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DEMONSTRATION OF THE DOUBLE REFRACTION OF ARAGONITE FOR RAYS TRAVELING IN THE NEIGHBORHOOD OF AN OPTIC AXIS

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The purpose of this note is to call attention to the fact that the demonstration of "internal conical refraction" is facilitated by the use of the universal stage and that an unusually accurate axial angle determination can be made for both the primary and secondary optic axes.

The microscope has previously been used for demonstrating the behavior of rays of light passing through aragonite near an optic axis direction.[1]

With the aid of the universal stage, which today is available in most mineralogical laboratories, the demonstration of so-called internal conical refraction is greatly facilitated.

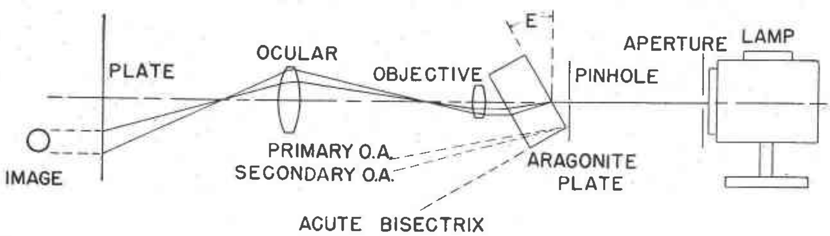

FIG. 1. Schematic diagram of the demonstration of "internal conical refraction".

Figure 1 shows schematically the essential features of the apparatus. The microscope, focused for projection of the pinhole image, is drawn as though made up of thin lenses. The plane of the drawing is taken as the axial plane of the crystal. To avoid confusion, only two rays, whose wave normals coincide with the primary optic axis, are shown. Rays traveling in such directions form a cone within the crystal and, because

[1] Clay, R. S., Treatise on Light, pp. 480–483, Macmillan & Co., Ltd. (**1911**).

of their exact parallelism (in air), have zero intensity and contribute to the dark circles shown in Figs. 2 and 3. Each ray slightly inclined to those shown is doubly refracted and contributes light to point images. The points from the rays in a small cone which encloses the incident ray illustrated in Fig. 1 lie on the bright concentric circles, as can be demonstrated by Sylvester's construction.[2] Figure 2 shows the pinhole images for seven positions of the crystal. If the pinhole diameter is too large for the thickness of the crystal employed, the concentric rings are not resolved, and the pair is seen as a single ring. The light seen in either case has simply undergone double refraction. The rays which are truly conically refracted do not contribute to the image. The theory is correctly treated by Wooster[3].

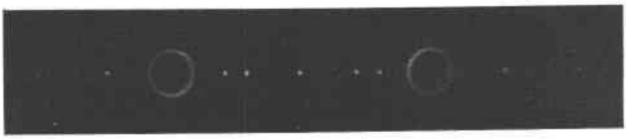

FIG. 2. Photograph of images of an illuminated pinhole as seen through an aragonite plate for seven selected positions of the crystal.

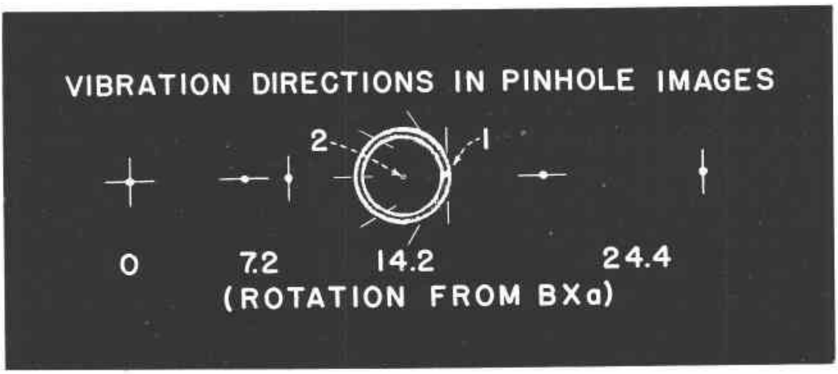

FIG. 3. Drawing of images of an illuminated pinhole as seen through an aragonite plate for four selected positions of the crystal. Straight lines indicate vibration directions. (1) Primary optic axis, (2) secondary optic axis.

To demonstrate the phenomenon, the polarizer and condenser were removed from the microscope, and a bushing was placed on the substage mount to permit a sheet of platinum foil, perforated by a small pinhole, to be located above the plane of the microscope stage. A thick plate of

[2] Wooster, W. A., A Textbook on Crystal Physics, pp. 136–138, Cambridge University Press (**1938**).
[3] *Ibid.*, pp. 148–154.

aragonite cut perpendicular to the acute bisectrix was mounted on a slide. The surfaces of the crystal plate were ground with 600 alundum, and a liquid film formed optical continuity between the usable central portion of the crystal and the slide. The edges of the crystal were cemented with Canada balsam. Also a thin cover plate was fastened to the upper surface of the crystal by means of a liquid of the same index as the β index of the crystal. The crystal assembly was mounted on the inner ring of the universal stage so that the east-west stage axis passed through the center of the crystal.

The crystal is approximately oriented geometrically, the final adjustment being made by viewing the pinhole through the crystal. With the crystal in a general position two spots are seen. When the acute bisectrix coincides with the optical axis of the microscope, only one spot is seen. When the crystal is rotated from the acute bisectrix position about β through an angle approaching E, the two spots become crescents, and when the primary optic axis falls within the very small cone of wave normals within the crystal, the circles are seen.

The vibration directions of the light forming the images may be conveniently demonstrated by inserting a rotating analyzer or polarizer into the system. The results are shown in Fig. 3, which shows the images of the pinhole for four positions of the crystal, rotated about β from the acute bisectrix position by the angles indicated.

It should be noted that the appearance of the rings affords an extremely precise method for the determination of $2\ E$ for the primary optic axes. A series of ten measurements on one crystal yielded a value of $2\ E$ of $28.40 \pm 0.03°$ (probable error) at a temperature of 21° C. for D light.

With the aid of a calibrated filar micrometer, the cone angle (twice the angle between the primary and secondary optic axes) can be computed, the thickness of the crystal having been measured. On the crystal studied the cone angle was found to be 1.9°. Thus the angle $2\ E$ for the above stated conditions for the secondary optic axes is 26.5°.

The visual demonstration of the phenomenon is not particularly difficult. If aragonite is used, white light is satisfactory because of the relatively low axial dispersion. The photography of the phenomenon is, however, a patience-trying task. The following dimensions of apparatus may be of use as a guide to those who might care to set up the demonstration:

Lamp aperture 2 cm.
Lamp to pinhole distance 35 cm.
Pinhole diameter 24μ.
Pinhole to rotation axis of crystal 5 mm.
Thickness of crystal 9 mm. (A much thinner crystal may be used, especially with a smaller pinhole, but the effect is less striking.)

Diameter of unmasked usable portion of crystal 3 mm.
Objective, Leitz 35 mm. with iris stopped down to reduce scattered light.
Ocular, Leitz number 1.

The photograph was made by focusing the microscope for infinite image distance, using a camera having a 25 cm. lens focused for infinite object distance. Of course, the image could be projected to the plate by means of the ocular only. The exposure for each optic axis position with the sodium Lab-Arc was 20 minutes. The exposure for the acute bisectrix spot was 45 seconds. Fast panchromatic press film was used.

The writer wishes to thank Dr. C. B. Slawson, of the University of Michigan, for furnishing the excellent aragonite crystals used, and for making numerous pertinent suggestions.

MORDENITE FROM TINTIC, UTAH, AND THE DISCREDITED MINERAL ARDUINITE

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Introduction

While mapping rock alteration in the Tintic Mining district, Utah, a small area was discovered in quartz latite which contained a zeolite originally thought to be arduinite (Stringham, 7). In order to make *x*-ray comparisons a sample of arduinite from the type locality in Italy was secured from the Harvard mineralogical collection, through Professor E. S. Larsen. The Tintic mineral proved to be identical to the type arduinite but it was finally found that the space group and unit cell of "arduinite" was identical with mordenite (Waymouth et al., 8); therefore, this study serves to discredit the species arduinite.

Arduinite was first found in the province of Val dei Zuccanti, Venecia, Italy, by E. Billows in 1912 who named and described it. His original paper could not be secured, but a review in the *Mineralogical Magazine* (5) states, "*Arduinite*, E. Billows, 1912. Two pamphlets both dated Padova 1912, entitled 'Analisi di alcuni minerali del veneto, Nota I, Arduinite, un nuovo Minerale,' one of 11 pages and the other of 14 pages. One of them is stated to be an extract from *Rev. Min. Crist. Ital.*, vol. **xli**; but the paper does not appear in that or in earlier volumes of that periodical." An analysis of arduinite was found in Appendix III to Dana's System of Mineralogy (2) together with a short description and it is here stated that Billows named the mineral after Giovani Arduino, a geologist of the 18th century. Doelter (3) gives the same analysis but states that it is an average of two analyses made by E. Billows. Later Barth and Berman (1) describe the mineral briefly and give optical data and provisional crystallographic data.