A new method for orthoscopic adjustment with the Fedorov stage.

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Summary. A new method is described to replace the standard procedure for completing the adjustment of an optical symmetry plane, with conditions for the accurate use of the biquartz. Extinction measurements are plotted to show the wide range of sensitivity (for the adjustment of A_1 and A_2) at various directions in the symmetry planes of a plagioclase. It is proposed that A_1 and A_2 should be adjusted at different settings of A_4 so as to obtain maximum sensitivity for each of those axes.

The standard procedure for adjusting a symmetry plane normal to the axis A_4 involves tilting about A_2 and A_4 and comparing the persistence of extinction. It has been described in nearly every textbook and is 'the most difficult and unsatisfactory feature of universal stage manipulation' (Emmons, 1931, p. 131).

For accurate work it is essential to realize that the sensitivity of adjustment is not only widely variable for different directions in the indicatrix, but that even for a given direction it may be completely different for A_1 and A_2. For example, when an optical symmetry axis is vertical in an adjusted symmetry plane, extinction persists for all values of A_2, which therefore cannot be given a precise setting, while A_5 and A_1 are very sensitive, since this direction is at the centre of the well-known conoscopic 'flash-figure'.

The method now proposed for completing the adjustment of the symmetry plane consists in examining the sensitivity for various settings of A_4. The setting of A_1 and A_2 is then completed by using those directions in A_4 along which the sensitivity has proved suitable.

Procedure. The microscope must be in complete adjustment. The condenser and any other substage optical fittings (except the weak auxiliary lens below the polarizer) must be removed. The condenser iris is retained as a screen to limit the beam to the useful part of the hemispheres, but need not be accurately centred. By means of the flat mirror the beam of the lamp is reflected axially so that an image of the lamp iris is seen at the back of the objective. This disc is carefully centred and the mirror is locked in position with the finger screws. The size of the disc is controlled by the lamp iris: it should not be as narrow as the objective iris opening, since the disc sometimes moves a little when the hemispheres are rotated. It may be twice the diameter chosen for the objective iris, or more. *It is essential that this disc should be completely and evenly illuminated*: a ground glass must therefore be inserted in the lamp after focusing, so as to break up any image of arc or filament.

The beam used for observation must be strictly coaxial with the microscope tube and of a conoscopic aperture (in the $5\times$ objective) about two degrees. This is approximately the diameter of the conoscopic reading mark in a Cooke objective (Manual, p. 143). Light outside this cone is excluded by the objective iris, which is contained in a section that can be screwed into the tube above the objective (if the objective does not already contain an iris). When the objective iris is nearly closed it has the same diameter as the reading mark; it then somewhat impairs the definition of the image, but this does not prevent accurate setting. During ordinary observation this iris must be opened; it should therefore have very easy movement (thick grease if present should be removed).

The biquartz. Although settings can be made by extinction, the biquartz has great advantages both in accuracy and in ease of adjustment. Tests with a Macé de Lépinay wedge showed that in the present measurements of a plagioclase a suitable rotation was $\pm 7^\circ$. The Nakamura plate with only 1·2° gives too little contrast under similar conditions. The biquartz plate is inserted in a slotted ocular which is preferably of the positive (Kellner) type in which no lenses are interposed between the analyser and the objective. The biquartz boundary must cross the centre of the field, since non-axial points are subject to small field errors.

With the universal stage the orthoscopic action of the biquartz differs from that in a homogeneous beam (e.g. in the ore-microscope). The light at any point in the field contains all the rotations belonging to rays coming from the sides of the isogyre, up to the boundary set by the objective iris, i.e. up to one degree or more from the trace of the optical symmetry plane (fig. 1). When the symmetry plane accurately bisects the iris opening, the effect upon the biquartz of light coming from the two sides will be equal and opposite and the biquartz will be matched. *It is essential, however, that the two sides of the isogyre shall be illuminated with equal intensity*: the back of the objective must show a uniformly illuminated disc bounded by the objective iris. It is often permissible to open the iris to a somewhat wider diameter (say $\pm 2°$). There is no definite extinction position for either side of the biquartz, but a marked failure in matching follows on a small displacement of the optical symmetry plane.

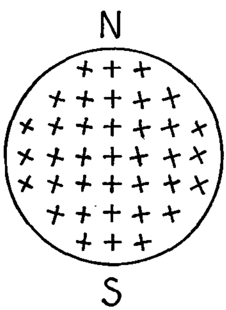

FIG. 1.

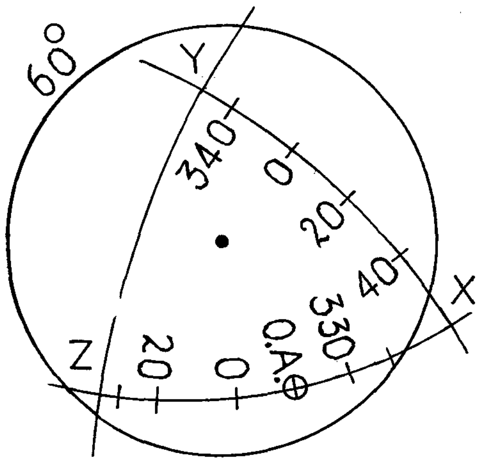

FIG. 2.

FIG. 1. Vibration directions in the objective iris with an optical symmetry plane in adjustment.

FIG. 2. Stereogram of a plagioclase crystal (optical symmetry planes) showing the position of extinction traverses (made with A_2) across the optical symmetry planes (figs. 3 and 4).

It should be noted that the biquartz becomes insensitive in the neighbourhood of an optic axis although extinction settings can be made.

Readings. With the objective iris open the crystal is brought to the centre of the field; the iris is closed and a symmetry plane is roughly adjusted. A_4 is locked at, say, 20° and the sensitivity of A_1 and A_2 is observed by making small rotations about those axes. If one of them produces a very rapid variation in the biquartz this setting of A_4 is reserved for adjusting that axis. If, on the other hand, this direction proves insensitive for A_1 or A_2 it is reserved for the other axis. A_4 is then reset to, say, 340° and a similar test is made; this normally yields a different relative sensitivity for A_1 and A_2. Thus it is possible to allot the adjustment of A_1 to one direction of A_4 and that of A_2 to the other, each being specially sensitive for the respective axis. The best condition is when one of the positions is completely insensitive, in which case the final adjustment by alternate settings can be very rapid.

When the biquartz has been matched at both the A_4 settings, the continuity of extinction is checked along the whole range of A_4, 330°–30°, and the readings for A_1 and A_2 are recorded.

Application. It is possible to use this procedure with ordinary extinction settings, but the biquartz is both more sensitive and more convenient, since it can be examined while the stage is stationary at the intended setting, whereas the position of maximum extinction can only be identified by making short alternate swinging movements about the axis under adjustment.

When the path-difference is large enough to give one or more complete rings in the interference figure the isogyre becomes comparable in width with the conoscopic reading mark and the conoscopic method, if practicable, will be preferred.

In many minerals the dispersion of the indicatrix may reach one degree; it is then essential to make the final adjustments with a monochromatic colour screen.

As a test for speed and accuracy, a series of planes in pairs at right angles were adjusted in various grains of a feldspar rock section. The average time for one plane was 2 minutes and the two great circles were rarely inclined at more than one degree from 90. Two of the grains presented all three symmetry planes; for these the values of $\Sigma \sin^2 A_2$ (Hallimond, 1950) were 1·0076 and 0·9911 for the hemisphere with n 1·54, and the three poles in each crystal fell within two degrees of the intersection of the great circles. The second of these crystals is shown in fig. 2. Figs. 3 and 4 illustrate the extreme changes in sensitivity for different inclinations about A_4. The extinctions plotted were measured on A_5, but the sensitivity for rotation of A_1 would not be very different. In fig. 2 the non-axial plane contains a position of insensitivity for A_2 near the middle of the arc (traverse at 20°, fig. 3); this unexpected result is in accordance with the Fresnel construction and is of great importance for the accurate adjustment of the feldspars. To adjust this symmetry plane in a plagioclase it will therefore be very useful to adjust A_1 with A_4 set at the middle of the arc YZ or YX, and A_2 at a position of A_4 nearer to an optical symmetry axis, i.e. nearer to the corner of the triangle (e.g. at 40° in fig. 2).

In fig. 4 the steep slope of those curves ($A_4 = 0°$ and 330°) that are nearest the optic axis reflects the narrowness of the isogyre at this position and the high sensitivity for A_2. At the axis the biquartz becomes insensitive and on passing through the axis the slope of the curves is reversed. Here it is best to adjust A_2 at a setting near the axis, say at

$A_4 = 0°$, while A_1 is adjusted with A_4 at a position nearer to the optical symmetry axis, say at 20° or 30°.

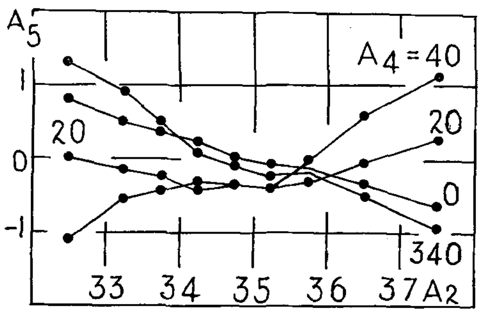

Fig. 3.

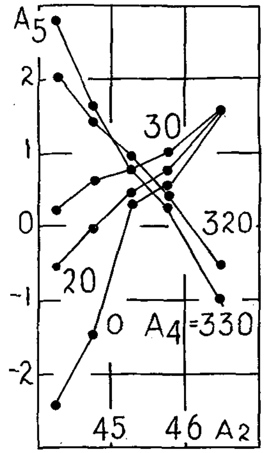

Fig. 4.

Fig. 3. Traverses across a non-axial symmetry plane in plagioclase (fig. 2). Extinction measurements on A_5 for various inclinations of A_2. The lines of traverse are marked in Fig. 2 with the readings of A_4 at which they were made.

Fig. 4. Traverses made as in fig. 3, across the axial plane in plagioclase (fig. 2).

Use of extinction curves. By special methods (e.g. N. Joel and I. D. Muir, 1958) it is possible to refine the location of a symmetry plane, but it may well be that the average of several settings made as here described would give a similar degree of accuracy. Even when extinctions are measured on A_5 the accuracy still depends upon the precise reading and the sensitivity of A_1 and A_2.

Joel and Muir plot the poles of the vibration directions, but it may be more convenient to plot extinction curves as in figs. 3 and 4. The curves as projected on the flat are in any case somewhat distorted, but since the only point to be determined is their intersection with a certain extinction value (that for the symmetry plane) the exact form of the rest of the curve is not material.

The axis A_3 used by Joel and Muir seems unnecessary, since it is equally easy to use A_2 as here described. Thus in fig. 3 the curves indicate a value for A_5 only slightly below $A_5 = 0°$; $A_2 = 35°$; this implies a negligible correction in A_1. In fig. 4 the indicated value for A_5 is $+\frac{1}{2}°$, $A_2 = 45\frac{1}{2}°$. A second set of curves showed that after an alteration of one degree in A_1 the intersection lay at $-\frac{1}{2}°$, with $A_2 = 45°$. It should be noted that complete intersection is only obtained when the optical symmetry plane is within about one degree of correct adjustment. It may be doubted, however, whether these methods should be used, since it is less laborious to take the mean of several adjustments of the symmetry plane made with the biquartz as here described.

In the preceding account it has been assumed that the reader has already a normal acquaintance with the use of the stage, but details of the microscope adjustment are given because they differ very widely from those in some textbooks. The measurements were made on a Cooke, Troughton, and Simms three-axis Fedorov stage, and 'Research' microscope stand (A. F. Hallimond and E. W. Taylor, 1946 and 1950), and with a seven-degree biquartz, which was kindly prepared for the purpose by that firm.

Note added in proof. The existence of variations in sensitivity was discussed by F. J. Turner (1942) who proposed a new method for adjusting an optical symmetry plane (O.S.P.). As described by P. F. Kerr (1959) [summarized with Berek notation]: A_1 is rotated to extinction; A_4 is set to a position of maximum illumination; A_2 is set to minimum illumination; A_4 is returned to zero. Extinction should then be complete, indicating that an O.S.P. is in adjustment. Obviously this method will not meet all cases, but it often gives very rapid adjustment for plagioclase. The explanation appears to be that the crystal must have 2V approx. 90°. Then the Fresnel construction shows that the extinction direction of a section is nearly always within a few degrees of the azimuth of an O.S.P., which will thus lie approx. N–S after the initial rotation of A_1: the O.S.P. is then made vertical by rotating A_2 at a sensitive setting of A_4. The method described in the present paper relates to precise adjustment in the general case.

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