

Resonant structure in 180° elastic scattering of electrons by N₂ and N₂O molecules

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The total cross sections for the scattering of electrons by N₂ and N₂O molecules and the back-scattering cross sections (the cross sections for scattering through an angle of 180°) have been studied in a common experiment for the first time. In nitrogen there is a complete correlation between the resonance structure in the total-scattering cross section and that in the cross section for 180° elastic scattering.

The total and differential cross sections for electron scattering by atoms and molecules have recently attracted considerable interest. Much information on the mechanism for the interaction of electrons with atoms and molecules can be extracted from a study of electron scattering through an angle of 180°. This particular geometry significantly reduces the effect of potential scattering, so that the resonances can be seen in their pure form.

We have assembled an apparatus and developed an experimental procedure for studying, in a common experiment, the total cross sections for electron scattering by atoms and molecules and the cross sections for backscattering (through 180°). In this letter we report a study of the scattering of electrons by N₂ and N₂O molecules over the energy interval 0.5–5 eV. This appears to be the first case of simultaneous measurements of the total cross section for electron scattering and the cross section for 180° scattering.

The experimental procedure is a further development of the electron-trap method which we have used previously¹ to determine the total cross sections for electron scattering by atoms. The method can be summarized as follows: A monoenergetic electron beam is formed in a longitudinal magnetic field by a trochoidal electron monochromator, accelerated to the desired energy, sent through the collision chamber, and detected by an electron detector. Auxiliary electrodes at the entrance and exit of the collision chamber are held near the cathode potential to form a potential barrier to retard scattered electrons. A complete collection of the scattered electrons is performed by the collision chamber. In the present experiments, the trochoidal monochromator is used not only as a dispersive element but also as a device for singling out electrons scattered elastically in a small solid angle centered on 180°. This is possible because in the crossed electric and magnetic fields the electrons undergo (in addition to their directed motion) a drift in a direction which is independent of the electron's velocity vector. Accordingly, the back-scattered electrons (those scattered through an angle of 180°) which have passed through the monochromator region (the region with the crossed fields) are displaced a certain distance with respect to the primary beam. By placing a collector at a certain distance from the axis of the primary beam one can thus detect the back-scattered electrons. Special measures are taken in

our apparatus (in contrast with that of Ref. 2) to eliminate reflected electrons and thus minimize the background that they create. Among these measures are the use of a highly uniform axial magnetic field, a careful treatment of the electrode surfaces in direct contact with the electron beam, a highly precise assembly and adjustment of the electron optics, and the use of specially designed detectors for the primary and scattered electrons. The net result is that the electron system has a high transmission (above 95%), and the background level is reduced to 5–10% of the level of the useful signal.

The spectrometer is inside a stainless-steel vacuum chamber with oil-free pumping with a nitrogen cold trap. During operation, the spectrometer is heated to 220–250 °C. The gas pressure in the chamber does not exceed 1×10^{-6} torr. The spectrally pure gas is admitted into the collision chamber through a calibrated needle valve, and the pressure is monitored by a thermocouple gauge. When gas is admitted into the collision chamber to a pressure $\sim 10^{-3}$ torr, the pressure in the vacuum chamber is $(5-7) \times 10^{-6}$ torr.

We studied the energy dependence of the total and differential (180°) cross sections for electron scattering by N_2 and N_2O molecules. We selected these particular molecules because of the resonance structure in their total scattering cross sections and because we intended to study the correlation between structural features in the total-scattering and back-scattering cross sections. The measurements were taken at an incident electron current $\sim 5 \times 10^{-9}$ A; the energy spread of the electrons did not exceed 0.04 eV in half-width. The electron energy scale was calibrated on the basis of a peak at 2.20 eV in the cross section for total scattering in N_2 . The accuracy of this calibration of the energy scale was no worse than ± 0.02 eV.

The results of the measurements are shown in Figs. 1 and 2. It has been shown in other studies^{4,5} that both the elastic scattering and the inelastic scattering by N_2 and N_2O molecules at energies ~ 2 eV occur predominantly through compound states, i.e.,

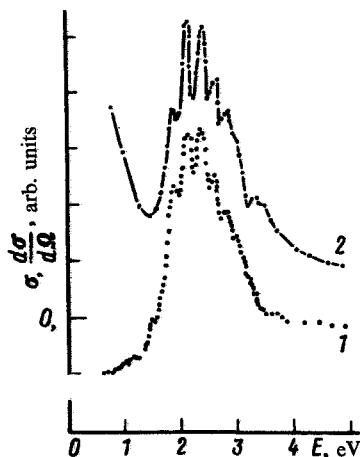


FIG. 1. Energy dependence of (1) the total cross section for electron scattering by N_2 molecules and (2) the cross section for elastic scattering through an angle of 180° .

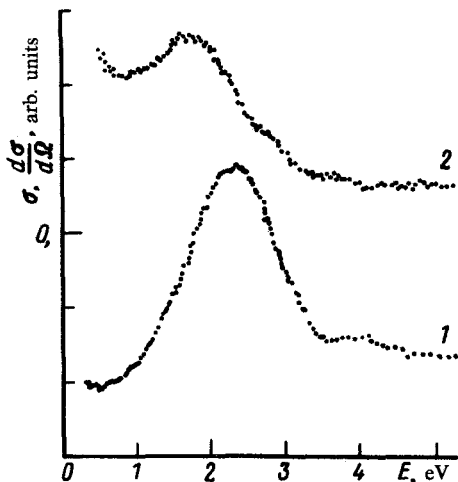


FIG. 2. Energy dependence of (1) the total cross section for electron scattering by N_2O molecules and (2) the cross section for elastic scattering through an angle of 180° .

through the formation and decay of short-lived states of negative ions. Since there is more than one pathway for the decay of these states, the elastic cross section is increased, as is the cross section for excitation of low-lying vibrational levels. Comparison of our curves of the total scattering cross section versus the energy with the data from other studies^{3,4} reveals a good agreement, including an agreement in terms of the resonance structure. In the case of N_2 , in contrast, the resonance structure in the backscattering cross section is seen much more clearly (Fig. 1). The reasons are that potential scattering has less effect at these angles and there is a high probability for resonant 180° scattering. This anisotropy, which involves the formation and decay of the $^2\Pi_g$ state of N_2^- , has also been found theoretically at incident-electron energies near the observed resonance structure.⁵

Turning to the N_2O , we note that there is a significant probability for elastic backscattering only in the energy interval 1.0–2.5 eV, and there is no correlation with the total scattering cross section (Fig. 2), where we see a broad maximum at 2.3 eV. This behavior suggests that the total cross section may be dominated by excited states of a low-lying electronic state of the molecule and that the different energy positions of the maxima are manifestations of the different states, $^2\Pi$ and $^2\Sigma^+$, of the negative ion N_2O^- which lie in this energy region.⁴

We note in conclusion that the sharp increase in the cross sections for elastic backscattering by these molecules at energies below 1 eV is a consequence of an increase in the angular acceptance of the scattered-electron detector with decreasing energy of the incident electrons. Furthermore, in the case of N_2O there is the possibility that this increase in the cross section may also stem from the presence of a nearly bound state of N_2O^- with $l = 0$. A state of this sort, which leads to a sharp increase in the cross section at low energies, has been established⁶ for the CO_2 molecule, which is isoelectronic with N_2O .

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