Telescope for Measurement of Optic Angle of Mica[*]

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The described instrument allows rapid measurement of the apparent optic angle to an accuracy of 5′ of arc for samples as large as 2 inches in diameter. This angle is a property pertinent to the quality of mica. Instrumentation is quite simple but dependent upon the complex phenomena of interference figures produced by biaxial crystals in polarized light. Magnification is great, dispersion can be determined, and the uniformity of samples can be observed.

1. Introduction

The optic angle and the uniformity of mica splittings are of interest, for these contribute to the quality of the material, and are properties covered in specifications on visual quality.[1]

The uniformity of the crystals can be determined with parallel, plane polarized light and a polarizing eyepiece of polarization plane at right angles to that of the incident light. The specimen behaves as a wave plate with a resultant pattern dependent upon the variation of thickness and index. The orthoscope arrangement of the petrographic microscope utilizes such procedure.

Direct measurement of the optic angle can be made with a number of instruments. For example, the conoscope arrangement of the petrographic microscope utilizes strongly divergent plane polarized light to produce an interference figure by which the angle can be determined with or without a universal stage, dependent upon the precision desired.[2] The universal stage can be used to a tenth of a degree. A basic spectrometer, i.e., collimator, goniometer, telescope modified with polarizing attachments, and rotary crystal holder can be utilized to greater precision. An instrument employing these components was developed for the precise location of the optic axis of polished quartz plates.[3] Although the instrument and the procedure [4] were for the uniaxial quartz, the instrument itself could be used for biaxial crystals. Such instruments as these are intricate and relatively expensive apparatus, which, further, examine only a very small region of the subject crystal.

Rough measurements, at the other extreme, can be obtained with small apparatus of the type suggested in the ASTM specifications.[5]

The described instrument, which has been used for a detailed study on mica behavior,[6] is relatively simple and readily assembled. It is used to deter-

mine both the uniformity of the crystals and the optic angle. In principle it is of the collimator-goniometer-telescope form except that the collimator and telescope are replaced with a primitive lens and the eye; yet, it has greater precision than the conoscope and universal stage. It differs from the previous instruments in that the entire area of a 2 in. diam specimen can be examined simultaneously to give crystal behavior in the large. Magnification of the interference pattern is much greater than that of the conoscope; apparent optic angle can be measured to an accuracy of 5′ of arc, and dispersion can be determined.

2. Theory and Structure

In general the velocity of propagation of light in a crystal is a function of the vibration direction of the wave, or of the direction of propagation and the orientation of the plane of vibration. The optic axis of such a crystal is that direction for which the velocity of propagation is independent of the orientation of the plane of vibration. Then, in any other direction a plane polarized wave may be resolved into two components vibrating at right angles to each other with different indices of refraction. Many crystals, and mica is one, are biaxial. The angle subtended by the axes is the optic angle, labeled $2V$ in figure 1. Waves propagated along the axes, A and B, are refracted upon emergence. The appar-

*Work supported by Defense Materials Service, General Services Administration.
[1] American Society for Testing Materials, Tentative specifications for natural muscovite mica based on visual quality, D351–53T.
[2] E.g., Manual of petrographic methods. A. Johannsen, 2nd Ed., 1918 (McGraw-Hill) or Optical crystallography, E. E. Wahlstrom, 2nd Ed., 1957, (John Wiley and Sons).
[3] E. Brodhun and O. Schönrock, Z. Instrumentenk, **22**, 353 (1902).
[4] E. Gumlich, Wiss. Abhand. der Physik.-tech. Reichanstalt **2**, 202 (1895).
[5] Appendix I, ASTM D 351–53T.
[6] Results to be published.

FIGURE 1. *Optic angle of a mica crystal.*

ent optic angle, labeled $2E$, is then that subtended by the refracted rays.

When divergent, plane polarized, monochromatic light of wavelength, λ, passes through a biaxial crystal and then a polarizing plate, or analyzer, an intereference figure is produced which is composed of a family of contour lines of light of equal phase (isochromes) and a superimposed pattern of equal vibration direction (isogyres). When the direction of polarization of the analyzer is at right angles to the plane of polarization, when the optic plane of the crystal is parallel to the direction of polarization of the polarizer or analyzer, and if the angle is symmetrical about the surface normal, the resultant pattern is as in figure 2. Here, the dark maltese cross, A_n-A_n' and $P_o'-P_o$, is the isogyre, formed by extinction of all light exit from the crystal and vibrating in the plane of polarization of analyzer or polarizer. The bright "circular" patterns are the isochromes, or contours of light of the equal phase difference of $(2n+1)\,\lambda/2$ at the point of emergence between those components whose vibration directions are at right angles. Each integral value of n describes a member of the family. Points A and B represent the intersection of the optic axes with the crystal surface. If the crystal is now rotated 45°, the isogyre breaks off into two hyperbolic brushes as in figure 3, with the optic axes centered in the vertices. The optic angle is then the arc spanning the vertices, A and B, and is the property to be measured.

White light produces a system of isochromes of various colors. In addition, if the optic angle and/or the orientation of the optic plane are frequency dependent, a dispersion pattern results for the 45° orientation. In this, the isogyres are separated into colored bands. In mica, the line of demarcation of the red and blue bands is sharp so that the intersection of this line with the optic plane serves as a fairly precise reference point.
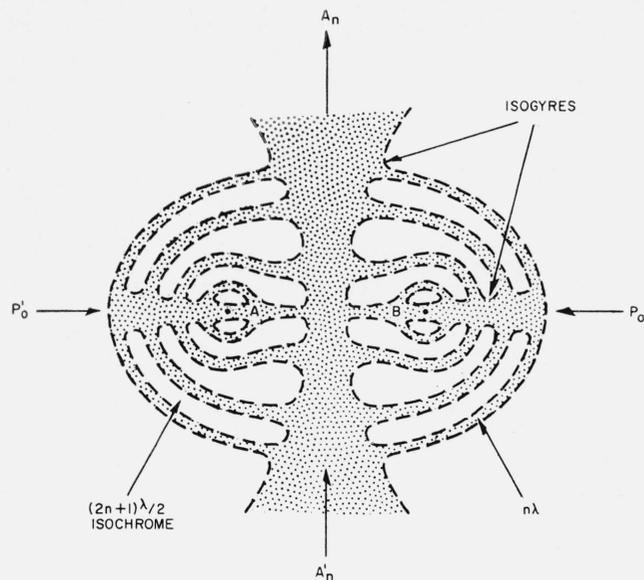
FIGURE 2. *Interference figure for optic plane parallel to one of directions of polarization.*
A_n-A_n' for analyzer. P_o-P_o' for polarizer. A, B for optic axes.
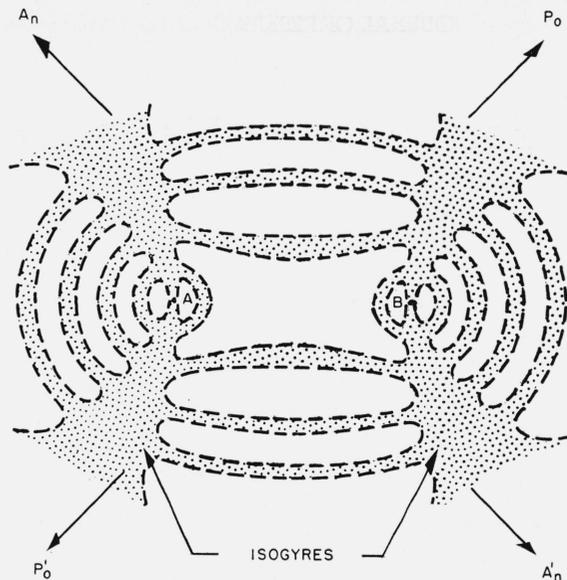
FIGURE 3. *Interference figure for analyzer and polarizer rotated 45°.*

The structure of the "telescope" is as shown in figure 4. A cross hair stretched across a large ground glass screen, illuminated from beyond by an ordinary incandescent light bulb, serves as an object and extended source. The crystal plate is
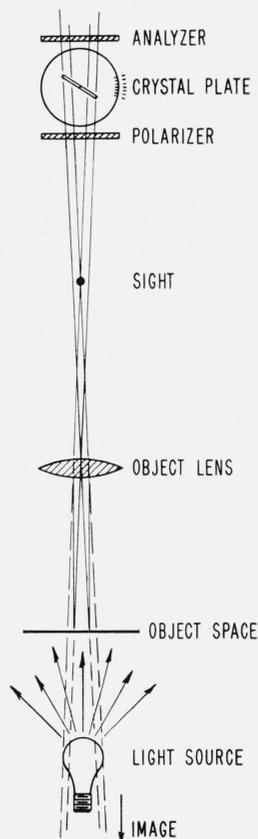
FIGURE 4. *Telescope.*

placed on a rotatable table equipped with protractor and vernier. The polarizer and analyzer are located before and after the table as closely as possible. A simple objective lens of large diameter is positioned approximately at its focal length from the object plane to produce normally a virtual image far beyond the object space. This can be done suitably in the following way. The crystal plate is rotated in its own plane and around a vertical axis in its plane until the 45° position is reached and a vertical trace of an isogyre is centered on the image of the cross hair. For this the eye is positioned above the analyzer in figure 4 and focused on the far off virtual image of the cross hair. The lens is then moved along the telescope axis until the image of the cross hair and the isogyre are parallax free. This procedure achieves a source of small divergence, which in turn produces an optic figure equivalent to great magnification. The line of demarcation of the red and blue fringes of the isogyre can now be fairly accurately centered; however, a vertical blade sight is also incorporated for greater precision. Alinement of the sight, isogyre, and cross hair insures that only axial rays are used and, hence, that the image is precisely centered. This also compensates for distortion by the large, simple lens and by crystal irregularity. The spanning of the specimen with polarizer and analyzer sheets of suitable diameter with close spacing and the use of a lens of large diameter create a large entrance aperture which is necessary to satisfy the demand for a beam of plane polarized light of large cross section needed to determine uniformity of fairly large splittings of mica.

The image secured with the telescope is so large that only a very small portion of the optic figure is seen. That portion about the optic axis fills the view, and the vertex of an isogyre is so extended as to appear as a vertical trace across the entire crystal. This facilitates accurate reading, and in addition shows any variation of the angle of the exit ray across the crystal, which variation does occur in mica. However, to some, the image of the isogyre so found may seem reversed in color sense from that as seen in the petrographic microscope. Actual measurement of the apparent optic angle for the red and blue fringes shows that this is not the case. The appearance of reversal is due to the difference in optics. That is, in the conoscope arrangement of the petrographic microscope the strongly diverging light passes up through the crystal as in figure 5 and is viewed from above. Let A_r and B_r represent the optic axes for red light, with A_b and B_b for blue light, and let the red optic angle be greater than the blue. Thus as one looks toward the surface of the crystal away from the light source, he sees the blue fringe outside the red fringe with respect to that surface normal, for red light propagating along a red optic axis is absorbed in the analyzer to leave a blue excess, and vice versa for the blue light at a blue optic axis. The whole figure may be seen at once. On the other hand, the telescope with its weakly divergent light, extended source, and limited pattern has the behavior of figure 6. Here, as one looks down the light from the axes, B_b and B_r in this
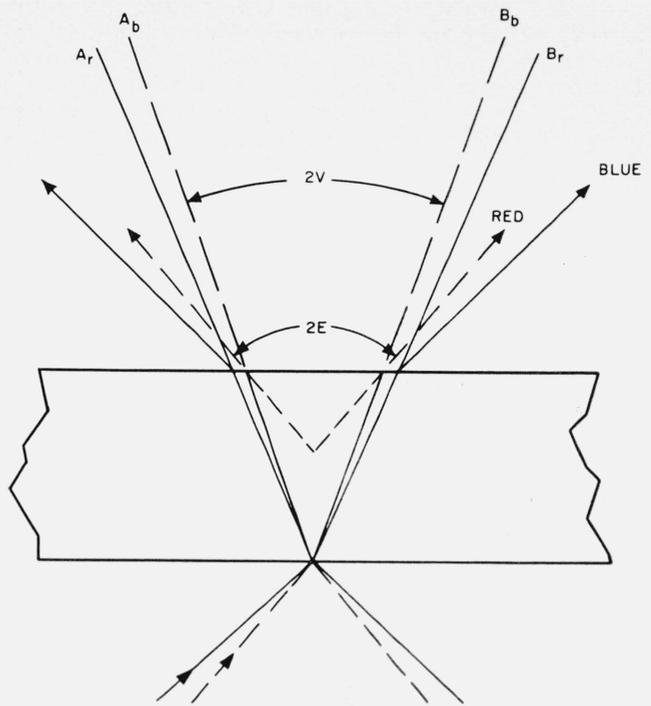
FIGURE 5. *Dispersion of isogyre with conoscope.*

A_r, B_r for red optic axes. A_b, B_b for blue optic axes. $2V$ is optic angle. $2E$ is apparent optic angle. $r > b$
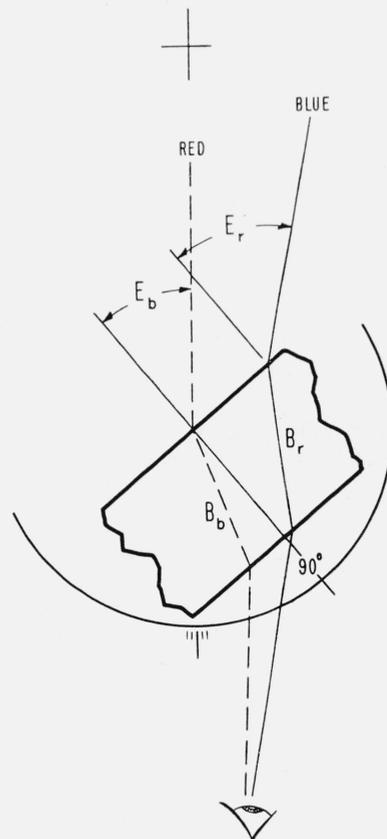
FIGURE 6. *Dispersion of isogyre with telescope.*

B_r is red optic axis. B_b is blue optic axis. $r > b$

example, toward the surface away from the light source, he sees the blue fringe inside the red fringe with respect to that surface normal, and he has only the one isogyre in view. This may seem reversed at first, but as can be seen the effect is due to the extension of the rays from the image plane to the eye through the blue and red optic axes. Thus, as the crystal is rotated in either direction from the position of symmetry, the red fringe, in this example, appears at the cross hair first.

The angle so measured is not the true optic angle but the apparent optic angle because of refraction of emergent rays.

When the crystal plate is normal to the telescope axis and the eye is focused on the specimen, the apparatus serves as a large sample orthoscope utilizing parallel rays. The sample acts as a wave plate to give a color pattern dependent on thickness, birefringence, and uniformity of the surface.

3. Operation

An apparatus is shown in figure 7. The objective lens is an ordinary 4-in. diam reading glass of 25 cm focal length. The analyzer and polarizer are Polaroid sheets of about 4.5 cm diam in rotary holders. The crystal holder and goniometer, which is the only critical part of the apparatus, is pictured in figure 8. Here, the specimen can be rotated in its own plane as well as around a vertical axis.

In use, a crystal is placed in the holder. Analyzer and polarizer are crossed at vertical and horizontal attitude. One's eye is positioned to focus on the crystal itself, which is rotated for maximum and then minimum transmission. This eye position utilizes the instrument for observation of uniformity.
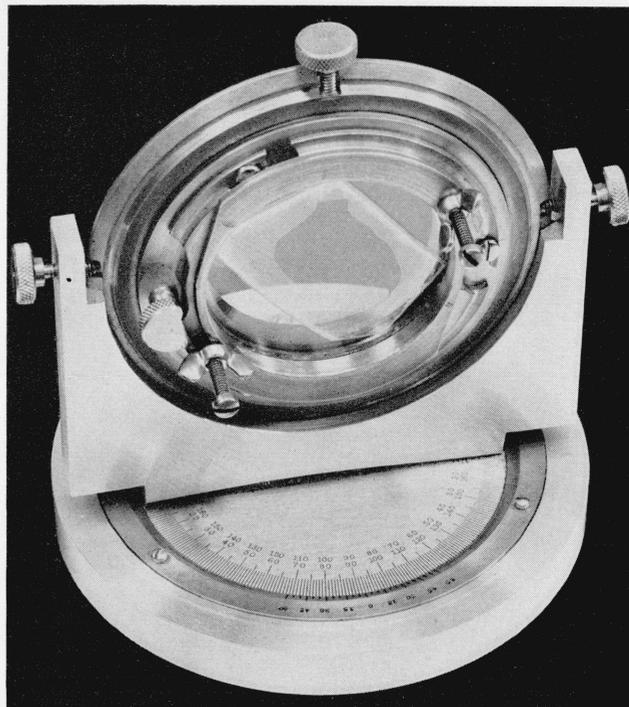
FIGURE 8. *Sample holder and goniometer.*
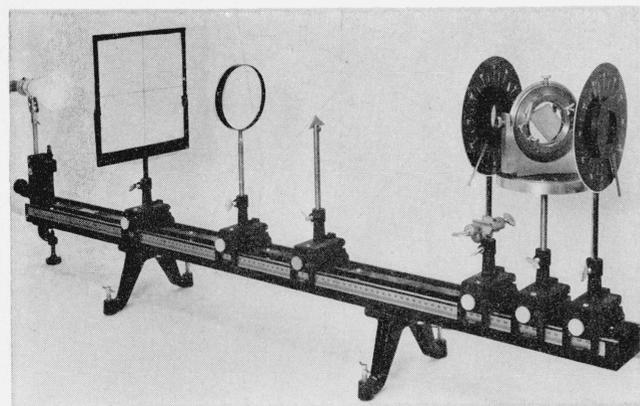
FIGURE 7. *Operational telescope.*

The eye is then moved in to the analyzer and focused on the image of the cross hair. This converts the instrument for measurement of apparent optic angle. For this the specimen is rotated until the optic plane is horizontal. The horizontal trace of the isogyre may be slightly displaced from the horizontal cross hair for mica. The table is rotated to bring one of the optic axes into view. The Polaroids are then rotated 45°, until the vertices of the isogyres are vertical. The eye is positioned so that the cross hair, sight, and isogyre are centered. The sight also serves to restrict change in vertical position of the eye. The apparent optic angle can so be determined.

Flat specimens allow reproducibility to better than the accuracy of the goniometer itself, which is 5′ of arc. In rippled specimens the measure is affected by local curvature through consequent variation of surface normal and hence refracted angle.

With the components used, the Polaroid sheets limited the field in the examination of uniformity, while the lens limited the field in the determination and inspection of apparent optic angle.

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