Measurements of the Absolute Cross Sections of Inelastic Processes for Slow Atomic Collisions

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Measurements of the absolute cross-sections of inelastic processes in ion-atom and ion-molecule collisions in the energy range from several hundred to a thousand electron volts are connected with experimental difficulties (low values of cross sections, scattering of the primary ion at large angles, problems with the total collection of the formed energetic products of the collisions). This accounts for discrepancies between the data of different authors. On the other hand, these data are necessary for solution of many fundamental and applied problems (plasma and upper atmosphere physics, gas discharge physics and so on).

Below are described the experimental methods and arrangements that have been developed and applied in our laboratory to measure absolute total and differential cross sections of excitation σ_{ex}, ionization σ_i, charge transfer σ_C and electron loss (stripping) σ_S processes.

The main parts of the our mass-spectrometer arrangement are (Fig. 1): an ion source H, an accelerating and focusing system L (quadrupole lenses), a magnetic mass-analyzer M, collimating slits (S_0-S_3), a collision chamber C and a detector of ions D. The target gas pressure in chamber C (about 10^{-4} torr) could be varied according to the single collision condition. The differential pumping system V achieved a vacuum of about 10^{-6} torr in another part of the arrangement. When measuring cross-sections of excitation processes, the radiation emitted at the collision was observed under a 90° angle to the direction of the primary ion beam. The spectral analysis of this radiation was performed in the visible (by a MDR monochromator) and vacuum ultraviolet spectral regions (by a Seya-Namioka monochromator). The intensity of the radiation was detected by photo-(PEM) and secondary electron (SEM) multipliers. A system of polaroid and quarter--wave plates P was used for checking the polarization of the radiation in the visible region. The investigations were carried out by different types of ion sources: alkali metal ions were generated in a surface ionization ion source; and H^+, H_2^+, H_g^+, He^+, O^+, N^+ ions by gas discharges and electron bombardment ion sources.

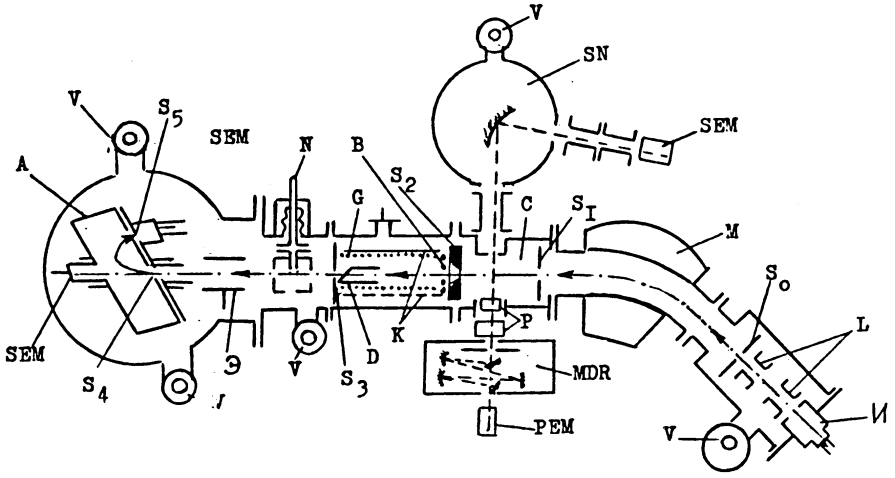

Figure 1

The optimum regime for the operation of these sources has been established by special control experiments. For example, in the case of the H_3^+-He pair it was determined that the vibrational excitation of H_3^+* molecules strongly influences the efficiency of the excitation of the L_α line (λ=120.0 nm) in the dissociation processes. The control experiment showed that by increasing the hydrogen pressure in the gas discharge ion source this efficiency is decreasing and reaches the saturation region at a pressure of about $3x10^{-3}$ torr. Under these conditions the deexcitation of vibrational excited H_3^+* molecules takes place in the time of collisions with H_2. The H_3^+ ions are formed in the ground state only [1].

Particular attention was devoted to the reliable determination and control of the relative and absolute spectral sensitivity of the recording system for the emitted radiation. This was done by measuring the output signal of the molecular bands and atomic lines excited by electrons in the collisions e+H_2, N_2, O_2. The relative spectral sensitivity and hence the values of the absolute cross sections were obtained by comparisons with cross sections for the same lines and molecular bands reported by other authors [2-6]. The spectra for e+H_2 and e+N_2 collisions at an electron energy E=200 eV are presented in Fig. 2.

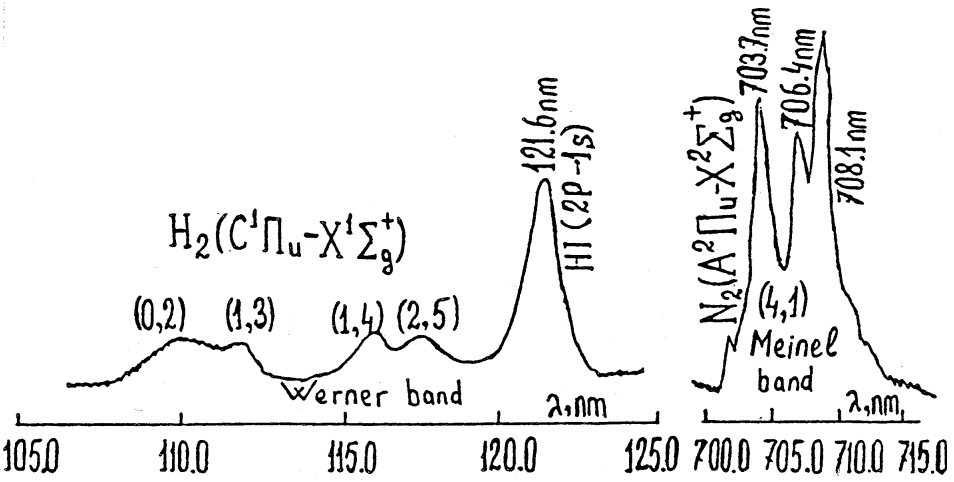

Figure 2

The transfer electrical field method (see for example [7]) is modified to measure the absolute values of total cross sections of ionization and charge transfer processes. The target gas ions and free electrons (secondary particles), arising as a result of collisions, are collected by the homogeneous electrical field of a plane capacitor K (Fig. 1). Absolute cross sections for the production of these particles, σ_+ and σ_-, are connected with cross sections σ_i, σ_c, σ_s by the following relations: $\sigma_+ \cong \sigma_i + \sigma_c$, $\sigma_- \cong \sigma_i + \sigma_s$. For the fixed homogeneous part of the field ("collision length") the capacitor electrode was divided by small plane parallel sections (1-10) and the charge distribution was studied with them. In front of the electrodes a grid G is placed to suppress the secondary electron emission from the surface of the sections. This grid is used to receive information about the energy spectrum of scattering particles by a "stopping potential," too. In Fig. 3 the ion current, scattering on the section closest to the entrance slit of chamber C (section 1, curves 3, 4) and on the middle section (section 5, curves 1, 2), is plotted as a function of the stopping potential for a K^+-Ar pair at energies E=1 keV and E=5 keV (curves 1, 3 and 3, 4 respectively). Considerable differences between these currents are caused by the strong possibility that the scattering primary ions are hitting the middle section. Therefore, section 1 was chosen for the measurements and hence an additional electrode system is introduced to provide homogeneity of the field in this region (electrodes B).

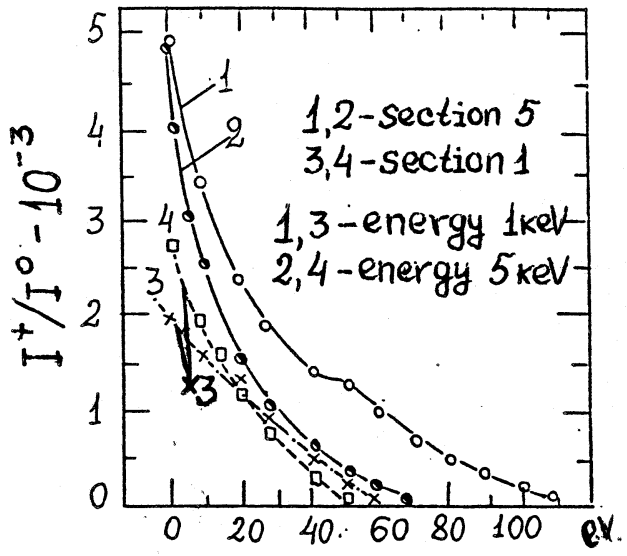

Figure 3

Absolute cross sections for the stripping processes σ_S were measured in separate experiments by mass spectrometer analysis of the primary beam after passing through the collision chamber.

To determine the energetic and angular dependences of differential cross sections a "Box" type electrostatic analyzer was used [8]. The primary ion beam crossed a narrow thermal energy beam of targeted particles, formed in the neutral particle source N (Fig. 1). The ion beam is then separated (slit S_4) and directed into analyzer A. The automatic regulation of the analyzer potential allows that ions with energy loss in the 0-100 eV region pass through outlet slit S_5 ($1x10^{-4}$ mm^2). The energy resolution of the analyzer is about 500. The whole analyzer system may be revolved in a horizontal plane around the center of the collision region in the angle interval of ±15°, with a resolution of about 0.5°. During the time of measuring the charge transfer cross sections σ_C, the charged component of scattered primary beam is removed by a plane capacitor and the neutral component is detected by SEM.

References

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