On the Interaction Between Lithium Ions and Matter

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The following quantities have been measured for Li^7 ions possessing energies between 0.5 and 5 Mev: specific ionization in hydrogen and air, ranges in hydrogen, air and NIKFI Ia-2 photographic emulsions, and the equilibrium charge distribution after passage through a celluloid film.

AT THE PRESENT TIME there exists only unsystematic evidence about the drag of Li ions in various environments[1-11]. Absence of full data about the average effective charge of Li ions makes it difficult to calculate the magnitude of their characteristic electronic interactions with matter.

In this work, specific ionization in hydrogen and air were measured for Li^7 ions. The equilibrium charge distribution after passage through a celluloid film, and ranges in hydrogen, air and photographic emulsion NIKFI-Ia-2 were also measured. The energy of Li^7 ions, accelerated in 72-cm cyclotron, was variable from .5 to 5 Mev. The velocity of the ions in the beam was determined from the intensity of the focusing magnetic field, calibrated by α-particles and deuterons of known energies. The error in velocity determination did not exceed 2%.

The focused beam of ions was passed through a retarding chamber 240 mm long after a passage through a system of collimating diaphragms and celluloid film 120 $\mu g/cm^2$ thick was used to measure the specific ionization. The pressure in the chamber was chosen so that the range of ions was fully within the chamber. The ions were registered by a proportional counter 6 mm thick, whose pulses were measured visually on the screen of a cathode-ray oscilloscope and the film of a loop oscillograph. The dependence of the number of pulses on the range of particles can be measured by moving the counter along the beam. The specific ionization is obtained in relative units. The curves thus obtained for the specific ionization are normalized according to the initial energy of the particles, assuming that the energy loss is proportional to the ionization. Figure 1 shows the results of the measurements (the solid curves are obtained by averaging several series of measurements). The extreme error in the specific ionization for ion velocities $v \geq 3 \times 10^8$ cm/sec did not exceed 9% in air and 13% in hydrogen.

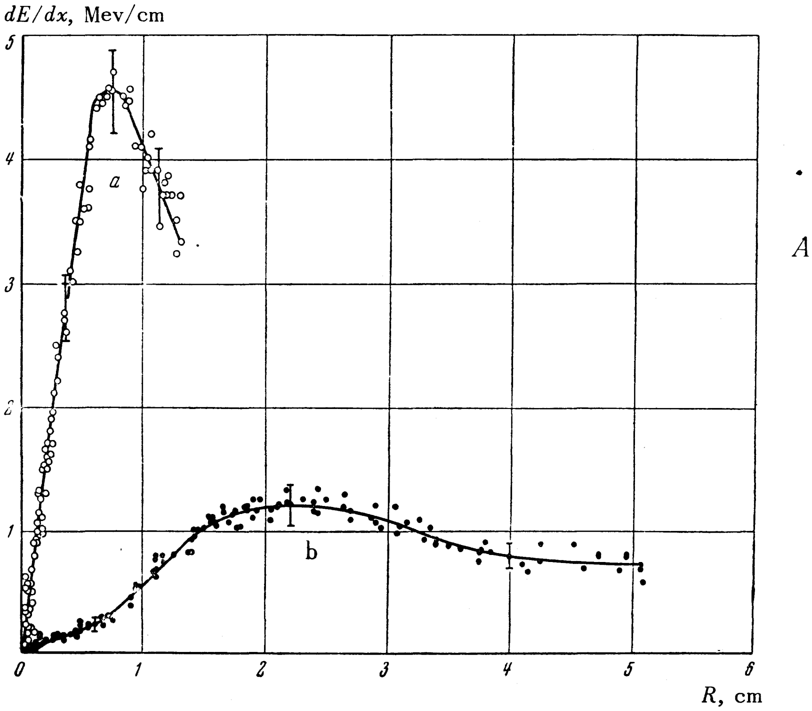
The ranges of Li^7 ions of various velocities were measured simultaneously with the specific ionization. The points on Fig. 2 represent the values obtained for the ranges. These results agree within the limits of experimental accuracy with the solid line obtained by integration of the corresponding specific ionization curves shown in Fig. 1-A.

The apparatus described by Nikolaev[12] was used to measure the equilibrium charge distribution. Celluloid films approximately 10 and 20 $\mu g/cm^2$ thick were used, and it became evident during the experiment that the equilibrium was reached with film thickness of only 10 $\mu g/cm^2$. The results of the measurements of the equilibrium distribution (Fig. 3) show that for $v \leq 8 \times 10^8$ cm/sec the ratio of the intensities of the neighboring groups Φ_{i+1}/Φ_i with charges $i + 1$ and i is proportional to v^{k_i}, where $k_i = 2.7$, 3.9, and 5.1 for $i = 1$, 2, and 3 repectively. If at the same time we substitute Φ_{i+1}/Φ_i in the region $v > 8 \times 10^8$ cm/sec, then k_i can be decreased at most to 2.9 for $i = 2$ and to 3.4 for $i = 3$. The equilibrium distribution and the average charge $\bar{i}$ calculated by using such a dependence of Φ_{i+1}/Φ_i on v, are shown solid in Fig. 3. The experimental values Φ_i and $\bar{i}$, shown in the same figure, are determined with an accuracy of $\pm 2\%$ for Φ_i and 0.5% for $\bar{i}$. With the resulting velocity dependence of the average charge one can hardly expect the breaks in the specific ionization curve, on the order of 20%, discovered by Kuznetzev *et al.*[8] and interpreted as discrete charge redistributions of the Li ions at definite velocities. (Such breaks were not found in our measurements of the specific ionization in air and hydrogen.)

The ranges of Li^7 ions obtained in the photographic NIKFI-Ia-2 emulsion and shown in Fig. 4 agreed with the results of range measurements in the Ilford C-2 emulsion reported previously[3-7,11] (the data for Li^6 and Li^8 ions were recalculated for Li^7 ions).

The Locher and Stoll[9] range data for the Kodak NTA emulsion were apparently somewhat lower since in the process of developing the authors chemically lifted from the emulsion surface the tracks of singly charged ions, thus possibly affecting the length of the measured tracks. The range data obtained in Refs. 8 and 9 do not agree with the results of other experiments[3-7,11] and with our data. We sought to explain the velocity dependence of the range by using our experimental data on the charge of Li^7 ions after passage through a celluloid film, since practically i does not depend on the material[12-14] in hard materials. The range was calculated from

$$R = \int mvdv/\langle i\rangle^2 f(v),$$



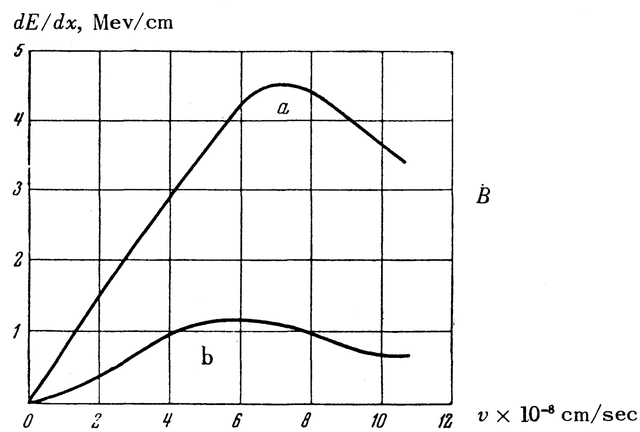


FIG. 1. Dependence of the energy loss of Li^7 ions in Mev per cm: A—on the residual range; B—on the velocity; a—in air, b—in hydrogen (760 mm Hg).

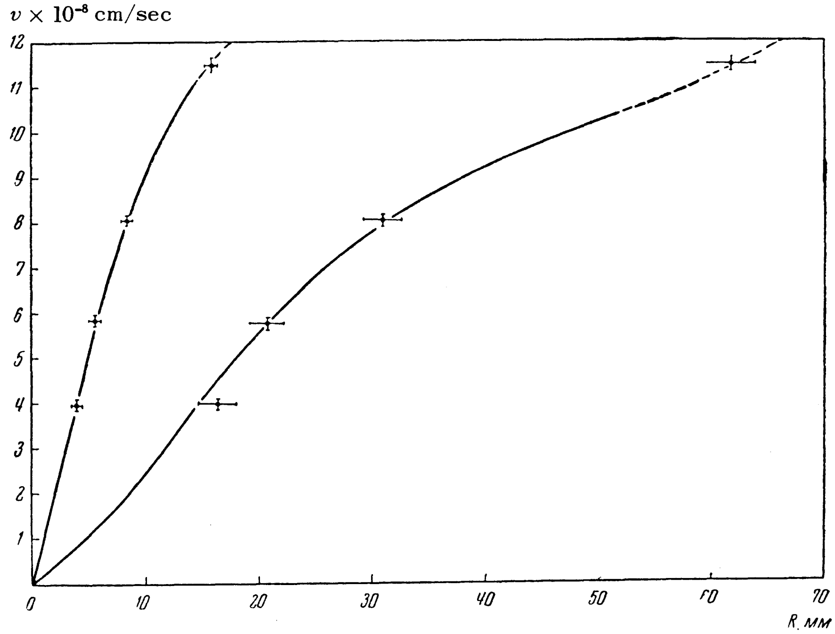


FIG. 2. Range *vs.* velocity for Li^7 ions at 760 mm Hg: *a*—in air, *b*—in hydrogen.

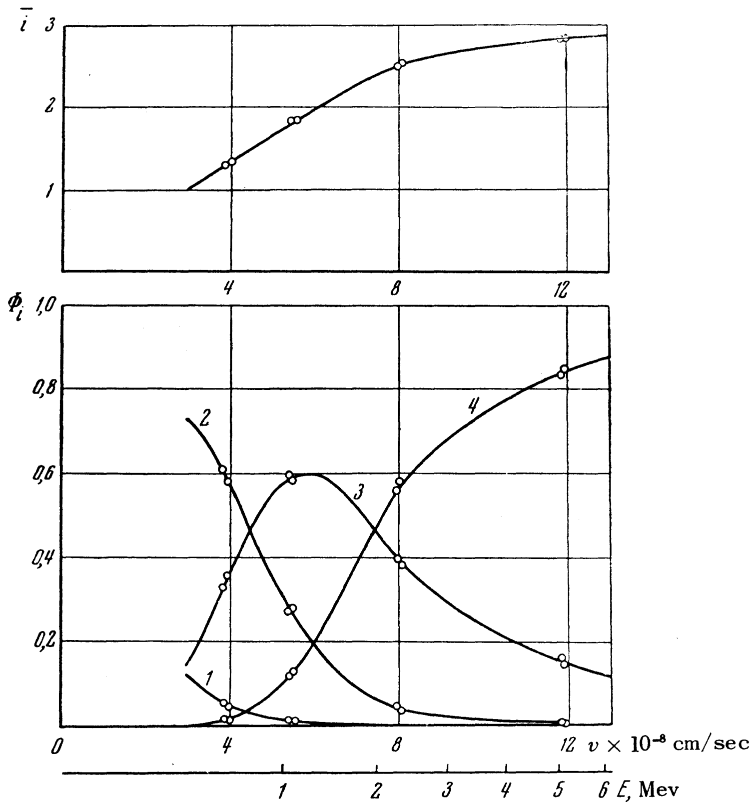


FIG. 3. Equilibrium charge distribution Φ_i and average charge $\bar{i}$ of Li^7 ions after passage through a celluloid film. 1 – $i=0$, 2 – $i=1$, 3 – $i=2$, 4 – $i=3$.

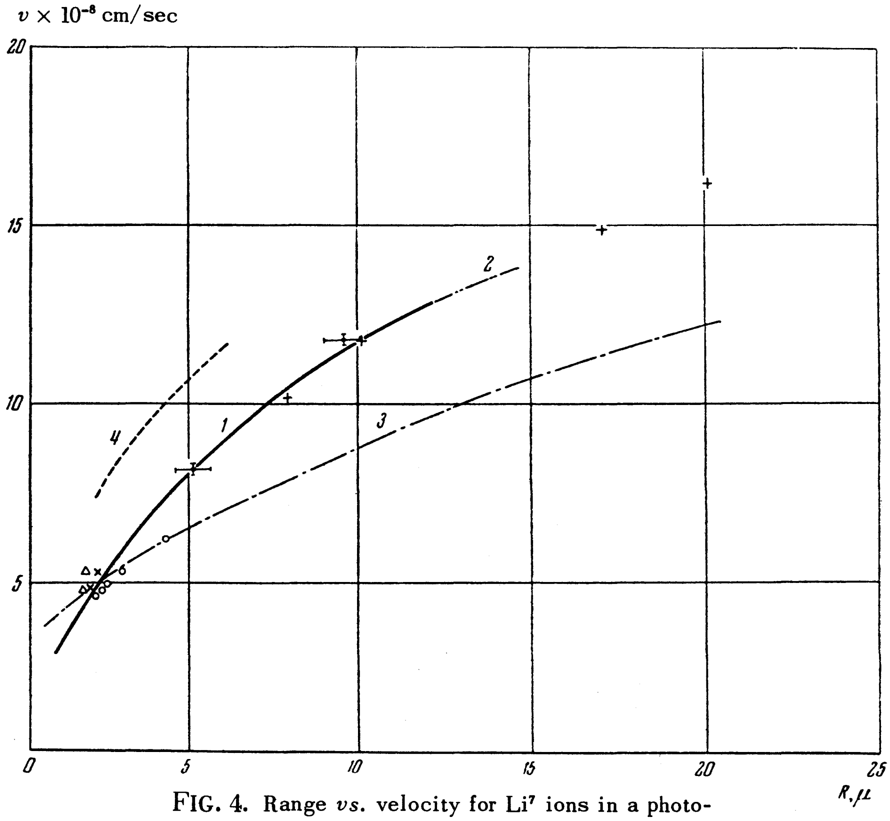


FIG. 4. Range *vs.* velocity for Li^7 ions in a photographic emulsion. Curve 1—calculated curve. The remaining curves and points correspond to the data from the following: 2—Ref. 3, 3—Ref. 8, 4—Ref. 9, +—Ref. 4, o—Ref. 5, △—Ref. 6, ×—Ref. 7, ●—our data.

where m is the mass of the ion, $f(v) = 1.04\, v^{-1.15}$ Mev/μ (*cf.* Ref. 3), $\langle \bar{i} \rangle$ is the mean-square charge. Since $\bar{i}$ is not known for low velocities, the calculated curve was compared with the experimental data on ranges for $v = 8.1 \times 10^8$ cm/sec. It is evident from Fig. 4 that the calculated curve (solid curve) agrees both with our results and with the data obtained by Livesey[3], Barkas[4], and others.

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[1] H. A. Wilcox, Phys. Rev. 74, 1743 (1948).
[2] L. Rosario, Phys. Rev. 74, 304, (1948).
[3] D. L. Livesey, Can. Journ. Res. 34, 261 (1956).
[4] W. H. Barkas, Phys. Rev. 89, 1019 (1953).
[5] Neuendorfer, Inglis, and Hanna, Phys. Rev. 81, 75 (1951).
[6] P. Cuer, J. P. Lonchamp, Compt. Rend. 232, 1824 (1951).
[7] H. Faraggi, Ann. Physik 6, 325 (1951).
[8] Kuznetzov, Lukirskii, and Perfilov, Dokl. Akad, Nauk SSSR 100, 655 (1955).
[9] K. Locher and P. Stoll, Phys. Rev. 90, 164 (1953).
[10] S. Devons and J. H. Towle, Proc. Phys. Soc. 69, 345 (1956).
[11] A. H. Armstrong and G. M. Frye, Phys. Rev. 103, 335 (1956).
[12] V. S. Nikolaev *et al.*, J. Exptl. Theoret. Phys. (U.S.S.R.) this issue, p. 965, Soviet Physics JETP 5, 789 (1957).
[13] T. Hall, Phys. Rev. 79, 504 (1950).
[14] G. A. Dissanaike, Phil. Mag. 44, 1051 (1953).

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