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NOTES AND NEWS

UNIVERSAL STAGE ACCESSORY FOR DIRECT DETERMINATION OF THE THREE PRINCIPAL INDICES OF REFRACTION*

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With rare exceptions only two principal indices of refraction of a biaxial crystal can be determined directly on the universal stage by the immersion method, since mechanical limitations prevent rotating all the way to the appropriate position for the third principal index. This usually must be determined by extrapolation from an intermediate index determined at a chosen rotation toward the third position. The extrapolated value, however, is subject to error, for the index at the intermediate position is measured where the change of index per degree of rotation is large. If the universal stage and lens system are not in optimum adjustment, the "corrected optical rotation" of the mineral grain and in turn the extrapolated value of the third principal index are erroneous.

A simple expedient enabling direct determination of all three indices on a single grain consists of mounting the grain on a spindle placed between the universal stage hemispheres in a slotted metal plate of the same thickness as the spindle (Fig. 1). Basically this accessory is a skeletal version of the convenient rotation device for flat stage work suggested by Rosenfield (1950) and elaborated by Wilcox (in press), and when combined with the universal stage, it enables direct angular measurements of certain additional optical and crystallographic elements of the grain, serving the purpose of the pin axis in the complex and little-used Lindley microscope-refractometer (Scheumann, 1931; Fisher, 1931; Winchell, 1937, p. 238). The mineral grain is oriented by the conventional universal stage procedure to permit determination of the first and second principal indices of refraction. Then a rotation of approximately 90° about the spindle axis places the grain in such a position that, with slight refinement of the orientation by the universal stage, the third principal index may be measured. A less desirable alternative would be to set the spindle by cut-and-try in such a position that all three optical symmetry axes may be oriented by suitably steep inclinations on the universal stage axes. These procedures apply likewise in orientating a uniaxial crystal grain.

The optic plane may be brought into a position most favorable for direct measurement of 2V, and likewise various crystallographic elements may be oriented by suitable manipulation on the spindle axis. Whereas the universal stage alone can bring crystal directions into the orthoscopic

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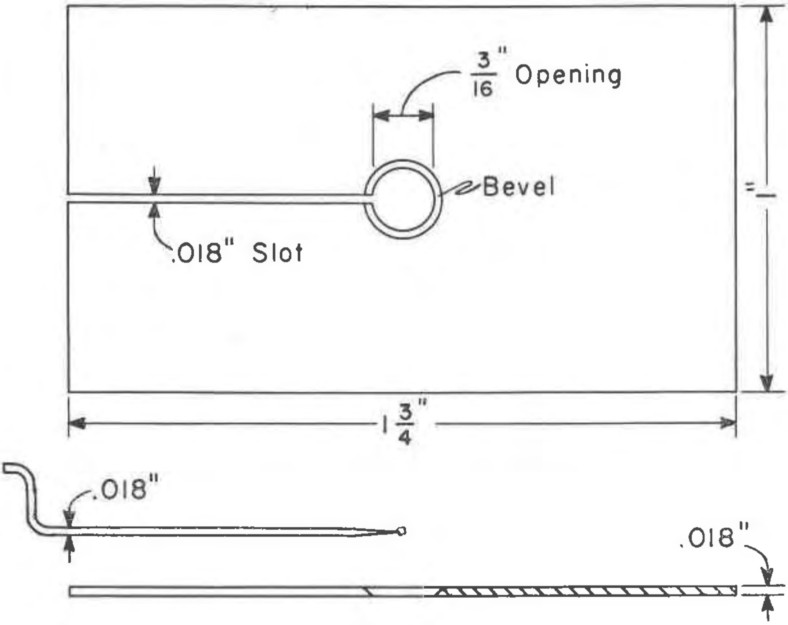

FIG. 1. Metal plate and spindle for grain mount on universal stage.

observation direction from within a cone having an apex angle of about 100°, the addition of the spindle, in effect, sweeps this 100-degree "cone-of-observation" through a full 360°, leaving a "cone-of-blindness" of only some 80° around the spindle axis. This simple device therefore greatly increases the ability to determine the geometric relations between the optical indicatrix and the crystallographic elements of a given grain. In addition it provides a means for holding the grain securely without strain during the measurements and, if desired, for relating the optical characteristics to x-ray results.

In Fig. 1 the spindle is a fine sewing needle measuring 0.018-inch diameter, from the eye-end of which the temper is removed to permit bending in the L-shape. The point of the needle is dulled on a whetstone to prevent creeping of the liquid adhesive and to give a flat surface to press against the grain during mounting. The plate here is made of stainless steel 0.018 inch thick, and a central hole $\frac{1}{8}$ to 3/16 inch diameter is beveled as shown to minimize reflections. A slot the width of the spindle or very slightly larger is cut through one half of the plate along the long axis.

The procedure for mounting the grain is essentially that described by the writer (Wilcox, in press) for the conventional spindle stage. A mineral grain somewhat smaller than the diameter of the spindle, say between 0.03 and 0.3 mm. diameter, is chosen for mounting. A drop of adhesive (such as carpenters' glue and molasses) is smeared on a surface and the point of the spindle barely touched to it, after which the point is touched to the desired grain under the binocular microscope. The slotted metal plate is placed directly on the water cell of the 5-axis universal stage over a drop or two of the chosen immersion liquid, and the spindle is placed in the slot with the L-arm flat. (Should the spindle fit too loosely, a bit of the adhesive in the slot provides sufficient firmness.) Immediately after adding another drop or two of the immersion liquid at the beveled hole, the upper hemisphere is set in place, taking care to avoid trapping bubbles in the hole of the metal plate.

The grain on the spindle point is then centered by shifting the metal plate, and if necessary, adjusting its position vertically in respect to the U-stage axes. Starting with the L-arm of the spindle flat, an optic symmetry axis is brought parallel to the microscope axis by the usual universal stage procedure (Emmons, 1943, p. 23 ff), in which position two of the principal indices are measured at their respective extinctions. The spindle arm is then turned to an upright position and the grain is again oriented to bring another optical symmetry axis parallel to the microscope axis, in which position the third principal index may be measured at its extinction. Direct measurement of optic angle is best made, of course, at a spindle setting requiring least tilting of the inner vertical axis of the universal stage, as are also the measurements of relation of crystallographic elements to the indicatrix. The latter data may be plotted in the usual manner on a stereographic net for a given setting of the spindle. For different spindle settings, crystallographic elements can be plotted in respect to each other by reference to the indicatrix at each setting and the "zero azimuth" of the spindle on the inner stage.

Several variations are possible in the basic form of this accessory, depending upon the measurements to be made and on the design of the particular universal stage on which it is to be used. The form sketched in Fig. 1 has been used successfully for indicatrix and crystallographic measurements with the Leitz 4- and 5-axis universal stages by the writer and for index determinations with the Bausch and Lomb 5-axis stage fitted for the double-variation method of refractive index determination by students of Professors R. C. Emmons, R. M. Gates, and S. W. Bailey at the University of Wisconsin, to whom the writer is indebted for suggestions. For accuracy of angular measurements, it is necessary of course that the thickness of the accessory plate should be near that for which the hemisphere assembly was designed (see Piller 1957). Economy of immersion liquid and convenience in changing liquids may be improved by decreasing the area of the plate, and for an extended series of index measurements, the slotted plate may be cemented in a centered position on the water cell. For measurements on universal stages without water cell, the slotted plate may be cemented to a glass slide to provide the proper total thickness of the mount between hemispheres.

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THE SYMMETRY OF THE COMPLETE TWIN

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In a recent paper (Curien & Le Corre, 1958, to be referred to as CLC) it was shown how the symbolism of the (black-white) Shubnikov groups can be used to designate the various twin laws, in the case of twinning by merohedry or by reticular merohedry.

Every such *twin law* gives the geometrical relationship between two crystals, a "black" one and a "white" one. It may usually be expressed by any one of several possible *twin operations*, which (as is well known) are all the symmetry operations that are deficient in the merohedral crystal symmetry but are present in the next-higher merohedry. If the crystal symmetry is a hemihedry, say $4/m$, only one twin law is possible: the next-higher merohedry, in this case, is the holohedry $4/m\ 2/m\ 2/m$, and the twin operation may be chosen at will from four 180° rotations or four reflections; the corresponding *twin elements* are primed in the *twin*

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