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Abstract

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Passage of Ions of Various Gases through Thin Silver Foil

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The passage of charged particles through metals has been well studied in the region of high energies (of the order of 100 keV and above). For intermediate energies there is only the work of H. Bethe[^1], in which data are given on the energy losses of protons in the interval from 4 to 60 keV for foils of various metals. There is no information in the literature on passage through foil by other ions of intermediate energies. This is explained by the difficulty of obtaining thin metallic foils and by the complexity of working with them.

We have developed a method for obtaining thin silver foil with a thickness down to 40 mμ and have investigated the passage of ions H^+, He^+, C^+, N^+, and O^+ through foils 40–60 mμ thick. In obtaining thin homogeneous foils it is necessary that the size of the crystals be considerably smaller than the thickness of the foil.

In works[^2][^3] the aging of thin metallic foils at various temperatures was studied. Copper foil prepared at the temperature of liquid nitrogen has crystal sizes of $\sim$ 40 Å, whereas at room temperature they are $\sim$ 400 Å. Therefore, for preparing a thin fine-crystalline silver foil, a metallic substrate cooled with liquid nitrogen is used. It consists of degreased rolled aluminum foil 1–2 μ thick and a polished copper plate. Silver is evaporated onto such a substrate at a residual-gas pressure of $1 \div 3 \cdot 10^{-7}$ mm Hg. Pieces of aluminum foil with the deposited layer of silver are placed in a NaOH solution. The aluminum dissolves, and a thin silver foil remains on the surface. It is removed from the solution, dried, and placed on the receiver for the investigations. This method makes it possible, quite simply and rapidly, to obtain silver foils of good quality, 50–80 mμ thick. Bombardment by helium ions with an energy of 20–40 keV reduces the foil thickness to 40 mμ; the foil thickness was determined with an accuracy of $\pm 4\%$, initially by weighing and, during operation, from the energy loss of protons in the foils, on the assumption that the loss is directly proportional to the foil thickness (see[^1]). The homogeneity of the foils was measured on a microphotometer. The measurements showed that fluctuations of the thickness do not exceed 2%.

The investigations were carried out on an apparatus of the type of a large magnetic mass spectrometer about 5 m long and with a beam deflection angle of 25°. Differential pumping was provided by three diffusion pumps with traps

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

cooled by liquid nitrogen. In the ion source, an arc-type discharge in a longitudinal magnetic field was used. The ion-current density in the region of the slit of the gas-discharge chamber reached 100 mA/cm^2, and it could be smoothly regulated during operation.

The receiver was surrounded by a copper jacket at the temperature of liquid nitrogen. The pressure in its region when working with helium and hydrogen was $6 \div 8 \cdot 10^{-7}$ mm Hg, and with heavy gases $\sim 1 \cdot 10^{-7}$ mm Hg,

which made it possible to maintain a clean foil surface during the investigations.

To determine the energy loss of the ions in passing through the foil, the retarding-potential method was used. The use of a common power supply for accelerating the ions from the source and decelerating them at the receiver made it possible to substantially reduce the measurement error, so that it did not exceed 1%. The energy distribution of the ions in the primary beam was measured with an accuracy of 0.04–0.12% of their energy.

Fig. 1

The basic design of the receiver and the measuring circuit are shown in Fig. 1. Diaphragm D_0 separated the receiver region of the apparatus from the rest of the vacuum volume and defined the beam. Plates P_1 and P_2 served to determine the intensity of the primary beam and its position.

Fig. 2. Dependence of the energy-loss cross section for H^+ and He^+ ions in silver foil on the mean ion velocity. The dashed curve is according to Bethe’ s data

The foil was mounted on diaphragm D_ϕ. Diaphragms D_2 and D_3 passed ions within an angle of ±4°. Diaphragms D_4, D_5, and D_6 served as protection against secondary negative particles. The receiver consisted of plate P and cylinder C.

The results of measurements of the dependence of the energy losses and velocity losses of H^+ and He^+ ions on the mean ion velocity are shown in Figs. 2 and 3. Table 1 gives the threshold values of energies and velocities at which transmission of various ions through silver foil of thickness 55 mµ is observed.

In Fig. 2, for comparison, data from work $^{(1)}$ are given, which diverge from the results of the present work at low velocities. This is probably explained by the presence of large errors in this velocity region in the measurement method used by H. Bøttcher. (He measured the loss of velocity from the deflection of

Fig. 3. Dependence of the velocity loss by H^+ and He^+ ions in silver foil on the mean ion velocity

Figure 3: Fig. 3. Dependence of the velocity loss by H^+ and He^+ ions in silver foil on the mean ion velocity

particles in a magnetic field with low resolving power, and recorded the number of protons with a gas-filled counter with a mica window.)

Table 1

Ion	E_{init} (keV)	Initial ion velocity $v_{\text{init}}\left(10^8\ \frac{\text{cm}}{\text{s}}\right)$	Mean velocity loss $-\frac{\Delta v}{\Delta x}\left(10^6\ \frac{\text{cm}}{\text{s}\,\mu}\right)$
He^+	7.2	0.6	0.95
C^+	21.5	0.6	1.03
N^+	24.5	0.59	1.02
O^+	28	0.59	1.02

From the results of the measurements it follows that, at equal velocities for all the atomic ions investigated, the velocity losses are the same within the limits of the experimental errors, while the energy losses increase in proportion to the ion masses. This indicates that the main and determining factor in the mechanism of energy transfer is the velocity of the ions passing through the foil.

Fig. 3. Dependence of the velocity loss by H^+ and He^+ ions in silver foil on the mean ion velocity

Then an estimate was made of the number of neutral particles emerging from the foil, for H^+ and He^+ at $E \geq 25$ keV and at the threshold energy values for the remaining ions. It was carried out from the secondary electron emission, since the latter, caused by neutral particles and ions, is the same (see (4)). This estimate is qualitative in character, since the secondary emission was measured with an undegassed target and, consequently, errors were possible in determining its coefficient.

From works (5,6) it is seen that negative and doubly charged positive ions in the energy range investigated by us amount to no more than 5%; therefore they were not taken into account.

For protons, the number of neutral particles is equal to the number of positive ones at an initial energy of 33-34 keV, which is in good agreement with work (5) and confirms the correctness of the assumption that the last few (~5) atomic layers determine the charge equilibrium of particles passing through the foil.

For the ions He^+, C^+, N^+, and O^+, in the energy range investigated, neutral atoms predominate, making up ~70–80% of their total number.

At angles greater than ±4°, only an insignificant fraction of charged and neutral particles (~4-9%) is scattered.

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