# ANGULAR DISTRIBUTION OF FAST PARTICLES LEAVING A METALLIC SURFACE WHEN IT IS IRRADIATED BY AN ION BEAM

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Fig. 1

Figure 1: Fig. 1

## Abstract

## Full Text

## PHYSICS

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# ANGULAR DISTRIBUTION OF FAST PARTICLES LEAVING A METALLIC SURFACE WHEN IT IS IRRADIATED BY AN ION BEAM

*(Presented by Academician L. A. Artsimovich, 18 V 1962)*

The study of the angular distribution of fast particles reflected from a metallic surface is of considerable interest for elucidating the mechanism of energy transfer by fast ions to a crystal lattice. However, the available experimental data are contradictory. Thus, in papers (1–4) the existence is indicated of an angle of preferential reflection of ions, close to the specular angle; moreover, the authors themselves of some of these papers (4) point out that this fact is inexplicable from the standpoint of ideas about the character of the interaction of ions with a solid. The authors of other papers (5–7) deny the existence of a specular angle. For example, in paper (7) it is indicated that the distribution of scattered ions over exit angles, in the case when the mass of the target atoms is greater than the mass of the ion, obeys the cosine law and that there is no preferential scattering at the specular or at any other angle.

The present work contains the results of measuring the angular distribution of fast reflected particles at angles of incidence of ions on the target close to grazing.

A beam of singly charged argon ions with an energy of 30 kev had an angular convergence of ±1° and a current density of the order of 1 $\text{ma/cm}^2$; the remaining experimental conditions were the same as in (8). Upon reflection of ions of elements with a high ionization potential, part of the ions is neutralized (9,10). In order to be able to measure, along with the ionic component, also the neutralized component of the beam of reflected fast particles, a device was made analogous to that used in (11) (see Fig. 1).

**Fig. 1**

Particles reflected from the target $M$ passed through the opening in the aperture

Fig. 2

Figure 2: Fig. 2

diaphragm $D_2$ of the ion receiver $P$ and fell on the inclined collector $K_1$, located inside the Faraday cylinder $\Phi$. The secondary electrons knocked out by them were collected by the collector $K_2$. In the course of the experiment, for each scattering angle the ion current $I_1$ and the secondary-electron-emission current $I_2$ were measured at one and the same value of the primary-ion current $I_0$. The distance from the target $M$ to the diaphragm $D_2$ was 160 mm. It exceeded by an order of magnitude—

exceeded the size of the irradiated surface of the specimen. Plates of copper, tungsten, and also graphite were used as targets. This choice of targets made it possible to carry out measurements at different values of the ratio of the ion mass to the mass of the atoms of the target material. The measurement results are shown in Figs. 2, 3, and 4.

**Fig. 2.** Copper target, $I_0 = 100\,\mu$a.
1—$\theta = 4°$; 2—6°; 3—8°; 4—10°; 5—12°;
6—14°; 7—16°; 8—current of reflected ions
at $I_0 = 250\,\mu$a, $\theta = 8°$.

Comparing the values of the current of reflected ions $I_1$ and of secondary electrons $I_2$ (the coefficient of secondary ion-electron emission under our conditions proved to be equal to 3.5), one may conclude that the greater part of the argon ions is neutralized at the target surface. This is in agreement with the results (10) obtained for ions of lower energies. Since the scattering angles studied by us are small, it may be assumed that, to a first approximation, the current of secondary electrons is proportional to the number of fast particles incident on $K_1$, so that the curves in Figs. 2, 3, and 4 describe the angular distribution of the reflected particles. It can be seen that, irrespective of the ratio of the masses of the ion and of the target atoms, the curves have one and the same form. At angles $\varphi < \theta$ the current is absent; as the scattering angle is increased from $\varphi = \theta$, the current at first rises sharply, then reaches a maximum, after which it begins to decrease monotonically. For one and the same specimen, independently of the angle of incidence of the ions on the target $\theta$, the angular width of that part of the curves where the current increases with increasing scattering angle is the same. This fact indicates that the increase in current is connected exclusively with the microrelief of the specimen. For one and the same specimen, the curves corresponding to different angles of incidence of the ions on the target practically coincide after passing through the maximum.

In Figs. 2 and 3, for comparison, quantities proportional to the differential effective scattering cross sections (dashed curves), calculated from the data of the theoretical work (12), are shown. It is easy to see that these

curves obtained under the assumption of a single collision of two free particles

Fig. 3. Tungsten target. $I_0 = 140\,\mu$A.
$1 - \theta = 4^\circ$; $2 - 6^\circ$; $3 - 8^\circ$; $4 - 10^\circ$; $5 - 12^\circ$; $6 - 14^\circ$

Figure 3: Fig. 3. Tungsten target. $I_0 = 140\,\mu$A. $1 - \theta = 4^\circ$; $2 - 6^\circ$; $3 - 8^\circ$; $4 - 10^\circ$; $5 - 12^\circ$; $6 - 14^\circ$

Fig. 4. Graphite target. $I_0 = 130\,\mu$A.
$1 - \theta = 4^\circ$; $2 - 6^\circ$; $3 - 8^\circ$; $4 - 10^\circ$; $5 - 12^\circ$; $6 - 14^\circ$

Figure 4: Fig. 4. Graphite target. $I_0 = 130\,\mu$A. $1 - \theta = 4^\circ$; $2 - 6^\circ$; $3 - 8^\circ$; $4 - 10^\circ$; $5 - 12^\circ$; $6 - 14^\circ$

interacting according to Coulomb' s law (with allowance for screening) reproduce the course of the experimentally found dependence qualitatively correctly. However, the quantitative agreement is not sufficiently good.

**Fig. 3.** Tungsten target. $I_0 = 140\,\mu$A.
$1 - \theta = 4^\circ$; $2 - 6^\circ$; $3 - 8^\circ$; $4 - 10^\circ$;
$5 - 12^\circ$; $6 - 14^\circ$

**Fig. 4.** Graphite target. $I_0 = 130\,\mu$A.
$1 - \theta = 4^\circ$; $2 - 6^\circ$; $3 - 8^\circ$; $4 - 10^\circ$; $5 - 12^\circ$;
$6 - 14^\circ$

This is especially clearly manifested in the case of a graphite target (see Fig. 4). Since the mass of a graphite atom is less than the mass of an argon ion, according to the concepts of a single collision of free particles one should expect the existence of a limiting scattering angle for argon ions (17.5° in the laboratory coordinate system). This angle is not observed experimentally, which indicates the need to take multiple collisions into account, in accordance with the conclusions of work ($^{13}$).

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