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The Arrangement of the Micro-Crystals in Compressed Single-Crystal-Plates of Aluminium, Part II

By

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Abstract

When a single-crystal-plate of aluminium is compressed, the micro-crystals produced by the destruction of the single crystal rotate themselves in such a way that their (110) planes, which make the slightest inclination to the flat surface of the specimen, become nearly parallel to the flat surface, by taking the [111], [110] or [112] axis which is nearly parallel to the flat surface of the specimen, as the axis of rotation. The relation between the maximum angle of rotation of micro-crystals and the reduction of thickness of the specimen was investigated, and it was found that the maximum angle of rotation takes the maximum value at a reduction of about 30%—50% in the thickness of the specimen. As the scattering of the orientation of the micro-crystals is affected by the manner of flow of the metal by compression, the relation between the scattering of the orientations of the micro-crystals and the manner of flow of the metal was also examined with specimens having various different shapes. When the specimen in the form of a circular plate is compressed beyond 70% reduction in thickness, the micro-crystals begin to rotate themselves around the crystallographic [110] axis which is perpendicular to the flat surface of the specimen.

In a former investigation,[1] the writer examined the manner of the arrangement of the micro-crystals in a slightly compressed single-crystal-plate of aluminium. In the present experiment, the arrangement of the micro-crystals in single-crystal-plates of aluminium of various forms, which were subjected to greater compression, was investigated as a continuation of the former experiment.

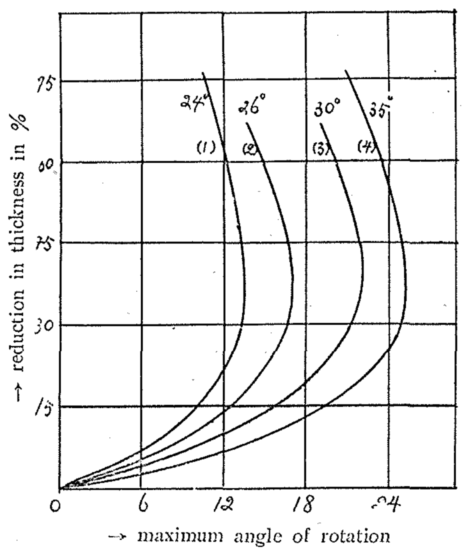
In order to carry out the present research, it is very important to know as accurately as possible the position of both ends of an

1. These Memoirs, **12**, 261 (1929)

elongated Laue-spot on a photographic plate. Thus the writer employed, in most cases, a Coolidge-X-ray-tube having a tungsten target, and a large photographic camera lest any elongated Laue-spot should be out of the range of the camera.

The Laue-photograph was taken by making a narrow and circular beam of the X-rays illuminate the specimen in a direction perpendicular to its flat surface; and the maximum angle of rotation of the micro-crystals was obtained by treating the elongated Laue-spots with the crystallographic globe devised by Prof. U. Yoshida.[1] The relation between the maximum angle of rotation of the micro-crystals and the reduction of the thickness of the plate by compression is shown in Fig. 1. In the former investigation, the relation between the maximum angle of rotation of the micro-crystals at the centre of a square plate and the reduction of thickness of the specimen by compression was investigated. It was found in that case that the crystallographic axis of rotation of the micro-crystals was one of the [110] axes which had the slightest inclination to the flat surface of the specimen. In Fig. 1, the shape of the specimen which corresponds to the curves (1) and (4) is a rectangle whose longer side is about 6 times longer than the shorter side. In this case, as will be stated more minutely later, the micro-crystals rotate around the one of the [110], [111] and [112] axes which is most nearly parallel to the longer side of the specimen throughout the whole process of compression. The relation between the maximum angle of rotation of the micro-crystals around such an axis and the reduction of thickness of the specimen by compression is shown in curves (1) and (4). Curves (2) and (3) in Fig. 1 correspond to a circular plate whose diameter is 10 mm. At the centre of these circular plates, the axis

Fig. 1



1. Jap. J. Phys., **4**, 133 (1927); These Memoirs, **12**, 257 (1929)

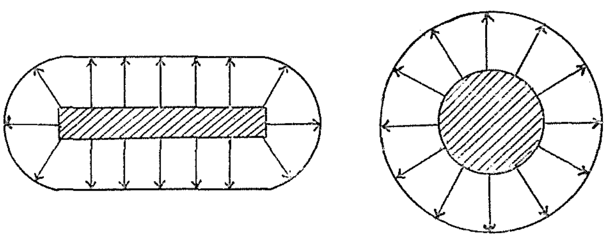
of rotation of the micro-crystals is found to be almost parallel to the flat surface of the specimen and remains unaltered till the specimen is compressed to 30% of the initial thickness. The relation between the maximum angle of rotation of the micro-crystals around such an axis and the reduction of thickness are shown in curves (2) and (3) in Fig. 1. From the curves shown in this figure we know that the maximum angle of such rotation of the micro-crystals increases very rapidly for slight compression, and takes the maximum value at 30% —50% reduction in thickness, irrespective of the initial crystallographic orientation, and then it decreases gradually as the process of compression proceeds further. Figs. 1, 2 and 3 in Plate I are the Laue-photographs taken with the specimen corresponding to curve (1) in Fig. 1, when its thickness was reduced by 21%, 47% and 70% of the initial thickness by compression respectively.

Next the writer found unexpectedly in one of the specimens, that in the micro-crystals produced by the destruction of a single crystal by compression there is a tendency for one of their (110) planes which have the smallest inclination to the flat surface of the specimen to become nearly parallel to the flat surface on compression. Then by means of the crystallographic globe all the other Laue-photographs taken with the other specimen were again examined, and the fact stated above was ascertained to hold good in every case. Thus it has now become clear that the micro-crystals produced by the destruction of a single crystal in the form of a plate rotate themselves on compression in such a way that their (110) planes which have the smallest inclination to the flat surface of the specimen become nearly parallel to the flat surface irrespective of the initial crystallographic orientation. When the thickness of the specimen is more reduced by compression, the tendency of the (110) planes to become nearly parallel to the flat surface increases. It seems to be due to this reason that the maximum angle of rotation decreases gradually, owing to the compression, at the stage when the reduction of thickness is more than 50%. The angles marked on curves (2) and (3) in Fig. 1 represent the angles between the normals to the flat surface of the specimen and to the (110) plane which has the smallest inclination to the flat surface, and the ones marked on curves (1) and (4) represent the components of such angles along the plane which is perpendicular to the longer side of the specimen. It is clear, from Fig. 1, that the greater the angles marked on these curves, the greater is the maximum angle of rotation of the micro-crystals.

As to the axis of rotation of the micro-crystals, the writer has stated in the former report, that the axis of rotation with slight compression is that one of the [110] axes which has the smallest inclination to the flat surface of the specimen. In the present experiment it is found that the [111] and [112] axes, beside the [110] axis, are also able to become the axis of rotation of the micro-crystals. Fig. 4 in Plate I and Fig. 1 and 2 in Plate II show the fibrous arrangements whose axes are the [111], [110] and [112] axes respectively. Next we shall consider the question which one of the axes [111], [110] and [112] will become the axis of rotation of the micro-crystals on compression. In order to solve this question we must consider the relation between the initial orientations of the crystallographic axes in the specimen and the manner of flow of the metal on compression. The specimens examined in the present experiment were a rectangular and a circular plate.

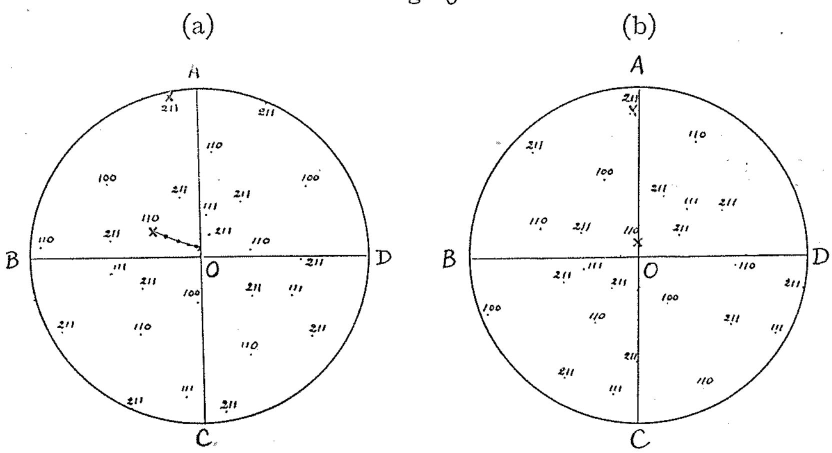
Fig. 2

(a) (b)



The shaded parts in Fig. 2 represent the initial undeformed portions of the specimens which are prepared from larger single-crystal-plates by etching off their outer portions with some dilute acid. The longer side of the rectangular shaded part of (a) in Fig. 2 is longer by about six times than the shorter side. The initial undeformed portion represented by the shadow in (b) of Fig. 2 is a circular plate. In the case of (a) in Fig. 2 the direction of flow of the metal on compression is shown sketchily by the parallel arrows which are perpendicular to the longer side of the specimen except at the two ends. In this case the crystallographic axis of rotation of the micro-crystals in the vicinity of the longer side of the specimen is found to be that one of the [111], [110] and [112] axes which has the slightest inclination to the longer side. It is also observed that such axis of rotation of the micro-crystals remains unchanged during the whole process of compression. It has already been stated that the micro-crystals in the specimens rotate themselves in such a way that one of their (110) planes, which has the slightest inclination to the flat surface of the specimen, becomes nearly parallel to the flat surface on compression. In the case of a rectangular plate, however, since the axis of rotation of the micro-crystals is fixed, as was stated before, the tendency of the (110) planes to become nearly parallel to the flat surface of the specimen must be more or less restrained according to the initial crystallographic orientation. Owing to these circumstances, the (110) planes of the micro-crystals which have the slightest inclination against the flat surface of the specimen are not generally able to become completely parallel to the flat surface of the specimen according to the initial crystallographic orientation, however far the process of compression proceeds. But it is discernible that the axis of rotation of the micro-crystals which is nearly parallel to the longer side changes its direction slightly on compression so that the (110) planes of the micro-crystals which had the smallest inclination to the flat surface of

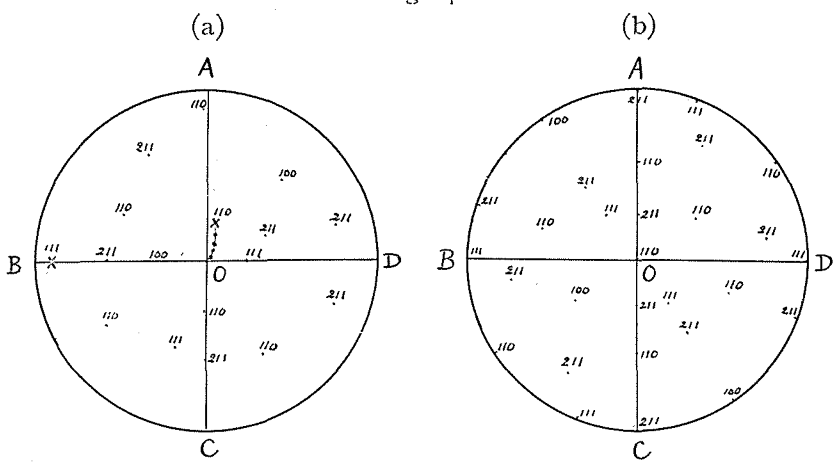
Fig. 3



the specimen become as nearly parallel as possible to the flat surface. This is represented more clearly in stereographic projection. The initial orientation of the rectangular plate, which corresponds to the curve (1) in Fig. 1, in reference to the crystallographic axes is shown in Fig. 3, (a). Here we consider the plane of the paper as the flat surface of the specimen, and consequently the point O at the centre of the figure represents the direction of the surface normal to the flat surface of the specimen. The line AC represents the direction of the longer side. The [110] axis, shown by a cross, is the nearest one to the point O initially among the [110] axes; and the [112] axis, shown by another cross, is the axis which has the smallest inclination to the longer side among the [111], [110] and [112] axes. Thus, on compression, the micro-crystals rotate themselves around the [112] axis shown by the cross, and the [110] axis shown by the other cross approaches gradually to O as shown by a curve. The dots on the curve show the successive mean orientations of the [110] axis under consideration from left to right when the specimen is compressed 20%, 30%, 50% and 70% respectively in the reduction of its thickness. Fig. 3. (b) represents the mean orientation of the micro-crystals when the specimen is compressed to a thickness of 70% in the reduction of the thickness. In this case, the [110] axis is almost on the line AB, and the [112] axis-the axis of rotation of the micro-crystals -changes its direction slightly so as to make the (110) face under consideration parallel to the flat surface as far as possible. In the case of (b) in Fig. 2, the direction of the flow of the metal is parallel to the radial direction from the centre of the circle as shown by the arrows. At the centre of such a circular plate, the micro-crystals rotate themselves on compression around a certain crystallographic axis which is almost parallel to the flat surface of the specimen. Such a crystallographic axis is found to be the one among the [111], [110] and [112] axes, which is most nearly parallel to the flat surface; and the micro-crystals rotate themselves in such a way that their (110) planes, which have the smallest inclination to the flat surface of the specimen, become nearly parallel to the flat surface by keeping the axis of rotation unchanged till the specimen is compressed to about 30% of the original thickness. As the Laue-photographs taken in every part of the specimen subjected to a slight compression are almost the same as that taken at the centre of the circular plate, the effect of the manner of flow of the metal seems to be roughly the same in every part of the specimen. But it is not exactly so. With a slight compression, reducing the thickness to below about 30%, all the micro-crystals in every part of the specimen rotate themselves around one and the same crystallographic axis, which is very nearly parallel to the flat surface. Consequently the degree of flow of the metal is somewhat different in different parts of the specimen, and the circular plate becomes somewhat elliptical by taking the direction to the specimen which is the nearest to the axis of rotation of the micro-crystal as the direction of the minor axis. For reductions of more than 50% in the thickness of the specimen by compression, such formation of an elliptical plate by the compression is not detected; and at the border of the circular plate the effect of the manner of flow of the metal becomes conspicuous and at last a certain axis, among the [111], [110] and [112] axes, which is the one most nearly parallel to the flat surface and most nearly perpendicular to the direction of flow, becomes the axis of rotation of the micro-crystals.

We shall represent the above stated facts in stereographic projection. Fig. 4, (a) represents the initial orientation of the circular plate which corresponds to curve (2) in Fig. 1, in reference to the crystallographic axes, the plane of the paper being considered as the flat surface of the specimen, and the direction of the normal to the flat

Fig. 4



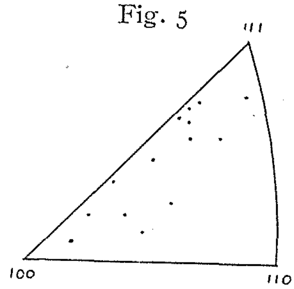
surface being represented by the point *O* at the centre of the figure. The micro-crystals rotate themselves on compression in such a way that their (110) planes, which have the slightest inclination to the flat surface of the specimen, become nearly parallel to the flat surface. Therefore, in the stereographic projection, the [110] axis, shown by a cross, which is the nearest to the point *O* among the [110] axes must approach to *O*. In order that the [110] axis shown by the cross shall approach to *O*, the [111] axis shown by another cross is the most favourable one among the [111], [110] and [112] axes to become the axis of rotation of the micro-crystals; and the micro-crystals of the specimen rotate themselves around the [111] axis in such a way that the [110] axis approaches to O as shown by a curve. The dots on the curve represent the successive mean orientations of the [110] axis of the micro-crystals when the specimen is compressed and reduced in thickness by 15%, 30%, 45% and 60% respectively. When the specimen is reduced in thickness by 60%, the micro-crystals take the orientation shown by (b) in Fig. 4. It has already been stated that, by examining the portions of the specimen at the border of the circular plate subjected to a strong compression causing more than 50% reduction in thickness, the crystallographic axis of the rotation of the micro-crystals was found to be that one of the [111], [110] and [112] axes, which is the most nearly parallel to the flat surface and most nearly perpendicular to the direction of flow of the metal on compression. Thus, in the case of the specimen represented in Fig. 4, if the point at the border of the circular plate corresponds to the point A in (b) of Fig. 4, the axis of rotation of the micro-crystals at this point is the [111] axis which is perpendicular to the direction of flow of the metal OA at this point and which is parallel to the flat surface of the specimen. Similarly the axis of rotation of the micro-crystals at another point in the border of the circular plate corresponding to B is the [112] axis which is perpendicular to the direction of flow of the metal OB at this point and which is parallel to the flat surface of the specimen.

Next the micro-crystals of the circular plate begin to rotate around the axis which is perpendicular to the flat surface of the specimen when the specimen is compressed to a thickness of less than 30% of the initial thickness. Fig. 3 in Plate II is a Laue-photograph taken with a specimen compressed to 10% of the original thickness, by sending the X-ray beam from a molybdenum target normally to the surface of the specimen. The K_α line of molybdenum, as shown in this figure, has a tendency to become concentric rings. This fact shows that the micro-crystals in the compressed circular plate rotate themselves on compression, at least to some extent, around the axis normal to the flat surface when the specimen is compressed thoroughly. It has already been stated that the micro-crystals in the plate rotate themselves in such a way that their (110) planes which have the slightest inclination to the flat surface, become nearly parallel to the flat surface on compression. Therefore, when a specimen is compressed thoroughly, the normal direction of the flat surface must coincide with the [110] axis for the majority of the micro-crystals. Consequently the axis of such rotation of the micro-crystals in a thoroughly compressed specimen can be expected to be the [110] axis for the majority of the micro-crystals. This supposition is ascertained to be correct with a Laue-photograph taken by sending the X-ray beam from a molybdenum target in the direction parallel to the flat surface of the specimen. Fig. 4 in Plate II is a Laue-photograph thus taken with a circular plate which was compressed to a thickness of 10% of the initial thickness. It was ascertained from this photograph that the axis of rotation of the micro-crystals was the [110] axis which was parallel to the normal to the flat surface. This result obtained by the writer with a circular single-crystal-plate is entirely the same as that observed by S. Tsuboi[1] with a compressed circular polycrystal plate.

Here it must be noticed that the part formed by the extension of the plate by compression was etched off with some dilute acid carefully at each step in the compression, and the original size was kept constant before each compression.

In the present experiment, 14 different specimens were examined in all. The crystallographic orientations of these specimens are shown in Fig. 5. The dots in this figure show, in stereographic projection, the initial orientation of the direction of the normal to the flat surface of the plates in reference to the directions of the crystallographic axes.

Fig. 5



In conclusion, the writer wishes to express his sincere thanks to Prof. U. Yoshida for his kind guidance during this research.

1. These Memoirs, **11**, 271 (1928)

Plate I

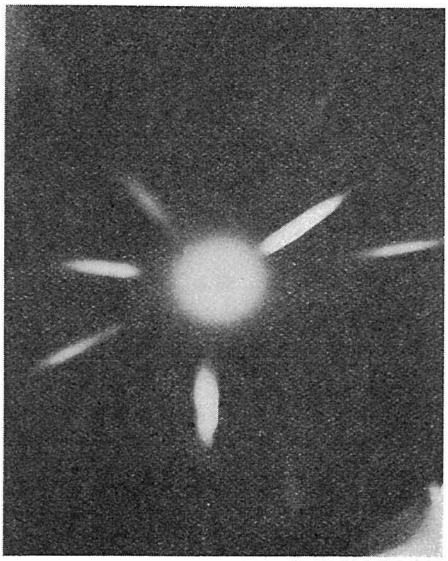


Fig. 1

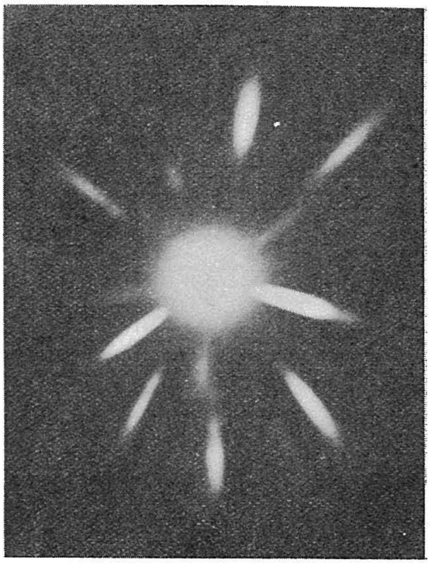


Fig. 2

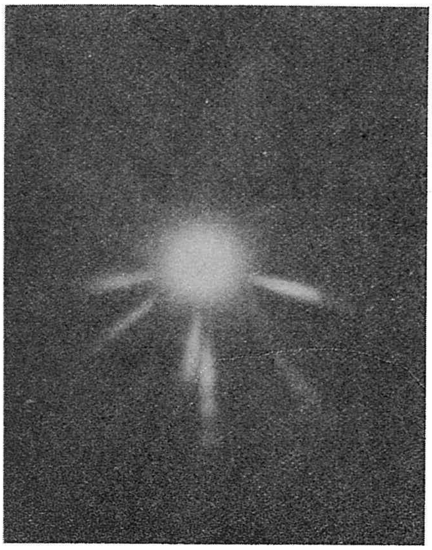


Fig. 3

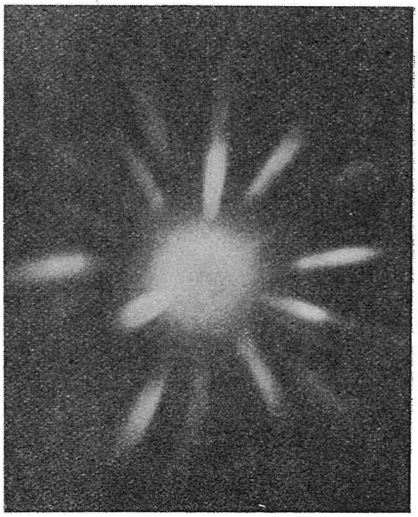


Fig. 4

Plate II

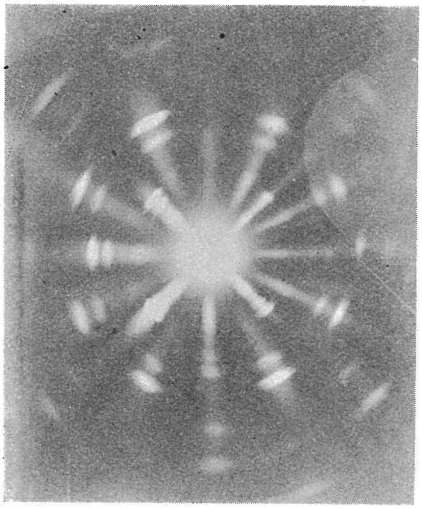


Fig. 1

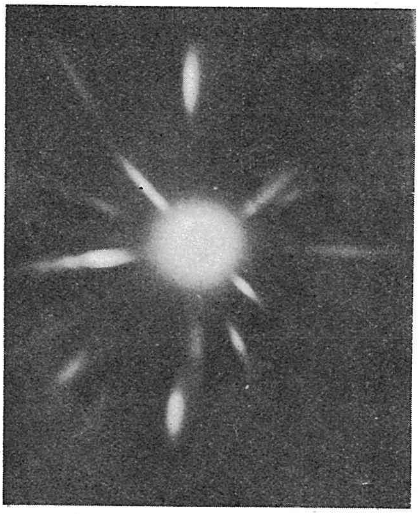


Fig. 2

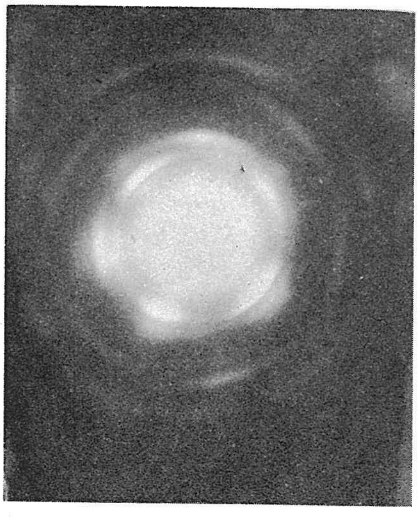


Fig. 3

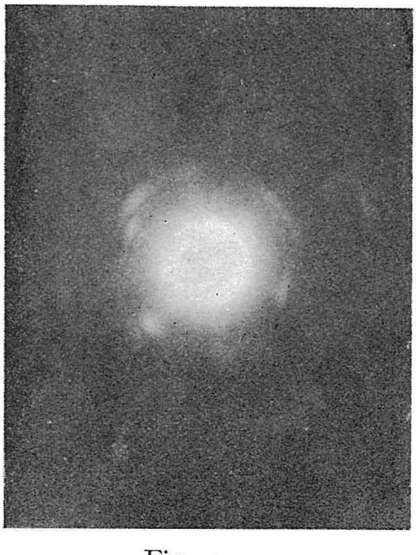


Fig. 4