An improved polarizing microscope. III. The slotted ocular and the slotted objective.[1]

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I. *Introduction.*

MEASUREMENTS with the petrological microscope may be divided into those made with the orthoscopic and those with the conoscopic arrangements. It was early realized that if the micrometer scale or compensator was inserted in the focal plane of the ocular, the same apparatus would serve for measurements of both kinds, provided that a Bertrand lens was available. The method was described by A. B. Dick[2] as early as 1888 in a form of microscope which has remained popular with many workers up to the present time. Additional slots at the level of the focal plane of the ocular were cut through the mount and the upper part of the microscope tube. Most European manufacturers, however, continued to provide only the usual slots in the lower part of the tube. These are often the sole means of inserting compensators, which in many cases cannot be focused at all by the eyepiece, even with the help of a slide for the Bertrand lens. The quartz-wedge cannot then be used, and recourse must be had to compensators of Nikitin type, such as those of Berek[3] and Ehringhaus.[4] To meet this difficulty, F. E. Wright[5] devised a well-known special ocular, resembling that described by J. Amann,[6] which serves to convert the standard type of tube to a form substantially similar to that used in Dick's microscope. An inevitable defect is that, since the eyepiece is to be placed in the unslotted tube, the slots must stand at a level above the top of the tube, with the

[1] Published by permission of the Director, Geological Survey and Museum.
[2] A. B. Dick, Min. Mag., 1888, vol. 8, pp. 160–163.
[3] M. Berek, Zentralbl. Min., 1913, pp. 388, 427, 464, 580.
[4] A. Ehringhaus, Zeits. Krist., 1931, vol. 76, pp. 315–321. [M.A. 5–127.]
[5] F. E. Wright, Amer. Journ. Sci., 1910, ser. 4, vol. 29, pp. 415–417.
[6] J. Amann, Zeits. wiss. Mikroskop., 1894, vol. 11, p. 440.

result that the tube-length is increased and a special Bertrand lens may be required.

All these slotted oculars required a cap nicol, and their use has been restricted, no doubt owing to the resulting limitations of field and eye-distance. With the introduction of polarizing film, it has become possible to design an ocular having an internal analyser of the usual sliding type, so that these inconveniences can be eliminated, though there might still remain the defect of an increased tube-length. In the ocular here described both difficulties have been fully met, since it is adapted to microscopes (Cooke Research and Universal models) in which the upper part of the tube can be replaced by a special ocular tube having slots at the correct level.

The second accessory to be described below is the slotted objective, a simpler device which renders possible the direct use of a graduated quartz-wedge over the interference-figure, but not over the orthoscopic image. The range of utility might at first seem to be severely restricted in comparison with the slotted ocular, but this is not the case, for it can be shown that measurements of extinction and birefringence may be made with greater accuracy on the interference-figure than on the orthoscopic image. Conoscopic methods are, in fact, to be preferred even when a slotted ocular is available, the principal advantages of the latter being in ease of manipulation, greater magnification, and the possibility of inserting micrometers over the orthoscopic image. For use with the universal stage it is possible to obtain a one-inch objective with slots, but most objectives will require compensators in the tube or eyepiece, in which case the quartz-wedge must be used in a slotted ocular.

II. *A revised slotted ocular.*

The general arrangement (fig. 1) resembles that already familiar to users of the Dick and Wright eyepieces. The new polaroid analyser and compensating glass disk are carried in a sliding fitting *A* immediately below the positive eyepiece *B*. The ocular itself[1] is a modified form of Kellner eyepiece ($\times 10$) which is very comfortable to use, and is characterized by freedom from distortion and an unusual eye-clearance; an important feature, not always to be found in ordinary wide-angle eyepieces, is that owing to the great width of the eye-lens the whole field is visible even when the eye is at the correct and rather distant eyepoint. It is carried in a sliding tube with a locking ring *C*, which permits the

[1] E. W. Taylor, The inverting eyepiece and its evolution. Journ. Sci. Instruments, 1945, vol. 22, p. 43, especially fig. 10 and para. 10.

focus to be adjusted on the quartz-wedge or cross-lines as required. The wedge and other compensators and micrometer scales can be inserted in carriers *D* fitting the slots, which are wide enough to accommodate micrometer nets, &c. that cover the whole field. An iris diaphragm *E* which is sufficiently defined though not sharply in focus can be used to isolate a mineral grain in the centre of the field. A brilliant small interference-figure due to the grain can then be examined in the Ramsden

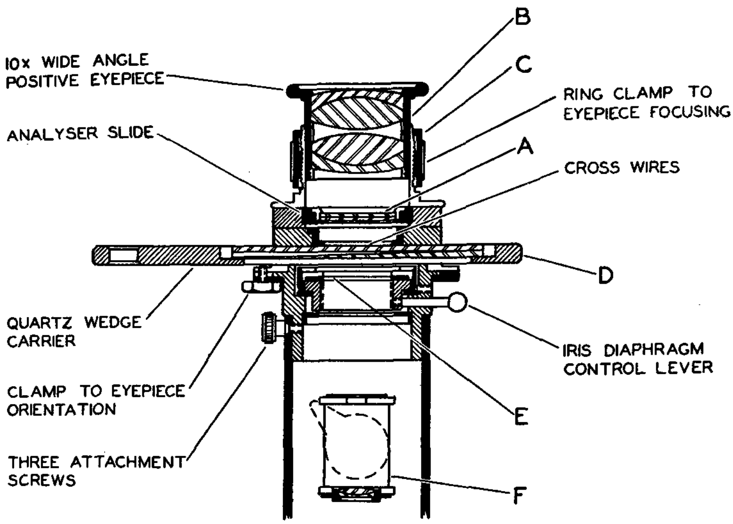

FIG. 1. Improved slotted ocular (in section). Half actual size.

circle by means of a $\times 10$ hand-lens (Becke or Klein method). It is possible, however, to obtain a similar degree of selectivity by bringing in the ordinary Bertrand lens *F* with its selecting diaphragm, in which case the figure is seen at greater magnification.

The ocular is fitted by removing the ordinary eye-tube at the shoulder above the Bertrand fitting and attaching the keyed special tube of the slotted ocular. The focal plane of the latter is then at the normal level for use with the Bertrand lens.

Accessories.—The equipment for all ordinary determinative work may be restricted to the following:

Graduated quartz-wedge; $\frac{1}{4}$ and 1λ compensator plates, preferably in rotatable mounts; Nakamura half-shadow plate (biquartz) if great accuracy is desired in setting extinction; net and other micrometers. It is advantageous if the wedge and compensators are of standard size so that they can be used in the tube or objective slots of the microscope; special carriers being provided by which they can be inserted in the slotted ocular when desired.

III. *The slotted objective.*

This device was introduced some years ago in metallurgical microscopes made by Messrs. Cooke, Troughton & Simms. When combined with the quartz-wedge it offers a very simple and yet highly accurate means for making the usual determinations on crystal sections. Slots of standard dimensions, equal to those in the microscope tube, are provided in the tubular portion of the objective mount above the lenses, a construction which is normally practicable for one-inch and higher powers. A graduated quartz-wedge can then be inserted almost in the same plane as the interference-figure and read by means of the Bertrand lens, any slight difference in focus being corrected by adjusting the eye-lens of the eyepiece. Other compensators or opaque stops can be used if desired. In fig. 2 the slotted 1/6th objective is shown in plan and section with a quartz-wedge *A* in position.

Orientation.—The slots must be at the 45° position. The objective is screwed firmly into the objective holder and the small set-screws *B* near the top of the mount are released. The slotted part is then rotated with the quartz-wedge in place until the diagonal markings *C* provided near the centre of the wedge are parallel with the cross-lines in the eyepiece, at which position the set-screws should be locked.

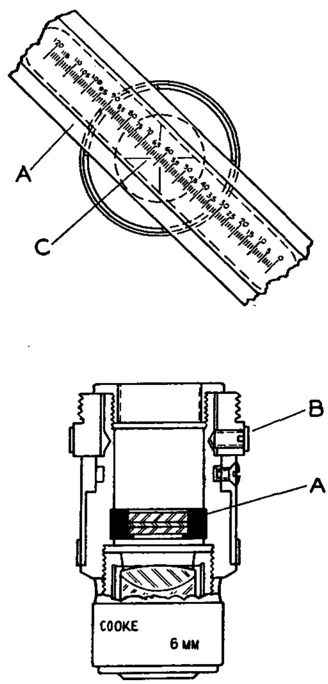

FIG. 2. Slotted objective with central part of a quartz-wedge in position (in part plan and section). Actual size.

The equipment will be the same as for the slotted ocular, but without the micrometers and special carriers. If the black zero band is to be obtained by inserting a first-order compensator in the tube slots, the objective (like the slotted ocular) must be oriented so that the quartz-wedge compensates the first-order plate. The results are then comparable with those obtainable by means of the Wright compensated wedge. If the slotted objective is used with a sprung objective changer, care should be taken not to disturb the centring during manipulation of the compensators.

Note on conoscopic methods (A. F. H.).

The following note, in which attention is drawn to the advantage of adjusting both extinction and compensation by means of the interference-figure, applies generally both to the slotted ocular and the slotted objective.

Path-difference.—It has been customary to measure the path-difference by compensating the interference effect in the orthoscopic image of the desired mineral grain, which must be placed at the centre of the field. Under these conditions it is often very instructive to note the appearance of the interference-figure on introducing the Bertrand lens.[1] The light coming from the interference-figure is, of course, all utilized in forming the orthoscopic image, and in many cases, especially with objectives of high power, it is at once evident that a great deal of uncompensated light is present. Compensation is, in fact, confined to one of the lemniscates (or another curve if the compensator is not 'homogeneous', e.g. a quartz-wedge), which now appears as a dark curve bordered by the usual sequence of bands. There is sometimes so much uncompensated light present that the darkening is hardly appreciable in the orthoscopic image. It is usual, therefore, to eliminate the oblique rays as much as possible by closing the condenser iris. This leads to a sharper compensation but unfortunately the orthoscopic image is then much impaired by excessive relief due to the narrow aperture, and by the weakness of the illumination. A great improvement in accuracy can be obtained if compensation is adjusted on the interference-figure (conoscopic method)[2] instead of the orthoscopic image. On closing the condenser iris the brightness of the central area is not diminished, and there

[1] F. Rinne and M. Berek, Anleitung zu optischen Untersuchungen mit dem Polarisationsmikroskop, 1934, p. 124.

[2] Such methods were referred to as 'stauroscopic' in an earlier paper (Min. Mag., 1946, vol. 27, pp. 183–5). The original implication of this term seems rather obscure. It first appears in reference to the 'stauroscope' of von Kobell, by which extinction was adjusted with the aid of the interference-figure due to a calcite plate. It was later used, but rarely, as a general term for any methods of determining the extinction position (H. Rosenbusch, Mikroskop. Physiogr., 5th edit. by E. A. Wülfing, 1921, vol. 1, pt. 1, p. 435). 'Conoscopic' seems free from objection and will be employed instead.

is no direct effect from the relief, since the surface is not in focus. The darkest point in the compensated lemniscate can now be adjusted to coincide very closely with the centre of the interference-figure; i.e., compensation is being made precisely for the ray normal to the crystal section, and the field is limited by the Bertrand diaphragm.

If a quartz-wedge is being used, it is convenient to set the compensation band (which in the conoscopic method is not necessarily perpendicular to the sides of the wedge) on the cross-lines of the eyepiece and then open the condenser iris or remove the Bertrand lens so that the graduations are visible against a wider field. Finally, a zero reading is taken after the object has been removed, and the path-difference is read from a calibration scale obtained by reading the interference-bands for the light used, with crossed and parallel positions of the analyser. On account of the dispersion of the birefringence the wedge should strictly be calibrated for the wave-length to be used. It is not quite accurate to assume that the path-difference is in the same ratio to the reading for all colours, though the error is small. For an ordinary quartz-wedge the zero band is missing since it coincides with the ultimate thin end of the wedge. Wright and others have devised combination wedges having a parallel crystal plate mounted under the wedge to compensate, say, the first-order interference-band, which then becomes the zero band and is easily read. The same result is obtained very simply, if additional slots are available, by inserting an ordinary first-order compensating plate in the tube slots: the zero band then appears at the desired position on the quartz-wedge.[1]

The graduated quartz-wedge can be read easily to one-twentieth of one wave-length, which is sufficient for an accuracy of 0·001 in the birefringence of a rock section. Its range can be extended by replacing the gypsum-plate in the second slots by a thick compensator of known additional path-difference, say, one order less than the wedge itself, so that the value can be checked by compensating it against the wedge.

Over a uniform field the distribution of intensity in the compensation band of a quartz-wedge is symmetrical, and the true compensation position is therefore the centre of the band. If the crystal section varies rapidly and unsymmetrically in birefringence for directions on either side of the axial ray, there may be a slight error due to the tendency to set the middle of the band, but in practice this is negligible and in any case the readings are nearly always taken on a principal optical direction, which is symmetrical.

[1] J. Amann, loc. cit.

If a 'homogeneous' compensator is used (e.g. Soleil), accurate setting may be improved by using a biquartz-plate, but with a quartz-wedge the gradation of the wedge itself gives the equivalent of a photometric setting for the centre of the dark band, which is quite narrowly defined if the illumination is sufficiently bright. J. Amann (loc. cit.) proposed to place the slit of a microspectroscope across the wedge like a cross-wire, and to adjust the wedge in white light so that the dark band in the spectrum indicated compensation at the desired wave-length; this does not seem to be more accurate than setting in monochromatic light. Compensators of the Nikitin type, while very convenient and compact, are probably somewhat less accurate than a well-made quartz-wedge. The latter has the great advantage of an almost linear scale, while that for some rotary compensators shows marked curvature between the half-wave values used in calibration, so that accurate interpolation can only be made with the help of the function calculated for the wedge.

Extinction.—As with path-difference, it is advisable to test the light used in the orthoscopic image by bringing in the Bertrand lens. The 'zero isogyre' is then seen and at the true extinction position it crosses the centre of the field. But there is then a proportion of light present from the rest of the interference-figure, and the first precaution is to exclude this by closing the condenser iris. In a bright light the centre of the isogyre can often be adjusted with sufficient accuracy by this means alone, but if the isogyre is broad the true extinction position may be detected by inserting a biquartz above the interference-figure. The advantages of increased brightness and the absence of irregularities in the field are the same here as in estimating path-difference.