A simplified method of 2 V determination using 3- and 4-axis stages

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Summary. A method is presented for use with a 3- or 4-axis stage whereby a biaxial mineral, after being oriented into the cardinal position by means of the inner vertical, NS., and EW. axes, can be placed into an orientation suitable for measurement of the 2 V as required by the Berek method. A table of the necessary manipulations is given. The stereographic projection is only used to determine rotational corrections.

THE orientation of a biaxial crystal on a 3- or 4-axis stage by the standard procedure, is described by Hartshorne and Stuart (pp. 417–419, 1960) as a tedious procedure. The first part of the operation requires setting one optical symmetry plane vertical and parallel to the NS. axis. This requires rotations on the inner vertical as well as the NS. axis. The orientation is verified by maintenance of extinction during wide rotation on the EW. axis. The original position of this optical symmetry plane is plotted on a stereographic projection. A second optical symmetry plane is made vertical and NS. and its original position is also plotted on the projection. The intersection of the two planes represents the angular position of α, β, or γ. This direction can be brought into verticality from its original position by appropriate rotation of the inner vertical and NS. axes.

If one is using a 4-axis Federov stage the outer vertical axis (A_3) is then rotated until the grain goes into extinction. The crystal is then in the cardinal position—with the three optical symmetry planes vertical and NS., vertical and EW., and horizontal. If the microscope stage is rotated 45° from this position, a direct determination of 2 V may be possible by appropriate rotation on either the NS. (A_2) axis or the EW. (A_4) axis. If the optical plane is vertical a rotation on one of these axes may bring the grain to extinction. If the optic axes are either in or near the horizontal plane, the method of Berek (1923) may be used for an indirect determination of 2 V. This method is described in detail by Emmons (1943).

If this same procedure is used on a 3-axis stage, the determined position of either α, β, or γ may be brought to verticality by appropriate rotations on the inner vertical axis and the NS. axis; but in order to bring the crystal into the cardinal position, a rotation on the microscope axis is then necessary (as no outer vertical axis is present). Rotation of the grain on the microscope axis removes the NS. and EW. axes from the NS. and EW. planes respectively, and hence either direct determination of 2 V or use of the Berek method becomes impossible.

The proposed method of orientation eliminates the necessity of plotting the two optic symmetry planes on the stereographic projection, and allows either the 3- or 4-axis stages to be utilized in determination of 2 V according to the Berek method. This method does not require use of the outer vertical axis, and can hence be used with equal facility on either type of stage.

Procedure. The mineral is first oriented in the standard manner with one of its optical symmetry planes vertical and NS. This utilizes the inner vertical axis and the NS. axis. The readings for this position are noted. The NS. axis is then rotated in either direction until the crystal departs from extinction. A rotation on the EW. axis will now turn the inclined NS. optical symmetry plane until either α, β, or γ is brought into the horizontal and the grain again goes into extinction. The NS. axis is then returned to its previously noted inclination, which places the crystal in the cardinal position. This procedure is identical to that described by Emmons (*ibid.*) in biaxial orientation with the 5-axis stage.

A direct determination may be possible if the optical plane is now vertical. This could be accomplished by a 45° rotation of the microscope stage followed by rotation of the EW. axis; if the crystal goes into extinction then 2 V lies in the original NS. plane and can be measured directly. If the optic plane were originally in the EW. vertical plane the 2 V could be determined directly by rotating the inner vertical axis 90° and interchanging the settings on the NS. and EW. axis. But rather than do this, it is far easier to use the Berek procedure, which will be necessary in any case if the optic plane is horizontal.

The object of the Berek procedure is to measure the extinction angle by rotation of the microscope stage after the crystal has been oriented so that the three pertinent optical directions are symmetrical to either the EW. or the NS. vertical plane, and the observer is looking down at the mid point between α, β, and γ. This is normally done with a 5-axis stage by rotating 45° on the outer vertical axis, and then rotating crystallographically 54·7° on the outer EW. axis. If the three optical symmetry planes were regarded as being parallel to the three faces of a cube (100), (010), and (001), the rotations just described would be equivalent to bringing the normal of an octahedron face to the vertical. Any one of the four equivalent octahedron face poles (111), $(1\bar{1}1)$, $(\bar{1}11)$, or $(\bar{1}\bar{1}1)$ would be suitable for this purpose.

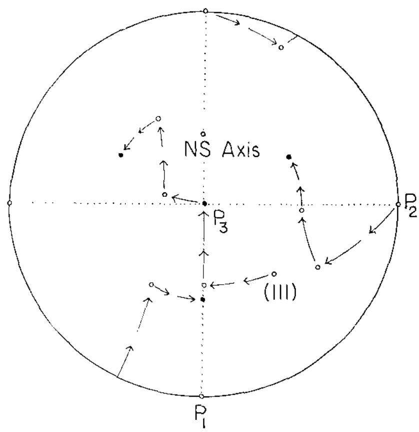

FIG. 1. A grain in the cardinal position is reoriented so that (111) is made vertical and the optical directions are symmetrical to the NS. vertical plane. The labelled positions P_1, P_2, and P_3 are the original cardinal orientation. The filled circles indicate the Berek position after the necessary rotations are completed.

This same operation can be performed on either a 3-axis or Federov stage after the crystal has been placed in the cardinal position. Discussion of this technique can be facilitated by making a distinction between rotation and tilting of an axis. Rotation will be used to indicate an inclination about an axis; thus a rotation about the NS. axis will incline the slide to the east or west. Tilting will be used to describe the change in orientation of the axis itself; thus a rotation about an EW. axis may tilt the NS. axis to the north or south.

In fig. 1 a grain is shown in a cardinal position. The three vibration directions are labelled P_1, P_2, and P_3, and the NS. axis is tilted to the south. A rotation of the NS. axis brings (111) into the NS. vertical plane. A second rotation on the EW. will bring (111) into the vertical, and finally a rotation of the microscope axis will bring the crystal into the Berek position with the three vibration directions symmetrical to the NS. vertical plane. From this orientation the microscope stage may be rotated counter-clockwise until the crystal goes into extinction. The extinction angle is related to the 2 V by the Berek curves.

An identical set of rotations cannot in general be used to place the crystal into the Berek orientation, because earlier placement of the crystal into the cardinal position usually necessitates tilting the NS. axis away from a horizontal orientation. Thus there must be a different set of manipulations for each cardinal orientation.

TABLE I. Rotations required to bring a crystal from the cardinal position to the Berek position, for various initial tilts of the NS. axis

Tilt of the NS. axis	Required rotation on the NS. axis	Required rotation on the EW. axis	Required rotation on the microscope stage
70°	38·5°	50·0°	46·0°
65	37·5	49·0	42·5
60	36·5	48·0	39·0
55	36·0	47·0	35·5
50	35·5	46·0	32·0
45	35·5	45·0	29·5
40	36·0	44·0	27·0
35	36·5	43·0	23·5
30	37·0	42·0	20·0
25	38·0	41·0	17·5
20	39·0	40·0	15·0
15	41·5	39·0	11·0
10	42·0	38·0	7·5
5	43·5	37·0	4·0
0	45·0	36·0	0·0

In detail, the operator must first decide which of the four {111} normals are to be brought into the vertical. If the NS. axis is tilted toward the south either (111) or $(1\bar{1}1)$ must be chosen (as these will minimize the necessary rotations). If the NS. axis is tilted to the north, then either $(\bar{1}11)$ or $(\bar{1}\bar{1}1)$ must be chosen. The choice of the particular octahedral direction will then be based upon minimizing the rotation about the NS. axis. Hence if the axis were tilted south and rotated east, one would choose (111) as the pole to bring into the vertical. The final rotation of the microscope stage must be clockwise if $(1\bar{1}1)$ or $(\bar{1}11)$ are used and counterclockwise if (111) or $(\bar{1}\bar{1}1)$ are used. The various rotations necessary for different degrees of tilt of the NS. axis are given in table I. In order to use the table it is only necessary first to decide which octahedral direction must be brought into the vertical and then proceed with the rotations in the proper directions. A final counterclockwise rotation of the microscope axis to extinction will yield an extinction angle that is related to the 2 V by Berek's curves as given by Berek (1923), Emmons (1943), or Hartshorne and Stuart (1960).

It may be noted that this method of placing a grain into the Berek orientation might occasionally be useful on the 5-axis stage in those cases where (because of grain orientation) it is mechanically impossible to achieve the required crystallographic rotation of 54·7° on the outer EW. axis.

The rotations required for this procedure must be corrected so that they are crystallographic, rather than apparent or observed angles. This can be done in the conventional manner by using the positions of the slide normal, and the indices of the segments and crystal as described by Emmons (pp. 41–54).

References

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