

*Projector for interference figures and for direct measurement of 2V.*

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THE instrument is designed for the study and measurement of the optical characters of crystals and anisotropic materials. The conoscopic phenomena, over a wide area for any selected orientation of the specimen, may be brought into view on a hemispherical screen, without the use of a microscope or lens system. The parts of the interference figure retain their true angular relationships, directly displaying for observation or measurement values of  $2V$  for any angular separation of the optic axes.

The polarizing microscope has certain limitations; for example, observations, usually monocular, can be made only by one person at a time and errors of interpretation may arise. The fixed position of the crystal in its mount allows no change or choice of orientation. In addition, the significant area of the figure is restricted, not only by the lens system, but also because the apparent angle in air,  $2E$  and not  $2V$ , is observed, so that only a minor portion of the convergent phenomena is visible in the field of view of the microscope, and only small optic axial angle separations may be observed. The microscope projector has the single advantage that the figure may be viewed on a flat screen by a group of observers using normal vision. However, this equipment is elaborate and unsuitable for individual studies and measurements. The optic axial goniometer and the universal stage are available for quantitative work, but special techniques restrict their use. T. T. Quirke<sup>1</sup> has described methods for projection and measurement, using a converging lens system and crystal sections with fixed orientation. The procedure is based on the apparent axial angle ( $2E$ ), giving a limited effective field, and is therefore applicable to crystals with small axial angles. H. Win-

<sup>1</sup> T. T. Quirke, Direct projection of optic figures. Amer. Min., 1938, vol. 23, pp. 595-605. [M.A. 7-249.]

chell<sup>1</sup> describes the use of cut spheres made of crystals such as corundum or quartz, for demonstration of optic figures when manipulated between polaroid sheets. The interference figure may be viewed inside the sphere and projection can be arranged. Quite recently, C. S. Hurlbut, by placing a glass (or plastic) sphere above the crystal section, shows the interference figure reflected in a mirror.<sup>2</sup>

In the method here described, the crystal, mounted at the centre of a transparent sphere, is capable of free revolution about its centre, and is illuminated by polarized light converging upon it at a wide angle from a reflector. The emergent rays traverse the analyser, and combine to produce a focused image of the interference figure on the spherical surface of the screen. The curvature and position of the screen are so arranged that the sphere and screen are concentric when the interference figure is in focus over the whole of the screen. The phenomena may be examined while the sphere is revolved, giving in effect a working model of the crystal and its indicatrix for any desired orientation. Two optic axes may be seen at one time on the screen, for an angular separation of up to 120 degrees, so that the true optic axial angle,  $2V$  acute, of any magnitude may be directly measured upon the screen. Simple in use and construction, the instrument is suitable for both class demonstration and individual operation; and, when the dimensions of the screen and its positioning are correctly arranged, accurate and reliable values for optic angles are directly measurable for crystal grains or plates of a diameter of two mm. and upwards. By removal of the screen, and also the sphere when necessary, and reduction of the light aperture, the instrument is converted to a parallel light polariscope.

The apparatus is shown, as a partially diagrammatic sectional view, in fig. 1. The overall dimensions there illustrated are adequate for much larger sphere and screen. The sphere, A, is constructed of two equal segments of glass.<sup>3</sup> Each segment has, cemented to its plane surface, a metal ring, the ring on one segment being an accurate fit within that on the other, and the dimensions are such that, when assembled, the segments are separated by a narrow space to accommodate the crystal, and externally form a sphere, with the outer metal ring forming part of the surface.

<sup>1</sup> H. Winchell, Demonstration of interference figures. Amer. Min., 1947, vol. 32, pp. 588-589. [M.A. 10-468.]

<sup>2</sup> C. S. Hurlbut, Jr., Demonstration polariscope. Amer. Min., 1955, vol. 40, pp. 120-122.

<sup>3</sup> H. C. G. Vincent, Min. Mag., 1954, vol. 30, p. 513.

The sphere is supported in the central opening of the circular metal stage, B, which rotates in a recess in the cover, C, of the reflector. The opening has three equally spaced hardened steel balls, D, let into its

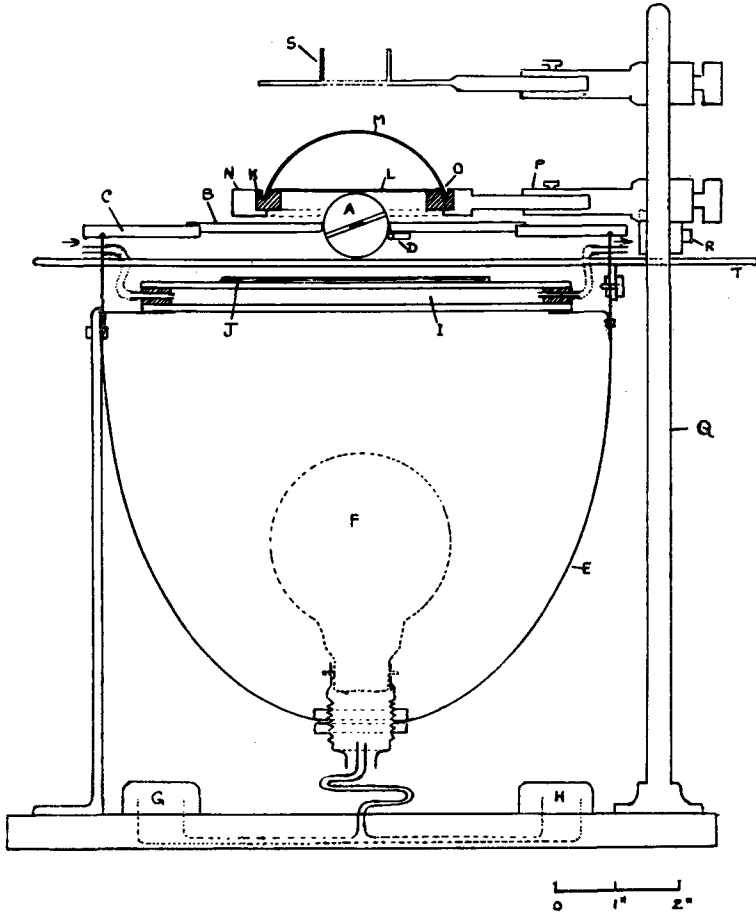


FIG. 1. Projection apparatus in convergent light. A sphere, B stage, C cover, D ball supports, E reflector, F lamp, G switch, H plug, I water cell, J polarizer, K inner ring, L analyser, M viewing screen, N outer ring, O groove, P horizontal arm, Q post, R adjustable stop, S masking tube, T strip.

circumference, and adjustable in position. The sphere revolves freely on this three-point support and the small clearance between the sphere and the plate may be screened by a ring of black velvet.

The cover carrying the stage and sphere fits over the circular edge of the reflector, E. The shape of the reflector is not critical, but should be chosen to give a strong concentration of light on the sphere over a wide angle, and the light bulb, F, should be adjustable in height. Illumination is conveniently provided by standard lamps on the mains supply. The reflector carries the water cell, I, the surface of which is preferably of 'perspex' or similar plastic, sanded to diffuse the light from below. The cell, fed slowly from a convenient supply, effectively absorbs the heat and allows continuous operation even when high consumption lamps are in use.

A circular sheet of polaroid, the polarizer, J, rests upon the upper surface of the cell and is of adequate diameter to allow the maximum angle for the cone of rays entering the sphere.

The projection screen and upper polaroid assembly is supported axially above the sphere, and consists of an inner metal ring, K, carrying the polaroid analyser, L, and the screen, M, which is free to rotate in an outer ring, N. The screen may be made from an accurately blown spherical ground-glass bulb of the proper diameter. Its radius of curvature should be equal to the distance from the centre of the sphere to the focal position of the interference figure. The position may be found by trial, using the optic axial figure of a thick flake of muscovite mounted in the sphere, focused on the upper surface of a sheet of ground-glass held above. The inner ring, K, has a shallow circular groove, O, in which the screen fits. Ring and screen may each be independently rotated. The disk of polaroid, L, is fitted into the central opening, which is maintained as large as the screen will allow. The screen assembly is supported by a stout horizontal arm, P, adjustable in length, which slides up and down along the rigid vertical post, Q, firmly attached to the base of the instrument. An adjustable stop, R, on the post fixes the correct height and position for the screen, at which point its surface is truly concentric with that of the sphere, and the screen assembly may also be swung to one side.

The relative positions indicated are designed to give the maximum effective area for the projection screen, allowing it to display, for one given orientation of the crystal, both optic axes with an angular separation of up to about 120 degrees, with associated indicatrix phenomena, over an area of about two-thirds of a hemisphere.

The masking tube, S, may be swung into position to limit the interference figure visible to a small area comparable to that seen in a polarizing microscope, and is useful in teaching.

A 'perspex' or glass strip, T, operates through horizontal slots on opposite sides of the reflector and is adjustable in height so that the sphere rests upon it and the weight of the sphere is partially taken by the strip. Thus, by moving the strip in any desired direction in its horizontal plane, the sphere may be revolved on any axis in order to vary the orientation of the crystal while the screen is under observation. The instrument should be well ventilated and necessary parts rendered dull black or screened. If the instrument is not intended for accurate measurement, sphere and screen may be made of 'perspex' or similar plastic.

Projection is best when the area of the crystal is relatively large, and the retardation moderate or high. Crystals as plates, cut sections, or grains, are mounted between cover-slip glass in a solid or liquid medium in optical continuity with the sphere. The refractive index of the embedding medium should preferably be near that of  $\beta$  for the crystal; and, to avoid total reflection effects, it may be advisable to use mounting materials with indices near or higher than that of the sphere. If necessary, special cover-slips may be ground for the purpose from high refractive index glass.

Of the rays entering the sphere, those which do not pass through the crystal may give a background of undesirable illumination on the screen, and so reduce the quality of the image. They may be eliminated when necessary by means of a mask of foil, with a central opening, attached to one of the segments.

The instrument is best used in a darkened room. After adjusting the light source for the most effective concentration, the inner ring is rotated to extinction, and the sphere, with the crystal mounted at the centre, is placed in its support. Specimens give the best results when the plane of separation of the segments is not too highly tilted and when the acute bisectrix, or an optic axis, is highly inclined to this plane. Stray illumination on one side of the screen arising when the orientation of the specimen is unfavourable should be screened off near the sphere. Utilizing the transparent strip, T, the sphere may be revolved to display the interference phenomena for any desired crystal orientation.

The crystal may also be revolved by turning the stage, and both analyser and screen have independent rotation. The behaviour of the isogyres, and other conoscopic phenomena, may therefore be observed and demonstrated for any chosen orientation. The interference figure of a thick flake of muscovite,  $2V\ 43^\circ$ , is shown in fig. 2.

The optic axial angle is afforded directly by the great circle measure-

ment on the screen between the two optic axes, which may be adjusted to fall upon the scale of degrees inscribed in the screen; or a strip of metal, fitting the curve of the screen and marked in degrees, may be used enabling measurements to be made at any position. The principal planes and points of emergence of the axes of the indicatrix are also available and may be temporarily inscribed on the screen if desired.

When the refractive index of the glass comprising the sphere differs from that of  $\beta$  of the crystal, correction of the observed value of  $2V$  is necessary. If  $\beta$  for the crystal is known, and also the great circle measurement

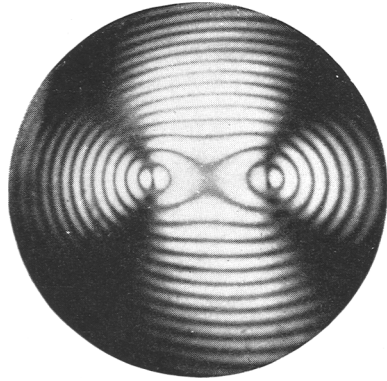


FIG. 2. Interference figure of muscovite.

from each optic axis to the polar point of emergence on the screen of the axis of the sphere perpendicular to the plane of separation of the segments, the true value for  $2V$  is readily available. The two opposite polar points having been marked on the sphere, the equivalent screen-point may be located and established, utilizing a drop of benzine held by surface tension against the surface of the screen by means of a glass slide. This acts as a lens and also renders the screen temporarily transparent, enabling the polar points on the sphere to be aligned and the equivalent point inscribed on the screen. By reference to a chart the amended angular readings are available and may be marked off from the polar point, thus giving each corrected optic axis position for measurement of  $2V$ . To improve accuracy in quantitative work the sphere may be reversed to obtain the mean of two sets of readings.

For studies in parallel polarized light the screen is removed and the illumination restricted to a small aperture at the centre of a disk placed upon the cell. Becke-line observations are made with a hand-lens for refractive index determination.

When monochromatic light is required, the sphere may be illuminated by a sodium-vapour lamp or other source inserted in an opening for the purpose in the side of the reflector and dyed photographic plates are useful as filters for demonstration work.