Extinction curves and equivibration curves obtained with a variable-axis spindle-stage

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Summary. A modification of the one-axis spindle-stage for the study of the optical indicatrix of crystal grains on the polarizing microscope is described. It allows the crystal to be rotated around axes within a range of about 40° without having to remount it. Some advantages of this variable-axis spindle-stage for obtaining extinction curves and equivibration curves (n_0 curves) are illustrated.

ONE-AXIS spindle-stages, as well as the universal stage, have been used recently for locating the three principal axes of a biaxial indicatrix and determining 2V by means of data obtained from extinction curves and equivibration curves. References will be found in the papers by Joel and Muir (1958), Joel (1963), Joel and Tocher (1964), and Tocher (1964*a*, 1964*b*).

Various forms of one-axis spindle-stage have been developed in the past (Bernal and Carlisle, 1947; Wilcox, 1959; Oppenheim, 1962; Hartshorne, 1963). Quite often, however, for instance in order to get extinction curves of suitable shape, it turns out to be necessary to change the direction of the rotation axis relative to the crystal's indicatrix. When a spindle-stage is being used, this means remounting the crystal in a different orientation. We have found it very convenient to use a modified spindle-stage that allows orientations to be selected within a range of about 40° without having to remount the crystal. In fact, the present work resulted from an attempt to combine the advantages of a spindle-stage with some of the advantages of the universal stage. We refer in this note to coplanar extinction curves only, and not to conical extinction curves (see Joel and Tocher, 1964).

The variable-axis spindle-stage (fig. 1). Its base plate (1) rests on the stage of the polarizing microscope. A horizontal axis (2) has at one end

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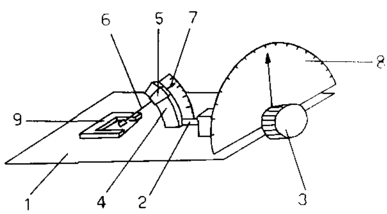
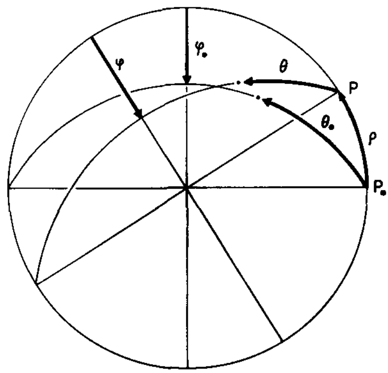
a drum (3) for performing the rotations, and at the other end a graduated arc (4) on which the crystal holder (5) can glide; the crystal is mounted at the end of the glass fibre (6). The angle ρ between the glass fibre (6) and the rotation axis (2) is measured by means of the pointer (7), which moves with the crystal holder (5) on the graduated arc (4). The drum (3) has a pointer that measures the rotations ϕ of the axis (2) on the





FIGS. 1 and 2: FIG. 1 (left). Main features of the variable-axis spindle-stage. (Reference to the numbers 1 to 9 is made in the text of this note). FIG. 2 (right). Two vibration directions (extinction directions) plotted on a stereographic projection: one (ϕ_0, θ_0) with $\rho = 0$, rotation axis P_0; the other (ϕ, θ) with the rotation axis P at an angle ρ from P_0.

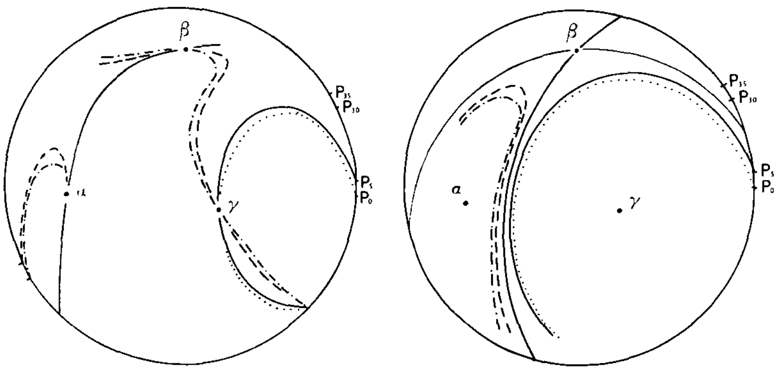
graduated semicircle (8). A cell (9), fixed on the base, enables the crystal to be immersed in a liquid of suitable refractive index.

Measurements and plotting. Any given value of ρ (the angle between the glass fibre and the rotation axis of the spindle stage) determines the direction of the rotation axis P in the crystal.

For the selected values of the rotation ϕ around the spindle-stage axis, the extinction angle θ is measured on the rotating stage of the microscope. With these data, the extinction curve can be drawn for the particular value chosen for ρ. If the zero setting for the rotation ϕ corresponds to the position in which the plane of the graduated arc is parallel to the stage (also the glass fibre is then in a plane parallel to the stage), and if the primitive circle of the stereographic projection is then chosen parallel to the microscope stage, all the rotation axes P in the crystal will be projected on this primitive circle.

Fig. 2 shows two vibration directions (extinction directions) plotted on a stereographic projection: one with $\rho = 0$, rotation axis P_0; and the other with the rotation axis P at an angle ρ from P_0.

If the glass fibre of the spindle-stage is fixed on a little capsule that can rotate on its holder around an axis parallel to the fibre, a wider range of original settings can be selected. But it is not recommended to use this additional rotation during the measurements as it causes the rotation axis P to move out of the primitive circle (it would move on a small circle of centre P_0 and radius ρ) and thus complicates the plotting.



FIGS. 3 and 4: FIG. 3 (left). Parts of four extinction curves of a crystal of baryte with $\rho = 0°$, $5°$, $30°$, and $35°$; their intersections determine the directions of α, β, γ. One of the two circular sections (not shown) crosses the primitive circle between P_5 and P_{30}. FIG. 4 (right). Parts of the equivibration curves obtained from the four extinction curves of fig. 3; from the length of their major and minor axes the angle 2V can be calculated. The two circular sections are also shown.

Advantage of this spindle-stage for obtaining extinction curves. To begin with, it is possible to plot several related extinction curves, which will all intersect at the points α, β, γ of the indicatrix (Joel and Muir, 1958; Joel and Tocher, 1964).[1] This enables an immediate determination of the directions of the three principal axes of the indicatrix. By suitable changes in the settings of ρ, it may be possible to obtain sharper intersections between the extinction curves. In particular, if a rotation ρ causes the axis P to pass from one side to the other of a circular section of the indicatrix, then the bisectrix that was formerly on the polar curve will now be on the equatorial curve, and vice versa; this may help in the determination of these bisectrices, as well as of the relevant circular section and hence of one of the optic axes (cf. Tocher, 1964*b*).

Fig. 3 shows parts of four extinction curves (immersion liquid, n 1·64; red light; objective n.a. 0·25) of a crystal of baryte with $\rho = 0°$,

[1] They also intersect at the points of the primitive circle which represent the two vibration directions within the plane of the stage.

5°, 30°, and 35°. Their intersections determine the directions of α, β, γ. One of the two circular sections (not shown) crosses the primitive circle between P_5 and P_{30}.

Advantage of this spindle-stage for obtaining equivibration curves. To each extinction curve corresponds an equivibration curve, or n_0 curve (Joel, 1963). Fig. 4 shows parts of the equivibration curves obtained from the four extinction curves of fig. 3. It can be seen that the equivibration curve runs close to the circular sections when the rotation axis P is close to one of the latter. It can also be seen that when one has rotation axes P on both sides of a circular section (P_0 and P_5; P_{30} and P_{35}), then the corresponding equivibration curves help to determine the circular sections. The angle 2V was calculated by means of the major and minor axes (Joel 1963) of the equivibration curves shown in fig. 4; an average of $36\frac{1}{2}°$ was obtained.

Another use of the equivibration curves follows from the fact that ideally they must be symmetric relative to the three principal planes of the indicatrix. The points of the equivibration curves obtained experimentally that break this symmetry requirement must correspond to extinction measurements affected by experimental errors. One thus has an additional criterion for separating the *good* points from the *bad* points on the extinction curves as well as on the equivibration curves.

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