# Cloud-Chamber Studies of Fission Fragment Tracks

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SHORTLY after the discovery of the fission phenomenon, cloud-chamber photographs of tracks of fission particles were published by Joliot[1] by Corson and Thornton[2] which illustrated the intense ionization and large tendency to branch by nuclear collisions of the fission particles with the gas in the chamber. Because of the great theoretical interest connected with the passage of such heavy and highly charged particles through matter, a more complete study of the phenomenon was taken up in this Institute.

For this purpose a 25-cm Wilson chamber was constructed with a special arrangement to permit use in the chamber of various gases at low pressure ($\sim$5 cm). A large number of photographs of tracks of fission fragments were obtained, partly from thick uranium targets within the cloud chamber and partly from targets thin enough to allow the tracks of the two fragments emitted in a fission process to be photographed simultaneously. These photographs, of which a few typical examples are reproduced here (Figs. 1 and 2), show striking differences from proton- and alpha-particle tracks in several respects. Branching by nuclear collision, instead of occurring only once in several thousand tracks, here occurs many times in a single track. Instead of pursuing a straight course to the end of their range, these particles show large irregular curvature, due to numerous collisions in which the momentum transfer in any single interaction is insufficient to give an observable branch. An analysis of the measurable branches indicates a range velocity relation radically different from that for light particles.

The histograms of Fig. 3 are the result of the measurement of branch lengths at various intervals along the ranges for about 40 fission tracks. All branches with length (in the chamber) greater than 1 mm were measured, and their lengths added together in groups. The ordinate in Fig. 3 represents the sum of the lengths of branches occurring in the interval given on the axis of abscissae. In all, some 400 branches are so classified. Since the ordinate can be taken to be a function of the energy loss due to branching, one would expect such a curve to give some indication of the variation of the velocity along the range. It seems, in a rough way at least, from these curves that a proportionately much larger number of branches are obtained in the region from 4 to 6 mm from the end of the range than one would expect if the velocity fell as rapidly in the last part of the range as does that of an alpha-particle. The steep falling off at the end is a result of the arbitrary minimum limitation on the lengths of the branches counted.

In a series of 150 fission fragment tracks taken in argon at low pressure, measurements on the

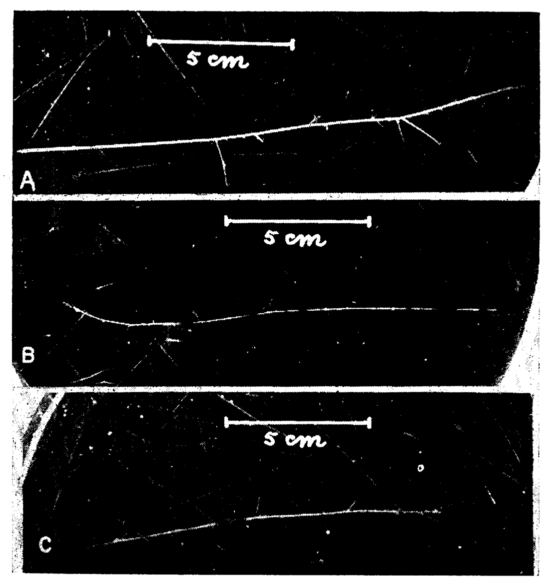



FIG. 1. A, Typical track in hydrogen, showing numerous collisions both with hydrogen and with oxygen or carbon atoms even relatively early in the range. The last $\frac{3}{4}$ of the total range is in the chamber. ($H_2+C_2H_6O$ and $H_2O$ vapor, press. 14.5 cm, $\sim$8 cm air.) B, Track in argon showing typical irregular curving. (Argon+20 percent oxygen+alcohol and water vapor, press. 7.5 cm, $\sim$8 cm air.) C, Track in low pressure hydrogen, showing large number of fine proton branches. ($H_2+H_2O$ vapor, press. 16 cm, $\sim$6 cm air.)

[1] F. Joliot, Comptes rendus **208**, 647 (1939).
[2] D. R. Corson and R. L. Thornton, Phys. Rev. **55**, 509 (1939).

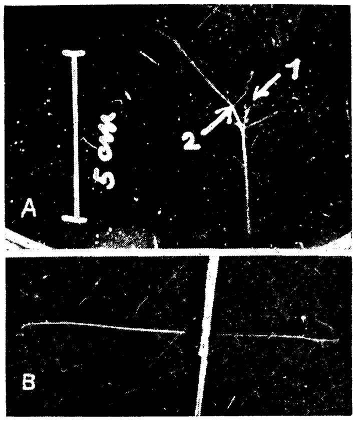



FIG. 2. A, Close encounter in argon; the end of fission fragment's track is indicated by arrow 1: at arrow 2, the projected argon nucleus collides with another, making an angle of 90°. (Argon+$H_2O$ vapor, press. 7.5 cm, ~7 cm air.) B, Tracks of two fragments expelled simultaneously from a fission occurring in a layer of uranium evaporated on a 1μ aluminum foil. (Argon+alcohol and water vapor, press. =31 cm, ~30 cm air.)

angle of bending were made. On a photographic reproduction of each track, tangents were drawn through points at 5, 45, 85 and 125 mm from the end—(or through as many as the length of the track would permit). The angles between these tangents were measured and plotted as angles *a*, *b*, *c*, etc., referring to the various pairs of tangents. In all cases where the track suffered sharp bends due to measurable branches, the corresponding angular deflections were subtracted. As is clearly seen in Fig. 4, the last 45 mm (~$\frac{1}{4}$ of the range) suffers very large deviations, about half of the material lying outside 15°. The angles "*b*" show a considerably smaller deviation and angles "*c*" are barely measurable.

In general, the curvatures exhibited by tracks in hydrogen are considerably smaller, although the tendency is certainly present. An interesting point which has appeared is that argon branches traveling in argon gas are themselves often branched and also exhibit this general curvature. This effect, together with the haphazard curvature of the main track, makes angle and range measurements extremely unreliable except for special cases; it seems impossible, for example, to obtain any measure of the mass sufficiently precise to distinguish the two types of fragments.

In the examination of about 300 fission fragment tracks in various gases, about 30 branches have been obtained which are suitable for a direct determination of the velocity-range function by simple application of conservation of momentum and energy considerations. In all these cases, the tracks were examined stereoscopically and measurements made as nearly as possible in the plane of the branch. In the computations, the range-velocity curves for argon and for oxygen of Blackett and Lees[3]

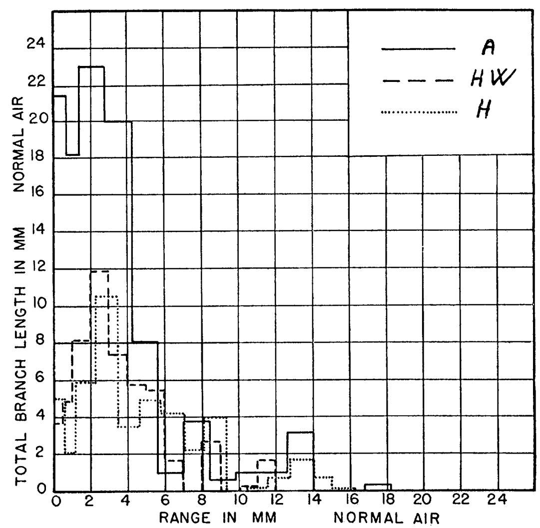



FIG. 3. Sum of lengths of all branches >1 mm long in various intervals along track. *A* = tracks in argon+alcohol and water vapor; press. = 8.8 cm, ~11 cm air, *H* = hydrogen +alcohol and water vapor; press. 14.5 cm, ~8 cm air, *HW* = hydrogen+water vapor 16 cm, ~6 cm air.

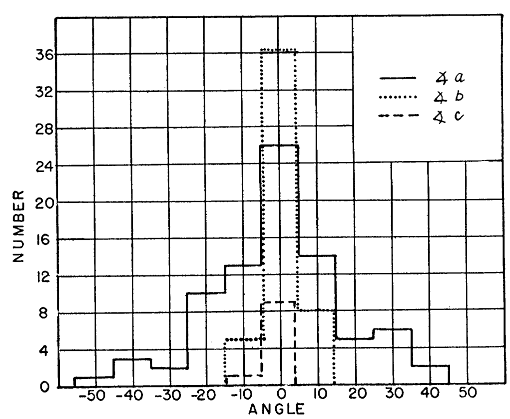



FIG. 4. Turning of fission fragment tracks. Angle "*a*" is the angle between tangent at 5 mm and that at 45 mm, from end of range. "*b*" is the corresponding angle at 45 and 85 mm and "*c*" refers to the region 85–125 mm. (Argon +alcohol and water vapor; press. 8.5 cm, ~11 cm air.)

[3] P. M. S. Blackett and D. S. Lees, Proc. Roy. Soc. **134**, 658 (1931).

were used. The ranges were reduced to normal air, with the factors for alpha-particle stopping.[4] The resulting range-velocity relation is shown in Fig. 5, with that of an alpha-particle for comparison.[5] Inasmuch as it is impossible to separate the effects of the two types of fission fragments, this curve must be considered as a representation of some mean value, mass $\sim 120$, charge 45.

It has appeared from direct measurement that the total ranges of the two types of particles do not differ greatly and have a value of about 25 mm, corresponding to starting velocities of 14 and $9\times 10^8$ cm/sec. From this it would seem that the curve of Fig. 5 should pass through a point at 25 mm range and velocity $\sim 11\times 10^8$ cm/sec. The general course of the curve would thus seem to be like that sketched in the figure, with a relatively rapid decrease in velocity from about $2\times 10^9$ to a velocity in the neighborhood of $3\times 10^8$ cm/sec., a more gentle slope down to perhaps $1\times 10^8$ and then a steep fall at the end. It does not seem possible, with our present material to obtain more information in the range above $3\times 10^8$ cm/sec., but just the fact that

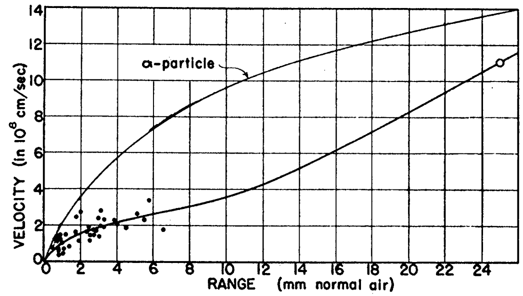


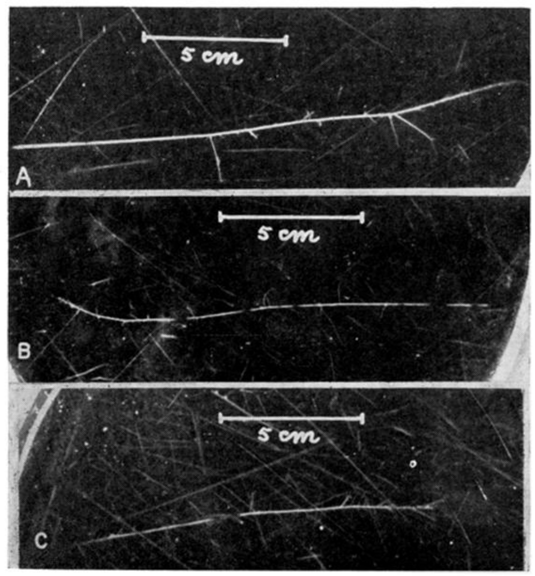

FIG. 5. Velocity *vs.* range for fission fragments. (Argon+alcohol and water vapor, press. = 8.5, $\sim 11$ cm air.)

branches become so rare here would indicate the starting of a more rapid increase of velocity with range at about this value.

A full account of this work will be published in the Communications of the Danish Academy of Science, where the photographs will be discussed in more detail.

It is a source of no little gratification to the authors to take this opportunity to express their most heartfelt appreciation of the advice and encouragement of Professor Niels Bohr, under whom this work was consummated. One of us (T. L.) is indebted to the Rockefeller Foundation for a stipend permitting his visit to Copenhagen.

[4] R. W. Gurney, Proc. Roy. Soc. **107**, 340 (1925).
[5] Cornell University curves, 1938.

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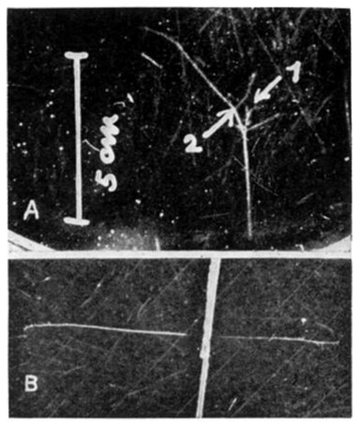


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