DIRECT PROJECTION OF OPTIC FIGURES

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Summary

Uranium glass causes transmitted light beams to appear luminous when viewed in a darkened room. A block of uranium glass permits the cone of light transmitted above a microscope stage from a substage converging lens to be viewed as a three-dimensional feature. An optic figure may be transmitted through such a glass block and be viewed upon a ground glass surface of the block. Making allowances for the index of refraction of the glass, and its thickness, a scale was drawn upon the surface from which the optic angle, 2E, of biaxial minerals has been read directly. By suitable apparatus here described the optic angle in air (2E) has been measured megascopically in terms of its tangent by one device and measured directly upon a semi-circular goniometer and upon a hemisphere. All these devices depend upon the use of a polaroid plate as an analyzer. Similar measurements have been made under the microscope by the use of a glass plate with ground glass surfaces on one-half of each side, using a micrometer ocular, Bertrand lens, and analyzing nicol. The writer describes a new detachable accessory stage which permits direct projection of optic figures upon a translucent hemisphere and direct reading of the azimuth and elevation of emergent optic axes.

Introduction

The writer has developed certain simplified methods for the demonstration of optic figures and for the measurement of optic angles, which may be found useful by other teachers. Suitable mineral sections of course are a requisite. Many of the devices here to be described may be made out of the materials usually available, even in unpretentious laboratories. It is the purpose of this paper to describe and explain the methods and the equipment used.

Use of Uranium Glass Block

Luminosity of light rays

A block of uranium glass may be used on the stage of a petrographic microscope to illustrate the form of a convergent light beam. A transmitted beam of light within uranium glass is luminous in a darkened room. The luminosity of the beam permits an observer to see where the convergent beam comes to a point within the glass block. By lowering and raising the sub-stage fixture the position of the focus of the convergent beam may be adjusted to coincide with the base of the glass block. From the side the beam appears conical in shape and from above clearly circular.

Use of polaroid plate

If one places a suitable section of a uniaxial mineral above the converging lens, and covers that with a piece of polaroid, an optic figure may be formed on a piece of ground glass or tracing paper held above the polaroid plate. Due to the fact that the beam of light is divergent upwards, the figure increases in size, and of course decreases in brightness, with increase in distance between the mineral section and the ground glass screen.

Uranium glass and polaroid plate in conjunction

One may combine the uranium glass block and the polaroid sheet, and project an optic figure upon one side of the block (previously prepared by fine grinding), while the luminous beams are clearly visible through the transparent sides of the block. The axial cross shows from the side as two black stripes, at positions 90 degrees apart, cutting through the luminous body of the projection. By this means the optic figure is revealed in three dimensions. Even more interesting are the demonstrations possible with biaxial minerals. In these cases phenomena depending upon rotation of the principal optic plane, including display of the optic angle, may be observed very conveniently.[1]

Calibration of the uranium glass block

For any mineral the optic angle, 2H, observed through the uranium glass is dependent both on the true angle, 2V, of the mineral and on the index of refraction of the glass, as well as upon the intermediate index

[1] This apparatus was demonstrated at the meetings of the Illinois State Acad. Science, Quincy, Illinois, April 27, 1936. *Trans. Illinois State Acad. Science*, vol. **29**, p. 177, 1936.

of the mineral concerned. Fortunately the glass block, supplied to the writer by the Bausch and Lomb Optical Company, is just one centimeter thick and a little more than 2 centimeters square. Careful measurement shows that the glass block has an index of refraction slightly greater than 1.50. The distance between isogyres of a biaxial mineral projected upon the ground glass surface of the block, is equal to twice the tangent of the angle H multiplied by the thickness of the block, which is unity, one centimeter. By Snell's Law, n sin H equals sin E; in this case n equals 1.5. A simple relation can be computed between the distance on the surface of the uranium glass block, the angle H in the glass, and the angle E, which is the corresponding angle for transmission through air. The writer constructed a graph from computation, and then scaled off distances from the center of the block to read directly the angle 2E as shown by the emergence of the optic eyes from a suitable mineral section. Thus, the optic axes of biaxial minerals may be projected through the block of uranium glass, and the angle 2E for each mineral section may then be read from the scale. The reading is only approximately correct, because the great magnification makes the isogyres wide relative to the scale divisions marked upon the ground glass surface. The writer found it convenient to draw the scale upon the ground glass surface with India ink.

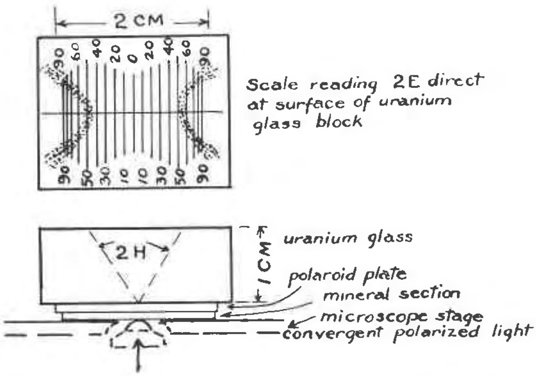

FIG. 1. Diagram to indicate the use of a block of uranium glass calibrated so as to show the value of 2E by direct projection with strong sub-stage illumination. Natural size.

The divisions are marked on the block as follows:

Distance	*Angle E*
1.2 mm.	10 degrees
2.4	20
3.6	30
4.8	40

6.0	50
7.2	60
8.2	70
8.7	80
9.0	90

For each mineral the value 2V must be computed from the value read for 2E, according to the value of the intermediate index of refraction of the mineral concerned.

In actual operation it was found that the thickness of the polaroid plate may become an obstacle to correct focussing of the converging lens upon the base of the uranium block. In that case the writer merely transferred the polaroid plate from the base to the surface of the uranium block, and read the position of the isogyres thus made visible upon the scale through the polaroid.

The values of 2E and 2V so obtained are correct within the limits of the small scale on which the angle 2E is read. However, the measurements are very quickly made, and the processes involved are simple to understand. In principle they are the same as those used in the well known Mallard's method for measurements made under the microscope.

Box Type 2E Goniometer

The disadvantages of making a special scale on the uranium glass block is avoided by another device in which the angles are read in air. This has the further advantage that the location of convergence of the optic angle is of no particular importance. The writer placed in a pasteboard box two celluloid scales marked in millimeters and centimeters in parallel position, one centimeter apart in a vertical direction, the edge of each parallel to a vertical plane, but lying on opposite sides of the plane. The top of the box has an open slot through which all the top scale and the central part of the lower scale may be read. There is a hole also in the bottom of the box. The lower scale is about $\frac{1}{2}$ cm. above the base of the box, but this distance is not material. This box may be placed over a polaroid plate on a suitable mineral section, the edges of the scales may be adjusted into the projection of the principal optic plane of the mineral. Each scale then shows one-half of the optic figure, the vertical plane between the scales passing through both optic eyes, and the isogyres appearing at the same time on both scales. The distance between the isogyres is read as closely as possible on each scale. The difference in the distances as read in both scales divided by two, is equal to the tangent of the optic angle in air (E). This is true no matter how thick the polaroid plate and how far away from the mineral section the two scales may be. So long as the scales are separated by a constant distance, they read at every distance from the mineral section the same angular inclination of the projected rays.

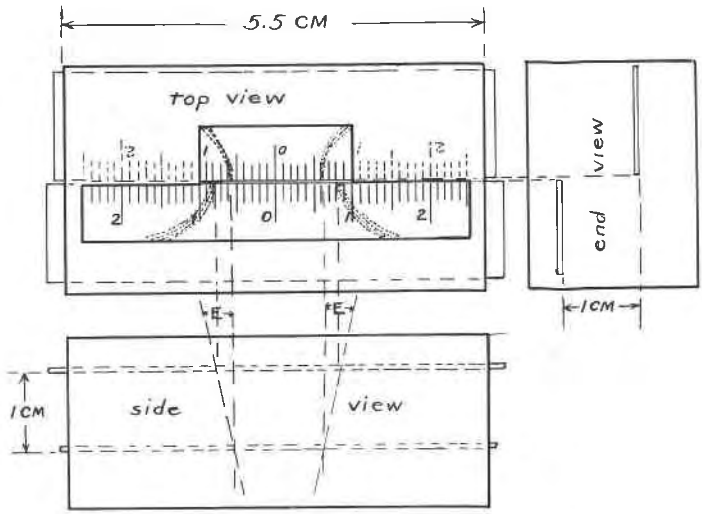

FIG. 2. Box type of 2E goniometer, having two scales one cm. apart, indicating the position of the isogyres of an optic figure on both scales simultaneously. Actual size.

This apparatus is easily and cheaply made, and it is more accurate in operation than the uranium glass block. It requires no calibration, because its measurements are of absolute value, not dependent upon any variables incident to its own construction or composition. It reads accurately up to values of about 140 degrees for 2E without being made more than 5 cm. long. Higher angles require a longer upper scale, which becomes unwieldy and very difficult to read with any confidence due to the spreading in width of the isogyre due to magnification, and to the faintness of projection due to the increased distance from the mineral grain to the point of emergence of the isogyre on the scale.

A New Microscope Method

From the foregoing megascopic devices may be derived a microscope method of considerable accuracy. This method may be applied to the examination of mineral grains in a thin rock section, and does not require the use of a polaroid plate. The writer measured the index of refraction of an ordinary microscope glass slide. Then he covered one half of each side of the slide with "Scotch cellulose tape," up to a medial line, in such a way that each clear side was faced with a covered side. Then he treated each clear side with a "ground glass" liquid. As soon as the ground glass surface developed and dried satisfactorily, the writer stripped off the cellulose tissue leaving the glass in those places bare and clean. Thus was produced a glass plate with ground glass surface covering one-half of each side. By placing this plate over a mineral section so that the plane of division between the two ground glass surfaces lies in the principal optic plane of the mineral, one provides a set-up comparable to that of the megascopic "box type" goniometer above described. Using a micrometer eyepiece with no objective, but retaining the Bertrand lens and crossed nicols, one may observe the optic figure on both the top and bottom of the glass plate, and the observer may measure the distances between the isogyres on both sides of the plate. One-half the difference in these distances divided by the thickness of the plate (measured in the same units) is equal to the tangent of the optic angle in the glass plate. Sine E equals the sine of the angle, H, in glass multiplied by n_x, the index of refraction of the glass plate.

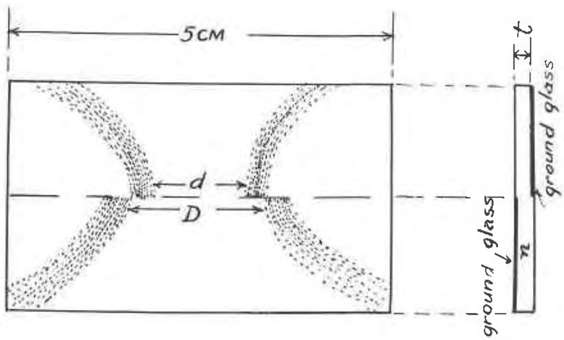

FIG. 3. Glass plate 2E goniometer for use under microscope. One-half of each side is ground glass. Diagram shows appearance of the optic figure projected onto each side of the plate simultaneously. Natural size.

$\frac{1}{2}(D-d) = \tan H \times 1/t$
$\sin E = n_x \sin H$
D = distance between the isogyres on the top of the glass
d = distance between the isogyres on the bottom of the glass
H = optic angle in the glass of the slide
t = thickness of the slide in micrometer units
n_x = index of refraction of the glass slide.

A Celluloid Protractor 2E Goniometer

Arising from the projection of biaxial optic figures upon tracing paper over an analyzing plate of polaroid came the use of a semicylindrical scale on which the angle 2E may be read directly.

This device[2] is made of two semicircular protractors, preferably of celluloid, 5 cm. in radius, which are attached to a base 10 cm. long and 2 cm. wide, and with a hole 1 cm. in diameter in the middle. The semicircles are joined by a semitranslucent strip 2 cm. in width, which is a protractor numbered from zero at the zenith to 90 degrees at each horizon. This is placed over a biaxial section which gives a good optic figure preferably in a position such that the acute bisectrix passes through the zenith. When the section is turned to the 45 degree position with the isogyres passing through the eye, the angle E can be read in both directions from zero. In case the acute bisectrix is really vertical these two angles will be the same, otherwise they may be added together, if they are not too eccentric, and their sum may be taken as being closely equivalent to 2E.

The principal sources of error of this instrument arise from the fact that the angle 2E as measured on this goniometer may not be exactly concentric with the curvature of the scale. It is assumed that the rays of light which pass through the center of the optic eye are exactly parallel to the radii of the goniometer, but in certain cases they may not be quite parallel because the point of convergence of the condensing lens may be either slightly above or slightly below the base line of the semicircular goniometer. That error is minimized by having the device made with a radius of 5 cm., which is so large in proportion to the probable lack of coincidence between the point of condensation of the lens and the center of the protractor's circle that any difference is practically negligible. In any case it seems impossible that this difference could amount to more than 1/10 of a cm. in a vertical direction, which, with a radius of 5 cm. and small angles, would be entirely insignificant and only in the case of readings where 2E is more than 40 degrees could the error amount to more than 1 degree.

Another model is made with a radius of $2\frac{1}{2}$ cm. This has the advantages of much greater brilliance of the projected figures, and use on the stage of the microscope without withdrawing the barrel, but it has the disadvantage that the error discussed above becomes much more serious, especially for minerals with high values for 2E.

This goniometer may be made out of sheet celluloid cut with slots and tabs to fit together. Once put together the parts may be fastened with an acetone-base cement, after which the projecting ends of the tabs may be cut off with scissors. The scale is drawn on tracing paper and cemented onto the celluloid strip after the main parts are put together. The polaroid analyzing plate must be accurately cemented in place on the base

[2] Trans. Ill. State Acad. Science: vol. **29**, pp. 177–178, 1936. *Am. Mineral.*, vol. **22**, p. 217, 1937.

piece of the goniometer before it is assembled. Care must be taken to be sure that the polarizing direction of the polaroid is such that it is crossed with reference to the substage polarizer when the goniometer is placed in the 45 degree position.

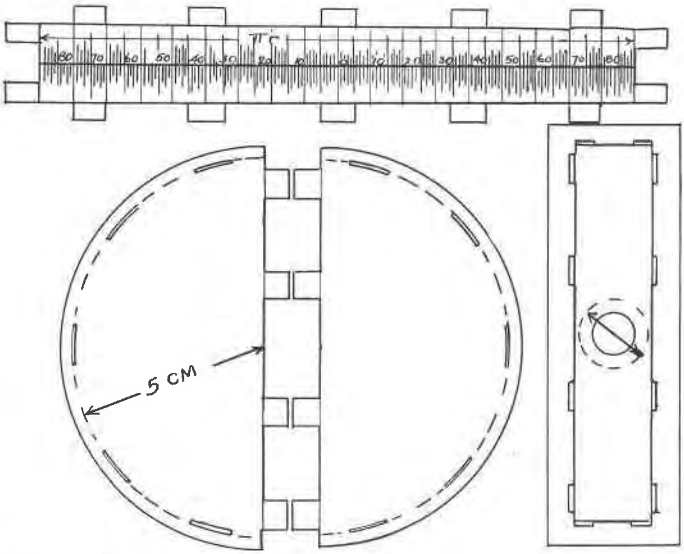

FIG. 4. Diagram showing constituent parts of the semicircular celluloid protractor, 2E goniometer, illustrated in figure 5. One-half natural size.

The following determinations were made of the optic angles displayed by the suite of sections available to the writer.[3]

Mineral	*Quality of optic figure*	*Temperature*	*2E*
Chrysoberyl	fair	28°C.	134°
Cerussite	good	27°	19°
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Barite	good	27°	70°
Gypsum	good	27°	92°
Struvite	good	28°	67°
Adularia	fair	27°	119°
Cordierite	good	27°	75°
Mica (lepidolite ?)	very good	27°	78°
Axinite	poor	27°	141°(?)
Sanidine	good	27°	13°
Cane sugar	good	27°	86°
Potassium bichromate	good	28°	108°

[3] The writer is indebted to Mr. W. F. Wrath for making these measurements.

These measurements appear to be close enough to the usually accepted values of the substances represented to be at least approximately correct. In the hope of gaining a more precise check upon the reliability of the instrument, the writer sent it to Dr. Stanley A. Tyler at the University of Wisconsin. He checked measurements made by two observers with the 2E goniometer against universal stage determinations, as follows:—

Mineral	*2E absolute*	*2E goniometer S. A. T.*	*2E goniometer R. W. M.*
Barite (from England)	63°18′	62°30′	64°
Muscovite (Mitchell Co., N. C.)	61°17′	61°	60°

In spite of lack of complete accuracy, this 2E goniometer is evidently accurate enough to be useful.

Projection Upon a Hemisphere

The apparent success of the 2E goniometer led to the construction of a translucent hemisphere over polaroid mounted upon an accessory stage. Such an apparatus was first demonstrated at the meetings of the Geological Society of America in Cincinnati, December 30, 1936, incidental to an explanation of the 2E goniometer.[4] The model shown at that time was attached to the arm of the microscope, and made so that it could be swung over and away from the stage of the microscope. The instrument was equipped with celluloid hemispheres of two sizes, one made from one-half a table-tennis ball, and another about 4 cm. in diameter. Each hemisphere was provided with a protractor over the zenith in a vertical plane, and another around the edge in the horizontal plane. With the aid of these protractors the position of emergence of the eyes of optic figures could be located by both latitude and longitude. The small hemisphere yielded the more brilliant figure, but the larger scales were easier to read. By these means it appeared possible to read rapidly the relative orientation of grains in a rock section; and certainly it was obvious that optic figures may be beautifully demonstrated.

Professor D. J. Fisher[5] has applied these ideas to the equipment of a universal stage with direct projection of optic figures upon a half table-tennis ball, attaining a much greater degree of accuracy than is possible without a universal stage. Professor Fisher's apparatus is far more accurate than that of the present writer, it serves more inclusive purposes, and of course it is designed for, and useful only in connection with a universal stage.

[4] *Proc. Geol. Soc. America for* **1936**, p. 50.

[5] Demonstrated at the meetings of the Geol. Soc. of America, Washington, D. C., December, 1937.

A new direct projection stage

Inasmuch as many petrographic laboratories do not possess a universal stage, the writer has designed and exhibited[6] an improved stage for the direct projection of optic figures. This stage is made attachable to the substage frame of any standard petrographic microscope. It includes a vertical bearing about which a polaroid holder is rotated, and upon which it may be adjusted with any convenient clearance above the regular stage. Above the polaroid plate is placed a translucent celluloid hemisphere with vertical and horizontal angular scales. This hemisphere is specially made 5 cm. in diameter. Mineral sections may be placed upon

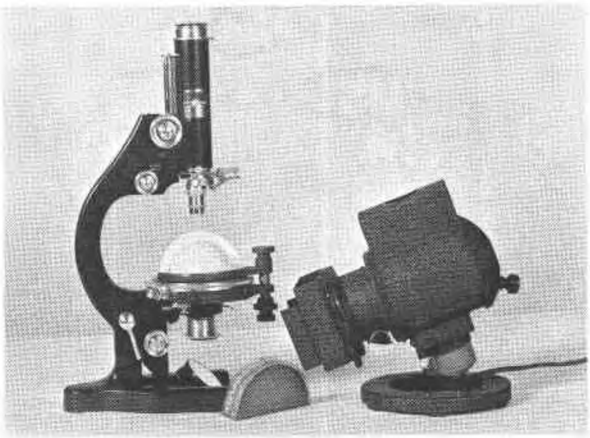

FIG. 5. A new accessory stage for the direct projection of optic figures, mounted as for use. A celluloid protractor 2E goniometer stands beside the microscope.

the stage of the microscope and the accessory stage may be operated above it, each stage being manipulated independently. In the case of research models of microscopes there is room enough beneath the objective for the accessory stage without removing the barrel of the microscope from its mounting. Accordingly, an observer may explore a rock section with a low power objective, using Johannsen's[7] micro-ball device, for grains yielding optic figures, and after centering such a grain, he may place over it the accessory stage for further observation of the optical figure and measurement of its orientation or the angle 2E. The illustration (Fig. 5) shows the improved direct projection accessory stage mounted upon a microscope, and beside it a model of the simple 2E

[6] Annual meetings of the Geological Society of America. Washington, D. C., 1937.

[7] Albert Johannsen, *Jour. Geology*, vol. **21**, pp. 96–98, 1913.

goniometer. The goniometer has in its base a sheet of polaroid which is placed so that when the main vertical plane of the goniometer is in the 45° position over a suitable mineral section, the polaroid analyzer is crossed with reference to the substage polarizer. In the case of the accessory stage, the polaroid analyzer is fixed in position such that when the accessory stage is centered with respect to the microscope stage, the analyzer is crossed with respect to the polarizer. In the mounting of this stage it is necessary to lower the substage equipment until the attachments are firmly screwed into place, and in the operation of the stage success depends upon such an adjustment of the illumination and placing of the converging lens that a sharp and brilliant optic figure appears upon the celluloid hemisphere. Ordinarily it is not necessary to darken the room for the use of this stage, but for demonstration purposes of course it is desirable.