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Secondary Electron Distribution of Atmospheric Nitrogen Molecule by 350 eV Electron Impact[‡]

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Electron collisions with nitrogen molecules have an important role for example in ionospheric and auroral phenomena in the upper atmosphere of the Earth. These processes are important in electrical discharges involving atmospheric gases. Due to the key features electron collisions with N_2 have been under particular interest and extensively studied for last decades. Cross-section data is extremely useful in understanding the systematic of the ionization process. Since the earliest cross-section measurements of N_2, there have been a great number of improvements and new developments on theoretical and experimental methods. A crossed-beam apparatus so called electron spectrometer that has an effusive gas source and electron gun is used to obtain the cross-sections. Scattered and ejected electrons are analyzed by hemispherical electron analyzer. Here we report recent measurements of double differential cross-section for N_2 as a function of electron angle at incident electron energy of 350 eV.

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1. Introduction

Electron impact ionization cross-sections of molecules are important quantities in the areas of plasmas, planetary, stellar and cometary atmospheres, radiation chemistry and chemical analysis. Because of the importance of the cross-sections in aforementioned applications, much emphasis has been devoted recently to the experimental studies of electron-impact ionization cross-sections of molecules and radicals. The study of the energy and angular distributions of electrons ejected by electron impact is a sensitive means of testing the theory of collision processes behind to some extent.

N_2 has a fundamental importance in many scientific and industrial activities. Typical examples are provided by air plasmas in environmental researchers, Earth's atmosphere and aerospace technologies. The airglow emissions of N_2 from the atmospheres of Earth and planetary satellites have been extensively observed. N_2 plays an inert role in the human body, being neither produced nor destroyed. In nature, nitrogen is converted into useful compounds by some living organisms and released into atmosphere in the process of decay, in dead plant and animal tissues. However, the current knowledge about the electron ejecting from isoelectronic molecules (such as N_2 and CO) is very limited. Consistent cross-section data is a necessity for accurate models of how upper atmospheres behave.

Some reviews are published by several authors data compilation for electron collision processes with N_2 molecule but mainly on total scattering, elastic scattering, ionization, electron attachment, and excitation processes [1–5]. The present paper aims to present only double differential cross-section (DDCS) measurements of N_2 up to this date. The DDCS, $d^2\sigma(E_b, \theta_b)$, cover almost the whole energy range of outgoing electrons called scattered and ejected electrons.

The pioneer measurements of the DDCS as a function of the ejected energy, angle and incident energy was made by Mohr and Nicoll in 1934 for 20–300 eV incident energy and 15° to 155° angular ranges [6]. Next work on DDCS measurements was done by Opal et al. in 1972 at 50 to 2000 eV incident electron energy range for 30° to 150° angles [7]. The energy and angular range of ejected electrons in measurements of Dubois and Rudd [8] were at 100, 125, 500 eV incident electron energy and 10°–150° angular range; and Oda et al. [9] 100 to 1000 eV electron energies covering 5° to 140° angular range for lowest ejected electron energy of 10 eV. Shyn [10, 11] has presented the results of experiments at 50, 70, 100, 200, and 400 eV where angular range of ejected electrons measured from 1 eV to one half of the difference between the incident energy and ionization potential in 12° to 156° angular ranges. Goruganthu et al. [12] presented DDCS measurements for incident energies of 200, 500, 1000, and 2000 eV. The scattering angle was varied from 30° to 150° in steps of 15°. Since then to best of our knowledge there is no experimental data on DDCS of N_2 molecule published in the literature. Considering the last DDCS measurements on N_2 are taken in 1987 and also in order to try and clarify matters seen in the previous studies, we update DDCS measurements at fixed incident electron energy of 350 eV for a wide detected energy and angular range. DDCS for electron impact ionization of N_2 molecule has been measured in a crossed-beam experiment. Angular dependences of cross-sections for ejected electrons are presented. Ejected electron energy and angle dependent differential cross-sections for ionization of N_2 by electron impact have been evaluated as 350 eV.

2. Experimental setup

The electron spectrometer used at Afyon Kocatepe University was developed by e-COL group and has been

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described previously in Ref. [13]. The electron spectrometer is a crossed-beams type in which the incident electron beam collides orthogonally with the target gas beam and has been used to measure the triple differential cross-sections (TDCS) for the electron-impact double excitation of helium [14, 15], for the electron impact ionization of argon [16] and H_2 [17, 18].The electron spectrometer was initially designed and constructed to measure angular and energy correlations between outgoing electrons. The same apparatus can also collect data on angular distribution of ejected or scattered electrons simply disabling the coincident circuit [19, 20]. In this paper, we report DDCSs measured by using electron spectrometer originally developed for coincidence measurements of ejected and scattered electrons. Figure 1 shows a schematic view of the experimental setup.

To summarize briefly, an electron beam produced by a tungsten filament and seven element lens system, is directed into gas target through a needle. The electron beam current (≈3 μA) was continuously monitored by a Faraday cup placed on the axis of the electron gun at 50 mm from the collision center. The electron beam source, electron energy analyzers, and the Faraday cup are situated together in a high-vacuum chamber. The magnetic field near the interaction region is reduced to ≈ 3 mG by μ-metal and Helmholtz coils. The flow of the target gas into interaction region was controlled by a needle valve at entrance to the vacuum chamber. The background pressure inside chamber is $\approx 8 \times 10^{-8}$ mbar and it increases to $\approx 7 \times 10^{-6}$ mbar while the experiment is operating. Ejected electrons emitted at an angle θ_b, are energy analyzed and detected by a channel electron multiplier (CEM) mounted on the hemispherical electron analyzer. Hemispherical electron analyzer, energy selects the electrons that are to be detected. Constant voltages of ≈2600 V applied to CEM to get the maximum detection efficiency for the electrons. The CEM signal is amplified and fed to discriminator generating output signal which is finally counted.

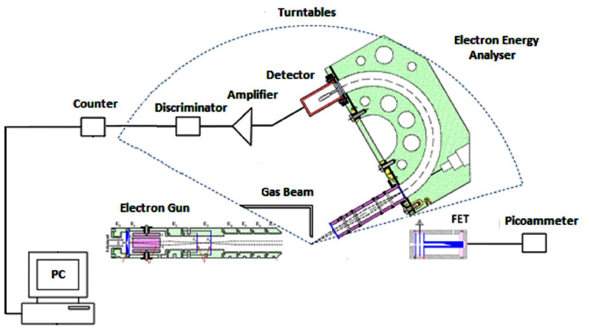

Fig. 1. Schematic diagram of the spectrometer and data acquisition system.

The DDCS are measured by the electron energy analyzer rotating around the collision centre in a plane. It is important to perform experimental calibrations of the electron spectrometer to ensure reliable operation. This entails an energy calibration of the incident electron beam and energy and angular calibration of the analyzer. Energy calibration is performed by measuring energy loss-spectrum of N_2 and ≈0.7 eV energy resolution is obtained for 250 eV electron impact energy.

DDCS, differential in energy and direction of one of the outgoing electrons, can be obtained through the measurement of the energy and angular distributions of outgoing electrons with only one analyzer. In this work, DDCS of N_2 molecule was measured for selected outgoing electron energies by adjusting the voltages of the hemispherical electron analyzer and counting the ejected signal.

3. Results and discussion

This paper presents the DDCS measurements of secondary electrons ejected from N_2 molecule by electron impact of 350 eV. The energy range of the detected electron energies were 10 to 300 eV while the angular range was 30° to 130°. Although it is impossible to determine with one analyzer which electrons of detected are the scattered or ejected ones, DDCS experiments give very important results about the ionization events. Although being aware of the indistinguishability between scattered and ejected electrons, we will use only ejected electron term while mentioning the results. DDCS can be measured by crossed beam method which a beam of energy selected electrons crosses a beam of target particle at 90°. An outgoing electron is detected according to its energy or angle. Thus, it is possible to conclude that DDCSs as a function of the scattering angle and the energy of the outgoing particle may provide valuable information on the mechanisms of ionization for different regions of collision kinematics.

DDCSs results for 350 eV incident electrons on N_2 molecule are given in Figs. 2–4. The analyzer is adjusted to detect for 25–300 eV ejected electrons after the collision for 30°–130° angular range. The 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.

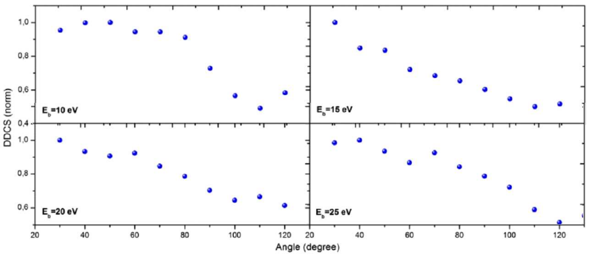

Fig. 2. DDCSs results for 350 eV incident electrons on N_2 molecule. Ejected electron energies (E_b) range are varied from 10 to 25 eV for angular 30°−130°.

In Fig. 2, for 10 and 15 eV ejected electron energies, we see minimum around 110°. This minimum disappears as the ejected energy is higher than 25 eV. for lower ejected

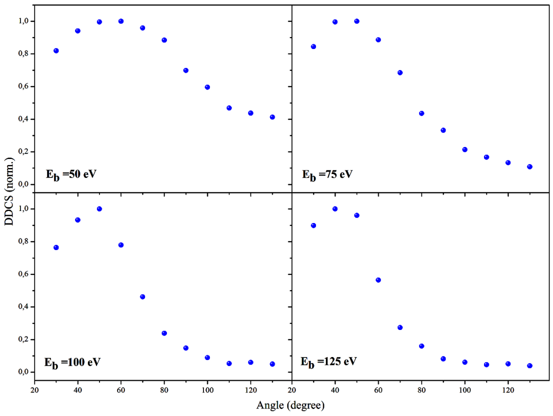

Fig. 3. As for Fig. 2 for (E_b) range 50–125 eV.

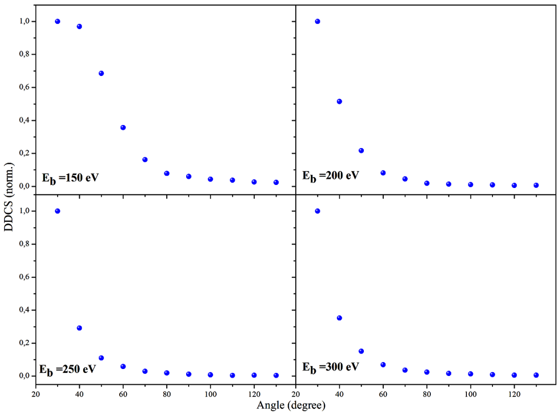

Fig. 4. As for Fig. 2 for (E_b) range 150–300 eV.

electron energies than 50 eV, we see maxima around 40°. Forward scattering is dominant for these energies and binary collision is seen for forward angles meaning around 100° and higher angles as ejected electron energy is increased between 10 to 25 eV. For higher ejected energies meaning 50 to 150 eV the scattering peak is moved to lower angles and observed around 50° (Fig. 3). When ejected energies of the electrons are increased to 250 and 300 eV then the peak is shifted to lower degrees (around 30°). The DDCSs show a smooth variation by both energy and angle (Fig. 4). There is a general behavior of strong forward scattering and these electrons are scattered in a narrow angular range. Ejected electrons with higher energies produce some structure in the cross-section due to a binary collision between the incident electron and an electron from the target. The lower energetic ejected electrons (< 50 eV) are mostly scattered isotropically in all directions.

It is possible to say that DDCS as a function of the ejected (or scattered) angle may provide valuable information on the mechanisms of ionization for different regions of collision kinematics. It is expected that these results aim further understanding of ionization mechanisms of small molecules.

As a possible extension of the present work, we plan to make comparisons of the DDCSs results with acceptable theoretical models to explain the strong angular dependence in details.

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