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On the Variation along Range of the Hρ-Distribution and the Charge of the Fission Fragments of the Light Group

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As mentioned in earlier papers[1,2] the Hρ-distribution of fission fragments has been determined by deflecting the fragments in the magnetic field of the cyclotron. By using the apparatus described in the first paper,[1] the Hρ-distribution has now been determined for fragments of the light group having traversed mica foils of various thicknesses; the foils were placed close to the uranium layer and the fragments were deflected in the magnetic field after their passage through the foils. Both these absorber foils and the mica window of the ionization chamber were examined for homogenity by means of monochromatic light.

Figure 1 gives the result of the measurements. The curve with the highest Hρ-values is the one obtained with no mica foil covering the uranium; then, by moving in the direction of decreasing Hρ-values, follow the curves corresponding to absorber foils of thicknesses 0.63, 1.0, and 1.3 mg/cm^2; the curves are drawn in such scales as to correspond to the same total number of fragments. The vertical lines indicating the statistical errors show that the curve obtained with an absorber of thickness 1.3 mg/cm^2 is not determined with the same degree of accuracy as are the other curves; this is due partly to the fact that smaller doses of neutrons were used, but the reliability of this curve is also somewhat smaller than of the other ones, because the pulses in the ionization chamber produced by fission particles having traversed the absorber and the mica window and aluminium foil of the chamber (1.3+0.79+0.25 mg/cm^2) are not much greater than the background pulses and, in fact, about half of the pulses due to fragments of the light group disappear in the background. When no

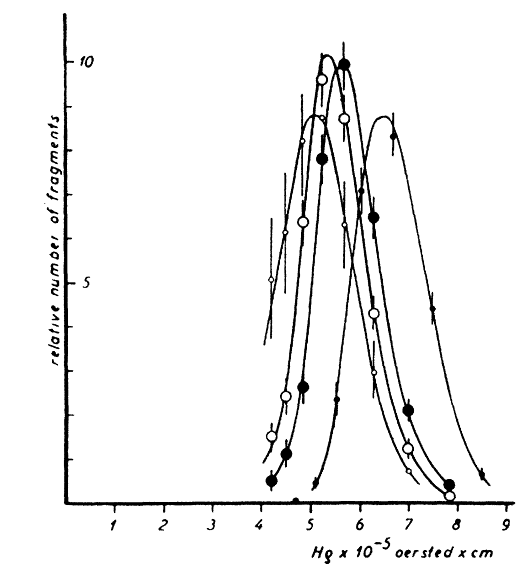

FIG. 1. Hρ-distribution-curves for fission fragments of the light group having traversed mica foils of various thicknesses. 1. Small black points: thickness of absorber 0 mg/cm^2; 2. Big black points: thickness of absorber 0.63 mg/cm^2; 3. Big white points: thickness of absorber 1.0 mg/cm^2; 4. Small white points: thickness of absorber 1.3 mg/cm^2.

[1] N. O. Lassen, Kgl. Danske Vid. Sels. Math.-Fys. Medd. **23**, No. 2 (1945).

[2] N. O. Lassen, Phys. Rev. **68**, 142 (1945).

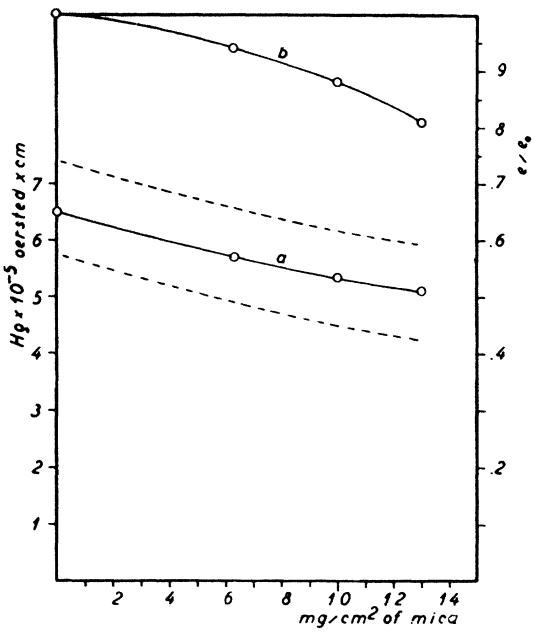

FIG. 2. (a) Most probable value of Hρ for fission fragments of the light group. Scale of ordinates to the left-hand side. (b) Most probable value of the ratio e/e_0 for fission fragments of the light group. Scale of ordinates to the right-hand side.

absorber is used, a rather good separation is obtained among the background pulses, the pulses due to fragments of the heavy group, and the pulses due to fragments of the light group[2]; when the absorber thickness is 0.63 or 1.0 mg/cm², the light group can still be clearly identified, while for an absorber of 1.3 mg/cm² no distinct separation can be made between background pulses and fission pulses. The heavy group cannot be seen for absorber thicknesses greater than 0.63 mg/cm², and when this absorber is used, about half of the group disappears in the background; the Hρ-distribution curve obtained for the rest of the group indicates that the fission fragments of the heavy group behave in almost the same manner as those of the light group.

Figure 2(a) gives Hρ for the light group as a function of the absorber thickness; the full drawn curve represents the most probable value while the two dotted curves give almost the limits of Hρ.

In Fig. 3 the most probable energy of the light group is plotted against the thickness of the traversed mica foils; except for the first one, the points are obtained in the way described in the papers referred to. As the mica window of the ionization chamber could not be avoided, the initial energy of the fragments could not be measured by means of the present arrangement, but the figure was taken from the paper of Flammersfeld, Jensen, and Gentner,[3] although this is perhaps not strictly permissible, since Flammersfeld *et al.* used slow neutrons while fast neutrons were used in these experiments; nevertheless, this is expected to cause no serious errors. The curve in Fig. 3 is in rather close agreement with the velocity-range-curve obtained by Bøggild, Brostrøm, and Lauritzen,[4] the two curves in all points giving within five percent the same value for the ratio of the velocity V to the initial velocity V_0.

Combining the most probable values of the energy E and of Hρ and denoting with indices 0 the initial values we get for the most probable value of the total fragment charge

$$\frac{e}{e_0}=\frac{(H\rho)_0}{H\rho}\cdot\left(\frac{E}{E_0}\right)^{\frac{1}{2}}.$$

Using this equation we get the curve Fig. 2(b); as seen, the decrease in charge is nearly 20

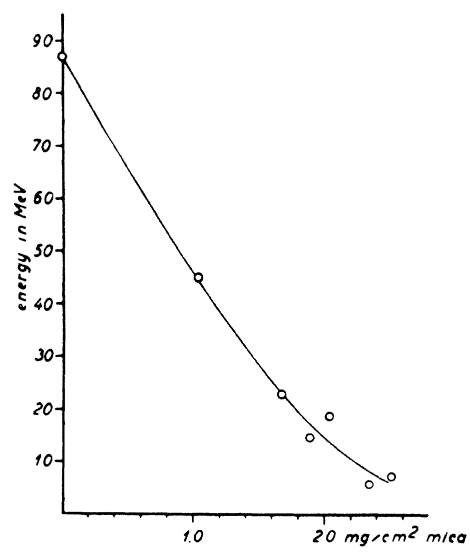

FIG. 3. Most probable value of energy E for fission fragments of the light group.

[3] Flammersfeld, Jensen, and Gentner, Zeits. f. Physik **120**, 450 (1943).

[4] Bøggild, Brostrøm, and Lauritzen, Kgl. Danske Vid. Sels. Math.-Fys. Medd. **18**, 4 (1940).

percent for an absorber of thickness 1.3 mg/cm² of mica ~9 mm of air.

In Table I is shown the value of the ratio e/e_0 for the various absorber thicknesses. The third and fourth columns give the corresponding values for $(V/V_0)^{\frac{1}{3}}$ as derived from Fig. 3 and from the velocity-range-curve of Bøggild *et al.*, respectively.

It will be seen that in the velocity interval considered e is closely proportional to $V^{\frac{1}{3}}$.

In a preliminary theoretical discussion of the stopping of fission fragments, Bohr[5] has, for the effective charge of the fragments, given the estimate

$$Z^{\text{eff}} = Z^{\frac{1}{3}} \cdot (V/V_{\text{H}}),$$

where Z is the atomic number and V_{H} the electron velocity in the hydrogen atom $(=\epsilon^2/\hbar)$. As seen, this simple formula cannot account for the experimentally found variation of the fragment charge for the considered velocities; as mentioned in the previous papers,[1,2] it neither accounts for the fact that the heavy group of the fission fragments has the higher initial e value and the light group the lower e value. As pointed out to me by Professor Bohr, the insufficiency of the formula is probably due to the relatively high value of the ratio Z^{eff}/Z which, in particular for the lighter fragments, makes the estimate of the electron binding used for the deduction of the formula somewhat too small. This point will be more closely discussed in a forthcoming paper by Bohr containing a general theoretical discussion of the stopping problems.

TABLE I.

Thickness of absorber mg/cm² of mica	e/e_0	$(V/V_0)^{\frac{1}{3}}$ this work	Bøggild *et al.*
0.63	0.94	0.92	0.90
1.00	0.88	0.85	0.84
1.29	0.81	0.80	0.79

The present experiments were carried out at the Institute of Theoretical Physics in Copenhagen, and I wish to express my heartiest thanks to the Director of the Institute, Professor Niels Bohr, and to Professor J. C. Jacobsen, for their continued interest in this work.

[5] N. Bohr, Phys. Rev. 59, 270 (1941).