

Experimental Measurement of H_3^+/H_5^+ and D_3^+/D_5^+ mobilities in their parent gases

P.N.B. Neves, J. Escada, F.I.G.M. Borges, L.M.N. Távora and C.A.N. Conde, *IEEE Life Member*

Abstract– The experimental study of the reduced mobility K_0 of the molecular ions H_3^+/H_5^+ in H_2 and D_3^+/D_5^+ in D_2 was carried out using a recently developed technique, that uses a Xe VUV flash lamp and a Gaseous Electron Multiplier (GEM) microstructure with a CsI deposit to produce the molecular ions by electron avalanche ionization. For both gases, the K_0 values were obtained at room temperature (295 K) and at pressures from 5 to 50 Torr for uniform reduced electric fields E/N from 4 to 40 Td. The reduced mobility derived from the measurements is an average of the K_0 value of the two molecular ions, and for the H_3^+ and H_5^+ ions is $11.1 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ while for D_3^+ and D_5^+ it ranges from 8.5 to $7.8 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$, for pressure from 5 to 50 Torr. A discussion of the obtained results is presented.

I-INTRODUCTION

The study of the drift velocity, v_d , of ions in a gas with number density, N , under an electric field, E , is an issue of interest in many fields of physics, namely in ion sources, plasma physics, ion mobility spectrometry, astrophysics, etc. The parameter usually considered is the reduced mobility K_0 defined by $K_0 = \frac{v_d}{E/N} N_0$, where N_0 is the number density at standard values of pressure and temperature. In most cases, K_0 is approximately constant for low E/N values.

The measurement of K_0 for H_3^+ , H_5^+ , D_3^+ and D_5^+ molecular ions in their parent gases is an issue of great interest. Although some published results for the reduced mobilities of the referred ions in their parent gases already exist ([1,2,3] and references therein), in this work we use a new technique recently developed [4,5] to obtain these values for hydrogen and deuterium ions in their parent gases, at a temperature of 295 K, pressures from 5 to 50 Torr and for reduced electric fields, E/N , from 4 to 40 Td ($1\text{Td}=10^{17} \text{ Vcm}^2$).

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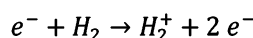
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P.N.B. Neves is with ATP Group CMAF, Lisboa, Portugal. J. Escada, F.I.G.M. Borges, and C.A.N. Conde are with LIP-Coimbra, Departamento de Física, Universidade de Coimbra, Coimbra, Portugal. L.M.N. Távora is with ESTG- Instituto Politécnico de Leiria, Leiria, Portugal

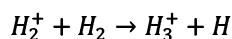
Corresponding author F.I.G.M. Borges e-mail: fborges@fis.uc.pt). Postal address LIP – Coimbra, Departamento de Física, Universidade de Coimbra, P-3004-516 Coimbra, Portugal.

II- EXPERIMENTAL TECHNIQUES AND RESULTS

The experimental system we used consists of a cylindrical vessel that includes a Gaseous Electron Multiplier (GEM) microstructure with a CsI deposit, a Xe VUV flash lamp (Hamamatsu L2439) and two grids 0.5 mm apart, one to collect the ions and a Frisch grid that shields the collecting one [4,5]. The UV photons strike the CsI photocathode on the GEM, originating photoelectrons which, through collisions with the gas atoms under an electric field inside the GEM holes, generate mainly the H_2^+ ion species through the process:

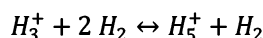


Under our operating conditions, this ion converts almost instantaneously to H_3^+ [6,7] through the reaction with the gas molecules



with a reaction rate $k=2.07 \times 10^{-9} \text{ cm}^3/\text{molecule/s}$.

Nevertheless, the H_5^+ ion can also be produced through a three body collision process:



which has an equilibrium constant $K_E=1.83 \times 10^{-18} \text{ cm}^3$, so both ions coexist and can be converted from one to another during their drift towards the grids, under the influence of a uniform reduced field, E/N [4]. Molecular cluster ions of order higher than 5 are not considered [8], since they are negligible at these operating conditions. The grids are 4.2 cm away from the GEM structure and when the ions are collected, the electronic signal generated is amplified through a voltage pre-amplifier, averaged and recorded in a digital oscilloscope (Tektronix TDS 2022B). The signal is then digitally processed, namely by subtracting the interfering pulse due to the lamp trigger pick up and a time of arrival spectrum is obtained. A typical time spectrum for the H_2 ions is presented in Fig. 1.

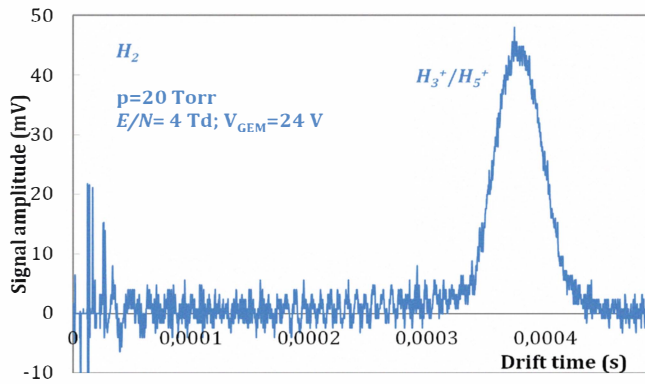


Fig. 1- Typical time spectrum obtained by averaging 128 digitized pulses, obtained in H_2 at a pressure of 20 Torr, $E/N=4$ Td and with 24 V across the GEM structure. The peak is fitted to a Gaussian and the drift time is obtained from the peak position.

From the spectrum the mean drift time, the drift velocity and the reduced mobility of the ions produced in the gas are obtained. However, as already explained, during the drift the H_3^+ and H_5^+ ions can be converted one to another, therefore the mobility values derived from the experiment are a weighted average of the mobilities of these two molecular ions, its value depending on the pressure in the vessel. Nevertheless, as it can be observed in Fig. 2, for the H_3^+/H_5^+ ions, in the pressure range studied, the mobility values remained fairly constant, with an average value of $11.1 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$. In deuterium, the K_0 values measured for the D_3^+/D_5^+ molecular ions showed a greater pressure dependence with values ranging from 8.5 to $7.8 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ for the same pressure range.

The measured reduced mobility K_0 for H_3^+/H_5^+ ions in H_2 at 5 Torr and for D_3^+/D_5^+ ions in D_2 at 5 and 15 Torr are plotted in Fig. 3. The extrapolated values for low E/N , $11.1 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ for the H_3^+/H_5^+ ions, and $8.5 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ for the D_3^+/D_5^+ molecular ions, agree with those obtained by Elford[1] and Graham [2], respectively.

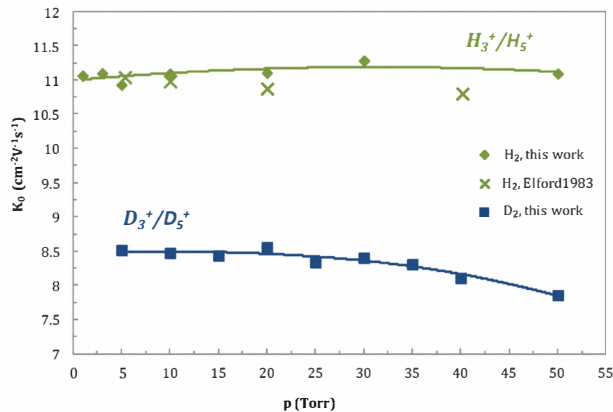


Fig. 2 – Measured reduced mobility values (K_0) for H_3^+/H_5^+ ions in H_2 and for D_3^+/D_5^+ ions in D_2 as a function of the pressure inside the chamber. Since no variation with E/N was observed (Fig. 3) for each pressure the K_0 value is an average of the K_0 values obtained for the different E/N reduced fields. The lines are polynomial fittings to the experimental values. Also plotted are the values obtained by Elford [1] for the H_2 case.

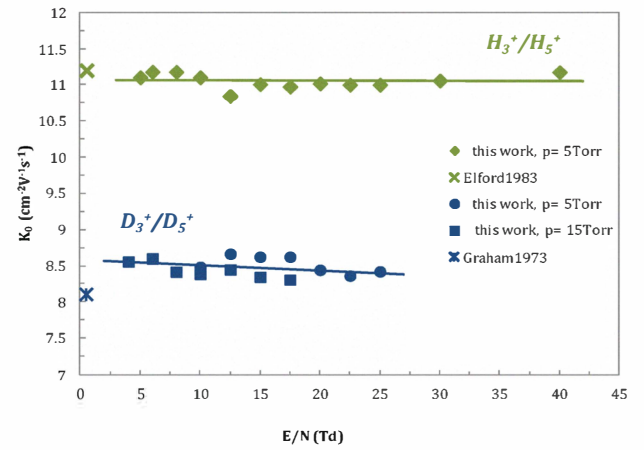


Fig. 3 – Measured reduced mobility values (K_0) for H_3^+/H_5^+ ions in H_2 and for D_3^+/D_5^+ ions as a function of the reduced electric field (E/N) at a pressure of 5 Torr in the H_2 case and for pressures of 5 and 15 Torr for the D_2 case. The lines are linear fittings to the K_0 values.

III- CONCLUSIONS

Our result for the mobilities of H_3^+/H_5^+ ions in H_2 agree well with the published data by Elford[1] for H_3^+ . Yet, we were not able to obtain the individual values for the mobility of H_5^+ in H_2 . The extrapolated D_3^+/D_5^+ mobility in D_2 is slightly higher than the published data by Graham [2] for D_3^+ , so further experimental work for a larger pressure range will have to be made.

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