Scattering of nonhomonuclear hydrogenous molecular ions by a metal surface

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In irradiating a metal with 20-keV ArH^+ ions, the kinetic energy of the bombarding protons was 500 eV. The energy spectra of the scattered protons under these conditions turned out to be narrow, $\Delta E/E \sim 30\%$, in contrast to that obtained with scattering of fast protons.

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Beams of light ions, protons or deuterons, with energies of hundreds of electron volts and with an intensity of several $\mu A/cm^2$, are required for experiments simulating the interaction of a hot plasma with a wall. Considerable difficulties arise in producing such beams and in order to increase the current density the molecular ions H_2^+ or

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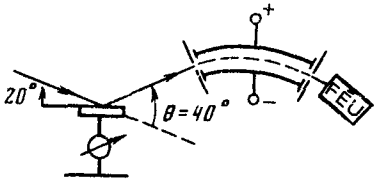

FIG. 1. Experimental setup.

H_3^+ are sometimes used. In this case, the accelerating voltage can be increased, correspondingly, by a factor of 2 or 3, while maintaining the previous energy per nucleon, but increasing the current density in the beam according to Langmuir's law. It is useful, however, to proceed further with this approach and to use nonhomonuclear molecular ions which contain hydrogen and a heavy nucleus. For example, in ArH^+ ions, the kinetic energy of the proton is only 1/40 of the kinetic energy of the entire ion and the accelerating voltage on the ion source can be greatly increased.

Of course, it is not always possible to use this technique; it can only be used when it is possible to separate reliably the effects caused by light and heavy ions, for example, when the ion scattering is being studied and attention is focused on the energy spectra of the reflected particles. However, there is no doubt that in this case, as well as under any other conditions, when molecular ions are used for bombardment, it is necessary to have a clear answer to the following question: Does the interaction of the molecular ion with the surface differ from the interaction of its atomic fragments, which hit the surface individually, with this surface? Furthermore, the differences in scattering of molecular and atomic ions are virtually unknown.

The experimental arrangement is shown in Fig. 1. The target was bombarded by monoenergetic ion beams, separated and formed with the help of a magnetic mass spectrometer. A gas discharge ion source of a dual plasmotron type, operating on a mixture of argon with hydrogen, was used to obtain the ions. Beams of ArH^+ ions with a current strength $\sim 5\,\mu A$ in the region of the target were easily obtained with an accelerating voltage of 20 keV. The energies of the scattered ions were analyzed with the help of an electrostatic analyzer and an electron multiplier was used for detecting the ions. The residual gas pressure in the target chamber did not exceed 1×10^{-8} Torr. Polycrystalline targets, prepared from gold, platinum, silver, copper, and scandium, were used in the experiments. An auxiliary beam of argon ions was used to clean the surface of the target. We note that in a number of cases, bombardment by argon ions in the ArH^+ molecular ion was sufficient for this purpose.

The energy spectrum of the scattered ions, obtained by bombarding copper with ArH^+ molecular ions is shown in Fig. 2a. The kinetic energy of the ArH^+ ion was 20 keV, of which the proton had 488 eV. For comparison, Fig. 2b shows the spectrum obtained under the same conditions with irradiation by atomic Ar^+ ions, whose energy was 20 keV. This spectrum has the usual form: It contains a peak due to Ar^+ ions scattered by target atoms and a peak corresponding to the ionized recoiled atoms of the target. No additional peaks were observed in the low-energy part of the spectrum.

Two typical peaks are also present in the spectra obtained with the use of ArH^+ ions, but they turn out to be shifted slightly to the left. This shift is close to the shift that arises from the simple difference in the initial energies of argon atoms, but exceeds

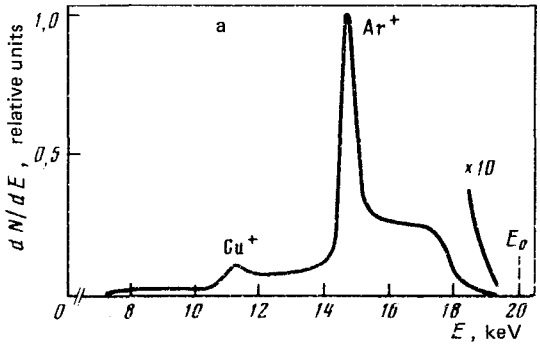

FIG. 2a. The energy spectrum of scattered ions with bombardment of the target by 20-keV ArH^+ ions, $\theta = 40°$, copper target.

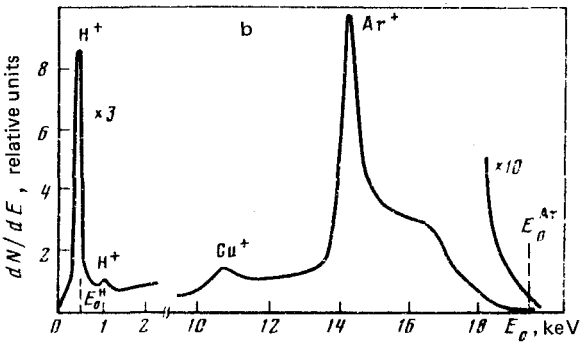

FIG. 2b. Same, with bombardment by 20-keV Ar^+ ions.

it slightly. In addition to the "usual" peaks, which are attributable to the scattering of argon ions, two new peaks appear in the low-energy part of the spectrum. These peaks cannot be linked with pair collisions between argon ions and copper atoms. In the opposite case, it would be necessary to assume an extremely high, for the given conditions, multiplicity of the charge of the ions responsible for these peaks (13 for argon and 22 for copper). In addition, no other multiply charged ions, other than doubly charged, where observed in the spectra. We emphasize again that these peaks are missing in the spectra obtained by irradiation with argon ions.

The position of the peak on the right side of these peaks coincides with the computed position of the peak formed by the reflected protons, if 19 512-eV argon ions are the collision partners and the protons are at rest. Generally, the particles knocked out could be protons which hit the surface together with the argon ions, i.e., the protons in the ArH^+ molecular ion, as well as protons which penetrate into the target at earlier stages of irradiation by ArH^+ ions.

The peak on the left is formed by scattering of 488-eV protons, when these protons were present in the 20-keV molecular ion containing a heavy nucleus. The width of these peaks at half-height is about 30% and it is situated on the high-energy part of "its" spectrum. We recall that such a result is completely uncharacteristic for scattering of protons of higher energy, when, instead of peaks there are wide, dome-shaped spectra, extending virtually through the entire spectrum (see Ref. 1). Thus, lowering the energy of protons that bombard the target narrows their energy spectra in the scattered flux.

These spectra exhibit clear indications of the "molecular" origin of the bombarding protons. The position of the right edge of the scattered proton peak indicates that protons with energies appreciably exceeding their initial kinetic energy are present in the scattered particle flux. In its turn, a gently sloping tail, which extends into the energy range above 19 512 eV, is adjacent to the high-energy slope of the argon peak. When atomic argon ions are used for irradiation, the tails are missing and ions with energies exceeding their initial kinetic energy are not observed in the spectrum. The observed features of the spectra indicate that when molecular ions are scattered there is a significant exchange of energy between their components. This exchange can occur either as a result of scattering of nuclei by each other or as a result of dissociation. In the latter case the internal energy of the ion is converted to the additional kinetic energy of its fragments. In order to establish which of these mechanisms is realized in reality, detailed measurements are required in the sections of the spectrum that are distinguished in the case of molecular and atomic bombarding ions.

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[1]E. S. Mashkova and V. A. Molchanov, Rasseyanie ionov srednikh énergiĭ poverkhnostyami tverdykh tel [Scattering of Medium-Energy Ions by Surfaces of Solids], Atomizdat, Moscow, 1980, p. 106.

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