THE AMERICAN MINERALOGIST, VOL. 50, JANUARY–FEBRUARY, 1965

A RAPID CONOSCOPIC METHOD FOR MEASUREMENT OF 2V ON THE SPINDLE STAGE[1]

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ABSTRACT

The optic axial angle of a crystal mounted on a spindle stage may be simply calculated from (a) either of two angle pairs that may be easily measured on the scales of the microscope and spindle axes during the process of orienting Y and either X or Z for index of refraction measurements and (b) the angle between an optic axis and the microscope axis when the optic plane is vertical, determined by means of Mallard's method. No stereographic plotting is required. Although probably not as accurate, the method is much faster than the various extinction-curve methods of determining 2V.

INTRODUCTION

A biaxial crystal fragment can be oriented rapidly on the spindle stage by the conoscopic method described by Rosenfeld (1950) (see also Wilcox, 1959) for measurement of the principal indices of refraction. However, previously described methods for quantitative determination of 2V on the spindle stage (Wilcox, 1960; Tocher, 1962, 1964; Joel, 1963, 1964; Garaycochea and Wittke, 1964) require a tedious, time-consuming, and complicated series of extinction-angle measurements and stereographic constructions. This paper describes a rapid conoscopic method for quantitative measurement of 2V. The work on which it is based was done partly on behalf of the U. S. Atomic Energy Commission.

MEASUREMENT OF 2V

On the spindle stage the optic plane can be placed parallel to the microscope axis by rotation about the spindle axis. This can be done rapidly and very accurately under conoscopic illumination (Wilcox, 1959).

One optic axis usually is included in the conoscopic image, especially if an objective of large numerical aperture (*e.g.*, N.A. 0.85) is used. Occasionally, when both optic axes are visible, 2V can be calculated from the separation of the optic axis by use of one of the methods based on Mallard's formula (Johannsen, 1918). The distances between the point of emergence of each optic axis and the center of the field of view are measured with a micrometer ocular, and the measurements are converted to 2V by calculation or by means of graphs (Winchell, 1946; Tobi, 1956).

When only one optic axis is visible, 2V is determined as follows. The angle V that includes the microscope axis (Fig. 1) is divided into two parts: ψ, the angle between the optic axis and the microscope axis, and ϕ, the angle between the microscope axis and the bisectrix. The angles

[1] Publication authorized by the Director, U. S. Geological Survey.

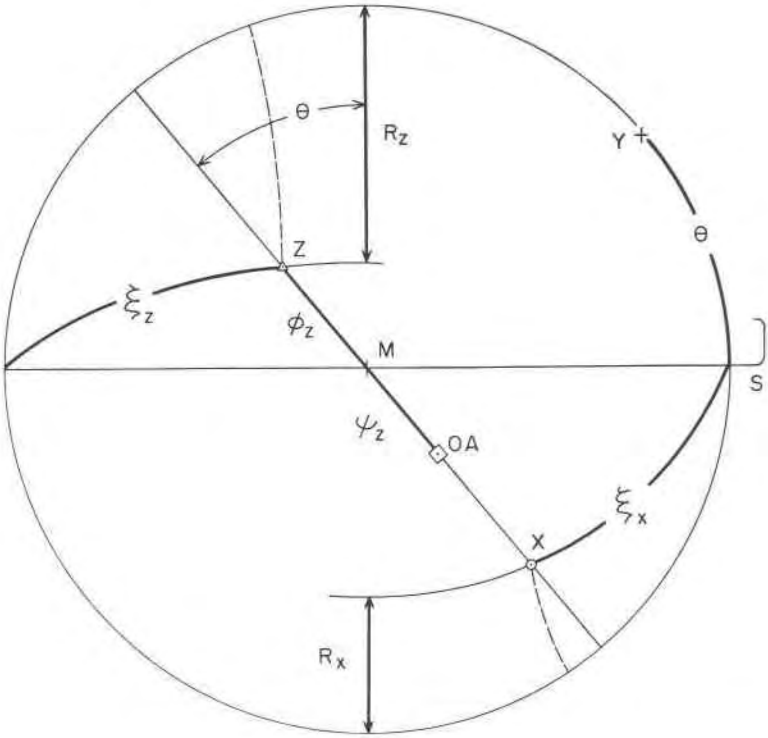

FIG. 1. Stereographic projection of a biaxial crystal, with its optic plane parallel to the microscope axis, M, that shows the various angles referred to in the text. Spindle axis, S, is east-west.

are termed ψ_x, ϕ_x and ψ_z, ϕ_z, if V_x or V_z, respectively, includes the microscope axis.

The angle ψ is determined using one of the methods based on Mallard's formula. The angle ϕ is calculated from angles θ and either ξ or R. The angle θ is the angle separating the spindle axis and Y whereas ξ is the angle between either X or Z and the spindle axis. Both angles are measured directly on the microscope stage when the principal axis under consideration is normal to the microscope axis. The angle R is defined as the amount of rotation about the spindle axis necessary to place either X or Z normal to the microscope axis, measured from that position of the spindle at which the optic plane is vertical. The angles ξ and R are designated ξ_x and R_x or ξ_z and R_z, depending on whether X or Z, respectively, has been made normal to the microscope axis.

As may be demonstrated by simple trigonometry, ϕ_x and ϕ_z are related to ξ_x, ξ_z, and θ by the equations

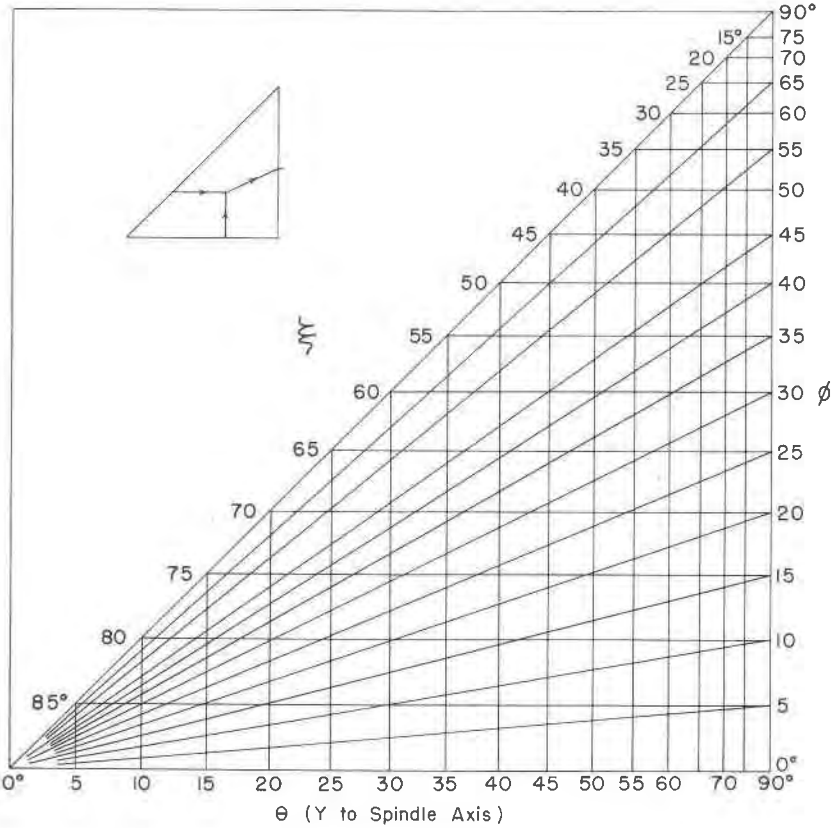

FIG. 2. Chart for solution of the equation $\sin \phi = \cos \xi / \sin \theta$. Method for use of chart is shown diagrammatically in upper left of figure.

$$\sin \phi_x = \cos \xi_x / \sin \theta \tag{1}$$

$$\sin \phi_z = \cos \xi_z / \sin \theta \tag{2}$$

and to R_x, R_z, and θ by the equations

$$\cot \phi_x = \tan R_x \cos \theta \tag{3}$$

$$\cot \phi_z = \tan R_z \cos \theta \tag{4}$$

As

$$\tan \phi_x = \cot \phi_z, \tag{5}$$

ϕ_x can be calculated from either ξ_z or R_z, and vice versa.

As can be shown mathematically or qualitatively by stereographic plotting, the parameter ξ becomes insensitive as θ approaches 0° whereas R becomes insensitive as θ approaches 90°. Thus ξ should be measured

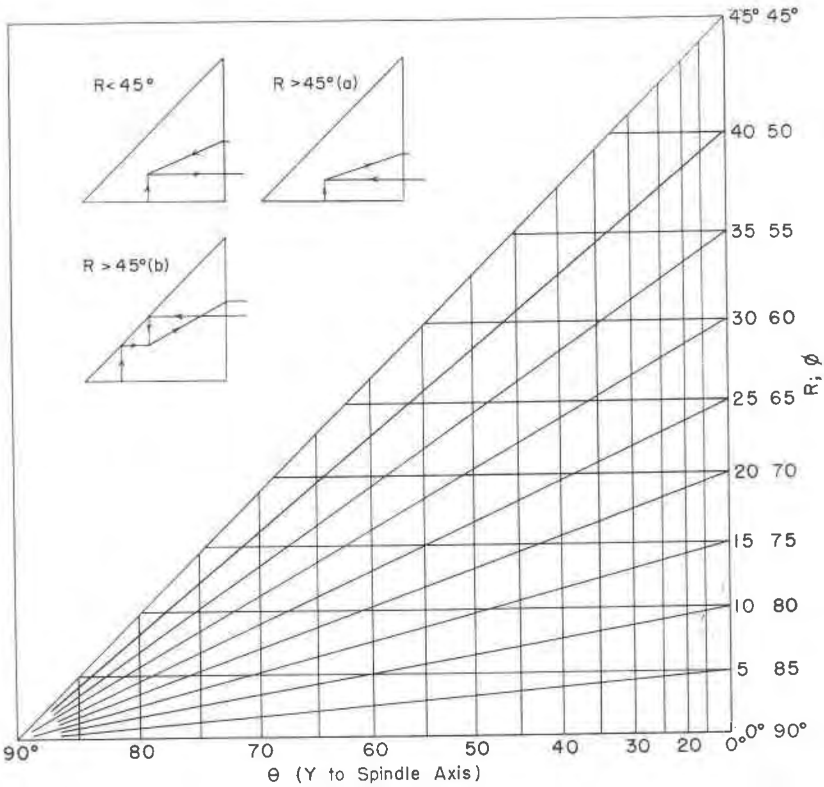

FIG. 3. Chart for solution of the equation $\cot \phi = \tan R \cos \theta$. Method for use of chart is shown diagrammatically in upper left of figure. The relative lengths of the short horizontal lines on the right sides of the key triangles indicate the ordinate scale to be used.

when the spindle axis lies at a low angle, and R used when the spindle axis lies at a high angle, to the optic plane.

By use of Figs. 2 and 3 equations (1), (2), (3), and (4) may be solved graphically in a fraction of the time required for paper and pencil calculation. A slide rule equipped with trigonometric scales may also be used.

ACCURACY

Repeated measurements of 2V were made on several grains of olivine, which were removed from the spindle and remounted in a different orientation for each measurement. A spindle stage of the type described by Wilcox (1959) was used. The results suggest that with care 2V can be determined to within approximately ± 1–$2°$ of the true value. This can probably be improved upon if (a) a spindle stage permitting more accu-

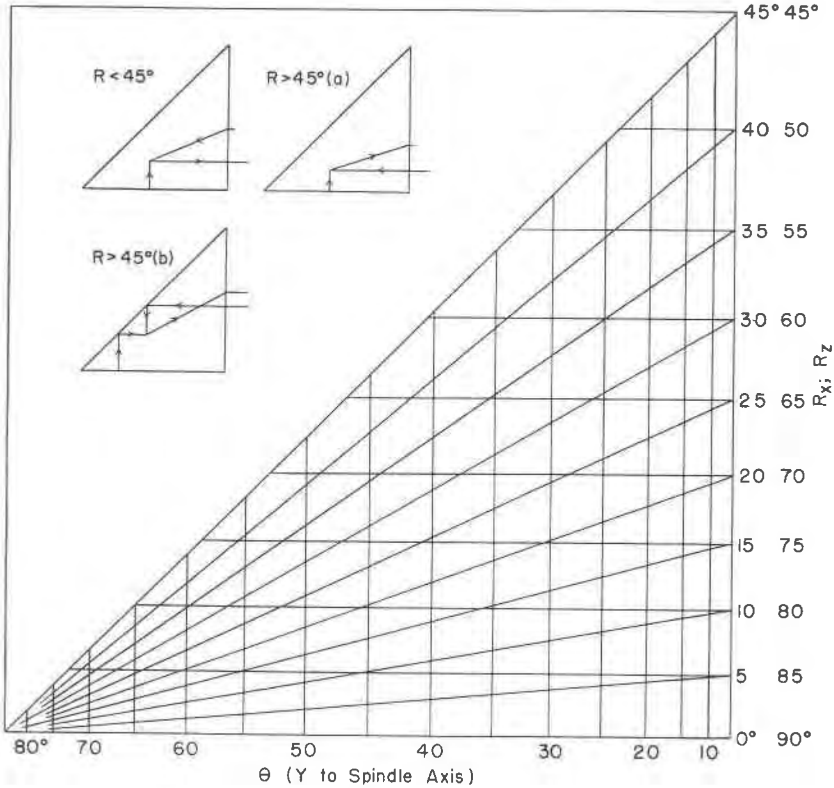

FIG. 4. Chart for solution of the equation cot R_x cot $R_z = \cos^2\theta$. Method for use of chart is shown diagrammatically in upper left of figure.

rate measurement of the rotation about the spindle axis (*e.g.*, Hartshorne, 1963) is used and (b) Mallard's constant is precisely determined for the particular microscope used. Although this method does not possess the potential accuracy of the various extinction curve methods, it is much faster and should prove useful when utmost accuracy is not essential.

Outline of Measurement Procedure

The series of manipulations required to determine 2V is outlined in the following section. Familiarity with the conoscopic method of indicatrix orientation as described by Wilcox (1959) is assumed.

1. Under conoscopic illumination make the optic plane of the crystal vertical and east-west by rotation about the spindle and microscope axes; measure θ on the scale of the microscope stage; record the reading on the spindle scale.
2. Place the optic plane quantitatively 45° from the vibration directions of the nicols by rotation about the microscope axis.

3. Measure ψ by means of one of the methods based on Mallard's formula. Using a compensator determine if ψ_x or ψ_z has been measured.
4. Place either X or Z normal to the microscope axis by rotation about the spindle axis. Determine ξ from the reading on the scale of the microscope stage or R from the reading on the scale of the spindle axis. Identify the principle axis using a compensator.
5. Compute ϕ_x or ϕ_z by using Figs. 2 or 3 or by using a slide rule.
6. Compute V by adding ψ and ϕ. (If, for example, ψ_x has been measured and ϕ_z has been calculated, $V_x = \psi_x + 90 - \phi_z$.)

Indirect Orientation of the Third Principal Axis

In some cases, because of unfavorable orientation of the crystal with respect to the spindle axis or because of high dispersion, it is difficult to accurately place X or Z normal to the microscope axis under conoscopic illumination. By the combination of equations (3), (4), and (5) the equation

$$\cot R_x \cot R_z = \cos^2\theta \tag{6}$$

is obtained. Thus, the amount of rotation about the spindle axis necessary to orient the crystal so that α or γ can be measured may be calculated from the rotation required to orient Y and Z or Y and X, respectively. Figure 4 permits a rapid graphical solution to equation (6).

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Manuscript received, June 15, 1964; accepted for publication, July 9, 1964.