Collisions of Alpha-Particles with Neon and Deuterium Nuclei*

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The tracks of about 600,000 Th C and C′ alpha-particle tracks were photographed in a Wilson cloud chamber filled with a mixture of neon and deuterium. An analysis of the elastic collisions with neon atoms gave points on a range-velocity diagram which fitted Eaton's curve fairly well except at the lower end. Reasons are given for thinking that this curve should be lowered slightly in the region of small velocities. A range-velocity curve is obtained from the collisions with deuterons. On the very reasonable assumption that, for a given velocity, the ranges of two isotopes are proportional to their masses, this curve indicates that Mano's calculations for protons are correct even for small velocities. It is shown that these collisions are elastic even when a high energy alpha-particle imparts considerable energy to a deuteron. No sign of inelastic collisions with either deuterons or neon atoms was obtained, although some were expected for the latter. The possible reasons for their nonappearance are discussed.

INTRODUCTION

THE cloud-chamber method has often been used to study the passage of alpha-particles and other atomic nuclei through gases. When a nucleus is struck by an alpha-particle with sufficient violence to produce a visible track, the velocity of the former can be computed from measurements made upon the forked tracks. Since the range of the nucleus can also be measured, an analysis of a number of collisions, on the assumption that energy and momentum are conserved, allows the construction of a range-velocity curve for the kind of atom in question. Various authors[1] have obtained such curves for a number of different elements, the work being limited somewhat by the difficulty in obtaining a desired element in a suitable gaseous form. Besides being essential for a full numerical investigation of the energy changes in transmutation experiments, these curves are also a part of our general knowledge of the manner in which heavy charged particles travel through gases.

All of the collisions between alpha-particles and atomic nuclei which have been observed in a cloud chamber have been found to be elastic except a few with nitrogen nuclei. Blackett[2] and others[3] obtained photographs in which an alpha-particle had disintegrated a nitrogen nucleus. These photographs are the most convincing evidence that the alpha-particle is captured in a proton disintegration.

In the present work a mixture of neon and deuterium was put in a cloud chamber and bombarded with alpha-particles from Th C and C′. The reasons for the investigation and the possibilities of its outcome were many:

(1) It was desired to study the collisions between alpha-particles and deuterons. The low stopping power of deuterium demanded the mixture of a heavier gas with it.

(2) Neon was chosen as this heavier gas because, although Eaton[4] failed to obtain a photograph of its disintegration by alpha-particles, recent experiments[5] have shown that the yield of this disintegration process is nearly as large as the yield for nitrogen. The photography of a proton disintegration would give further proof of the capture of the alpha-particle and would allow a calculation of the nuclear energy change which takes place in the reaction:

$${}_{10}\mathrm{Ne}^{20}+{}_{2}\mathrm{He}^{4}\rightarrow{}_{11}\mathrm{Na}^{23}+{}_{1}\mathrm{H}^{1}.$$

(3) Protons and deuterons are the only two isotopes accessible to study in this way. There is every reason to suppose the range of a particle to be proportional to its mass.[6] From the range-

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[1] P. M. S. Blackett, Proc. Roy. Soc. **A102**, 294 (1922); **103**, 62 (1923); P. M. S. Blackett and D. S. Lees, Proc. Roy. Soc. **A134**, 658 (1932); N. Feather, Proc. Roy. Soc. **A141**, 194 (1933); W. W. Eaton, Phys. Rev. **48**, 921 (1935); R. L. Anthony, Phys. Rev. **50**, 726 (1935).

[2] P. M. S. Blackett, Proc. Roy. Soc. **A107**, 349 (1925).

[3] P. M. S. Blackett and D. S. Lees, Proc. Roy. Soc. **A136**, 325 (1932); W. D. Harkins, Zeits. f. Physik **50**, 97 (1928); W. D. Harkins and A. E. Schuh, Phys. Rev. **35**, 809 (1930).

[4] W. W. Eaton, reference 1.

[5] E. Pollard and C. J. Brasefield, Phys. Rev. **51**, 8 (1937).

[6] H. Neuert, Physik. Zeits. **36** (1935), footnote p. 642.

velocity curves for two isotopes it is possible to test this proportionality and, in the present case, also to test the validity of the proton curve in the region of small velocities where some published curves are considered to be dubious.

(4) Although there has not been much need of a deuteron range-velocity curve in the past, the increasing use of these particles as bombarding particles for transmutations suggests the value of such a curve in the future.

(5) Schultz[7] has recently observed the emission of neutrons by deuterium under bombardment by the alpha-particles of Ra C′ or Th C′. Although the very low yields obtainable discourage the hope of observing this reaction in a cloud chamber, there is a slight possibility that one of the alpha-particle deuteron collisions might prove to be of this inelastic type.

Experimental Procedure

The cloud chamber used was of the conventional sylphon type built according to plans published by Dahl, Hafstad and Tuve.[8] It was filled with a gas mixture containing about equal parts of neon and deuterium at a pressure of about 90 cm of Hg.

Stereoscopic photographs were taken of the tracks by a camera of a type originally designed by Kurie.[9] This camera, by the use of mirrors and a single lens, takes two photographs side by side on the same film which are equivalent to photographs taken by two cameras at right angles. The photographs are reprojected by replacing the developed film in the camera and using it as a projection apparatus. The technique used for photography, reprojection and final analysis of the tracks was the same as that used and described by Eaton.[4]

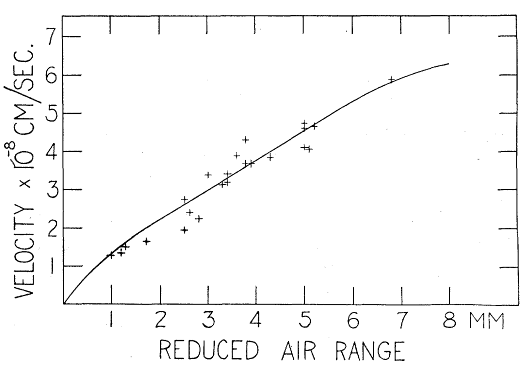


Fig. 1. Range velocity curve for neon.

[7] H. L. Schultz, Washington Meeting, American Physical Society, April 1937.

[8] O. Dahl, L. R. Hafstad and M. A. Tuve, Rev. Sci. Inst. **4**, 373 (1933).

[9] F. N. D. Kurie, Rev. Sci. Inst. **3**, 655 (1932).

The source of alpha-particles was a monel metal button having on its surface thorium active deposit obtained by radioactive recoil from a source of radiothorium. The alpha-particles were introduced into the chamber through a very thin sheet of mica, the space between the source button and the mica being evacuated at all times. When disintegration photographs are hoped for, the alpha-particles should be retarded as little as possible before entering the chamber. A sheet of mica equivalent to 5 mm of air (as determined by weighing) was finally chosen as the thinnest which would not break under the strain of gas pressure.

The measured lengths of the forks of a collision were reduced to the corresponding lengths in standard air (76 cm pressure at 15°) by multiplication by the stopping power of the gas. Since the exact composition of the gas was not known, the mean stopping power was determined by measuring the average range of alpha-particles in the gas and comparing it with the known range of the particles in air under standard conditions. The stopping power for recoil atoms is arbitrarily assumed to be the same as that for alpha-particles. This assumption is probably valid for deuterons but is admittedly questionable for heavy atoms.

The range-velocity curve for alpha-particles necessary for the analysis of the collisions was

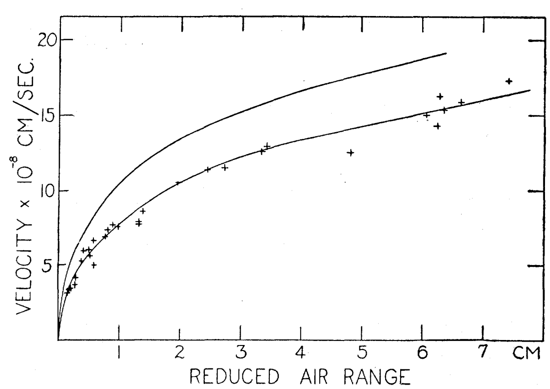


Fig. 2. Range velocity curves for protons and deuterons.

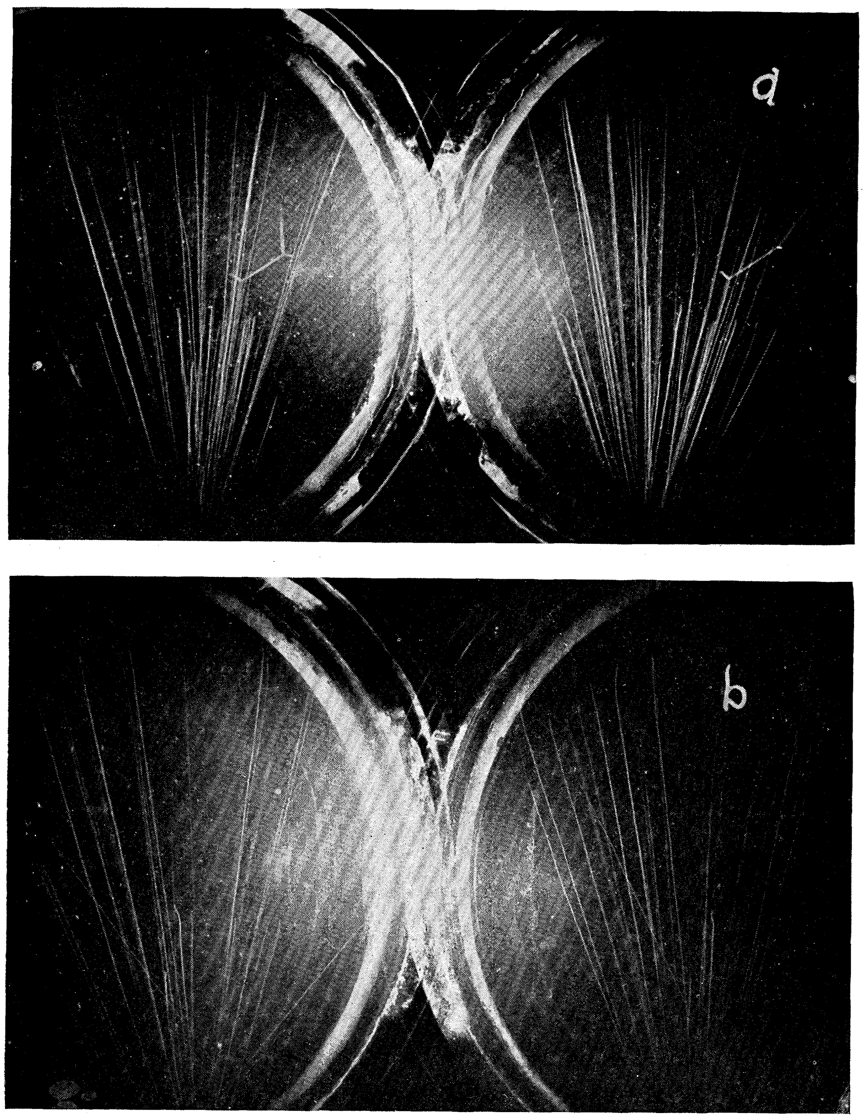


FIG. 3. a. Unusual event: an alpha-particle suffers two successive collisions with neon nuclei. b, c, and d. Examples of collisions of alpha-particles with deuterons.

one constructed from the work of Blackett and Lees[1] and Mano.[10] The results of the former seem to be the most reliable for particles of small ranges, and Mano's curve is probably the best for large ranges.

RESULTS

Of the 15,000 stereoscopic photographs taken of alpha-ray tracks in a mixture of neon and deuterium it is roughly estimated that there were on the average 40 tracks per photograph. Hence a total of 600,000 tracks were studied, of which approximately two-thirds were of the long range type from Th C′. Of the neon collisions which were analyzed, 25 were chosen for velocity calculation. The points corresponding to these collisions are plotted together with Eaton's curve in Fig. 1. It is seen that these points group about the curve fairly closely but seem to suggest that the first part of the curve should be

[10] G. Mano, Ann. de physique 1, 407 (1934).

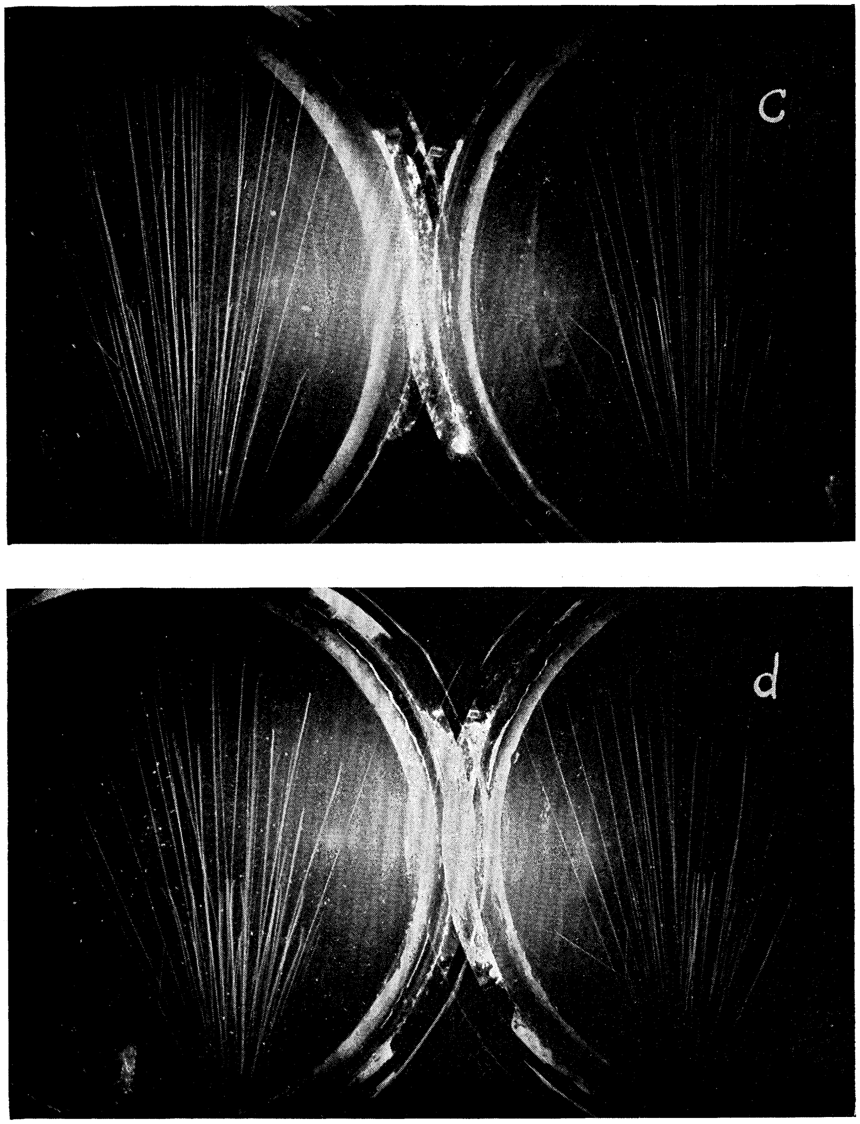


FIG. 3. c and d.

lower. Two other considerations seem to make the same suggestion:

(1) The neon curve crosses the curve for fluorine at the lower end. This crossing is unexpected and has been ascribed by Eaton to a spurious effect arising from the different methods of calculating stopping powers. Eaton took account of the variation of stopping power with velocity, while in Feather's work on fluorine and in the present work the mean value of the stopping power was used. This difference of procedure would be expected to show slightly different results for small ranges.

(2) Anthony[1] found that, for large velocities, the ratio of the ranges of neon atoms and alpha-particles for the same velocity was a constant for points along the two curves. This situation is true for smaller velocities also if the neon curve is dropped slightly below the fluorine curve in this region. The constancy of this ratio probably has some significance, since it has been found to hold true for the curves of any pair of

elements which are in the same column of the periodic table.

In Fig. 3a is shown an unusual type of event: an alpha-particle suffered two successive collisions with neon nuclei, striking both of them hard enough to produce recoil spurs.

Although deuteron collisions were relatively infrequent and were occasionally poorly photographed because of the long thin character of the deuteron track, finally about 30 alpha-particle deuteron collisions were obtained which were good enough for complete analysis. The points plotted on the graph in Fig. 2 are those obtained from these collisions. The upper curve is the range-velocity curve for protons, plotted from the calculations of Mano.[11] The lower curve applies to deuterons and is drawn from the proton curve on the assumption that the range of a deuteron is twice that of a proton of the same velocity. The experimental points are seen to fit this curve very well.

This good agreement is in divergence with the results of Parkinson, Herb, Bellamy and Hudson[12] who, by means of a two million volt generator, have measured the range of protons in air as a function of energy. Their data disagree considerably with the theoretical values of Mano at energies below 0.7 Mev. The "visual" range-energy curve obtained in somewhat the same manner by Tuve, Heydenburg and Hafstad,[13] disagrees even more. At high velocities and energies the calculations of different theoretical authors agree and are probably correct, because the hypotheses on which the theories are based are better satisfied at higher velocities.

Examples of deuteron collisions are given in Fig. 3b, c, d. The characteristic appearance of these collisions usually makes them easy to identify.

Three of the highest points on the deuteron graph represent collisions in which the deuteron has been given a kinetic energy greater than its binding energy. The collision corresponding to one of these points is shown in Fig. 3b. A deuteron with a velocity of 16×10^8 cm per sec. has a kinetic energy of 2.66 Mev, while the binding energy is only 2.14 Mev. Furthermore, in these collisions the impinging alpha-particle had an initial energy of 7.11, 7.19 and 7.83 Mev in the three cases. In order to disintegrate a deuteron an incident alpha-particle must possess a kinetic energy of at least three times the binding energy of the deuteron.[14] This condition is fulfilled in each of the three above cases and yet the collisions were elastic. Likewise with other elements it has been found by other investigators that in certain collisions the alpha-particle can approach very closely to the nucleus and impart considerable energy to it without causing a disintegration.

No inelastic collisions with either a deuteron or a neon nucleus were photographed. This might be expected for the deuterons but is surprising and disappointing for neon in view of the large number of tracks photographed both in the present work and in Eaton's work. Altogether it is estimated that about a million effective tracks have been photographed in neon. Since the yield from neon is about two-thirds that from nitrogen, about eight disintegration processes would be expected to occur in the course of the combined work. That not one of these events was observed is indeed unfortunate. Although the films were inspected carefully several times and all suspicious collisions were completely analyzed, it is possible that an inelastic collision was overlooked. Fig. 3c illustrates the kind of collision which was often suspected to be a neon disintegration, the long fine track being a possible proton. Analysis showed that in reality it is a deuteron collision with a short recoil alpha-ray track.

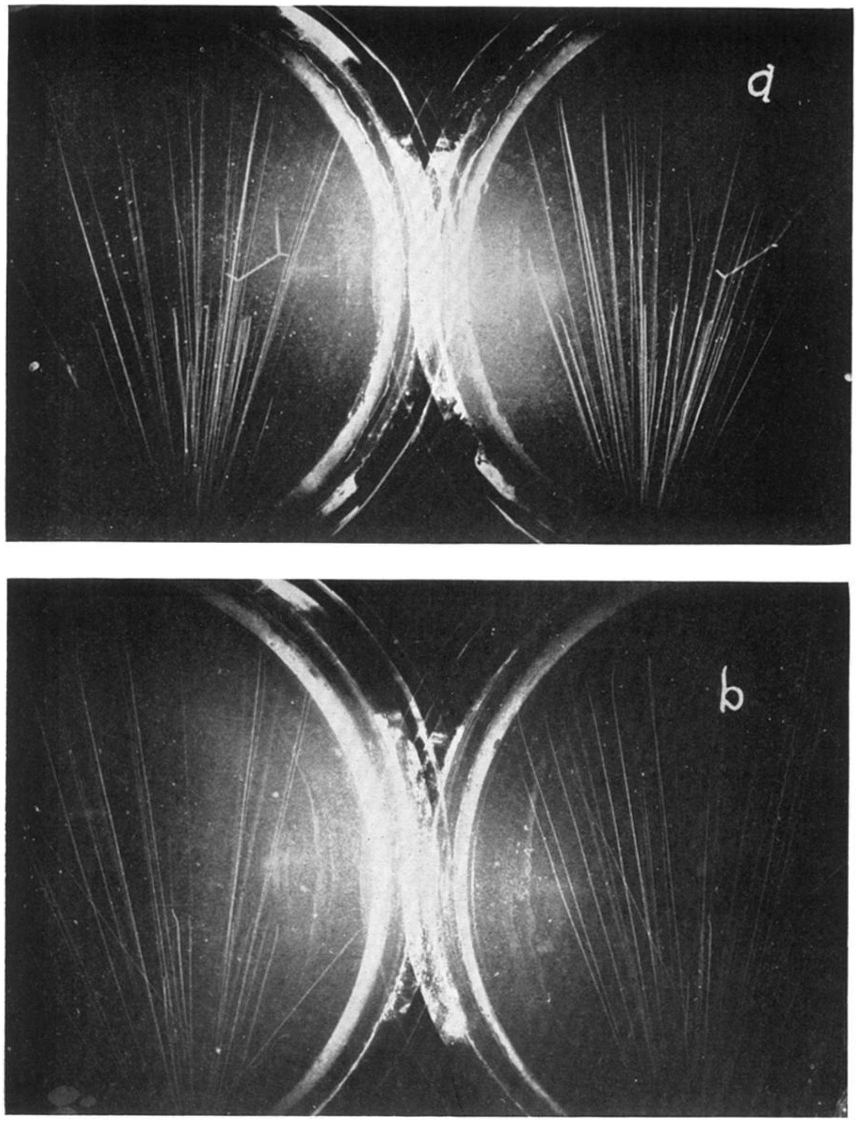
In conclusion, the author is pleased to express gratitude to Professor A. F. Kovarik for his advice and assistance during the course of the present work and to Dr. Ernest Pollard for many helpful discussions.

[11] G. Mano, J. de phys. et rad. **5**, 628 (1934).

[12] D. B. Parkinson, R. G. Herb, J. C. Bellamy and C. M. Hudson, Phys. Rev. **52**, 75 (1937).

[13] M. A. Tuve, N. P. Heydenburg and L. R. Hafstad, Phys. Rev. **50**, 806 (1936).

[14] H. S. W. Massey and C. B. O. Mohr, Proc. Roy. Soc. **A148**, 206 (1935).



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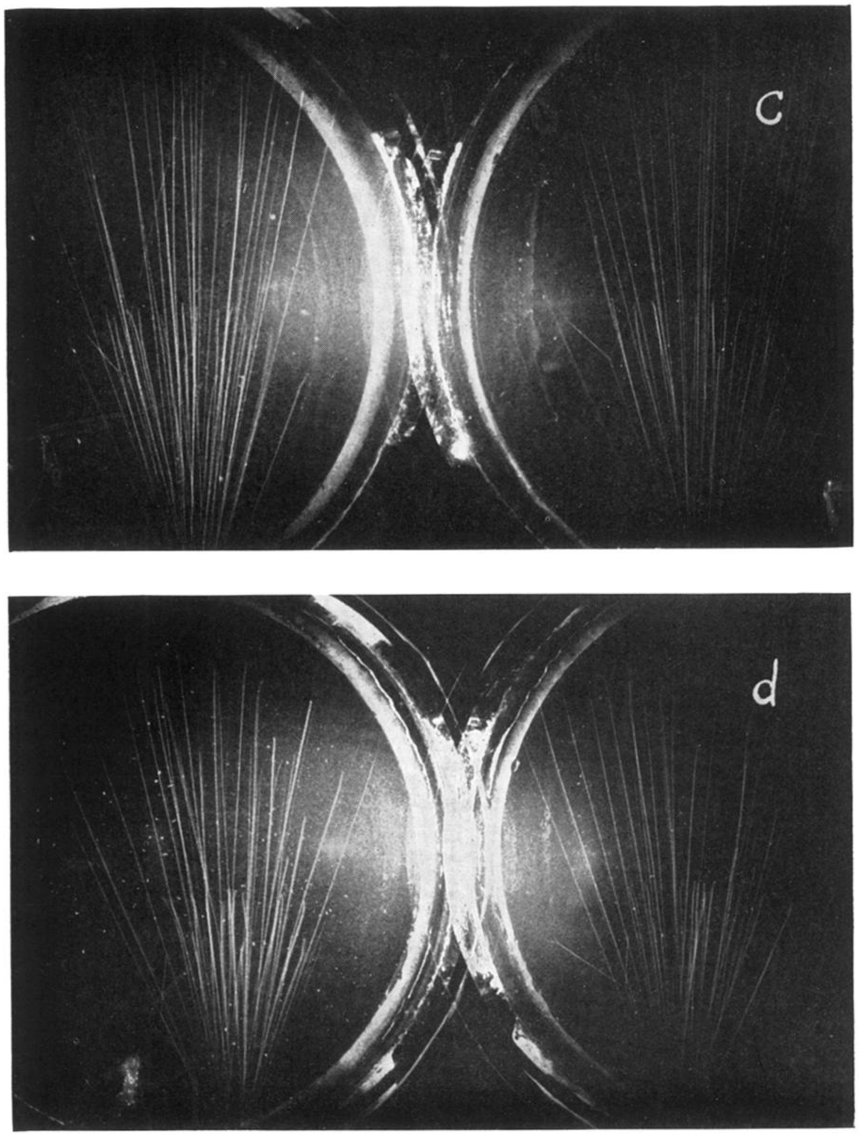

FIG. 3. c and d.