Resonances and the electron-beam excitation of metastable molecular levels

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The method of intersecting beams—gas-dynamical molecular beam and monochromatic electron beam—is used for the first time to measure the energy and angular dependence of the formation of metastable H_2, N_2, and O_2 molecules due to an electron impact.

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The resonance effects in electron-atom (molecular) collisions are the subject of extensive current investigations based on the observed structure of optical excitation functions. In addition, considerable information on the resonances can be obtained by

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studying the excitation of metastable states. This method is highly accurate and sensitive, thus allowing to find not only the position of resonances with respect to energy and their width, but also, in certain cases, it makes it possible to determine to what energy level they belong. In this work we report new data on the excitation of metastable states of molecular hydrogen, nitrogen, and oxygen by monochromatic electrons, and also the angular distribution of metastable particles produced in the electron impact.

The experiments were performed in a device consisting of a gas-dynamical source of molecular beam (GSMB), monochromatic electron source, and movable detector for recording metastable particles. The individual components of this device were described in detail earlier.[1,2] The intensity of molecular beams as a function of gas was $1-3\times10^{19}$ mole/cm^2·sec·sterad, and the angular divergence was 1–1.5°. The total width of the energy spread at half height of the maximum of the electron beam distribution, which was produced by a 127-degree selector, was $\Delta E\sim0.08$. The metastable particles were detected by means of a channel electron multiplier (VEU-6) mounted on a movable platform. The detector's zero angle of deflection, which coincides with the direction of the axis of the neutral beam, was determined by means of a mercury lamp whose ultraviolet (UV) output was directed through the shaping slits of GSMB at the detector aperture. The angular resolution of the detector in the $\pm$ 60-degree range was

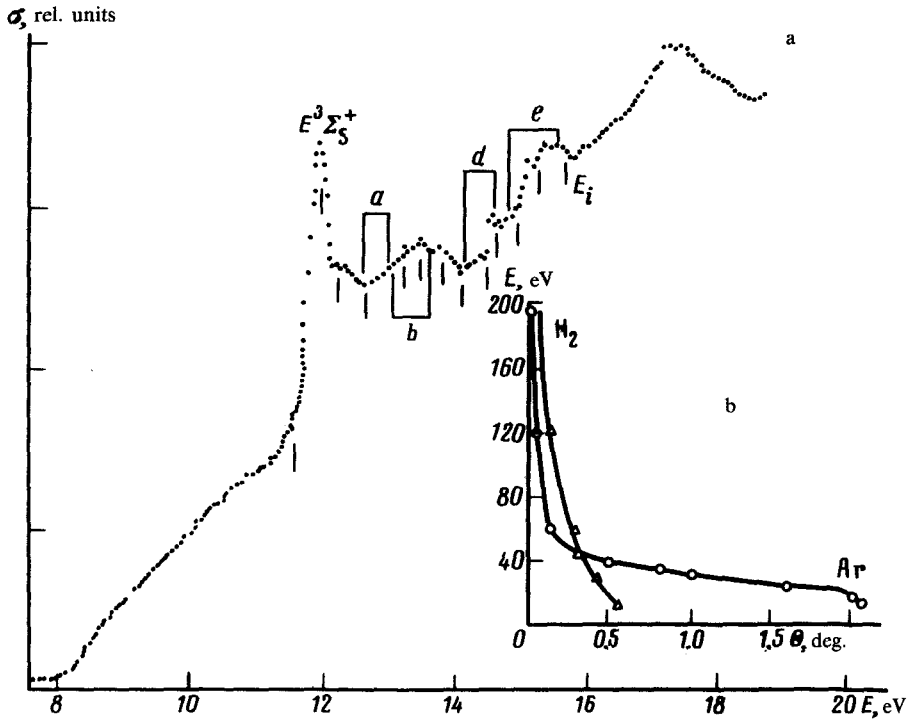

FIG. 1. (a) Excitation function of the metastable state of the N_2 molecule, (b) angular dependence of the yield of the metastable particles on the energy of the electrons.

0.016 rad. The useful signal was recorded by means of a time-analog device with an automatic scanning of the electron-beam energy in 0.025-eV intervals. The experimental methodology was confined to measuring the total number of metastable particles incident on the detector, as a function of the energy of the incident electrons, which varied in the range 7–19 eV. The calibration accuracy of the energy scale was $\geqslant \pm 0.05$ eV. The relative error for determining the relative cross section for production of the metastable particles was $\sim 3\%$. To eliminate the effect of charged particles on detection of the useful signal, an ion-optical system, consisting of stacked lenses and a cylindrical condenser, was mounted at the VEU-6 output. In addition, a delay pulse was applied to one of the lenses to prevent "exposure" of the detector to the UV radiation. This system provided a 10/1 signal-to-noise ratio.

Figures 1–3 show the results of our measurements.[1)] We note that the excitation function of the metastable nitrogen level was measured earlier[3]; however, the molecular beam was generated by an effusion source with a large angular divergence. Despite the substantial difference in this regard, the shape of the function we measured (Fig. 1a) is in a good agreement with the result in Ref. 3. The resonance width for this function at $E = 11.92$ eV almost coincides with the half-width of the energy spread of the electron beam, a fact which allowed us to use it for calibrating the energy of the pump electrons. As regards similar experiments with H_2 and O_2 molecules, none, to

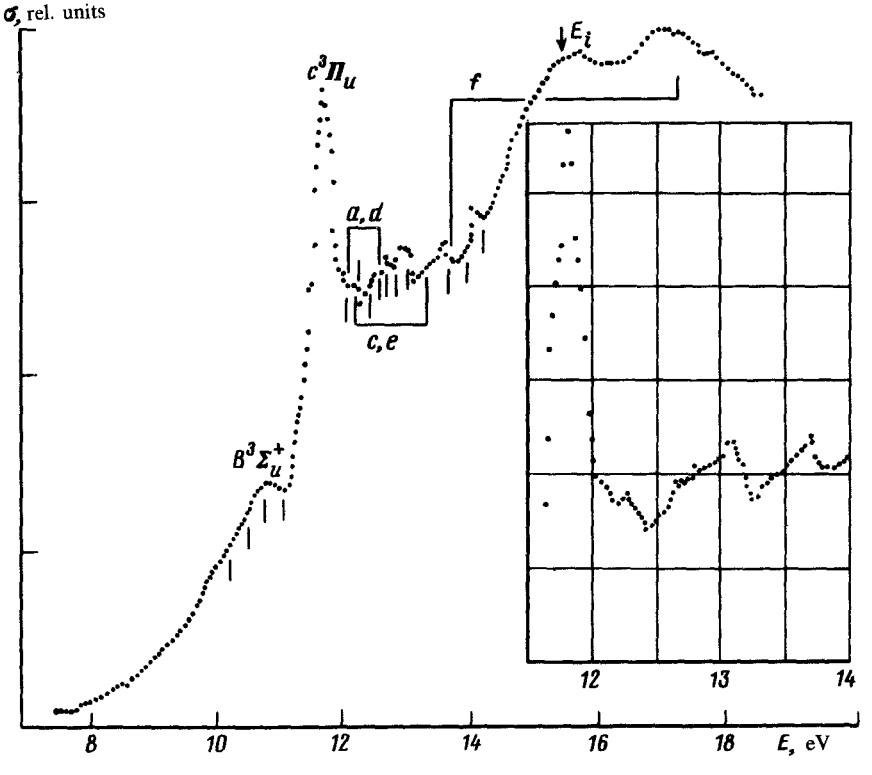

FIG. 2. Excitation function of the metastable state of the H_2 molecule.

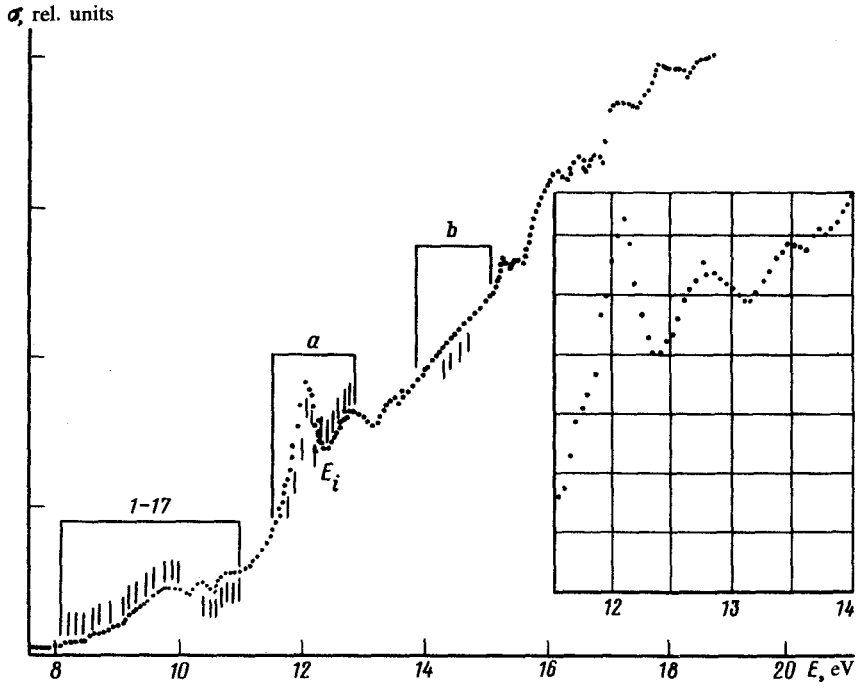

FIG. 3. Excitation function of the metastable state of the O_2 molecule.

our knowledge, have been carried out. The energy location of resonances on the excitation functions of H_2 (see Fig. 2) correlates rather well with the energy levels of the negative ions H_2^-, identified in the experiments on "electron transmission,"[4] and it corresponds to excitation of the "*a*," "*b*," "*c*," "*e*," and "*f*" bands. A similar situation also exists for the O_2 molecules (Fig. 3); however, the interesting fact in this case is the presence of a high maximum near the ionization threshold, and its correspondence to the excitation potential of the metastable $^1\Sigma_\mu^+$ level. As seen from Figs. 1–3, the excitation functions of metastable states of the H_2, N_2, and O_2 molecules exhibit a series of maxima beyond the ionization potential (E_i). It is most likely that their origin is attributable to the self-ionization states of molecules.

The small angular divergence of the molecular beam produced by GSMB and the capability to move the metastability detector with respect to molecular beam axis have resulted in a highly-accurate measurement of the position of the maximum of the intensity distribution of the metastable particles and have allowed us to study the angular distribution of their yield (see Fig. 1b). We were the first to measure the angular dependence of the intensity of the Ar metastable atoms and H_2, N_2 and O_2 molecules at different electron energies. We observed experimentally that the momentum transfer (recoil momentum) occurs up to a certain energy of the electrons, above which the direction of the metastable particles coincides with that of the primary molecular beam. The calculation of the angle of drift of the metastable particles, which is attributable to the electron impact based on the method of Ref. 5, is in good agree-

ment with the obtained experimental results (with the exception of H_2). The measured angular dependences of the yield of the metastable particles on the electron energy for H_2, N_2, O_2, and Ar shows that at energies > 150 eV the drift angle approaches zero. Thus, it was experimentally confirmed that the momentum transferred by the electrons to the target particles is reduced considerably with increasing energy of the electrons. This confirms that the excitation probability decreases rapidly with increasing scattering angle of the electrons.

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[1)]The bands and resonances in the figures follow a notation used by Schulz,[4)] and the energy positions of the resonances were taken from Refs. 3 and 4.

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