IONIZATION OF HIGHLY EXCITED ATOMS AND IONS OF NOBLE GASES IN AN ELECTRIC FIELD AND NEAR A METALLIC SURFACE

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The ionization of fast highly excited hydrogen atoms in strong electric and magnetic fields was investigated by Fedorenko et al. [1] The hydrogen atoms were produced by charge exchange of protons or by dissociation of molecular ions by different targets.

No such investigations were made on highly excited multi-electron atoms or ions produced by electron impact [2-4]. In such particles, only one of the electrons is excited in various states with large principal quantum numbers n, and the remaining electrons are in the ground state. Such excited particles are hydrogenlike. They should therefore have the same properties as excited hydrogen atoms, namely large lifetimes for large n and ability to become ionized in electric and magnetic fields. In view of the small electron binding energy in such states, one might expect these particles to become ionized near metallic surfaces.

The purpose of the present work was to investigate the ionization of multi-electron highly excited hydrogenlike particles: 1) near a metallic surface and 2) in a relatively weak electric field.

We present in this communication the results of direct experiments proving that these phenomena do occur for excited multi-electron particles. The experiments were made with a double mass spectrometer. The first phenomenon was proved by placing metallic grids in the paths of beams of excited atoms and ions, and the second by producing electric fields $\sim 10^3 - 10^4$ V/cm and investigating their influence on the mass spectra of the ions.

To obtain beams of excited helium and argon atoms and argon and xenon ions, special sources were developed, in which the ionization and excitation of the atoms were produced by means of electrons with controlled energies and currents. One of the sources was of the two-chamber type [4], to which one more grid was added. The presence of additional electrodes and grids in the sources made it possible to study the influence of both the electric field and the metallic grids on the beams of excited atoms and ions passing through them.

The following results were obtained, some of which are shown in Figs. 1 and 2. If copper grids are placed in the path of a beam of slow (thermal) argon and helium atoms, then the number of sharp symmetrical peaks appearing in the mass spectrum and produced by singly-charged positive ions is equal to the number of grids. These peaks are numbered 1 and 2 in Fig. 1. In addition, broad asymmetrical peaks appear if the atoms pass through regions in which electric fields are produced. The sharp peaks appear also in the absence of electric fields near the grids. By varying the voltages on the electrodes connected to the grids it possible to move these peaks along the mass scale in the mass spectrum, and to superimpose one on the other. If the grid is removed and an electric field $\gtrsim 10^3$ V/cm is produced on the path of the atom beam, then a broad asymmetrical peak appears in the mass spectrum. This peak is numbered 4 in Fig. 1. If the electric field is produced near an electrode with a grid, then the broad peak forms a "tail" near the sharp peak; this is numbered 3.

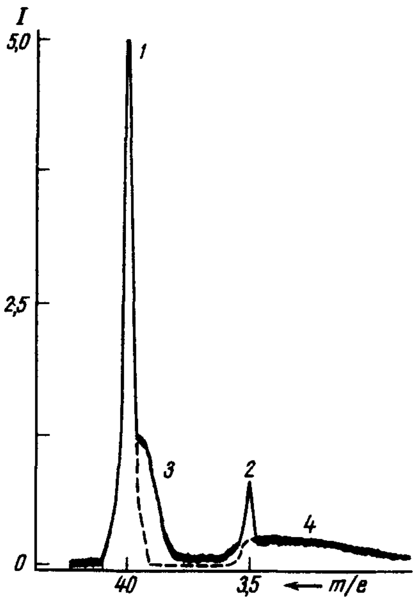

Fig. 1. Mass spectrum of Ar^+ ions produced when a beam of highly-excited Ar^* ions passes through two grids. The dashed line shows the variation due to the absence of the second grid and of the electric field from the region of the first grid.

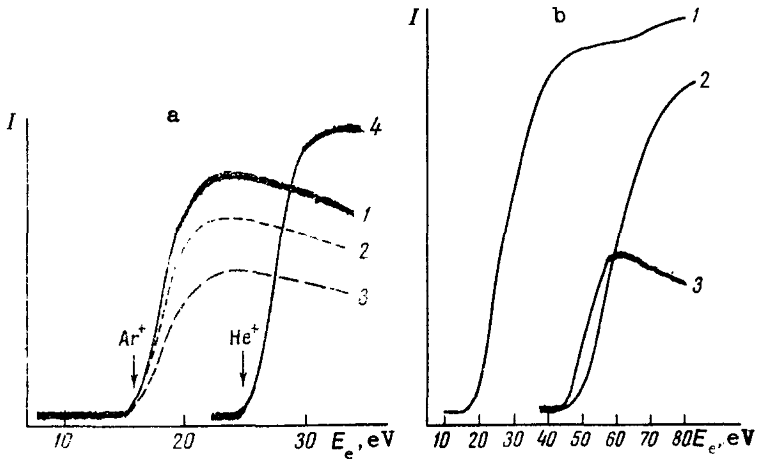

Fig. 2. Influence of the electron energy E_e on the ion current I (arbitrary units). a) Atom source. Curves 1, 2, and 3 pertain to Ar^+ ions, whose peaks are designated in Fig. 1 by 1, 3, and 2, respectively; curve 4 pertains to He^+. b) Ion source. Curves 1 and 2 pertain respectively to the ions Ar^+ and Ar^{++} produced upon collision of electrons with argon atoms. Curve 3 pertains to Ar^{++} ions produced from Ar^{+*} ions when the latter pass through a metallic grid.

Ions forming sharp and broad peaks appear in the mass spectrum of argon or helium at electron energies which are approximately 0.3 eV lower than the threshold for the appearance of singly-charged ions (see Fig. 2a), corresponding to the threshold for the appearance of highly-excited atoms [3,4]. The heights of the peaks depend linearly on the gas pressure and on the electron current.

A detailed investigation consisting of a study of the influence of the electron energy and current, the gas pressure, and the electric field intensities without and with the grids, shows that the sharp peaks of Ar and He are due to singly-charged ions resulting from ionization of the excited atoms near the metal surface, and the broad peaks are due to singly-charged ions produced in the space between the electrodes by ionization of the excited atoms in the electric field. In this case the ions receive a different energy, and therefor form a broad peak.

Similar experiments were made with excited Ar^{+*} ions. In this case, covering the slits with grids also led to the appearance of new sharp and symmetrical peaks, but produced by the doubly-charged Ar^{++} ions. These peaks appear at electron energies approximately 0.3 eV below the threshold for the appearance of doubly-charged ions produced as a result of the collision of electrons with atoms, as shown in Fig. 2b, i.e., at the threshold for the appearance of highly-excited singly-charged ions [2]. The positions of the peaks on the mass scale depend on the voltages on the electrodes connected to the grids. When working with Ar^{+*} ions, the grids were placed in the path of the beam not only in the source and beyond it, but also past the first magnetic analyzer of the double mass spectrometer. The latter experiments were made also with Xe^{+*} ions. In all these cases the metallic grids could be moved without breaking the vacuum in the equipment. The influence of the electric field and of the grids was similar to that observed for axited-atom beams. When working with Xe^{+} ions, we investigated in addition the influence of the width ℓ of the slit between the magnetic analyzers. The intensity of the singly-charged ions decreased with decreasing ℓ, while the intensity of the doubly-charged ions, produced from the excited singly-charged ones, remained practically unchanged. As a result, the relative intensity ℓ' increased like ℓ^{-1}.

Analysis of all the results leads to the conclusion that highly-excited multi-electron atoms and ions become ionized near a metallic surface and in an electric field. In our experiments these processes produced in the mass spectra sharp and broad peaks, respectively. The existence of the former follows from the fact that the sharp peaks appear only in the presence of grids or narrow collimating slits in the path of motion of the excited particles, and are produced even without the presence of electric fields near the grids. The second conclusion follows from the facts that the broad peaks appear only when electric fields are present in the path of motion of the excited particles, that the peaks vary with the electric fields, and that the presence of grids is not essential for their appearance.

It can be assumed that atoms and ions of other substances in highly-excited hydrogen-like states, as well as highly excited hydrogen atoms, will become ionized near a metallic surface. Thus, by measuring with a collector the current of the positive ions produced by ionizing excited particles as a result of interaction with the metallic surface of the grid, or by measuring the electron-current in the grid, it is possible to detect atoms and ions in highly-excited states.

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