PASSAGE OF LITHIUM IONS THROUGH CONDENSED TARGETS

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Measurements were made of the equilibrium charge distributions, the specific energy losses and the angles of the resultant deviation of lithium particles after passing through celluloid and carbon films. The values of the total transmission of a beam of lithium ions were also determined, allowing for the angular distribution. The measurements were carried out in the energy range from 20 to 145 keV.

1. INTRODUCTION

MEASUREMENTS of the equilibrium distributions of charge in lithium ion beams which had passed through hydrogen, helium, and nitrogen, were carried out by Allison et al.,[1] in the energy range 10—475 keV. Leviant et al.[2] investigated the equilibrium fractions in 80—250 keV lithium and sodium beams interacting with air molecules. Measurements of the equilibrium fractions for lithium ions passing through organic films were carried out by Bethge and Fabricius[3], in the energy range 3—10 keV, and by Teplova et al.[4] in the energy range 0.5—5 MeV.

The present work reports the results of measurements, in the energy range 20—145 keV, of the charged components of an equilibrium beam of ion particles which have passed through celluloid and carbon films. In addition to the measurement of the charged components of the beam, the angular distribution of the particles emerging from the target was also determined. The angular distribution measurements make it possible, first, to determine the value of the total transmission of a particle beam, i.e., the relative fraction of the incident particle flux which passes through the target at all angles and, secondly, to compare with theoretical calculations the angle of the resultant deviation after multiple scattering.

We also measured the specific energy losses of lithium ions passing through celluloid and carbon films.

2. EXPERIMENTAL APPARATUS AND MEASUREMENT METHOD

The apparatus is shown schematically in Fig. 1. A beam of positive lithium ions was generated by a thermionic source 2. Lithium ions were evaporated from the lithium aluminosilicate surface, which had been deposited on the tantalum ribbon (0.1 mm thick and 1.5 mm wide). The ends of the tantalum ribbon were attached by screws to thick molybdenum terminals used for supplying the heating current to the ribbon. The ions evaporated from the aluminosilicate surface were accelerated by a small potential difference (established by a dry battery) and entered the magnetic mass analyzer 3, in which they were rotated by 90°. The beam of Li ions selected by the mass analyzer passed through the analyzer chamber 5 to the end of which the 3 mm diameter diaphragm 6 was attached. The use of the mass analyzer 3, placed under a high-voltage conductor 4, was necessary because the lithium aluminosilicates usually contained other alkali metals as chemical impurities.

The lithium ions, having entered the accelerating tube 9, were accelerated and formed by the diaphragms 6, 7 and 8, into an ion beam, 1.5 mm in diameter and having an angle of $\approx 0.25°$ at the exit of the tube. Immediately next to the exit of the accelerating tube, was the cylinder 10 with peripheral rings, to which the investigated films were attached.

By rotating the cylinder, we could place a film in the path of the beam without disturbing the vacuum, or remove the film after the tests. The beam which had traversed the film was separated into its charged components by the electric field of a capacitor 12. The beam intensity was measured with scintillation counters, consisting of CsI crystals and FÉU-38 photomultipliers (14). These counters were developed and their counting efficiency studied in our earlier work.[5] In accordance with the latter, the upper parts of the photomultipliers were placed in vacuum and the scintil-

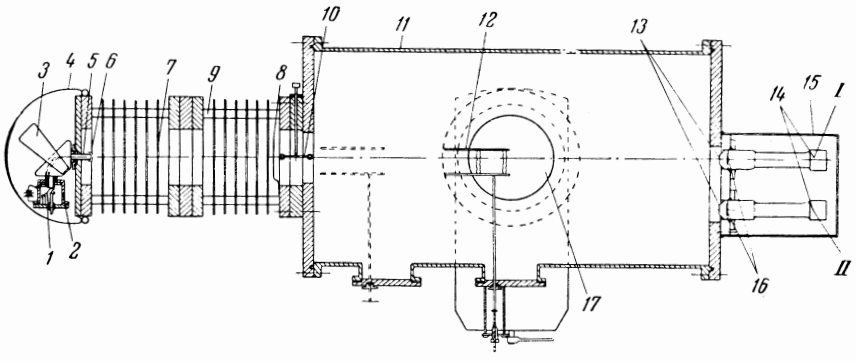

FIG. 1. Schematic representation of the apparatus.

lators 16 in direct contact with the photocathode. Narrow vertical slits, measuring 0.7 × 3 mm, were made in the middle of the aluminum reflectors 13. The particles were counted by means of an electronic circuit, consisting of an amplifier, a discriminator, and a scaler. The apparatus was pumped with an oil diffusion pump M-100 (17). During the measurements, the pressure in the apparatus never exceeded 10^{-5} mm Hg.

The celluloid films were prepared by spreading a solution of celluloid in butyl acetate on the surface of distilled water. The film thickness could be varied by varying the percentage content of celluloid in the solution. The carbon films were made by vacuum evaporation of carbon onto a glass plate; they were separated from the glass in water. The thickness of the celluloid films was determined from the content of celluloid in solution and from the area of the surface on which they had spread; it was checked against the value of the transmission of the ion beam. The thickness of the carbon films was measured using lines of equal chromatic order.

To determine the electrostatic analyzer constant, we recorded the dependence of the primary ion beam energy (the intensity maximum was found with the counter II placed at a distance of 100 mm from the central counter I) on the value of the deflecting voltage across the plates of the capacitor 12 (Fig. 1). These measurements showed that the experimental points fitted a straight line to within ± 2.5%. In measurements on celluloid films the capacitor 12 was placed 350 mm from the cylinder 10. In measurements on carbon films the capacitor 12 was placed 40 mm from the cylinder 10.

First of all we investigated the distribution of particles, reaching the counter II, as a function of the voltage across the electrostatic analyzer for given energies of Li^+ ions. Figure 2 gives the characteristic curves for Li^+ ions, which have not passed through a film, and for those which have passed through a celluloid film of thickness d = 6 $\mu g/cm^2$. The distribution curves for Li^{2+} ions formed on passage through the film were identical, within the experimental error, with the curves showing the distribution of Li^+ ions for the same values of the ion energy and film thickness. The distribution curves of this type were recorded for various values of the energy of Li^+ ions incident on celluloid films 2 and 6 $\mu g/cm^2$ thick and on carbon films 17 $\mu g/cm^2$ thick.

The practically symmetrical nature of the distribution curves of particles which have passed through films made it possible to determine the angles of the resultant deviations after multiple scattering. From the displacement of the maxima of these curves with respect to the undisplaced maxima we could determine the value of the energy loss.

Random experimental errors in the values of the charged fractions did not exceed ±5%. The errors in measurements of the values of the specific energy loss were of the order of ±15—20%. The errors in the determination of the resultant deviation angle were ±3—8%.

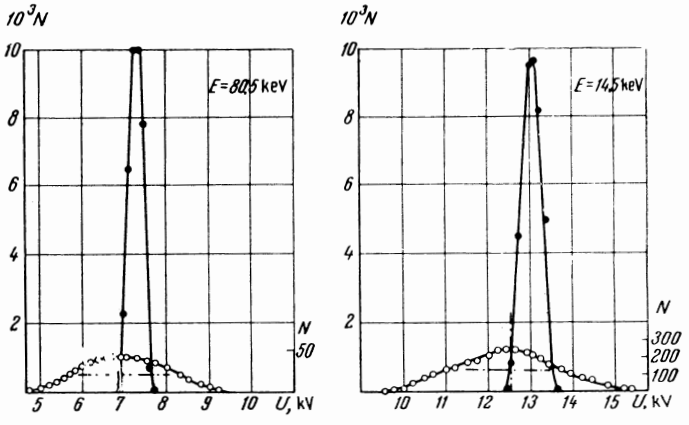

FIG. 2. Distribution of particles in a beam as a function of the voltage across the electrostatic analyzer: ● – in the absence of a film; ○ – after passing through a film.

3. RESULTS OF MEASUREMENTS

In all the measurements described below we used a beam of $(Li^7)^+$ ions, celluloid films of 2 and 6 $\mu g/cm^2$ thickness and carbon films of 17 $\mu g/cm^2$ thickness.

Measurements of the charge distribution in equilibrium beams showed that the equilibrium was reached in practice in a celluloid film $d \approx 2\,\mu g/cm^2$ thick. The relative contents of the $F_{0\infty}$, $F_{1\infty}$, and $F_{2\infty}$ components of the beam were measured. The components Li^+ and Li^{2+} were separated by the electrostatic analyzer and their intensities were measured with the counter II. The intensity of the Li^0 beam was measured with the counter I. The latter counter was used also to measure the total intensity of the beam before its separation into the charged components. Owing to this check we were able to avoid errors due to inaccurate determination of the maximum beam intensity, since in each measurement we checked the equality $N^0 + N^+ + N^{2+} = N_0$, where N^0, N^+, and N^{2+} represent the number of particles with the indicated charge, and N_0 is the total number of particles in the unresolved beam. The results of measurements of the equilibrium distribution are shown in Fig. 3.

The same figure includes, for comparison, the data taken from the work of Allison et al.[1] for Li^0, Li^+ and Li^{2+} in nitrogen.

It is evident from Fig. 3 that the maximum intensity of the neutral component of the beam which has passed through a celluloid film was reached at 20—30 keV and fell relatively rapidly on further increase of the ion energy. In the case of carbon films the maximum value of the fraction $F_{0\infty}$ was somewhat greater than for celluloid films, and displaced toward higher energies. We must bear in mind that owing to the considerably higher energy losses in carbon films the results obtained for such films should be ascribed to energies which are lower by 10% than those given in Fig. 3, since in that figure the energies of the incident ion beam are quoted. Comparison of our results with the data of Allison et al.[1] showed that the neutral particle content in the transmitted beam was 2—2.5 times greater for solid films than for gas targets (hydrogen, helium, nitrogen), and the maxima were reached at correspondingly lower energies of lithium ions. Moreover, the content of the doubly charged lithium ions in the beam was considerably higher for condensed targets and the rate of rise of $F_{2\infty}$ increased correspondingly with increase of the ion energy.

Figure 4 shows the dependence of the average charge $\bar{i}$ on the velocity of lithium ions passing through celluloid films. For comparison we give also the data for a nitrogen gas target taken from the work of Allison et al.[1] In contrast to high velocities, the average charge in the condensed target is lower than in the gas one, which contradicts the assumption that in a dense medium $\bar{i}$ is higher than in gas.

As mentioned earlier, the angles of the resultant deviation and the energy losses of lithium ions were found from the curves of the distribution of the number of particles $N = f(U)$ plotted as a function of the voltage across the electrostatic analyzer (Fig. 2). Since the angular distributions were Gaussian in type, the relative error in the determination of the angle of the resultant deviation θ_r was less than the experimental error in the determination of the number of particles corresponding to θ_r.

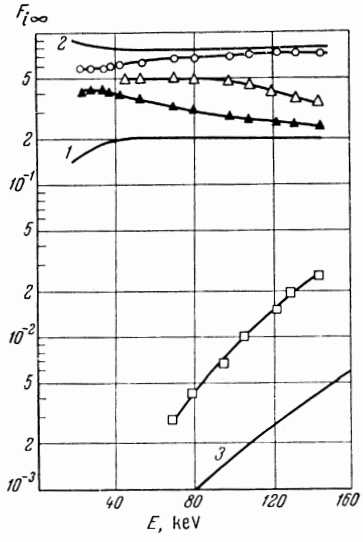

FIG. 3. Dependence of the equilibrium charged fractions on the energy of Li^+ ions; ▲, ○, □ – $F_{0\infty}$, $F_{1\infty}$, $F_{2\infty}$, respectively, for a celluloid film; △ – $F_{0\infty}$ for a carbon film. Curves 1, 2, and 3 represent $F_{0\infty}$, $F_{1\infty}$ and $F_{2\infty}$ for gaseous nitrogen, taken from[1].

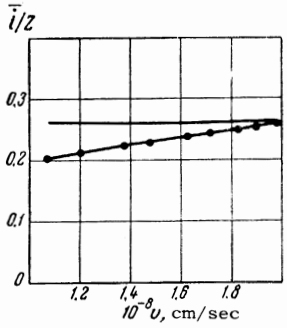

FIG. 4. Dependence of the degree of ionization on the velocity of Li^+ ions: ● – for a celluloid film; continuous curve – for gaseous nitrogen, taken from[1].

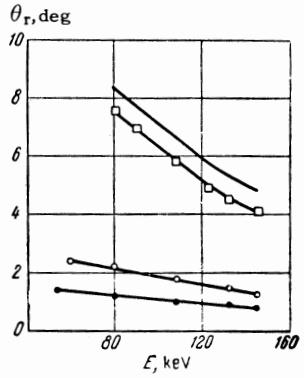

FIG. 5. Dependence of the angle of the resultant deviation on the energy of Li^+ ions: ● – in a celluloid film 2 $\mu g/cm^2$ thick; ○ – in a celluloid film 6 $\mu g/cm^2$ thick; □ – in a carbon film 17 $\mu g/cm^2$ thick; continuous curve represents the data from[6].

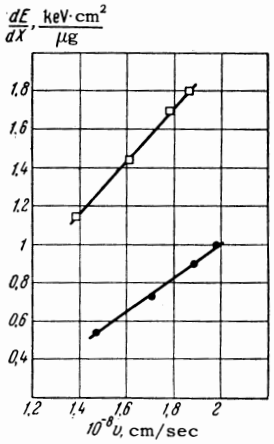

FIG. 6. Dependence of the specific energy loss on the velocity of Li^+ ions: ● – in a celluloid target; □ – in a carbon target.

Figure 5 shows the variation of the angle of the resultant deviation in celluloid and carbon films as a function of the energy of ions in the incident beam. Due to the relatively high energy losses in carbon films, the angles of scattering in such films should be ascribed to energies lower by 10% than those quoted in Fig. 5. The same figure gives the angles of the resultant deviation in a carbon film, calculated using an approximate formula due to Fermi.[6] It is evident that the dependence of θ_r on the energy is in qualitative agreement with the multiple scattering theory. The scattering angles are approximately inversely proportional to the energy and directly proportional to $\sqrt{d}$ (where d is the film thickness), as is evident for celluloid films. The measured angles of the resultant deviation in carbon films are systematically lower than the calculated ones by 10—16%. If we allow for the displacement of the curve toward lower energies (by $\approx$ 10%), then this difference becomes somewhat greater.

The energy losses and the corresponding specific energy losses were found from the displacement of the maxima of the N = f(U) curves for beams which have passed through films. The results of measurements of the specific energy losses in celluloid and carbon targets are shown in Fig. 6. In the investigated range of energies the specific energy losses are proportional to the ion velocity. The extrapolation of the results obtained for a celloloid film to high velocities (from 2 to 3 $\times$ 10^8 cm/sec) gives good agreement with the data obtained by Teplova et al.[7] Linear increase of the specific energy losses with the ion velocity at low energies is in qualitative agreement with the theoretical calculations of Fermi and Teller.[8]

Figure 7 shows the dependences of the beam transmission on the ion energy. The transmission D is defined as the ratio of the total flux of particles which have crossed the film to the flux of primary particles incident on that film. The intensity of the transmitted particle flux was determined with allowance for angular dispersion; for this purpose the results were integrated over the deviation angles.

Since it is evident that ln D is a linear function of the ion energy, we can easily estimate the energies at which the transmission becomes close to unity.

In conclusion it is worth noting some information that we obtained on the stability of films through which lithium particles were transmitted. Measurements were carried out on films deposited across apertures of 10 mm diameter. For thin celluloid films the energy losses and the scattering angles were small and the transmission correspondingly high.

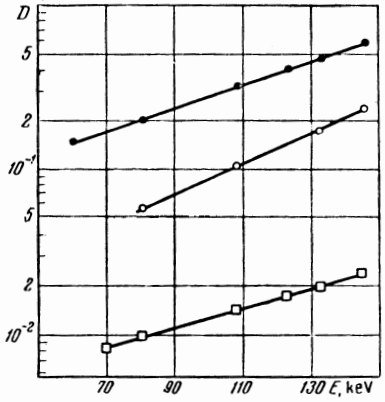

FIG. 7. Dependence of the transmission of the beam on the energy of the Li^+ ions: ●, ○ – for celluloid films 2 and 6 $\mu g/cm^2$ thick, respectively; □ – for a carbon film 17 $\mu g/cm^2$ thick.

However, the practical value of thin celluloid films was found to be small since they were rapidly destroyed by currents of densities less than 1 $\mu A/cm^2$. Carbon films were much more stable. For example, at current densities of 25—30 $\mu A/cm^2$ and ion energies of 130 keV a carbon film of 17 $\mu g/cm^2$ thickness was not affected by a bombardment for 10 hours. This shows that carbon films can be used successfully to transform lithium ions in the investigated range of energies, producing intensities sufficient for many experimental studies.

In conclusion, it is our pleasant duty to thank Professor A. K. Val'ter for his interest in this work.

[1] Allison, Cuevas, and Garcia-Munoz, Phys. Rev. **120**, 1266 (1960).

[2] Leviant, Korsunskiĭ, Pivovar, and Podgornyĭ, DAN SSSR **103**, 403 (1955).

[3] K. Bethge and H. Fabricius, Z. Physik **168**, 143 (1962).

[4] Teplova, Dmitriev, Nikolaev, and Fateeva, JETP **32**, 974 (1957), Soviet Phys. JETP **5**, 797 (1957).

[5] Pivovar, Nikolaĭchuk, and Vlasenko, PTÉ No. 5, 70 (1963).

[6] E. Fermi, Collection: Nuclear Physics (Russ. Transl.), IIL, 1951.

[7] Teplova, Nikolaev, Dmitriev, and Fateeva, JETP **42**, 44 (1962), Soviet Phys. JETP **15**, 31 (1962).

[8] E. Fermi and E. Teller, Phys. Rev. **72**, 399 (1947).

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