



RESEARCH ARTICLE

DIFFERENTIAL CROSS-SECTIONS FOR ELASTIC SCATTERING OF ELECTRONS
FROM MOLECULAR NITROGEN

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ABSTRACT

In the field of molecular collisions, there has been a kind of rebirth with respect to the scattering of electrons both experimentally and theoretically. From experimental point of view, most data are available only in a limited energy and angular range. From the theoretical side, new and different models have been developed and experimental data is needed to test these theoretical models. The basic concept in elastic scattering of electrons from atoms and molecules is the differential cross-section (DCS). As a function of scattering angle and electron impact energy the cross-sections can be measured and these results reveal important information about projectile, target and also about the atomic and molecular structures. In this work experimentally measured DCSs for elastic scattering of electrons by molecular nitrogen are presented.

Keywords: Elastic scattering, Differential cross-section, Nitrogen molecule, Electron impact

1. INTRODUCTION

The excitation/ionization of molecules by electron-molecule collision in the laboratory or the breaking of molecular bonds into smaller molecules or into atoms contributes to the understanding of the structure of molecules in the natural environment. By the energy loss spectrometry, it is possible to observe the energy levels of molecules where vibrational and optical transitions that are forbidden and that they can be measured in wide energy ranges. Product particles (electron, photon or ion) resulting from the interaction between electrons and target atoms or molecules contain important information related to the dynamics of the reaction. Within the development of technology, the importance of collision physics has increased in industry and other fields of science. Electrons are the core element of plasma-etching technologies and are used in the manufacture of micro-electronic components and semiconductor devices. In the field of astrophysics, the examination of molecular structures in the atmosphere and the changes caused by photochemical processes that occur as a result of interaction with sunlight are also related to collision physics. In addition to these studies; researches can be done to determine the atoms and molecules in other planets and stars in space, to find the basic building blocks in the formation of biomolecules and whether there is life outside of the earth. In the health sector, collision physics is used effectively in the diagnosis and treatment process.

Electron atom/molecule collisions result as scattering, excitation, ionization events. If there is no energy exchange between the target atom/molecule and the electron after the collision, the scattering is elastic. If the energy of the scattering particle is not equal to the energy in the first case, then inelastic collision occurs. Only the excitation, only ionization, or both events can be seen in the collision event. The event of ionization is the phenomenon of electron ejection after the collision from the target atom/molecule. Ionization events occur in different shapes. These are autoionization, ionization from single and multiple inner or outer shells. The most common case of ionization is direct single ionization of the target particle.

The cross-section is a measure of the probability of a collision event occurring under certain conditions. The cross-section depends on the colliding particles and the interactions that occur during the collision. The oldest works in the field of elastic scattering were in the dates of 1930s. These measurements could be able to done for limited scattering angles and also with poor angular resolution. Some of the relative experimental data on N_2 molecule for scattering processes are reviewed recently in Refs. [1, 2].

N_2 molecule is important for living things since the beginning of life. Since the beginning of life, nitrogen-containing molecules have been found in the atmosphere and oceans. For example, living things need oxygen and carbon dioxide to survive, as well as N_2 to grow, because it is an important component of proteins and DNA. Nitrogen is found in 15% of the body, especially in the structure of nucleic acids, proteins, and vitamins.

DCS measurements taken for the N_2 molecule were taken with the relative flow technique by Nickel and Mott [3] at low energies. In addition, Lee and Iga [4] computed integral and momentum transfer cross-sections for scattered waves by combining the Schwinger variational iterative method and the distorted-wave approximation approach at higher energies (20-800 eV). On the other side, elastic scattering of electron from this molecule is highly worked both by experimentalists and theoreticians [1, 5-11].

In recent years, many theoretical and experimental (e,2e) studies have been carried out with molecular targets. However, most studies have been done on high-energy electron collisions or ionization of small molecules by electron effect. For the nitrogen molecule in the literature; Gao et al. [12] theoretically investigated the interference effects on ionization of this molecule with low energy electron effect. Young's interference effect in double-slit was investigated for scattering phenomena in symmetric and antisymmetric planes with low energy electron (75.6 eV) effect and distorted wave approach for ionization of nitrogen molecule.

Another important study was done by Hargreaves et al. [13]. The content of this study is to examine the interference effect (e, 2e) on the ionization of nitrogen molecules with the coincidence technique. Hydrogen (H_2) and nitrogen (N_2) molecules are used as target atoms. Kinematics determined for these measurements are found in Milne-Brownlie et al. [14] in high asymmetric kinematics. Triple differential cross-section (TDCS) measurements were performed to show evidence of the expected oscillation effects.

Experimental studies for the nitrogen molecule include Naja et al. [15] also include the coincidence (e, 2e) test for the nitrogen molecule in the large energy transfers made. This group has taken TDCS measurements by electron effect for the nitrogen molecule at electron energies from 600 eV in non-planar asymmetric geometries. Another study on the ionization of the nitrogen molecule was carried out by Lahman-Bennani [16]. TDCS measurements were taken in coplanar asymmetric geometries at 500-700 eV incoming electron energies.

Another study in the field of ionization of N_2 by electron effect was done by Toth and Nagy [17]. They calculated the recoil and binary peak ratios for the outer orbitals of the N_2 molecule, $3\sigma_g$, $1\pi_u$, 2σ , using the model they produced. In a study to examine interference effects, Chaluvadi et al. [18]. With this study, results showing that interference effects are observed as a result of ionization of nitrogen molecule for the first time in the literature.

In the last years, the large discrepancies between the results of experiments and theory needed to provide new experimental data for this process specially and intermediate impact energies and large angular ranges. Several authors published sets of cross-sections for electron impact on N_2 [2, 19]. There are multiple sets of data available on N_2 molecule in the literature including some disagreement

among them and no recommendation is made. In this paper, a set of DCS data for electron collisions with N₂ molecule for high angular range is presented.

To examine the cross-sections obtained as a result of the ionization and scattering of N₂ molecule by the electron impact, obtained as a result of the experimental studies carried out in the Electron Impact laboratory. Electron spectrometer is used for studying the elastic of inelastic scattering processes in this work. DCS measurements were performed on N₂ molecule at 50, 150, 250 and 350 eV impact energies and between 30°-130° scattering angles.

2. MATERIALS AND METHODS-EXPERIMENTAL APPARATUS

Measuring the DCS of molecules scattered as a result of collisions with particles such as electron/photon, whose basic physical properties such as energy, momentum, charge and spin provides valuable information about the structure and interaction process of the target studied. Among these processes that are the subject of collision physics, electron scattering experiments, in which molecules are targeted, are one of the interesting areas. The scattering phenomenon is experimentally investigated by cross-section measurements and electron spectrometers are used as an experimental setup.

Electron collision experiments are performed by simultaneously detecting the particles formed as a result of colliding a well-focused electron beam with a beam of gas sent in vertical direction (cross beam type) according to their energy and angles, processing the obtained signals and analyzing them in a computer environment.

The experimental apparatus and working procedure are described in details in Refs [20, 21]. Briefly, the electron spectrometer used for such an experiment, consists of a primary beam source, a collision chamber and a rotatable analyzing system. The DCSs are measured by rotating the analyzing system around the collision center in a plane that contains the incident and the scattered beam. The scattering angle is described as the angle that incident electron beam is scattered in front of the electron energy analyzer. Scattering electrons pass the input lens system of a hemispherical electron energy analyzer and detected.

The electron beam source and the analyzing system are all positioned in a high vacuum chamber. The high vacuum pressure is measured with a calibrated ion gauge and is around 10⁻⁷ mbar when the gas beam is off. An electron gun is used to produce primary electron beam with a filament that gives energy spread of 0.6 eV (FWHM). The primary beam current is measured by a Faraday cup in the vacuum chamber. The cross-section measurements can be done in 30°-130° angular range.

The focusing quality of the electron gun used, the energy range and the energy analyzers must have a perfect energy resolution to obtain detailed information about the ionization phenomenon by the electron effect. In modern (e, 2e) experimental setups, electron guns with wide energy range, high focusing quality and transmission and energy analyzers with high energy resolution are used. The energy analyzed scattered electrons are detected by a channeltron electron multiplier (CEM) and the pulses from here are transferred signal processing system and then to the computer program.

3. RESULTS

In this research, excitation cross-section (energy loss spectrum) and elastic scattering DCS measurements of N₂ molecule were made using electron collision spectrometry. Scan able angle values of the analyzer is in between 30°-130°. Elastic DCS spectra were obtained as a result of determining the angular distribution by setting the analyzer to detect electrons at a certain energy and moving it on rotary tables.

Electron-N₂ scattering experiments were carried out for both analyzers to control the electron gun and energy analyzers. Results from an analyzer are given here, as they are identical results. First, elastic scattering was examined; cross-section measurements were made according to the analyzer angle and compared with previous studies. Secondly, the excitation event from inelastic scattering events in the e-N₂ collision was investigated. Energy loss spectra for the excitation cross-section are taken at different angles. For this, again, the energy detected by the analyzer was changed and the count in each step was recorded at equal time intervals. In this way, the energy resolution of the spectrometer can be determined.

First, elastic scattering measurements were taken at the energy analyzer of Figure 1 at 10° and at E₀ = 150 eV for electrons with kinetic energy of 10 eV. The resolution of the energy analyzer is around 0.6 eV.

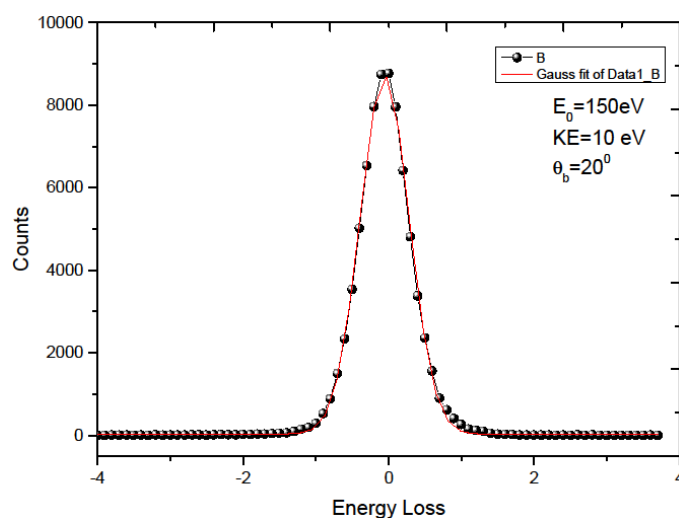


Figure 1. Elastic peak for 150 eV electron impact at 20°

Again, the inelastic excitation energy loss spectrum taken in the same kinematics is given in Figure 2 and different energy levels of the N₂ molecule are determined depending on the resolution of the energy analyzer. In this way, the energy levels determined for the molecule could be determined at different angles.

The interaction between electron and a molecule depends on the electron velocity as well as the angle of scattering and the nature of the process. Therefore, the cross-section that gives the probability of a reaction type to occur depends on the energies and angles of the incident and detected electrons. There is no change in the internal structure of the two particles colliding in an elastic collision. The incident electron changes direction without transferring kinetic energy to the internal energy of the target atom. There is no energy exchange between electron and atom in this collision. But there is momentum transfer due to the change of direction. Here, elastic DCS spectra were obtained by setting the analyzer at 50, 150, 250 and 350 eV energies and determining the angular distribution in the range 30°-130°. Figure 3 shows the results obtained.

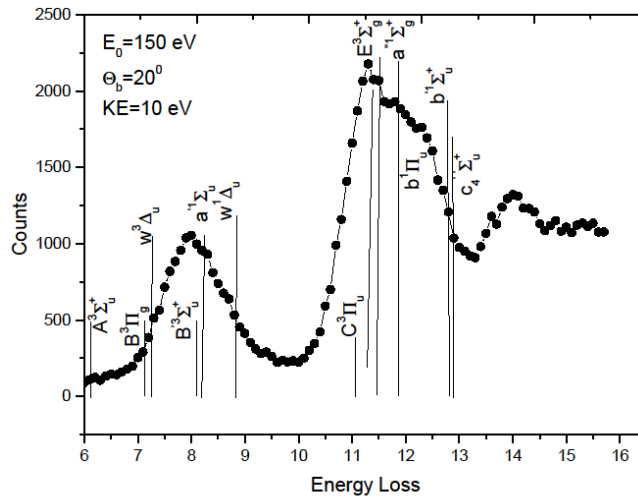


Figure 2. Inelastic peak for 150 eV electron impact at 20°

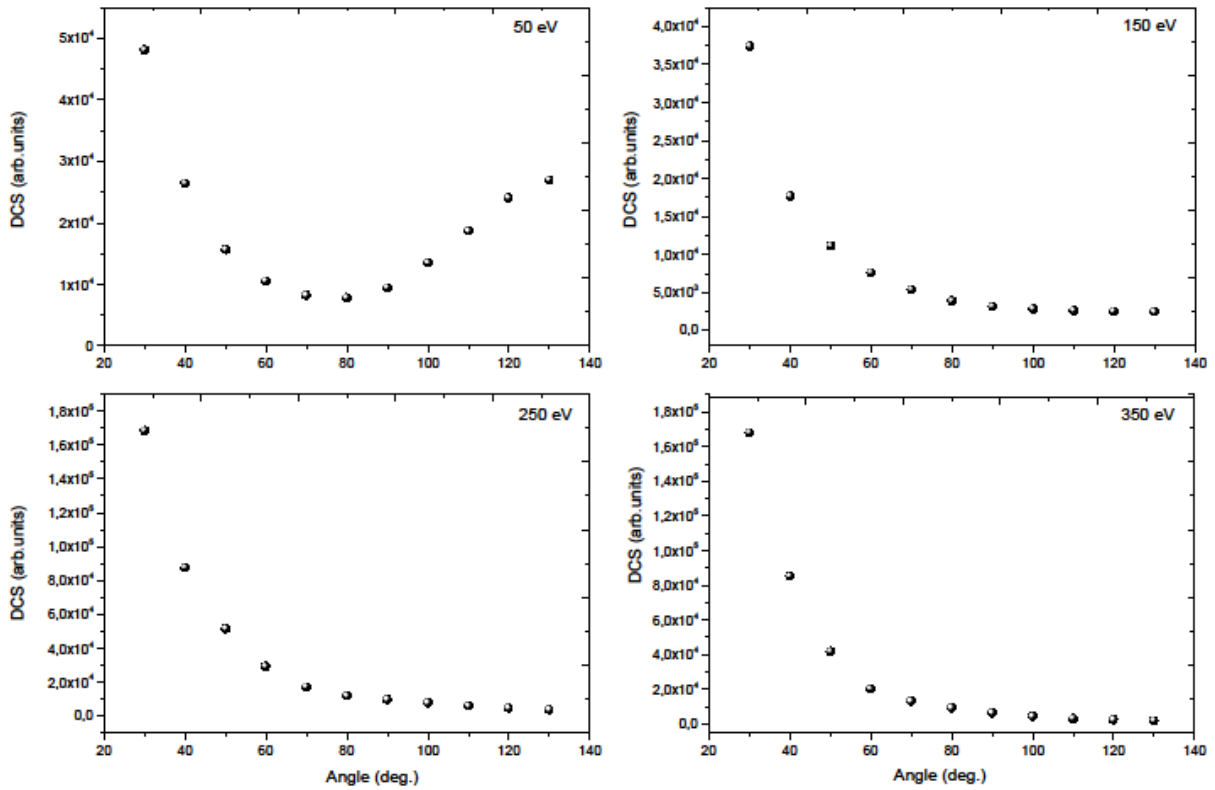


Figure 3. Electron impact DCSs of N₂ molecule for 50, 150, 250 and 350 eV

In DCSs spectra, there is a smooth variation in the structure as the energy increases whereas for 50 eV there is a minimum seen around 80° scattering angle. The pattern in the spectra is moving to lower values as the impact energy increases.

4. CONCLUSION

In this study, DCS measurements were made by the interaction of N₂ molecule with electrons of 50, 150, 250 and 350 eV energy. In the measurements the scanned angle range was taken as 30°-130°.

In particular, interactions between electrons cause significant changes in cross-sections depending on angle and energy. The investigation is mainly concerned with elastic scattering of electrons by N₂ molecule at these electron impact energies and for various scattering angles. The results show monotonic behavior with the increase of energy except with minima for 50 eV electron impact. The pattern in DCS starts at much lower angles by the increment in the energy.

Experimentally, the ionization event is examined by cross-section measurements, and the most detailed information about the interactions and the target can be obtained by analyzing the particles resulting from the collision. Since theoretical modeling is difficult, especially for molecules with two or more atoms, calculations can only be made with some approaches. Conducting experimental studies by creating natural electron-molecule collision environments under laboratory conditions provides concrete experimental data for theoretical studies.

Analyzing the obtained measurements, obtaining information about the ionization dynamics of N₂ molecule, contributing to the newly developed literature on this subject and testing the theoretical models developed for molecular systems are among the future goals.

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REFERENCES

- [1] Khandker MH, Arony NT, Haque AKF, Maaza M, Billah M, Uddin MA. Scattering of e[±] from N₂ in the energy range 1 eV–10 keV. *Mol Phys* 2020; 118(14), e1699183.
- [2] Itikawa Y. Cross-sections for electron collisions with nitrogen molecules. *J Phys Chem Ref Data* 2006; 35, 31-53.
- [3] Nickel JC, Mott C, Kanik I, McCollum DC. Absolute elastic differential electron scattering cross-sections for carbon monoxide and molecular nitrogen in the intermediate energy region. *J Phys B* 1988; 21, 1867-1877.
- [4] Lee MT, Iga I. Elastic and total cross-sections for electron scattering by nitrogen molecule in the intermediate energy range. *J Phys B* 1998; 32, 453-462.
- [5] Shyn TW, Carignan GR. Angular distribution of electrons elastically scattered from gases: 1.5-400 eV on N₂ II. *Phys Rev A* 1980; 22(3), 923.
- [6] Srivastava SK, Chutjian A, Trajmar S. Absolute elastic differential electron scattering cross-sections in the intermediate energy region II—N₂. *J Chem Phys* 1976; 64(4), 1340-1344.
- [7] DuBois RD, Rudd ME. Differential cross-sections for elastic scattering of electrons from argon, neon, nitrogen and carbon monoxide. *J Phys B: At Mol Opt Phys* 1976; 9(15), 2657.
- [8] Jansen RHJ, De Heer FJ, Luyken HJ, Van Wingerden B, Blaauw HJ. Absolute differential cross-sections for elastic scattering of electrons by helium, neon, argon and molecular nitrogen. *J Phys B: At Mol Opt Phys* 1976; 9(2), 185.

- [9] Bromberg JP. Absolute differential cross-sections of elastically scattered electrons. I. He, N₂, and CO at 500 eV. *J Chem Phys* 1969; 50(9), 3906-3921.
- [10] Ozer ZN. Differential cross-sections of nitrogen containing molecules at intermediate electron impact energy. *AIP Conf Proc*, AIP Publishing LLC, 2018; 020027.
- [11] Ulu M, Ozer ZN, Yavuz M, Dogan M. Double Differential Cross-section Measurements for Electron Impact Ionization of Atmospheric Gases. *J Phys Conf Ser* 2015; 635, 072075.
- [12] Gao J, Madison DH, Peacher JL. Interference effects for low-energy electron-impact ionization of nitrogen molecules. *Phys Rev A* 2005; 72(3), 032721.
- [13] Hargreaves LR, Colyer C, Stevenson MA, Lohmann B, Al-Hagan O, Madison DH, Ning CG. (e,2e) study of two-center interference effects in the ionization of N₂. *Phys Rev A* 2009; 80(6), 062704.
- [14] Milne-Brownlie DS, Foster M, Gao J, Lohmann B, Madison DH. Young-Type Interference in (e,2e) Ionization of H₂. *Phys Rev Lett* 2006; 96(23), 233201.
- [15] Naja A, Staicu-Casagrande EM, Lahmam-Bennani A, Nekkab M, Mezdari F, Joulakian B, Chuluunbaatar O, Madison DH. Triply differential (e,2e) cross-sections for ionization of the nitrogen molecule at large energy transfer. *J Phys B* 2007; 40, 3775-3783.
- [16] Lahmam-Bennani A, Staicu Casagrande EM, Naja A. Experimental investigation of the triple differential cross-section for electron impact ionization of N₂ and CO₂ molecules at intermediate impact energy and large ion recoil momentum. *J Phys B* 2009; 43, 235205.
- [17] Toth I, Nagy L. Ionization of molecular nitrogen by electron impact in (e,2e) processes. *J Phys B* 2011; 44, 195205.
- [18] Chaluvadi H, Ozer ZN, Dogan M, Ning C, Colgan J, Madison D. Observation of two-center interference effects for electron impact ionization of N₂. *J Phys B: At Mol Opt Phys* 2015; 48(15), 155203.
- [19] Roychowdhury M, Chauhan D, Limbachiya C, Tokesi K, Champion C, Weck PF, Tribedi LC. Double differential distributions of e-emission in ionization of N₂ by 3, 4 and 5 keV electron impact. *J Phys B: At Mol Opt Phys* 2020; 1-10.
- [20] Ozer ZN, Chaluvadi H, Ulu M, Dogan M, Aktas B, Madison D. Young's double-slit interference for quantum particles. *Phys Rev A* 2013; 87(4), 042704.
- [21] Dogan M, Ulu M, Ozer ZN, Yavuz M., Bozkurt G. Double differential cross-sections for electron impact ionization of atoms and molecules. *J Spectrosc* 2013; 192917.