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Double Differential Cross-Section Measurements for Methane Molecule at 350 eV

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Double differential cross-sections have been measured after ionizing electron collisions with methane at primary energy of 350 eV using a conventional electron spectrometer. An electrostatic analyzer was used to measure angular distributions of secondary electrons with energies between 25 eV and 300 eV. Angles of emission were 25° to 130°. It was found that the outgoing electrons belong to one of the two energetically separated groups, either the fast electrons which are scattered mainly in forward direction or the slow electrons which are distributed isotropically into all angles. For higher ejection energies the maxima shifted towards smaller angles as expected from binary type collision.

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1. Introduction

Only a few problems in the physics of atomic collisions date back to the beginning of the century. Studies on the ionization of atomic systems by charged particle impacts fall into this venerable class [1]. These studies have had a dramatic impact on both our understanding of the nature of atomic and molecular systems [2] and the evolution of quantum mechanics. However, despite the considerable progress in this area of atomic collisions, the theory of impact ionization is still rather incomplete especially for molecular targets.

Methane molecule is the basis for all biological processes and therefore for life on the earth. The ionization dynamics of electron–methane interactions has attracted more and more interest from researchers in many fields [3–5]. The energy released by the combustion of methane is used to heat many places. One of the reasons is also that the planets, including Jupiter, Saturn, Uranus, and Neptune are composed primarily of H_2, He, and CH_4 [6]. Interactions of electrons are naturally dominant in atmospheres and the development of modeling in astrophysics has gained important encouragement from laboratory experiments on atomic/molecular ionization dynamics. These interactions are of crucial importance in medicine because of the fact that the methane molecule is the simplest of all organic composition. It is also noted that electron impact includes optically forbidden excited states. So these interaction results have the central importance to define events in nature.

The measurements of double differential cross-sections (DDCS) for the ionization of methane molecule exist very scarce in literature [7, 8]. Opal et al. [7] present data for several gases and a large range of primary energies in tabular form but their energy range does not include the higher energies where most of the scattered primary electrons of degraded energy are found. Also, Oda [8] has measured cross-sections over the entire ionization continuum for several targets using 500 eV primary electrons.

There has recently been an interest in the collision dynamics for methane molecule at intermediate [9] and low [10–12] energies through triple differential cross-section (TDCS) measurements. On the theoretical side electron–molecule collisions are important to research the relation between the theoretical results and experimentally observable events. Any information obtained from theoretical calculations for comparison with experimental data is limited due to the many-body problem for molecular targets [13, 14].

In this study the main emphasis is on the ionization events of methane molecule with the double differential cross-section measurements by intermediate energy electron impact. We have investigated experimentally, DDCS of methane molecule by 350 eV electron impact in angular range from 25° to 130° and secondary electron energy range from 25 to 300 eV.

2. Experiment

The electron spectrometer developed at e-COL Laboratory, Afyon in Turkey is especially designed for electron–electron coincidence experiments. A brief description of this spectrometer is given elsewhere [15, 16]. The experimental setup is illustrated in Fig. 1. The spectrometer consists of an electron gun, a Faraday cup, two electrostatic energy analyzers. Electrons are emitted from a cathode in the electron gun, and passing through electrostatic lenses which are used to control its geometric shaping. The produced electron beam is perpendicularly crossed by atomic/molecular beam in the interaction region. The Faraday cup measure the electron beam current continuously and also it collects the unscattered electrons after collision. Outgoing electrons (scattered or ejected) are detected with the 180° hemispherical electron energy analyzers with respect to their energy. The rotatable energy analyzers are equipped with a channel electron multiplier, CEM, which a detector produces a signal proportional to incoming electrons. Thus output

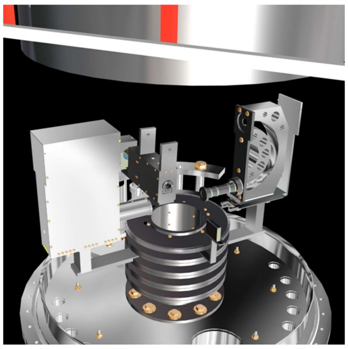

Fig. 1. Illustration of the electron spectrometer.

signal has been processed by signal processing devices and fast timing electronics.

During the experiments, background pressure was $\approx 6 \times 10^{-6}$ mbar. The spectrometer was operated at an electron current of 1 μA. The overall energy resolution of the system was limited by both the thermal spread of the electrons emitted from tungsten hairpin cathode and the analyzer system. By measuring the full width at half-maximum (FWHM) of the elastic peak obtained in the energy loss mode, it was found to be ≈ 0.75 eV. The angular resolution was better than $\pm 1°$.

3. Results and discussion

Although it is impossible to determine with one detector which electrons of detected is the scattered or ejected one, DDCS experiments give very important results about the ionization events. DDCS measurements are the fundamental studies to which other measurements may be related. As an experimental confirmation of our results, elastic differential cross-section measurements of methane for 200 eV incident electrons are taken and compared with previous results [17, 18] (Fig. 2). The agreement was good between present and previous results.

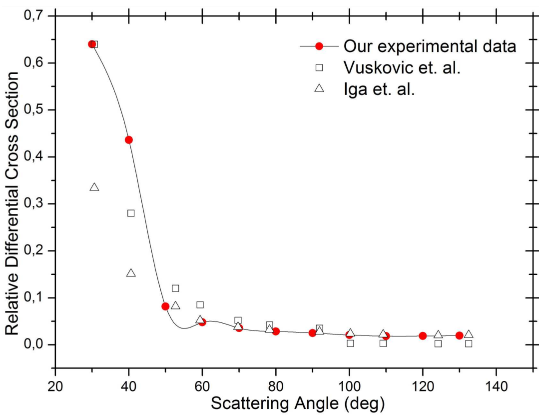

Fig. 2. Elastic differential cross-section for the elastic scattering of electrons from methane molecule. The symbols represent experimental data as follows: • present experiment, □ Vuskovic et al. 1983, △ Iga et al. 2000.

DDCS results for 350 eV incident electrons on a methane molecule are given in Fig. 3. The analyser is adjusted to detect 25–300 eV outgoing electrons after collision. These curves have been obtained by measuring angular distributions of electrons scattered by the target and then the counting rate for particles scattered by the background gas in the vacuum chamber. All counting rates normalized to unity, no other corrections have been made.

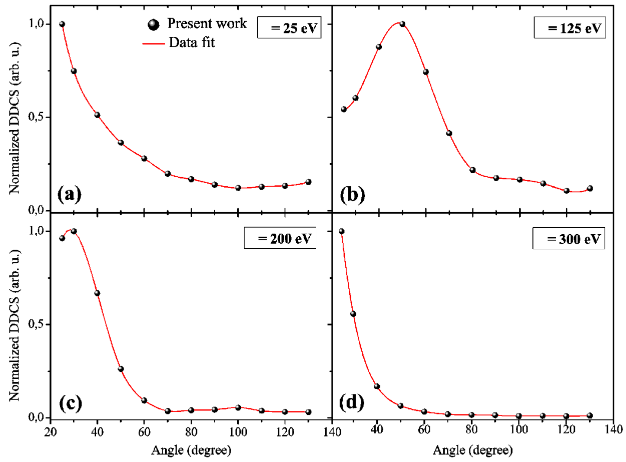

Fig. 3. Experimental DDCS results obtained at incident energy of 350 eV. Angular distributions for secondary electron energy, ε, of (a) $\varepsilon = 25$ eV, (b) $\varepsilon = 125$ eV, (c) $\varepsilon = 200$ eV, and (d) $\varepsilon = 300$ eV. Full circle represents present work and red lines represent interpolated data fit.

The maxima in Fig. 3b and c are a consequence of the binary character of the collision. Since most of the faster electrons are scattered into the forward direction, the maximum shows that the angle between the scattered and ejected electrons for most of the collision processes is $\theta < 90°$. This result is in agreement with the expectations from a two body collision and the predictions from the binary encounter theory which attributes this forward peak to electron exchange [19, 20]. Similar structures confirming these results were also obtained in our previous paper [21]

As shown in the figures, the angular position of the binary peak changes from 50° to about 25° if the energy of outgoing electron increases. For relatively more energetic outgoing electrons, the angular distribution (Fig. 3d) shows a dominant scattering process. From these findings one can expect that most of the electrons scattered into smaller angles result from collisions of the binary type whereas those scattered into larger angles have suffered a collision of the recoil type. There is no significant structure for low outgoing electron energies (Fig. 3a). The angular distribution of DDCS of methane molecule by electron impact has been investigated experimentally. This work is the first on DDCS measurements that covers a wide energy range for electron impact ionization of methane molecule. It is expected that these results aim further understanding of ionization mechanisms of small molecules.

Acknowledgments

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