Letters to the Editor

ON N. V. PLESHIVTSEV'S ARTICLE "SPUTTERING OF COPPER BY HYDROGEN IONS WITH ENERGY UP TO 50 kev"

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THE cited article by Pleshivtsev[1] contains data on the sputtering of copper by hydrogen ions in a wide energy range (10 kev — 10 Mev). The values obtained for the sputtering coefficient differ greatly both from the results of similar experiments[2-4] and from the theoretical predictions,[5] it being stated that the latter is incorrect from both the qualitative and the quantitative points of view. The principal difference between Pleshivtsev's and other procedures was that the ion beam contained several different components. According to his data, the beam contained the following ions: H^+ (30 — 40%), H_2^+ (40 — 50%), H_3^+ (30 — 10%), O_2^+ and N_2^+ (1 — 3%). We shall show that the sputtering coefficient S_{Obs} observed in that reference could differ greatly from the true coefficient S_{H^+} of sputtering by the hydrogen ion.

If the beam is not too dense we can assume that each ion is sputtered independently of the others. We can then write for the part of S_{Obs} connected with the sputtering by different hydrogen ions

$$S_{\mathrm{obs}}^{\mathrm{H}} = n_{\mathrm{H}^+} S_{\mathrm{H}^+}(E) + n_{\mathrm{H}_2^+} S_{\mathrm{H}_2^+}(E) + n_{\mathrm{H}_3^+} S_{\mathrm{H}_3^+}(E) \qquad (1)$$

(where n_i — fraction of the corresponding ions in the beam). To estimate this quantity we assume that the complex ion exerts approximately the same sputtering action as if all of the particles it contains were separately incident with velocity equal to the velocity of the complex ion (see [2,6]). We can then rewrite (1) in the form

$$\frac{S_{\mathrm{obs}}(E)}{S_{\mathrm{H}^+}(E)} = n_{\mathrm{H}^+} + 2n_{\mathrm{H}_2^+}\frac{S_{\mathrm{H}^+}(E/2)}{S_{\mathrm{H}^+}(E)} + 3n_{\mathrm{H}_3^+}\frac{S_{\mathrm{H}^+}(E/3)}{S_{\mathrm{H}^+}(E)}\,. \qquad (2)$$

If $E_{H^+} \gg 500$ ev, we have according to the theory of Goldman and Simon[5]

$$S(E) \sim \ln(E/E_d)/E,$$

where E_d — binding energy of the atom of the sputtered metal in the lattice (25 ev for copper[7]). Under the least favorable conditions allowed by the author ($n_{H^+} = 20\%$, $n_{H_2^+} = 50\%$, $n_{H_3^+} = 30\%$), we find from these formulas that $S_{Obs}^{H} \sim 4S_{H^+}$ at about 50 kev. The error in the determination of the sputtering coefficient can thus reach 400% even in the absence of heavy-ion impurities.

Let us estimate the contribution of heavy impurities to the observed sputtering coefficient. It is known[6] that in the 5 — 25 kev energy range nitrogen ions N^+ sputter copper with a coefficient $S_{H^+} \approx 2$ atoms/ion. In this region the sputtering coefficient vs energy curve for nitrogen passes through a flat maximum and hardly varies with the energy. The observed sputtering coefficient for nitrogen ions is

$$n_{\mathrm{N}_2^+} S_{\mathrm{N}_2^+}(E) \approx 2n_{\mathrm{N}_2^+} S_{\mathrm{N}^+}(E/2) \approx 0.12 \text{ atom/ion}\,.$$

Oxygen ions produce somewhat stronger sputtering than nitrogen ions[2,8]; therefore if we assume that the beam has as many oxygen as nitrogen ions we can expect the given values of the sputtering coefficient to contain a constant component with value close to 0.25 atom/ion, due to the presence of heavy impurities. Under these assumptions, recalculations of Pleshivtsev's data lead to a sputtering coefficient that is in satisfactory agreement with the data given in the literature.

As to the preliminary results of the experiments on the sputtering of copper by high-energy hydrogen ions (up to 10 Mev), we note that the observed increase in the sputtering coefficient with increasing ion energy cannot be reliably ascribed to the action of high-energy protons until the monochromaticity of the sputtering beam is rigorously established. Pleshivtsev's procedure has therefore an important shortcoming, which greatly distorts the results obtained and makes the conclusions concerning the incorrectness of the theory[5] unfounded.

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LARGE-ANGLE SCATTERING OF HIGH-ENERGY PIONS

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RECENTLY there has been discussed in the literature[1,2] the possibility of scattering of high-energy pions at c.m.s. angles close to 180°, in reactions of exchange scattering

$$\pi^- + p \rightarrow \pi^0 + n \qquad (1)$$

and elastic scattering

$$\pi^+ + p \rightarrow \pi^+ + p \qquad (2)$$

The presence or absence of such scattering indicates the presence or absence of a contribution of Feynman diagrams with virtual nucleons and is connected with the nature of the dependence of the nuclear forces on the distance at high energies. Complete cancellation of the backward scattering signifies, in particular, that the impact parameters involved in the scattering can be made as large as desired, but the amplitudes of the partial waves are very small.

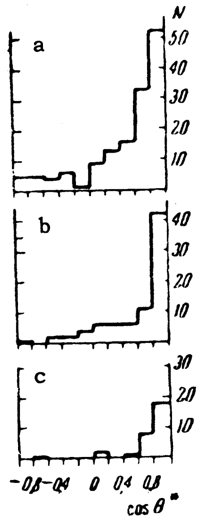
We have previously[3,4] investigated in detail the reaction

$$\pi^- + n \rightarrow \pi^- + n, \qquad (3)$$

which is isotopically symmetrical to reaction (2), for an incoming meson with momentum 2.8 Bev/c. It was shown that the cross section for scattering at c.m.s. angles greater than 90° is less than 0.006 mb/sr, and that the probability that the elastic-scattering angles exceed the angle corresponding to the first diffraction minimum is small and decreases sharply with increasing momentum of the incoming pion. Data on exchange scattering at large angles in the energy region above 1 Bev are lacking at the present time.

The total cross section of reaction (1) at 2.8 Bev/c was estimated in a paper by one of the authors and Shebanov[5] using a bubble chamber filled with a propane-xenon mixture; we studied prongless stars accompanied by electron-positron pairs of conversion γ-quanta from the decay of π^0 mesons. In the present note we give the results of a different reduction of the data obtained in the same investigation.

The figure shows the angular distribution of the γ quanta in the πN c.m.s. without account of the chamber γ-quantum counting efficiency. Plot a in this figure corresponds to the case when there are 3 to 6 electron-positron pairs in the direction towards the point of disappearance of the π^- meson,



plot b corresponds to two pairs, and plot c to one conversion pair. The high average efficiency for the registration of γ quanta (~ 0.52) enables us to distinguish between process (1) and a reaction in which several π^0 mesons are produced. It is seen from this figure that elastic charge exchange with emission of a π^- meson backward is not observed in practice: one case in the figure (plot b) is connected either with the creation of one more π^0 meson or with the escape of the π^0 meson from the reaction (1) at an angle greater than 1 sr (relative to 180°). The corresponding estimate of the upper limit of the cross section is $\sigma < 0.01$ mb/sr.

The data enable us to estimate the cross section of elastic charge exchange with emission of a π^0 meson at a c.m.s. angle greater than 90°, found to be $\lesssim 0.002$ mb/sr. Similar data are obtained if the bubble chamber is filled with freon.