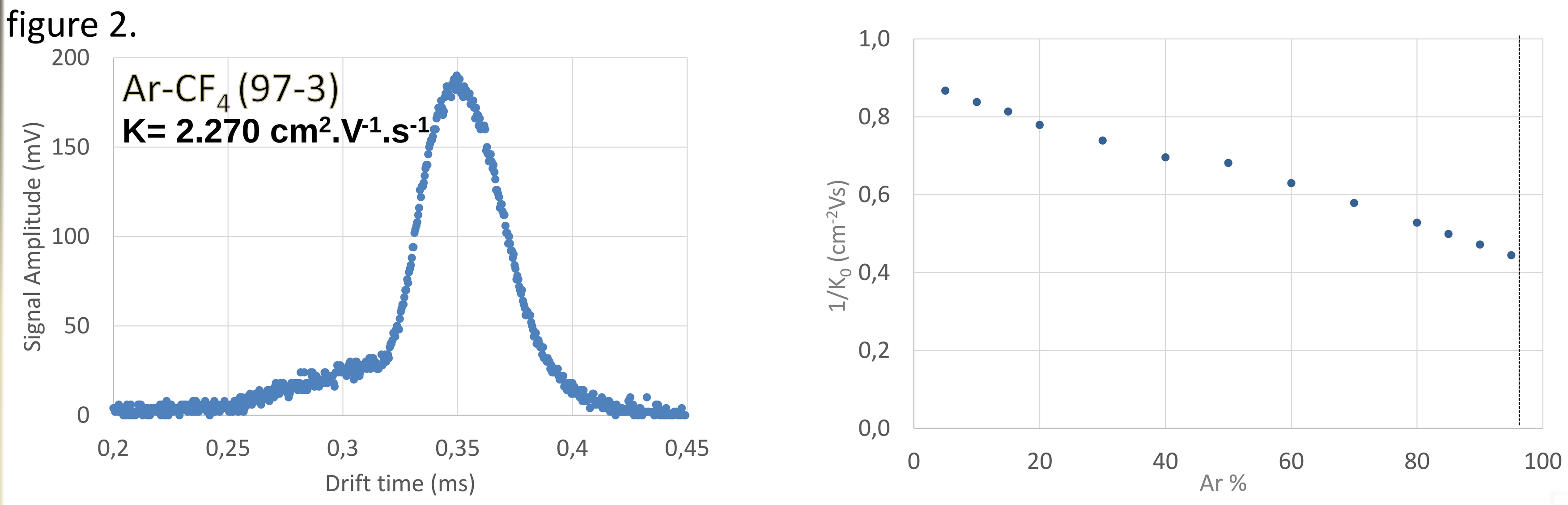


Figure 2- At the left a typical drift spectrum of Ar-CF_4 (97-3); at the right the inverse of the reduced mobility of the ions produced in the same mixture varying the relative concentration of the gases.

In CF_4-iC_4H_{10} mixtures, one or two peaks are observed in the entire range of mixtures studied, with the mobility increasing with CF_4, as can be seen in figure 3.

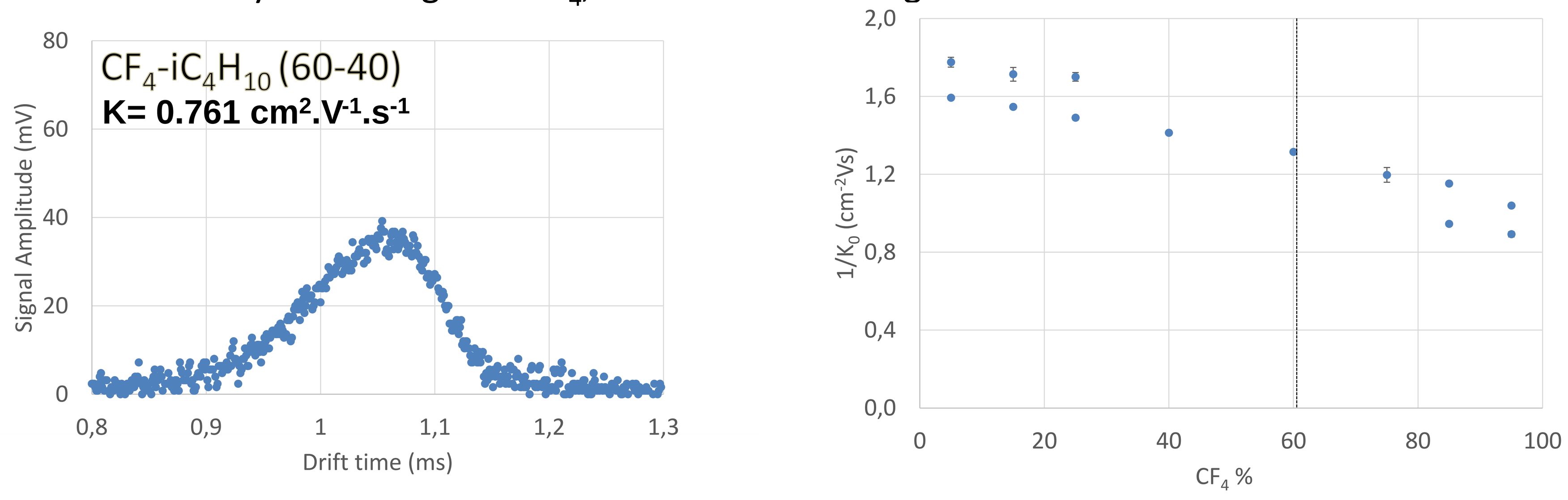


Figure 3- At the left a typical drift spectrum of CF_4-iC_4H_{10} (60-40); at the right the inverse of the reduced mobility of the ions for the same mixture varying the relative concentration of the gases (same conditions).

In Ar-iC_4H_{10} mixtures, one peak is observed in the entire range of mixtures studied, with the mobility increasing with Ar, as can be seen in figure 4. The ion responsible for the peak observed comes from iC_4H_{10}.

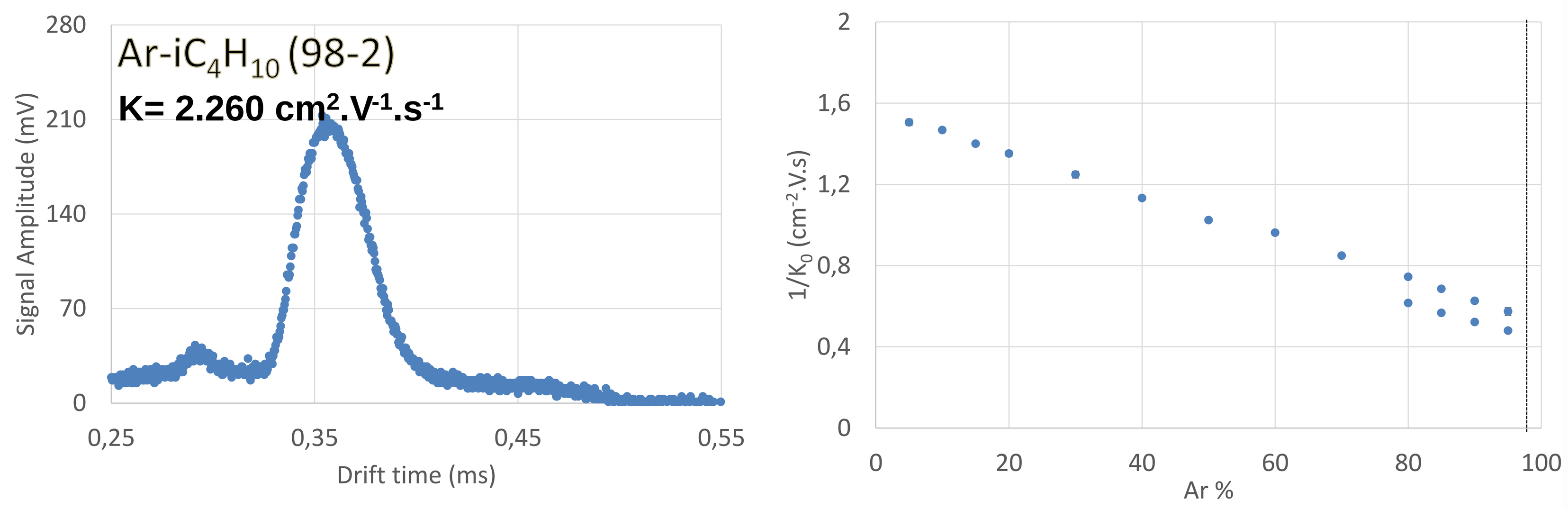
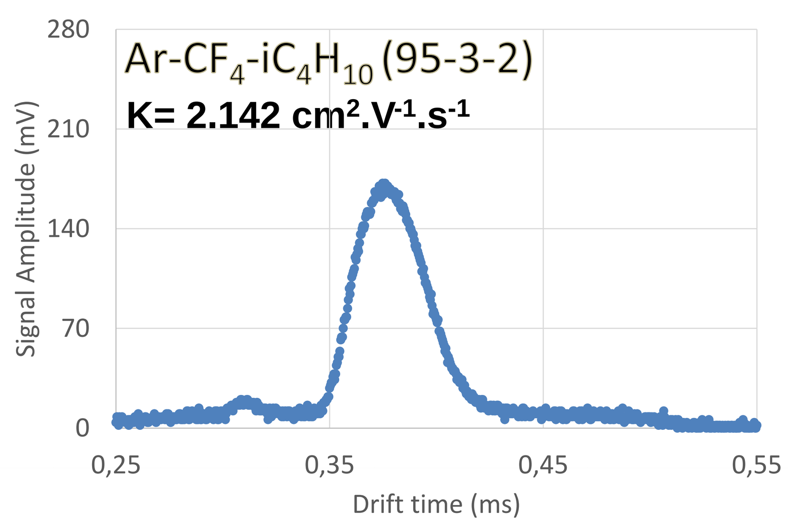


Figure 4- At the left a typical drift spectrum of Ar-iC_4H_{10} (98-2); at the right the inverse of the reduced mobility of the ions for the same mixture varying the relative concentration of the gases.

In the Ar-CF_4-iC_4H_{10} (95-3-2) mixture intended for the LCTPC Collaboration one peak is observed,. The ions responsible for the peak observed are the same as in the Ar-iC_4H_{10}.



Main conclusions:

- Mobility in the ternary gas mixture follows Blanc's law for iC_4H_{10} (within about 1%);
- Mobility increases with Ar concentration;
- Small bump is due to the presence of impurities (mainly water).

Figure 5- At the left a typical drift spectrum of Ar-CF_4-iC_4H_{10} (95-3-2); at the right the inverse of the reduced mobility of the ions for the same mixture varying the relative concentration of the gases.

Conclusions

With this study we were able to fully characterize in terms of ion mobility the different binary gas mixtures that form the one relevant for the LCTPC Collaboration. In Ar-CF_4 mixtures the mobility increases with Ar concentration. In CF_4-iC_4H_{10} mixtures, the mobility is seen to increase with CF_4. In Ar-iC_4H_{10} mixtures the mobility was seen to increase with Ar. This is a direct result of the mass of the atoms/molecules and of the ion involved in this process. In the mixtures of three gases the mass of the ion formed will determine if the mobility increases or not.

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