The isolation of the directions-image of small objects.

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THERE are two distinct kinds of image which are the subject of optical investigation: object-images, in which the form of the object is reproduced, and directions-images, in which every point represents a direction followed by light before reaching the objective. An instrument that shows a directions-image may be described as a hodoscope.[1] It is focused not on the object but on infinity, so that parallel rays are collected at the same point in the image. Such an instrument is the telescope employed in the determination of the critical angle of total reflection, or in goniometric measurements, or a microscope modified for the observation of the interference-figures of crystalline substances. There is, however, this difference, that in the last the angular aperture is made as large as possible, whereas in the telescope it is comparatively small.

Where it is desired to study the directions-image of a comparatively small object, a difficulty arises that a portion of the light illuminating the directions-image does not come from the object under investigation, and must be excluded if the directions-image is to be studied to the best advantage. If the observation is between crossed nicols, only the light traversing other anisotropic substances will interfere with the effects to be studied, but in other cases even diffused light from the medium in which the object lies will interfere with the observation.

[1] This term, from ὁδός, a path, was first suggested by the author in Journ. Quekett Microscopical Club, 1915, vol. xii, p. 618. The instrument has also been called a konoscope, but this is misleading, for it is the individual directions, not the cone that includes them, which are studied.

This exclusion of extraneous light from the directions-image of an object may be described as the *isolation* of its directions-image. Isolation may be carried out by means of some form of diaphragm, which must either be interposed in the path of the light before it reaches the object, so as to prevent the illumination of adjoining objects, or in the path of the light after it has passed the object, so as to cut off all light that has not traversed it or (in the case of the goniometer) reflected from it. For the isolation to be effective the diaphragm must either be in close proximity to the object, or else in a focus conjugate to it, so that the image of the aperture of the diaphragm and the object are seen together.

The application of these principles to the directions-image in a petrological microscope will be first considered.

Attempts have been made in the case of a mineral in a thin section to effect the isolation by painting either the glass slip or the cover-glass with opaque material. This is obviously a difficult and tedious process, which has little to recommend it except its simplicity and directness.

The method most frequently employed at present is only applicable when the directions-image is studied in the principal focus of the objective after the removal of the eyepiece (Lasaulx method). The process of isolation appears to have been originally described by S. Czapski (Zeits. Kryst. Min., 1894, vol. xxii, pp. 160, 161). The microscope is adjusted by the focusing screw till the primary object-image is brought to the upper end of the tube. To ascertain when this has been effected, a lens should be focused on the place where the object-image is to be formed. Then by moving the glass slip carrying the section about the stage, the image of the object is brought into the centre of the field, and a cap with an aperture in the centre, not exceeding the size of this image, is placed on the eyepiece. The lens is now removed and the eye applied to the aperture in the diaphragm, when the directions-image of the object will be seen unaffected by any extraneous light. Czapski employed for this purpose what is known as the Czapski eyepiece, an iris-diaphragm surmounted by a Ramsden eyepiece, focused on the diaphragm. The microscope is focused so as to bring an object-image into the plane of the diaphragm, which is adjusted so as to exclude everything except the object to be examined. The Ramsden eyepiece is then removed and the directions-image examined through the diaphragm.

E. Sommerfeldt (Zeits. wiss. Mikr., 1905, vol. xxii, pp. 361–362) and F. E. Wright (Amer. Journ. Sci., 1910, vol. xxix, p. 412) have each devised a system of slides by which the aperture may be accommodated to the shape and size of the object and the maximum amount of illumination of the directions-image obtained. This is, however, only possible when the stage is fixed. With a rotating stage there is no advantage in having an aperture of any shape other than circular, and the adjustment of the aperture of the diaphragm so as to coincide with the image of the centre of rotation of the object becomes important.

If the image is observed by means of the Bertrand (Amici) lens, the question of isolation is not so simple. There is, as a matter of fact, an object-image formed above the Bertrand lens and below the eyepiece, and if a diaphragm were inserted there, isolation could be effected. It would however, be necessary to remove the eyepiece and insert another lens, or use a lens in combination with the eyepiece, to see the object-image, so as to be able to bring it into the position of the diaphragm by focusing and adjust the aperture of the diaphragm. (S. Czapski, loc. cit., p. 162.) This method is, as a matter of fact, never employed, as it involves the cutting of a new slot in the microscope tube, but a diaphragm is frequently placed immediately above or below the Bertrand lens so that it can be inserted in the same slot. If it be placed above the Bertrand lens, a comparatively small elevation of the microscope will bring the object-image to the position of the diaphragm, but the consequent increase in the distance of the objective from the object will seriously diminish the angular aperture of the instrument as a hodoscope, so far as concerns the directions traversing the object. If, however, as is usually the case, the diaphragm be placed below the Bertrand lens (C. Leiss, 'Die optischen Instrumente, &c.,' Leipzig, 1899, p. 190; and F. E. Wright, 'The Methods of Petrographic-Microscopic Research,' Carnegie Institution, Washington, 1911, p. 59), a far greater elevation of the microscope is required, for the Bertrand lens then no longer assists in bringing the object-image down to the diaphragm. The result is that the angular aperture is so contracted that the directions-image is of very little value, or would be, if isolation were completely effected by the coincidence of the directions-image with the diaphragm. Apparently, however, when such a diaphragm is employed, no precautions are as a rule taken to see that complete isolation is secured, and the directions-image, though greatly contracted, is more or less affected by the presence of extraneous light.

An alternative method, when the Bertrand lens is employed, is to make use of a small image of the object that is then formed above the eyepiece (F. Becke, Min. Petr. Mitt., 1894, vol. xiv, p. 378). If a cap or other diaphragm be placed in this position and the image of the object observed by means of a lens, the diaphragm may be adjusted so as to exclude the rest of the field. The lens may then be laid aside and the directions-image examined through the aperture in the diaphragm. A preliminary centring of the object may be effected before the insertion of the Bertrand lens in the ordinary object-image seen in the focus of the eyepiece.

All these methods have serious disadvantages. If the eyepiece be removed (Lasaulx method), the directions-image is very small, while in the two methods in which the Bertrand lens is employed, the real object-image, in which isolation is effected, is but slightly magnified; so that in the case of small minerals or narrow twin-lamellæ, the perforation in the diaphragm must be very minute and its adjustment a tedious process.

These difficulties are avoided by adopting the method proposed by Becke (loc. cit., pp. 375–378), which has the further advantage that it does not require any interference with the microscopic tube. Instead of inserting the Bertrand lens in the tube the directions-image is obtained by placing over the ordinary eyepiece a lens, or system of lenses essentially similar to a Ramsden eyepiece, in a suitable fitting. This accessory, which is known as the Klein or Becke lens, magnifies the small directions-image which is formed in the Ramsden circle. It should be capable of an up and down movement by which it may be focused.[1]

The object-image is first observed in the focus of the eyepiece in the usual manner, and the object to be examined is brought into the centre of the field. A diaphragm is then inserted through the slot in the focus of the eyepiece, so that only the object under investigation is visible. The Becke lens is now placed in position, and the directions-image, even of very small minerals, will be seen entirely unmixed with extraneous light.

The observation and magnification of the directions-image in the Ramsden circle were first carried out by C. Klein (Sitzungsber. Preuss. Akad., 1893, p. 222, note 1, and p. 226). He inserted the 'No. 1' or 'No. 2' eyepiece in the tube of the microscope and superposed the 'No. 2' or 'No. 3' eyepiece to get the necessary magnification of the small directions-image. Becke, however, appears to have been the first to provide a special fitting for the purpose, and to employ in conjunction with it a diaphragm in the focus of the eyepiece for the purpose of isola-

[1] The position will vary according to the objective employed, the eye of the observer, and the part of the field under investigation.

tion, and a scale for measurement of the directions-image in the focus of the lens. It was originally employed by him in conjunction with the Czapski eyepiece, on which it was superposed after the diaphragm had been adjusted.

It is curious that although the Becke lens was employed by Becke specially with a view to the isolation of the directions-image of small minerals, this is not referred to in any of the textbooks which mention the lens, and I personally used this method of isolation for some time before I was aware that it had been described.

The advantage of the Becke method of isolation is that the real object-image is considerably magnified, which facilitates the adjustments, especially in the case of minute objects, since the movements required in the adjustment of the diaphragm are correspondingly larger than they would be with a smaller image. The further magnification by the eye-lens of the eyepiece is also of assistance. If the stage is fixed, the shape of the diaphragm can be adjusted to that of the object in any way which may be convenient (see p. 47). If not, the centring of the object and aperture with the image of the centre of rotation is, of course, important.

I recently devised a method of isolation in which the diaphragm is placed below the condenser, which is adjusted so that the perforation in the diaphragm is seen in the microscope simultaneously with the object-image, and is adjusted so that only the mineral under observation is illuminated. If the stage rotates, the object must of course be brought into the centre of rotation, and so must the condenser and the image of the aperture in the diaphragm.

This procedure has the advantage that it may be employed with any method of observing the directions-image. On the other hand, the conjugate image[1] of the object in the position of the diaphragm is comparatively small, unless it is much farther from the condenser than the object, in which case the angular aperture of the illumination would be considerably diminished. The adjustment of the diaphragm therefore requires more care than if the procedure devised by Becke be employed.

The isolation of the directions-image in optical instruments with only a small angular aperture must proceed of course on the same general lines as in the petrological microscope. As a rule, the instrument by which the directions-image is observed in such cases is primarily a tele-

[1] This is not, of course, a real image, though it would become real if the direction of the transmission of the light were reversed.

scope, but it can be converted into a microscope by placing a lens either in front of the objective or behind the eyepiece, that is to say, between it and the observer.

In the former case the isolating diaphragm cannot be on the side of the lens nearer the eye, for the whole ocular system is transformed by the removal of the lens. It may be placed in close proximity to the object so as to restrict the light either before or after reaching it. H. L. Bowman (Mineralogical Magazine, 1908, vol. xv, pp. 177–179) adopted the former course in determining the angular position of the laminae of perovskite by a goniometer and confined the illumination to a single lamina by placing a perforated screen in close proximity to the mineral.

The diaphragm may also be placed at a focus of the collimator lens conjugate to the object. This will be on the same side of the lens as the signal but at a greater distance. The perforation in the diaphragm can then be adjusted so that the illumination is confined to the crystal, or portion of the crystal, under examination. This method is quite satisfactory, and is probably the best where the observing telescope is converted into a microscope by a lens placed before the objective.

The most convenient arrangements, however, are those in which the observing instrument is transformed from a telescope to a microscope, or vice versa, by the interposition of a lens or system of lenses behind the eyepiece.

It appears to have been S. Czapski (Zeits. Instrumentenk., 1893, vol. xiii, p. 5) in his two-circle goniometer who first converted the observing telescope into a microscope by placing a lens behind the eyepiece so as to magnify the object-image that is formed just outside it, and by placing a perforated diaphragm in this position excluded all light except that coming from the object under investigation. When the diaphragm was adjusted the extra lens was thrown out and the isolated directions-image seen through the aperture in the diaphragm.[1] He was followed in this procedure by C. Pulfrich (Zeits. Instrumentenk., 1899, vol. xix, pp. 5, 6) and C. Leiss (ibid., 1902, vol. xxii, p. 332), who applied it in instruments for determining the critical angle of total reflection. The chief objection to this method is the small size of the image where the diaphragm is applied, which makes the manipulation of the latter difficult with minute objects.

For this reason a preferable course would seem to be to reverse the process and, as in the examination of interference-figures, to employ an

[1] See also V. Souza-Brandão, Zeits Kryst. Min., 1908, vol. xlv, pp. 331, 332.

instrument which is primarily a microscope, and convert it into a telescope by the addition of a lens.

A. Hutchinson (Mineralogical Magazine, 1911, vol. xvi, pp. 102–105) has done this in his 'Universal Goniometer', which is mainly employed in carrying out the Kohlrausch method of determining the critical angle of total reflection. He employs a microscope of considerable magnification and converts it into a telescope, focused on infinity, by inserting the Bertrand lens. No provision is, however, made for isolation. This could, of course, be effected by employing in place of the Bertrand lens the Becke lens in the manner already described. For this purpose it should admit of sufficient movement to enable the directions-image to be focused even when a low power objective is in use.
