doubler, named after its inventor, and shown in a very simple form in Fig. 265.

To one edge of a wooden base, 6 in. square and three-fourths of an inch thick, is secured a vertical standard, 1 in. square and about 15 in. high, and to the top of the standard is attached an arm extending over the center of the base, and apertured to receive the short tube containing the analyzing prism or bundle of glass plates. The tube may be made of paper, hard wood, or metal, and it should be fitted with a shoulder, so that it will turn readily in the aperture of the arm. To the standard below the arm is fitted a stage formed of a thin piece of wood centrally apertured and blackened.

The stage is notched to receive the standard, and is attached to a short vertical bar 1 in. wide. A clip of wood extending across the back of the bar, and two small clips secured to the sides of the short vertical bar, bear with sufficient friction on the standard to hold the stage in any desired position.

About 6 in. above the base a grooved wooden strip is pivoted to the standard, by means of a common wood-screw passing loosely through the grooved strip and tightly through the standard. A wooden knob is turned on the end of the screw, and serves as a nut to bind the grooved strip in any desired position. The strip, screw, and knob are shown in detail at 2, Fig. 265.

Into the groove of the strip is wedged or cemented a plate of glass, 4 by 9 in. A fine piece of ordinary window glass will answer, but plate glass is preferable.

Upon the base is laid a square of ordinary looking glass, or, better, a piece of plate mirror.

The tube, shown in detail partly in section at 3, is provided with an inner tube of pasteboard or wood, divided obliquely at an angle of 35° 25′ with the axis of the tube, and upon the oblique end of one-half of the tube are placed twelve or fifteen well cleaned elliptical microscope cover glasses, which are held in place by the other half of the divided tube. This bundle of glass plates, if of good quality and well cleaned, forms a very good analyzer; but

instead of this, if it can be afforded, a small Nicol prism should be secured and mounted in a centrally apertured cork, the latter being inserted in the analyzer tube, as shown at 4.

The object to be examined may be laid either on the stage or on the mirror below. If viewed on the stage, the usual effects will be observed; but if laid on the mirror, it is traversed twice by the light, once by the incident beam and once by the reflected beam. This is particularly noticeable in thin films of mica and selenite, and it serves as an excellent means for selecting eighth and quarter wave plates, which are useful in the study of circular and elliptical polarization.*

It is quite difficult to produce a perfectly uniform thin film of selenite, owing to the brittleness of the material. For this reason mica is generally used, as it possesses considerable flexibility and toughness. The common method of cleaving off thin films of mica is to split off a moderately thin plate and then separate the laminæ at one of the corners by bending it between the thumb and fingers. A medium sized sewing needle secured point outward in a slender handle is probably the best instrument for teasing the laminæ apart; but after the separation begins, the thin end of the ivory handle of an ink eraser seems to serve the purpose exceedingly well.

A score or so of plates are split, and examined one by one in the Norremberg doubler, by laying them on the mirror and turning them in their own planes, while the polarizer and analyzer are crossed. Should the plates exhibit any unevenness under the test, they should be at once rejected. Such as exhibit an even tint should be preserved carefully, and examined further to determine which, if any,

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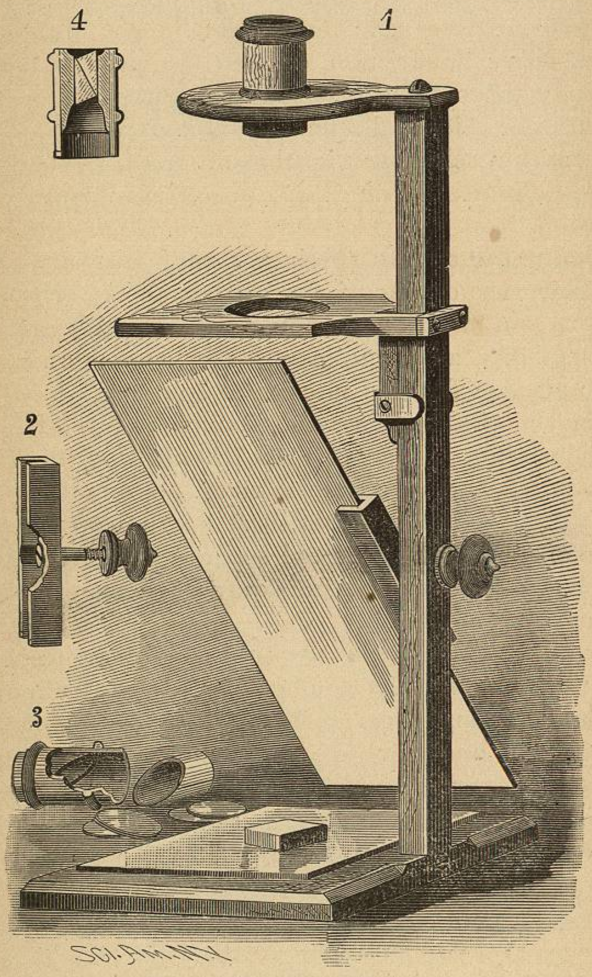
* The writer intends to deal sparingly with the theoretical part of this subject, especially the portion relating to circular and elliptical polarization, it having been treated extensively in many physical works and in books especially devoted to light and optics. Daniel's "Physics," prominent among works of its class, "Light," by Lewis Wright, and "Polarization of Light," by William Spottiswoode, are excellent books, bearing directly on the subject. The writer knows of no better means of securing a good knowledge of polarized light than by reading these three books.

possess the required qualities. Not every piece of mica will split evenly, therefore it may be necessary to make several trials before success is attained.

Should the film, when placed on the stage, exhibit a dull plum color, slightly inclined toward red, when the polarizer and analyzer are parallel, it produces a difference of phase of half a wave length, and is called a half wave film. As

FIG. 265.



Simple Norremberg Doubler.

a matter of course, if two films of like thickness, superposed and arranged with their axes in the same direction, produce the same color under the same circumstances, they are one-fourth wave films; and if a pair of films exhibit the same color when similarly arranged on the mirror of the doubler, they may be regarded as eighth wave films, as the polarized beam passes twice through the film to produce the same tint. These films should be carefully mounted between glass plates, either dry or in benzole balsam, the latter being preferable.

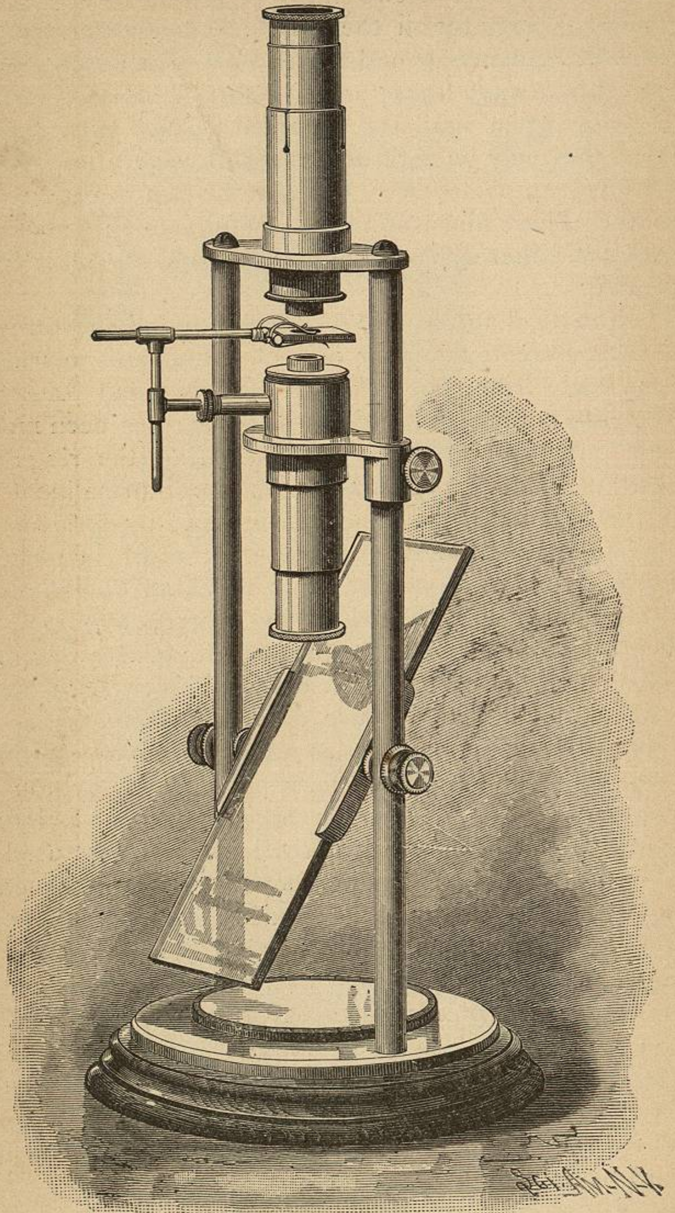
The practical application of the eighth and quarter wave films will be treated further on. Beautiful and instructive designs made from thin films are described and illustrated in Wright's "Light," to which reference has been made.

The only simple device for exhibiting the rings and brushes of wide-angled crystals is the tourmaline tongs (Fig. 274), of the kind commonly employed by opticians for testing spectacle lenses; but the dark color of ordinary tourmaline renders a polariscope of this kind objectionable.

A system of lenses devised by Norremberg, and improved by Hoffman, is at present employed for observing the phenomena of wide-angled crystals; but it is a matter of some difficulty to secure exactly such lenses as are required for the apparatus as constructed by Hoffman. Very good results, however, may be obtained by the employment of lenses designed for other purposes. Reference is made to the hemispherical condensing lenses used by microscopists, and ordinary meniscus (periscopic) spectacle lenses. Six lenses in all are required. The converging and collecting systems are exactly alike, but they are oppositely arranged with respect to each other. In the present case the two systems are adapted to a Norremberg doubler, Fig. 266, substantially like that described in a former part of this article, the main difference being that the instrument now illustrated is made principally of metal.

The tube of the upper system of lenses is prolonged upward beyond the upper lens, Fig. 267, to receive a Nicol prism, E, or other analyzer, which is mounted in a short inner tube arranged to revolve in the outer tube.

Fig 266.



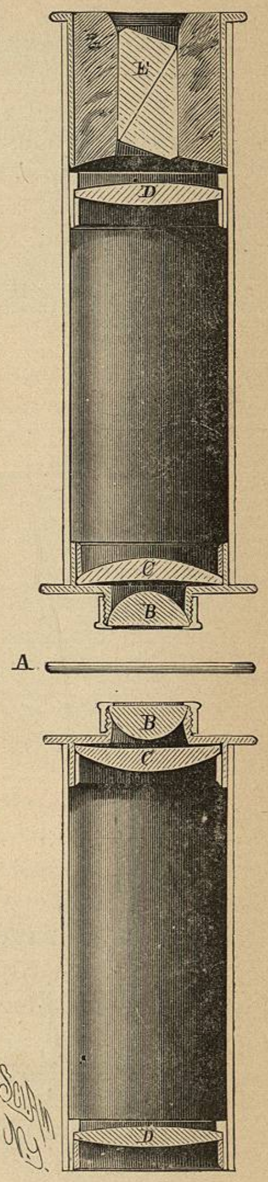
Polariscope for exhibiting Wide-angled Crystals.

The lower system of lenses is contained by a tube fitted to the stage of the doubler. The arrangement of the lenses and analyzer is shown in Fig. 267. The two systems of lenses being alike, a description of one will answer for both. The object, A, to be observed is held between the adjacent ends of the two tubes in the universal holder shown in Fig. 266.

The lens, B, next the object is nearly a hemisphere, about eleven-sixteenths inch in diameter and three-eighths inch focus. The second lens, C, a meniscus (periscopic) spectacle lens of 3 inch focus, is arranged with the concave face one-sixteenth inch from the convex side of the hemisphere. Beyond the 3 inch meniscus, 3½ inches distant, is placed a biconvex spectacle lens, D, of 4 inch focus. The inner surfaces of the tubes are made dead black by the application of a varnish formed of lampblack and alcohol, in which only a trace of shellac has been dissolved.

The tubes may have any suitable diameter, and the proportions of the doubler may be about the same as indicated by Fig. 266, which is one-quarter actual size. The tubes and lenses shown in Fig. 267 are one-half size. The exact proportions, except as to the focal lengths and distances apart of the lenses, are immaterial. The lower system of lenses must produce a very convergent beam of light, while the upper system is

Fig. 267.



Longitudinal Section of Tubes of Polariscope.

arranged to collect the rays after they pass through the crystal, and bring them within the range of vision.

The angle between the optic axes in some crystals is so small as to permit of seeing them readily. Niter and carbonate of lead are examples of such crystals; but there are other crystals whose angle is so great as to render it exceedingly difficult to exhibit them, and in some crystals the angle is so wide as to render it impossible to see both axes at once. The only method of exhibiting them is by tilting the crystal first in one direction and then in the other, and viewing them separately.

Figs. 268 to 273, inclusive, represent the figures shown by several crystals in the instrument illustrated. The drawings, having been made directly from the objects by the aid of the instrument, are correct in form and proportion, but the beautiful coloring is necessarily absent.

Fig. 268 shows the rings and brushes exhibited by calcite in a convergent beam of polarized light, with the polarizer and analyzer crossed. With the polarizer and analyzer parallel, the dark cross is replaced by a white one.

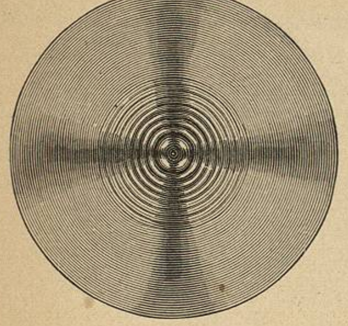
Niter is shown in Fig. 269 as it appears when the analyzer is crossed. With the analyzer parallel with the polarizing plate, the dark brushes are replaced by light ones. Turning the crystal in its own plane produces different effects.

In Fig. 270 is shown a figure produced by a slice of quartz cut at right angles to the axis of the crystal, and examined in the instrument with the analyzer arranged at an angle of 45° with the polarizer. Crystals of quartz vary in their effects on the polarized beam, some requiring the turning of the analyzer to the right and others to the left to produce like results. For this reason the plates are called right or left handed, according to the direction in which the analyzer is required to be turned.

By superposing a right hand quartz on a left hand quartz, the beautiful spirals discovered by Airy, and named after their discoverer, may be exhibited. These spirals are shown in Fig. 271.

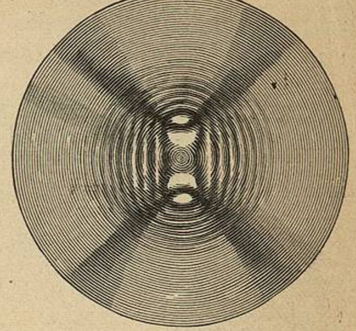
In Fig. 272 is shown the figure produced by the inter-

FIG. 268.



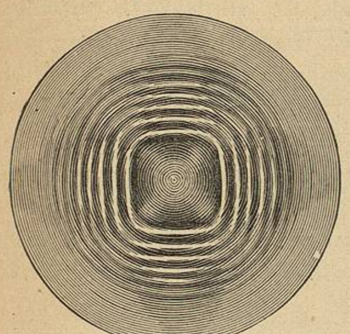
Calcite.

FIG. 269.



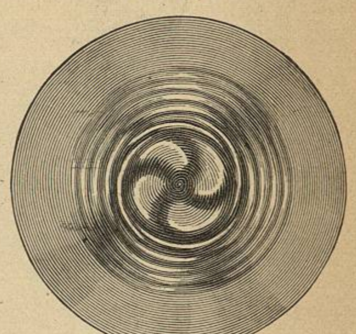
Niter.

FIG. 270.



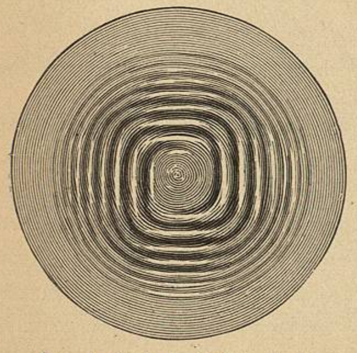
Quartz.

FIG. 271.



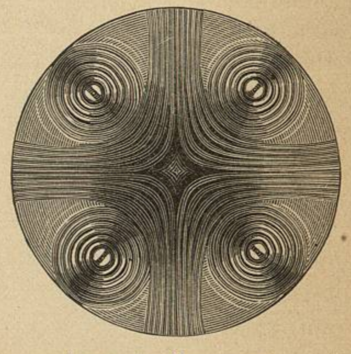
Airy's Spirals.

FIG. 272.



Quartz Polarized Circularly.

FIG. 273.

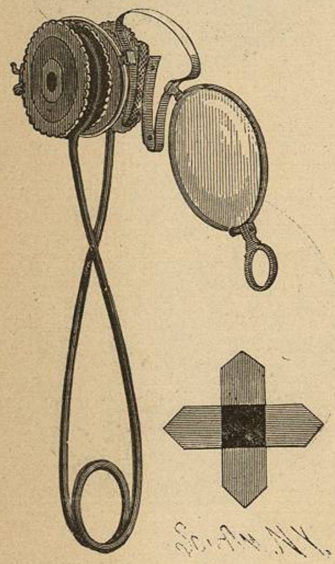


Aragonite Hemitrope.

position of a quarter wave mica film between the polarizer and a plate of quartz viewed in the instrument. This altered appearance is due to circular polarization, a phenomenon treated extensively in the literature of the subject, but requiring an explanation too elaborate for the space at command.

Calcite polarized circularly shows singularly broken up and disjointed rings, the brush-like cross being absent, and when analyzed circularly, or viewed through a quarter wave plate, as well as through the analyzer, the rings appear perfect, and there are no transverse markings.

Fig. 274.



Tourmaline Tongs.

Fig. 273 shows the intricate figure produced by aragonite hemitrope, or a pair of crystals arranged at right angles with each other. Somewhat similar figures are produced by crossed plates of mica.

The following is a list of some additional objects which may be viewed in the instrument:

Sulphate of nickel, sugar, aragonite, bichromate of potash, chrysoberyl, chrysolite, topaz, anhydrite. Instead of employing the Norremberg doubler for polarization, the lower tube may be prolonged, and a large Nicol prism inserted and arranged like the analyzer.

In Fig. 274 is shown the tourmaline tongs, the simplest polariscope known. It consists of two plates of tourmaline, cut parallel to the optic axis of the crystal, and mounted in cells arranged to turn in eyes formed at the extremities of the looped wire. When the plates are parallel, light passes through them; but when they are arranged at right angles with each other, the light is completely extinguished. If a plate of quartz crystal, a Brazilian pebble spectacle lens for

Fig. 275.

Polariscope for Large Objects.

example, be placed between the tourmalines arranged in this way, the light will again pass, showing that it has been depolarized by the rock crystal.

This has been accepted as an infallible test of the genuineness of quartz lenses. In the hands of an expert it is undoubtedly valuable, but glass lenses may be put under strain by heating them and allowing them to cool rather quickly. They will then, to some degree, act on the polarized beam like the true crystal.

This form of polariscope is useful in the examination of crystals generally, but on account of the natural dark color of the tourmaline, the utility of the instrument is limited.

In Fig. 275 is shown a polariscope designed for the examination of large objects, such as glassware, etc. It consists of a bundle of 16 glass plates, about 20 or 24 inches square, arranged with reference to the Nicol prism employed as an analyzer at an angle of 35° 25′. Behind the series of plates is hinged a board covered with black velvet, which may be raised up parallel with the glass plates when it is desired to polarize the beam by reflection.

The analyzer, a Nicol prism, is mounted in a revoluble tube, supported by the small adjustable standard. Articles to be examined are placed on the small table between the polarizer and analyzer.

The light for the polariscope should be taken through either a white paper or cloth screen or a plate of ground glass. Any strain in the article examined will exhibit itself by its depolarizing effect on the polarized beam.

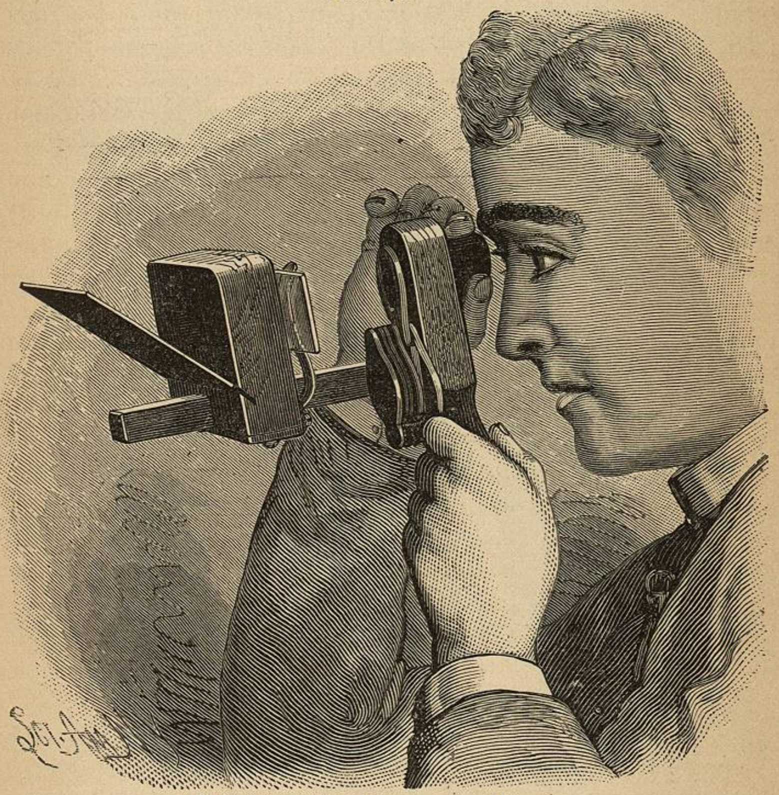
SIMPLE POLARISCOPE FOR MICROSCOPIC OBJECTS.

The examination of microscopic crystals by the aid of the polariscope is an exceedingly interesting part of the study of polarized light. The indescribable play of colors, and the variety of exquisite forms of the smaller crystals, render this branch of the subject very fascinating. But to undertake the examination of this class of objects in the usual way requires a microscope with the addition of a polariscope, which calls for an outlay of at least fifty dollars, besides the cost of the objects, and while it is believed that such an outlay would be indirectly, if not directly, profitable, it is not necessary to expend a fiftieth of that amount to arrive at very satisfactory results.

The cost of the compact and efficient little instrument shown in Fig. 276 is as follows:

One pocket magnifier, having two lenses $1\frac{1}{2}$ inches and 2 inches focus respectively, giving when combined a $\frac{3}{4}$ inch focus, 50 cents; eighteen elliptical microscope cover glasses for analyzer, 38 cents. The cost of wood for the principal parts, the pasteboard tubes, the glass for the polarizer, and the metal strips for the slide-holding springs, can hardly be counted, and the labor must be charged to the account of recreation; so that less than one dollar pays for an instru-

Fig. 276.



Polariscope for Microscopic Objects.