Pair Electrons Formed in the Field of an Electron

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The observation of pair electrons which were formed in the field of an electron is reported. These triplets were photographed in a cloud chamber which was irradiated with gamma-rays from radioactive sodium. Measurements on the tracks of the triplets show that energy and momentum are conserved in the process.

THE theory of pair production in the field of an electron was first considered by Perrin,[1] who calculated that the threshold for the process is 4 mc^2. Since in this case one observes the recoil electron as well as the positive-negative electrons of the pair, the three observed particles are often referred to as a triplet.

DaSilva[2] believes to have observed a triplet which was produced in a lead foil. This case is not completely satisfactory since the vertex of the triplet was in the lead foil and, therefore, not clearly visible. Shinohara and Hatoyama[3] report the observation of a triplet formed in the air of a cloud chamber but, in the photograph pub-

* Now engaged in military research.
[1] F. Perrin, Comptes rendus **197**, 1100 (1933).
[2] A. M. DaSilva, Comptes rendus **206**, 1365 (1938).
[3] K. Shinohara and M. Hatoyama, Phys. Rev. **59**, 461 (1941).

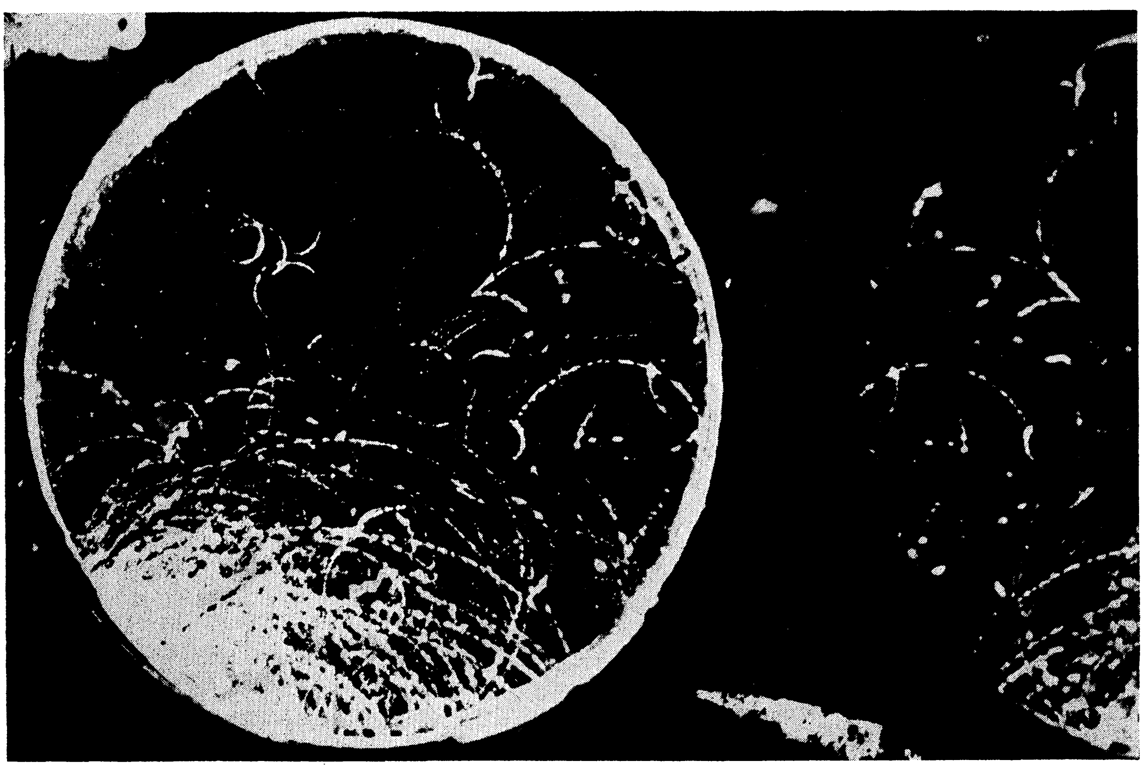

FIG. 1. Triplet No. 1. The direct image and one-half of the stereoscopic view are shown. The triplet is visible in the upper right quadrant of the direct view and in the corresponding section of the stereoscopic view. From both views it is clear that all three tracks of the triplet have a common origin. The gamma-rays enter the cloud chamber from the lower left-hand quadrant.

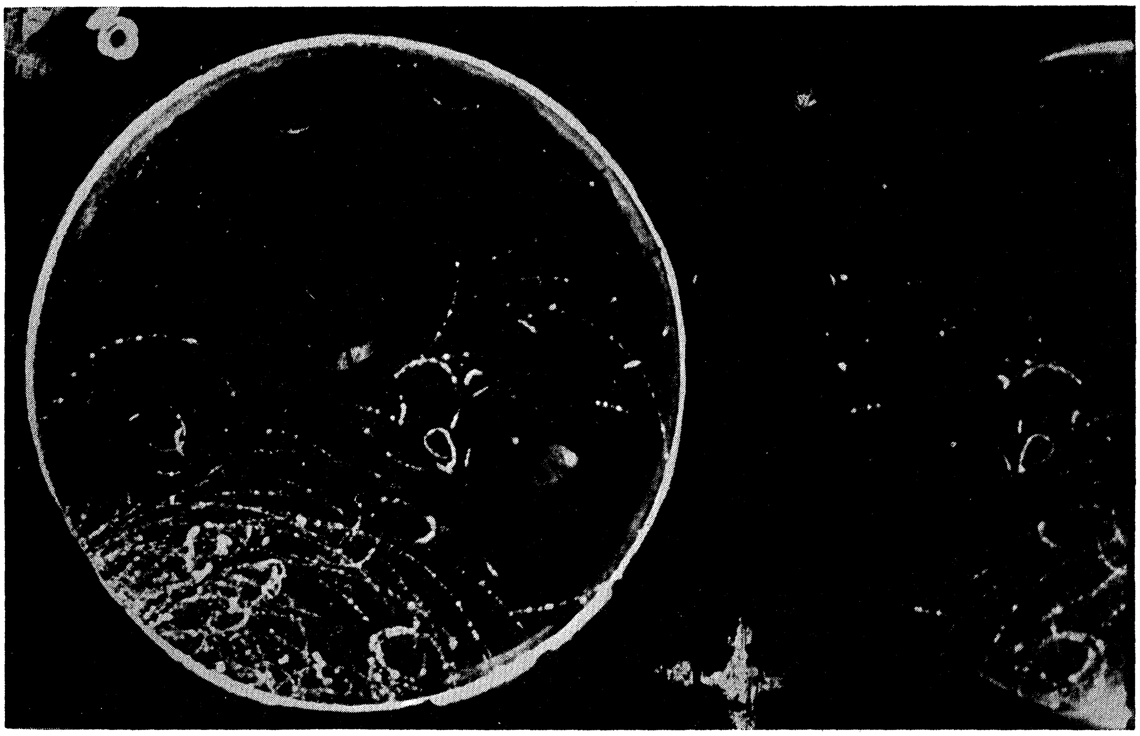

FIG. 2a. Triplet No. 2. Here the triplet origin is near the center of the cloud chamber. Conditions are the same as those in Fig. 1. The triplet is not as nearly coplanar as triplet No. 1 but the calculations on momentum and energy give nearly as good a check as those from triplet No. 1.

lished, it is not clear that there are three particles involved in the event and no data are included to show that momentum is conserved in the process. Groshev[4] looked for triplets while examining the pair produced by RaTh gamma-rays in nitrogen, krypton, and xenon. While observing a total of 435 pairs, no triplets were found. For these reasons the authors wish to report the following data on two triplets which were observed while examining the pairs reported in the preceding paper.

Since the experimental procedure and method of making measurements on the tracks was described fully in the preceding paper it will not be repeated here.

Figures 1 and 2 show photographs of the two triplets which were observed. No conversion foil was used. It is clear from the photographs that all three tracks of the triplets have the same origin in the gas of the cloud chamber.

The experimental data on these triplets, including momentum and energy calculations, are given in Table I.[5] Measurements on the radii of the tracks, of the magnetic field, and the calculation of the electron energies were made according to the procedure described in the preceding paper. The angle that each track of a triplet at its origin makes with the initial direction of the gamma-ray was determined on a photograph of the triplet enlarged to twice life size. To do this the radius of curvature of each track of the triplet on that enlargement was measured with the measuring engine. Then a circle of that radius was drawn in coincidence with the measured track. A line parallel to the direction of the incident gamma-ray was drawn through the origin of the triplet. Now, the angle between a radius constructed from the center of the circle to the vertex of the triplet, and the direction of the incident gamma-ray is comple-

[4] L. V. Groshev, J. Phys. Acad. Sci. U.S.S.R. 5, 135 (1941).

[5] A preliminary report on these data was given previously. Ogle and Kruger, Phys. Rev. 65, 61A (1944).

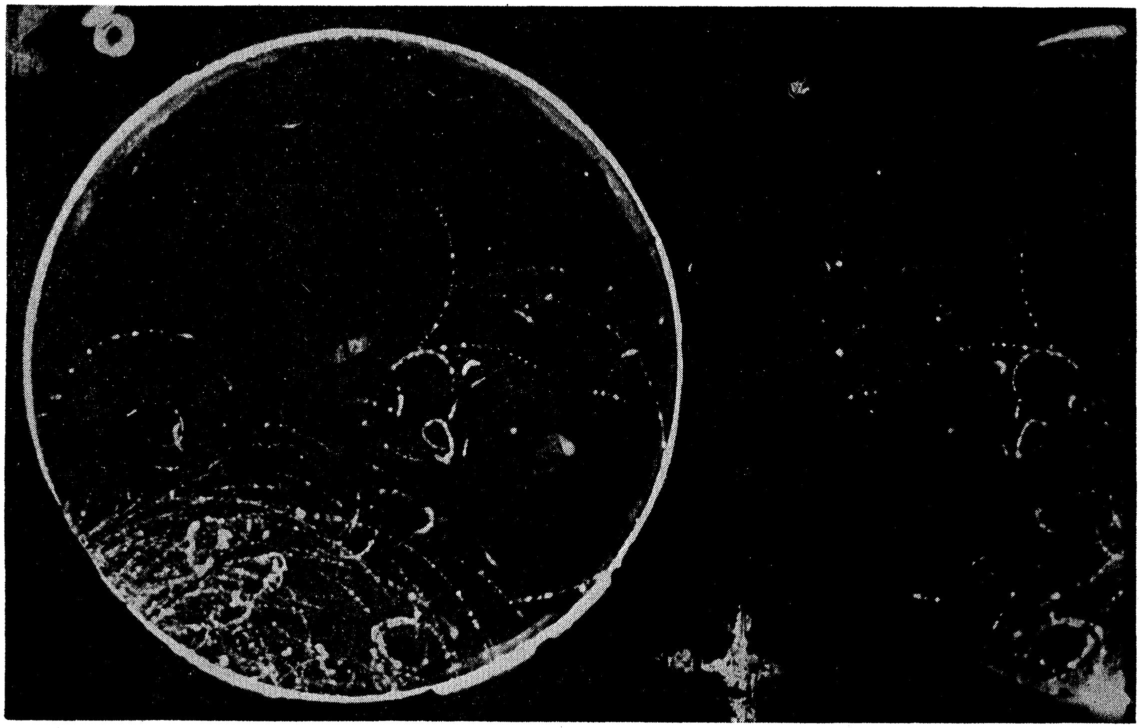

FIG. 2b. Triplet No. 2. Same as Fig. 2a except that several faint droplets near the end of the triplet tracks have been retouched so as to assure good reproduction in the Physical Review.

mentary to the angle between the initial direction of the electron and the direction of the incident gamma-ray. Thus, the initial direction of the electron can be found with an accuracy of about $\pm 2°$.

The energy of the gamma-rays producing

TABLE I. Experimental data on triplets.

ϕ = Initial angle of electron track with respect to the direction of incident gamma-ray.
Hr = Momentum in gauss-cm.
E = Energy in million electron volts.
M = Momentum in g cm/sec. (times 10^{16}).
$h\nu/c$ = Momentum of incident gamma-ray in g cm/sec. ($\times 10^{16}$).
y = the direction of the incident gamma-ray.
x = the direction at right angles to that of the incident gamma-ray.

Electron	ϕ	Hr. (Total)	E	Hr_x	Hr_y	M_x	M_y	$h\nu/c$
			Data from triplet in Fig. 1					
positron	0°	2613	0.425	0	2613	0	0.414	
electron	−10.2°	4660	0.978	−817	4588	−0.1294	0.726	
electron	26.0°	1924	0.259	842	1729	0.1334	0.274	
sum			1.662	25	8930	0.0040	1.414	1.433
		$2mc^2=$	1.022					
			2.684 Mev.					
			Data from triplet in Fig. 2					
positron	8.7°	3566	0.674	523	3525	0.0828	0.558	
electron	3.4°	4388	0.900	260	4380	0.0415	0.693	
electron	−26.5°	898	0.067	−401	804	−0.0635	0.127	
sum			1.641	382	8709	0.0608	1.378	1.422
		$2mc^2=$	1.022					
			2.663 Mev.					

these triplets, as calculated from these measurements, is 2.68 Mev and 2.66 Mev. This agrees with the 2.68 Mev gamma-ray from $Na^{24} \rightarrow Mg^{24}$ reported in the preceding paper. Momentum relations check well except for the x-component of triplet No. 2. In this case the discrepancy is about 4 percent of the total momentum and represents a not impossible experimental error.

In these studies two triplets were observed while 56 pairs were observed. The probability of ordinary pair production in the field of a nucleus is proportional to Z^2. Since a triplet is formed in the field of an electron the probability of triplet production in an atom should be proportional to Z, the number of electrons present in the atom. Thus the ratio of triplets to ordinary pairs observed should be of the order of $1/Z$. This should hold approximately at high energy but not near the threshold for the processes, since one threshold is at 2 mc^2 and the other at 4 mc^2. However, if it is assumed that, near the threshold, the shape of the triplet production curve is similar to the pair production curve, the relative probability of the two processes at low energy can be estimated roughly. The pair production probability at 2.7 Mev (5.3 mc^2), as given by Heitler is 0.79 in units of $Z^2r_0^2/137$. 5.3 mc^2 is 1.3 mc^2 above the threshold for triplet production. The pair probability at 1.3 mc^2 above the pair threshold is 0.225 in the same units as above. By assuming that this probability also applies to triplet formation at 1.3 mc^2 above the triplet threshold, the ratio of triplet production to pair production is 0.225/0.79 or 1/3.5. Since the triplets and pairs observed were formed in air in a cloud chamber, the above ratio must be reduced by $1/Z$, which for air is about 1/7.2. Thus, the ratio becomes 1/25. The observed ratio of 1/28 is in much better agreement with the estimated ratio than should be expected when so few triplets are observed.

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Atomic Distribution Function of Liquid Argon

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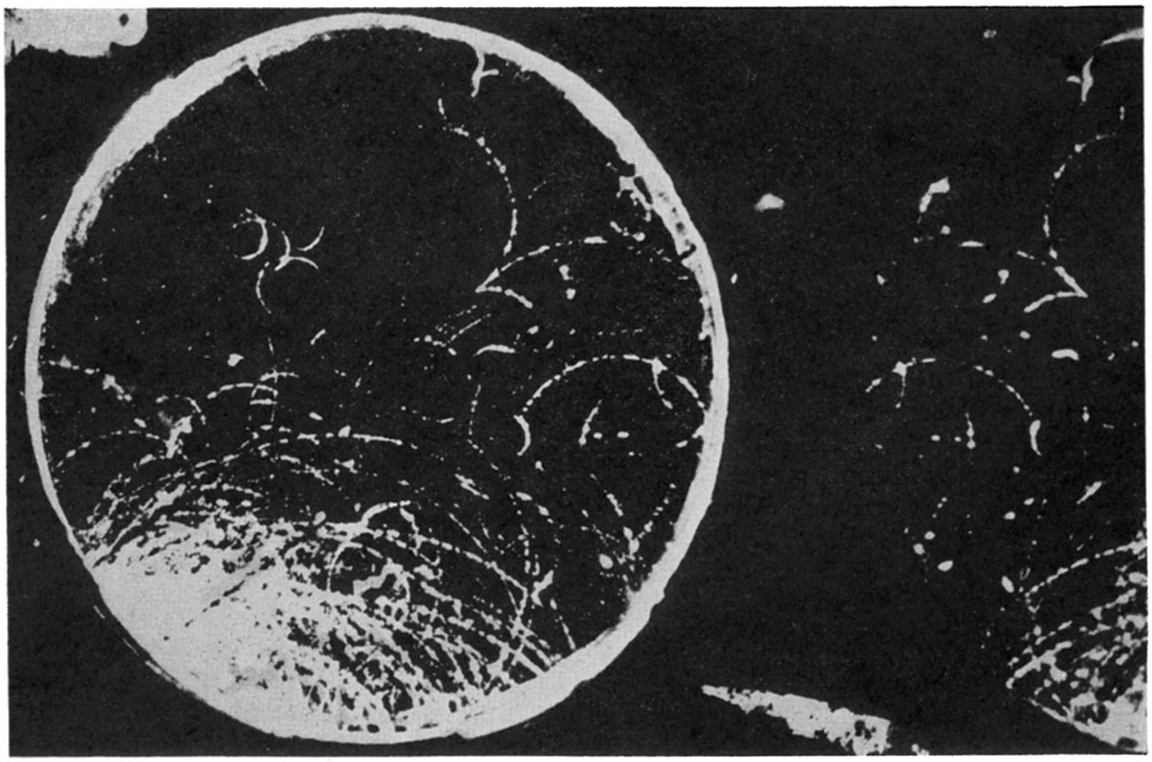
An atomic distribution curve for a simple monatomic liquid, such as argon, is generally characterized by a prominent first peak. This peak may be used to determine the elements of the first coordination shell, i.e., the radius of the shell and the number of nearest neighbors of an atom. Frequently this peak can be closely approximated by a simple polynomial involving a parameter σ. This parameter may be determined empirically by a process of fitting. In the case of liquid argon, where the force function between the atoms is known, it is possible to make a theoretical determination of σ provided the elements of the first coordination shell are given. This has been done for liquid argon at a temperature of 91.8°K and under a pressure of 1.8 atmos. The theoretical value of σ is compared with various empirical values obtained from the experimental distribution curve for liquid argon under these conditions as given by Eisenstein and Gingrich. It is found that the theoretical value is somewhat smaller than the empirical value of σ obtained by fitting and slightly larger than that obtained by the Coulson-Rushbrooke method. A possible interpretation of these results is given.

INTRODUCTION

ATOMIC distribution curves for liquid argon over a considerable range of temperatures and pressures have been obtained by Eisenstein and Gingrich[1] by an analysis of x-ray diffraction patterns of the liquid. Previous to this work, Rushbrooke[2] calculated the first peak of the distribution curve for liquid argon at 90°K by use of a general expression for liquid distribution

[1] A. Eisenstein and N. S. Gingrich, Phys. Rev. **62**, 261 (1942).

[2] G. S. Rushbrooke, Proc. Roy. Soc. Edinburgh **60**, 182 (1940); J. G. Kirkwood and E. M. Boggs, J. Chem. Phys. **10**, 394 (1942).



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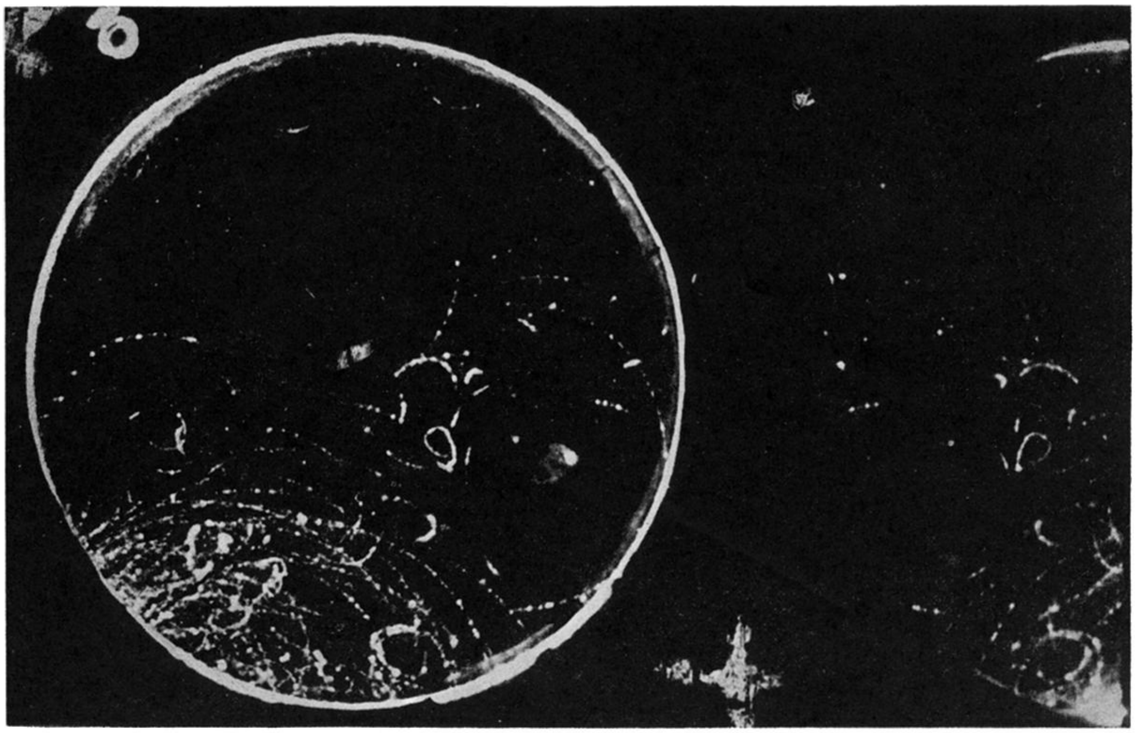

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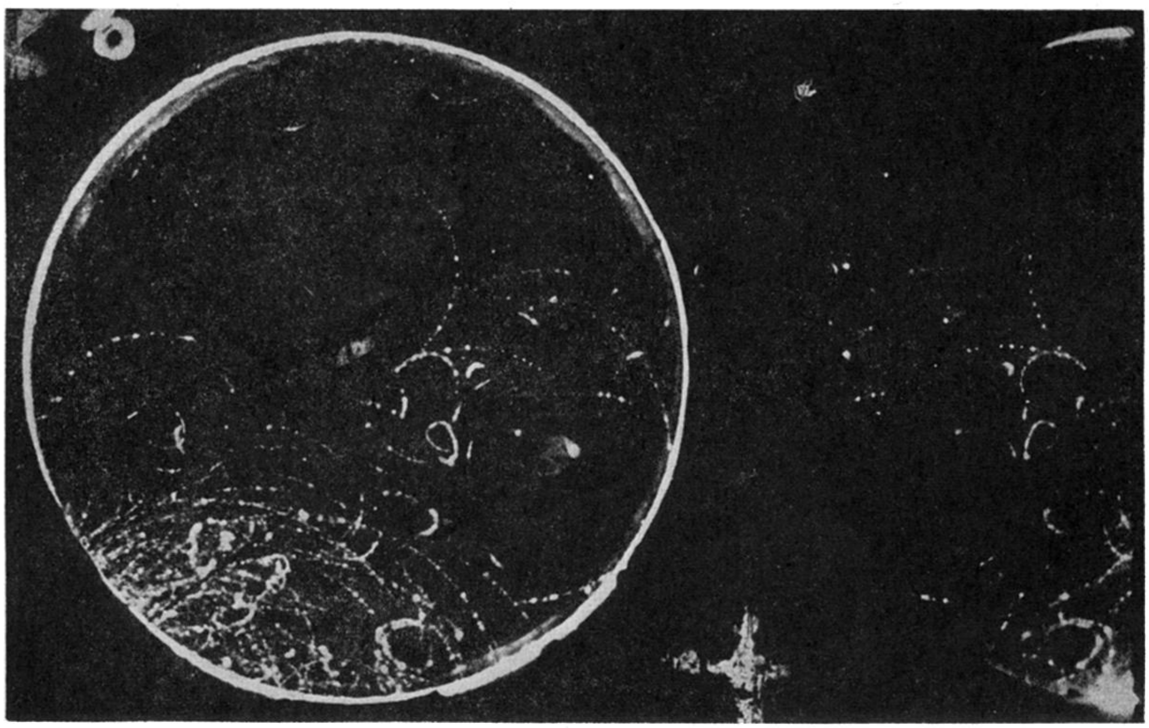

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