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ENERGY AND ANGULAR DISTRIBUTION OF POSITIVE IONS FROM DISSOCIATIVE IONIZATION PROCESSES[1]

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(Invited talk presented at the 3rd General Conference of BPU)

Abstract. - In this paper we present the preliminary results of positive ion energy and angular distribution measurements from H_2, H_2O and CH_4 molecules as a result of dissociative ionization by electron impact. For H_2 our results agree well with numereous previously published data. The results for H_2O and CH_4 molecules are scarce and are mainly devoted to the ion energy distribution determinations. To our knowledge these are the first positive ion angular distribution measurements for these molecules.

1. INTRODUCTION

Electron - impact ionization cross sections of small molecules, containing atoms of H, C and O, are of great importance for the explanation of many processes in physics and related sciences. This includes discharges of different kinds, in nature and experimental. Therefore, experimentally measured and theoretically calculated data on ionization processes are collected by different data centers and are regularly reviewed in the literature ([1] - [4]).

Detailed analysis of the dissociative ionization processes of small molecules exist only for a limited number of species, since experiments of these kinds are somewhat more complicated than those for total and partial ionization cross section measurements. The most investigated molecule is H_2, as the simplest one, whose behavior can also be explained and predicted theoretically. More complex molecules (H_2O, CO_2, CH_4, *etc.*), have been investigated so far in a small number of experiments, although they are on the top of the list by their importance.

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[2]and Faculty of Physics, University of Beograd.

2. EXPERIMENTAL

The first attempt to investigate the dissociative ionization at the Institute of Physics in Beograd was as early as 1984. An experimental apparatus was constructed and some preliminary experiments were reported [5]. Recently, the apparatus was reactivated and improved [6], [7], [8].

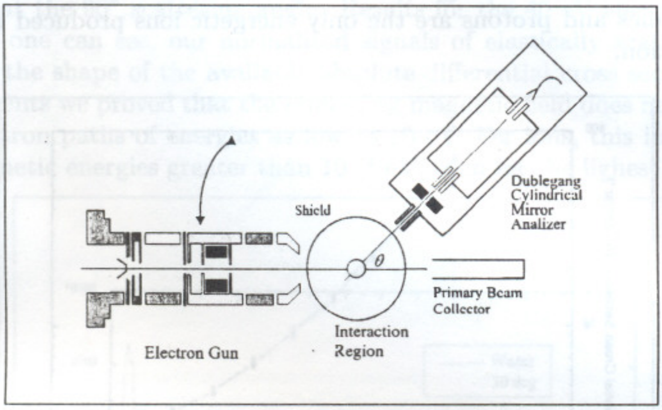

Fig. 1. - Schematic drawing of the experimental apparatus for the measurements of energy and angular distributions of ions from dissociative ionization processes.

Schematically the experimental set up is presented in Fig. 1. It has four sub - units: a) electron gun, b) primary electron beam collector, c) ion energy analyzer, and d) ion detector. The electron gun and the electron beam collector are fixed on a turntable, that can be rotated around the interaction chamber axis in an angular range from $-5°$ to $+120°$ with respect to the axis of the electrostatic entrance optics of the ion energy analyzer. Ion energy analyzer is mounted on the side flange of the vacuum chamber. The background pressure is about 2×10^{-7} mbar. The double μ - metal shield reduces the Earth and other stray magnetic fields less than 2×10^{-7} T in the whole experimental volume.

The simple electron gun produces nonmonoenergetic, collimated electron beam of up to 2 μA. With the present design the electron beam energy can be varied from 10 to 500 eV.

The effusive molecular beam is obtained by passing the target gas through a nonmagnetic, stainless steel needle. The particle density in the forward direction, in the interaction region (about 2 mm from the top of the needle) is estimated to be 10^{14} cm^{-3}, corresponding to a gas pressure of 10^{-2} mbar. Thus, binary collision conditions are fulfilled. The gas needle coincides with the rotation axes and is perpendicular to the incident electron beam.

The ion energy distribution was determined by a cylindrical mirror energy analyzer ([10], [11]) with an energy resolution of $\Delta\varepsilon/\varepsilon = 0.03$. Ions drifting from the interaction region, with kinetic energies gained during the dissociative ionization process, are accepted, accelerated and focused by a four element cylindrical lens system [12]. Ions that pass the energy analyzer are detected by a channel electron multiplier, in the single counting mode. Pulses from the detector shaped and collected in the usual multichannel analyzer mode.

Hydrogen was used as a target for testing and calibration as it is one of the most studied molecules and protons are the only energetic ions produced by the electron impact ionization.

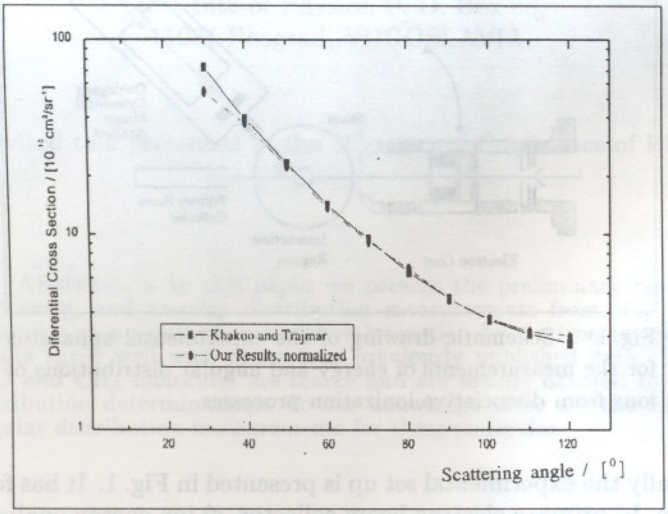

Fig. 2. - Normalized differential elastic cross sections by H_2 molecules at 40 eV incident energy electrons.

3. ELASTIC SCATTERING OF ELECTRONS BY HYDROGEN MOLECULES

The μ - metal shield has a number of openings for vacuum chamber pumping, rotational feedthroughs, electrical cables *etc.*, through which the Earth magnetic field can penetrate toward the interaction region with an unknown intensity and distribution. With the rotation of the electron gun and collector turntable around the vacuum chamber axis, relative positions of these openings to the electron and ion beam directions change, and with it the remaining magnetic field distribution in the vicinity of the collision center. In order to investigate any possible influence of the remaining magnetic field, angular distribution of elastically scattered electrons by hydrogen molecules have been undertaken.

With a constant incident electron energy, ε_0, molecular number density in the beam, $\eta_{\rm m}$, and change of the scattering angle, θ, formed between the electron beam direction, $\mathbf{k}_0$, and the direction toward the energy analyzer, $\mathbf{k}_1$, the detected electron beam intensity is seen to be proportional to the differential cross section for the elastic scattering of electrons. The scattering angle θ was varied from $-5°$ to $+120°$. This covers the forward direction, $\theta = 0°$, on both sides. In the narrow angular range it enables the determination of the primary electron beam shape and its symmetry.

Measured angular distributions of elastically scattered electrons, of energies 20, 40 and 60 eV, have been normalized to the most recent absolute elastic differential cross sections [13], at the 90° scattering angle. Results for the 40 eV electrons are shown in Fig. 2. As one can see, our normalized signals of elastically scattered electrons follow closely the shape of the available absolute differential cross section curve. By these experiments we proved that the remaining magnetic field does not influence the scattered electron paths of energies as low as 20 eV. For ions, this influence can be ignored for kinetic energies greater than 10^{-2} eV, even for the lighest H^+ ions.

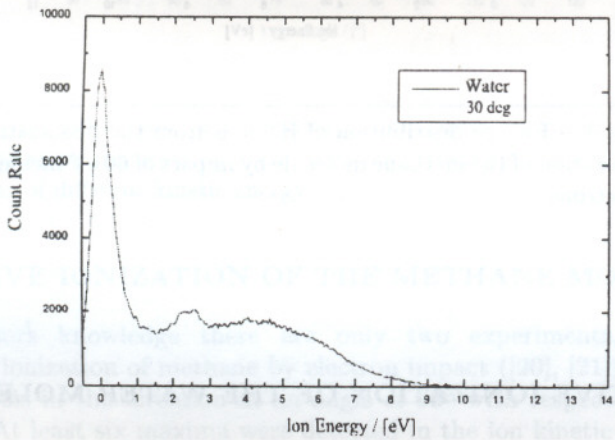

Fig. 3. - Kinetic energy distributions of H^+ ions from H_2O dissociative ionization processes, as obtained in the present experiment for the incident electron energy of 50 eV.

4. DISSOCIATIVE IONIZATION OF THE HYDROGEN MOLECULE

There is a rather large number of papers dealing with positive ions from the dissociative ionization of hydrogen molecules [14] - [17]. For further check of the apparatus we compared H^+ ion energy and angular distributions with some of the previous results [14], [15]. Excellent agreement was achieved for 60 eV incident electron energy and ion kinetic energy of 8,6 eV, where this energy spectrum has a local maximum, corresponding to transitions to a known excited state of the H_2^+ molecular ion [14].

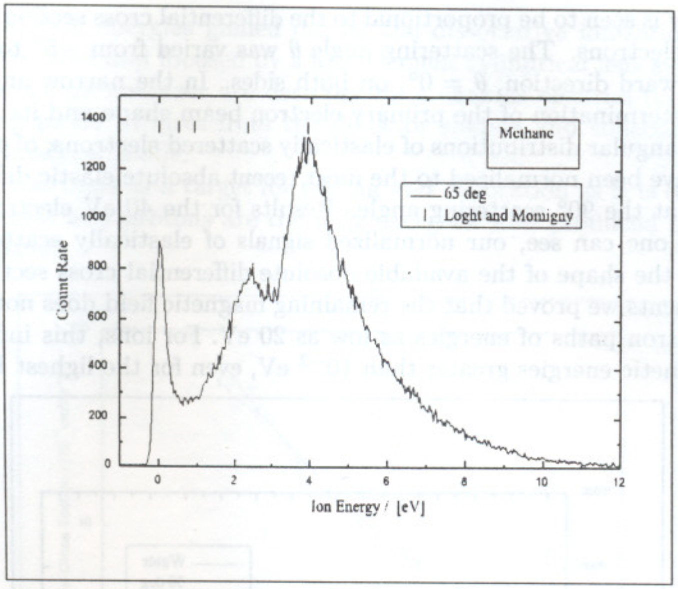

Fig. 4. - Energy distribution of H^+ ions from the dissociative ionization of the methane molecule by impact of 60 eV incident electrons.

5. DISSOCIATIVE IONIZATION OF THE WATER MOLECULE

In the previous experiments, only the H^+ ion energy distributions from the dissociative ionization of H_2O were reported ([18], [19]), ions being detected at an angle of 90° with respect to the primary electron beam direction.

In our experiments an energy range of incident electrons from 20 - 60 eV was covered. An example of the positive ion energy distribution for 60 eV electrons is presented in Fig. 3. In our experimental set - up we have no mass analysis of the detected ions but for the case of the water molecule these are presumably mostly protons. The most intense maximum at 0 eV is formed by dissociation of a molecular excited state with a repulsive potential energy surface [19], the others have no definite explanation so far.

We measured the angular distributions of different positive ion kinetic energies, chosen according to the prediction that they correspond to different dissociative processes [19]. The strongest anisotropy was obtained for the low energy ions, where the ratio of ion signals at 20° and 90° reaches a value close to 2000.

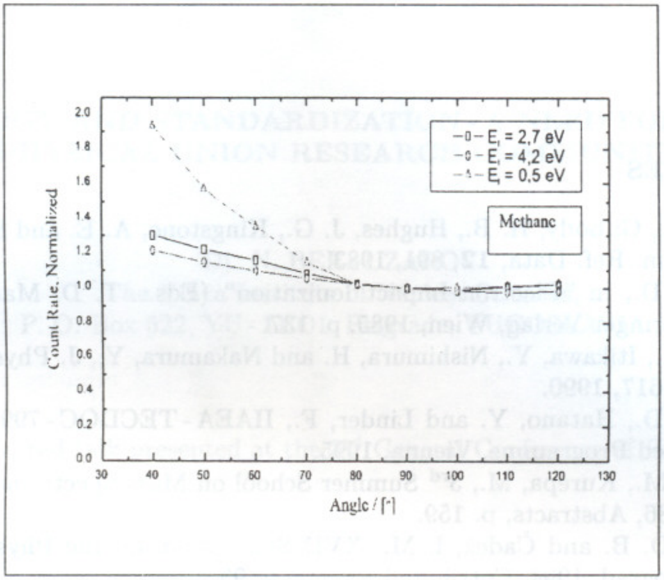

Fig. 5. - H^+ ion angular distributions from dissociative ionization processes of CH_4 from our experiment and for ions of different kinetic energy.

6. DISSICIATIVE IONIZATION OF THE METHANE MOLECULE

To the author's knowledge there are only two experiments, dealing with the dissociative ionization of methane by electron impact ([20], [21]); both with the ion energy analysis in the direction at an angle of 90° with respect to the incident electron beam. At least six maxima were detected in the ion kinetic energy spectra, due to transitions to different molecular or molecular ion excited states.

An example of the positive ion energy distribution from the dissociative ionization processes of the methane molecule by 60 eV incident electrons in the present experiment is given in Fig. 4. We see that our curve follows closely the previously obtained one [21]. Again, due to the molecular structure the detected energetic ions are presumably H^+

We measured angular distributions for the ions of three kinetic energies, shown in Fig. 5, which correspond to different dissociative ionization processes. For the time being, though, it is impossible to ascribe them to transitions to any particular excited state of the molecule or molecular ions. Only when combined with the appearance measurements [21] at various ion emission angles, more information could be derived.

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BALKAN PHYSICS LETTER **6(1)** 1 January 1998

Table of Contents

ISSN 1301-83290-1

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