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Specific Ionization by Fission Fragments

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A shallow ionization chamber was used to measure the variation along range of the ionization per unit length by fission fragments. Curves giving this variation for each of the two groups of fission fragments were determined; the two curves were found to intersect each other, the heavy group ionizing more than the light group in the beginning of the path while the opposite was the case in later parts of the path.

AS is well known, the ionization by fission fragments varies along range in quite another way than does the ionization by α-particles. This is in agreement with the fact that the effective charge of the fragments, which is rather high in the beginning of the path, decreases along the path, the fragments capturing electrons as their velocities decrease.[1-4] Bøggild, Brostrøm, and Lauritsen[5] and later Bøggild[6] have investigated the range-velocity relation by use of a cloud chamber, but so far as I know the specific ionization itself has not been directly determined earlier; the present paper contains a preliminary report of a direct measurement of the variation of this quantity along range; a more detailed account will soon be published.

The ionization chamber used is shown in Fig. 1. It consisted of two plates placed parallel to each other at a distance of 5.0 ± 0.1 mm; the particles entered through one of the plates, this being only a framework covered with a thin foil of aluminum or gold. The chamber was enclosed in an airtight box (a 5″ copper tube closed in the ends with flanges) in which was also placed a sort of gun delivering the fission fragments; this gun was made of a piece of mica with a thin layer of uranium (0.33 mg/cm^2) evaporated upon it and in front of this a diaphragm consisting of a large number (349) of holes about 10 mm in length and with a diameter of 3 mm, which caused the fragments entering the chamber to move in directions almost perpendicular to the plates. The gun was supported by a brass rod which could be moved from outside, the distance be-

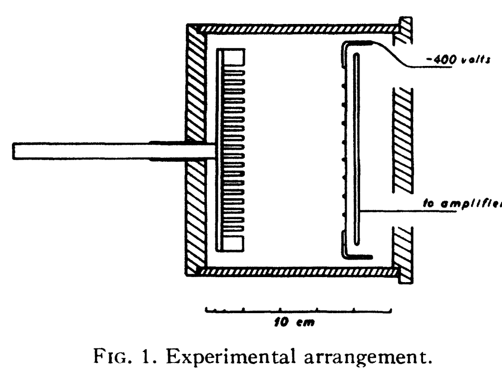

FIG. 1. Experimental arrangement.

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[2] N. O. Lassen, Phys. Rev. **68**, 142 (1945).
[3] N. O. Lassen, Phys. Rev. **69**, 137 (1946).
[4] N. Bohr, Phys. Rev. **59**, 270 (1941).
[5] Bøggild, Brostrøm, and Lauritsen, Kgl. Danske Vid. Sels. Math.-fys. Medd. **18**, No. 4 (1940).
[6] J. K. Bøggild, Phys. Rev. **60**, 827 (1941).

tween the uranium layer and the ionization chamber thus being varied. In some experiments the mentioned diaphragm was replaced by another one with about 3000 holes of diameter 1.0 mm and length 3.0 mm; in these experiments the foil of the ionization chamber was of gold (0.18 mg/cm²) while in the other experiments an aluminum foil (0.24 mg/cm²) was used. The ionization chamber was placed about 25 cm apart from an internal Be target in the cyclotron of this Institute behind some 5 cm of paraffin. The chamber was connected to a linear amplifier and this in turn to a cathode-ray oscillograph which was photographed on a moving film.

The box was filled with pure argon, and pressures of 75, 150, and 300 mm Hg were used. With these rather low pressures saturation was easily obtained but in order to diminish the background due to coincidences between recoiling argon atoms in the ionization chamber and to the very intense γ-radiation, it was found necessary to make the time constants of the coupling elements between the various stages of the amplifier rather small (5×10^{-5} sec.), and as a consequence the output pulse sizes varied when the potential across the ionization chamber was varied. Thus it was impossible to get absolute measurements while on the other hand careful investigations indicated that the output pulse sizes were proportional to the number of ions produced in the ionization chamber as long as the pressure and the voltage were not varied.

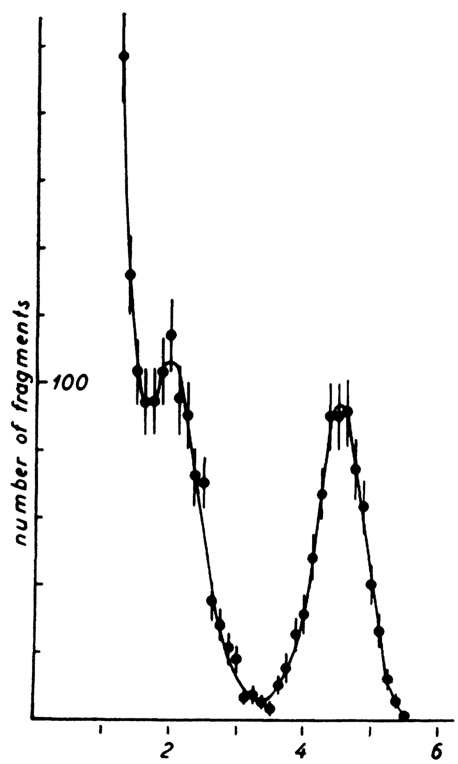

FIG. 2. Number of pulses plotted against size of pulse. Path traversed by fragments inside ionization chamber, 2 mm. Distance from uranium layer to middle of ionization chamber, 10 mm.

Figure 2 refers to the case where the distance a between the uranium layer and the middle of the ionization chamber is equal to 10 mm of argon at atmospheric pressure and the path traversed by the fragments inside the chamber to 2 mm. The curve is obtained by plotting the number of pulses of different sizes against the sizes; concerning the adjustment of the pulse sizes in Mev, see later. As seen, there are a lot of pulses of small sizes corresponding to the background previously mentioned and besides the curve shows two peaks corresponding to the two groups of fission fragments; the light group is seen to be completely separated from the heavy group, while the latter and the background pulses overlap.

For other distances of the uranium layer from the ionization chamber similar curves are obtained, yet when the distance a is increased, the peaks move to the left; for $a=12$ mm the peak corresponding to the heavy group is reduced to a hump on the curve and for $a=14$ mm the heavy group completely disappears in the background. The light group can be seen for $a=12$, 14, and 16, while for $a=18$ it is reduced to a hump on the curve and for $a=20$ it cannot be recognized directly, although the curve is found to be somewhat steeper for $a=22$ than for $a=20$.

When a is decreased the peaks move against higher abscissae and at the same time they approach each other, the peak corresponding to the heavy group moving faster than the other one. For $a=8$ two peaks clearly separated from each other and from the background appear; for $a=6$ the separation from the background is even better but now the heavy group only causes a hump on the left side of the curve for the light group; for $a=4$ the separation between the background and the fission fragments is complete, but now only one peak is seen; this is valid also for smaller a's, yet for $a = 1.5$ the curve has a hump on the right side.

From Fig. 2 the positions of the two maxima can be taken, and, further, the "upper and lower limits" of the light group and the "upper limit" of the heavy group can be determined as the intersection points between the axis of abscissae and the steepest tangents to the curve. By treating the curves corresponding to the various distances in this way and by plotting the values obtained we get the curves on Fig. 3. Here the circles represent the positions of the maxima and the heavily drawn curves thus give the most frequent values of the ionization per mm as a function of the distance traversed, while the thinner drawn curves correspond to the upper and lower limits.

Of course, it is impossible to determine by this method which of the two groups ionize most for $a = 1.5$ mm and, hence, whether the two curves intersect each other or not; nevertheless, there are reasons to believe that they really intersect. By the measurements we only get relative figures for the ionization; the adjustment is performed in such a way that the area beneath the curve for the light fragment corresponds to 86 Mev, which figure was chosen because Flammersfeld, Jensen, and Gentner[7] have found 87 Mev for the most frequent value of the total energy and because about 1 Mev is on an average absorbed in the uranium layer. The total energy of the heavy fragment is then found to be 52 Mev in rather good agreement with the value 58 Mev of Flammersfeld, *et al.;* the slight discrepancy may be easily understood regarding that the extrapolation of the curves (the dotted lines) are rather uncertain and, in fact, may be considered to be wrong, as Bøggild, Brostrøm, and Lauritsen[5] found for the mean ranges 18 and 24 mm argon, while the extrapolated curves intersect the axis at the points $a = 14.4$ and 22.4.

By drawing the curves in such a way that they do not intersect each other it would be impossible to get agreement with Flammersfeld, *et al.* and other authors[8] concerning the ratio between the energies of the two fragments. It is also interesting that the intersecting of the two curves corresponds to a variation in the effective charge of the two fragments which is at any rate in qualitive agreement with direct measurements of the total charge of the fragments recently published.[2,3] This question, however, will be more closely discussed by Professor Bohr in a forthcoming paper on stopping effects to appear in the Communications of the Copenhagen Academy of Science.

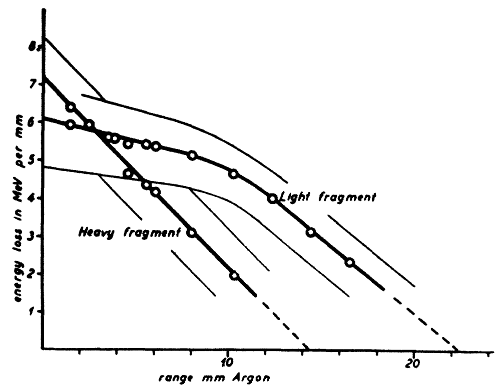

FIG. 3. Ionization per mm as a function of the distance traversed. Upper and lower limits are indicated by light lines.

The writer wishes to express his heartiest thanks to the Director of the Institute, Professor N. Bohr, and to Professor J. C. Jacobsen, for their continued interest in the work.

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

[8] Jentschke and Prankl, Physik. Zeits. **40**, 706 (1939).