OPTICAL INSTRUMENTS AND METHODS.

324. Measurement of Refractive Indices. Refractometer.—For the determination of the refractive indices of crystallized minerals various methods are employed. The most accurate results, when suitable material is at hand, may be obtained by the ordinary refractometer. This requires the observation of the angle of minimum deviation (δ) of a light-ray on passing through a prism of the given material, having a known angle (a), and with its edge cut in the proper direction. The measurements of a and δ can be made with an ordinary refractometer or with the horizontal goniometer described in Art. **210**. For the latter instrument, the collimator is made stationary, being fastened to a leg of the tripod support, but the observing telescope with the verniers moves freely. Further, for this object the graduated circle is clamped, and the screw attachments connected with the axis carrying the support, and the vernier circle and observing telescope are loosened. Light from a monochromatic source passes through an appropriate slit and an image of this is thrown by the collimator upon the prism. With a doubly refracting substance two images are yielded and the angle of minimum deviation must be measured for each; the proper direction for the edge of the prism in this case is discussed later. In cases where the highest degree of accuracy is desired sunlight is employed and the angle of deviation measured for the prominent Fraunhofer lines (p. 171). When a and δ are known the formula in Art. **304** is used.

325. Total Reflectometer.—The principle of total reflection (Art. **303**) may also be made use of to determine the refractive index. No prism is required, but only a small fragment having a single polished surface; this may have any direction with an isometric crystal, but in other cases must have a definite orientation, as described later. The arrangements required (as developed by F. Kohlrausch) are, in their simplest form, a wide-mouthed bottle filled with a liquid of high refractive power, as carbon disulphide ($\mu_y = 1{\cdot}6442$ Na) or α-bromnaphthalin ($\mu_y = 1{\cdot}6626$ Na). The top is formed by a fixed graduated circle, and a vertical rod, with a vernier attached, passes through the plate and carries the crystal section on its extremity, immersed in the liquid. The angle through which the crystal surface lying in the axis is turned is thus measured by the vernier on the stationary graduated circle. The front of the bottle is made of a piece of plate glass, and through this passes the horizontal observing telescope, arranged for parallel light. The rest of the surface of the bottle is covered with tissue-paper, through which the diffuse illumination from say a sodium flame has access; the rear of the bottle is suitably darkened. When now the observer looks through the telescope, at the same time turning the axis carrying the crystal section, he will finally see, if the source of illumination is in a proper oblique direction, a sharp line marking the limit of the total reflection. The angle is measured off on the graduated circle, when this line coincides with one of the spider lines of the telescope. Now the crystal is turned in the opposite direction, and the angle again read off. Half the observed angle (2α) is the angle of total reflection; if μ is the refractive index of the carbon disulphide, then the required refractive index, n, is equal to

$$\mu \sin \alpha.$$

Under favorable conditions the results are accurate to four decimal places. This method is limited, obviously, to substances whose refractive index is less than that of the liquid medium with which the bottle is filled.

Different forms of total reflectometers* have been devised by Soret, Pulfrich, Czapski, and others.

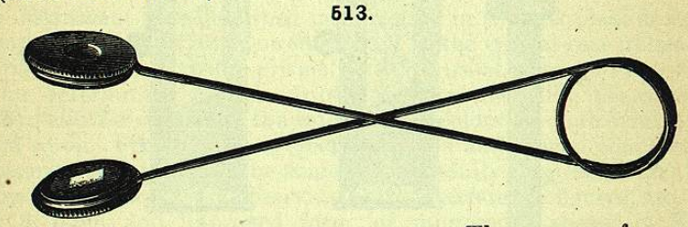
326. The method of obtaining the refractive index of a transparent medium, first described by Duke de Chaulnes (1767), has been shown by Sorby† to allow, under suitable conditions, of determinations of considerable accuracy. This method consists essentially in observing the distance (d) which the focal distance of the objective is changed when a plane-parallel plate of known thickness (t) is introduced perpendicular to the axis of the microscope between the objective and the focal point, here

$$\mu = \frac{t}{t - d}.$$

Sorby made use of a glass micrometer, upon which two systems of lines perpendicular to each other were ruled. A micrometer-screw in the microscope makes it possible to measure the distance through which the tube is raised and lowered down to ·001 mm.; consequently both t and d can be obtained with a high degree of accuracy.‡

327. Tourmaline Tongs.—A very simple form of polariscope for converging light is shown in Fig. 513; it is convenient in use, but of limited application. Here the polarizer and analyzer are two tourmaline plates such as were described in Art. **317**. They are mounted in pieces of cork and held in a kind of wire pincers. The object to be examined is placed between them and supported there by the spring in the wire. In use they are held close to the eye, and in this position the crystal section is viewed in *converging* polarized light, with the result of showing (under proper conditions) the axial interference-figures (Arts. **360** and **387**).

513.



328. Polariscope. Conoscope. Stauroscope.—The common forms of polariscope§ employing nicol prisms are shown in Figs. 514 and 515.‖ Fig. 514 represents the instrument arranged for converging light, which is often called a *conoscope*.

The essential parts are the mirror S, reflecting the light, which after passing through the lens e is polarized by the prism p. It is then rendered strongly converging by the system of lenses nn, before passing through the

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* See Groth, Phys. Kryst., 1895, pp. 654–679; also Das Reflectometer, etc., von Dr. C. Pulfrich, Leipzig, 1890.

† Min. Mag., **2**, 1. 101, 1878.

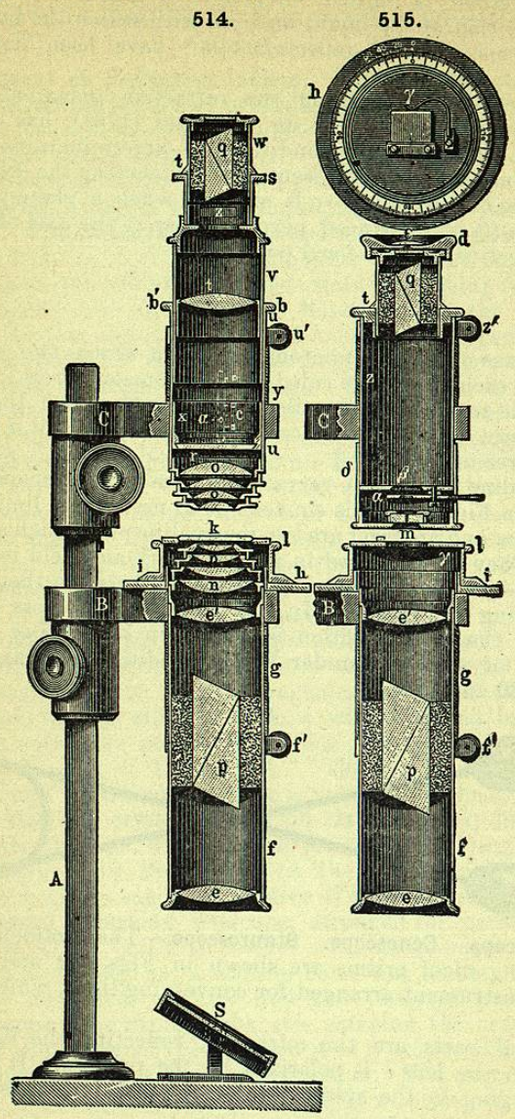
‡ Cf. Rosenbusch, Micr. Phys. Min., p. 84, 1892, who mentions particularly methods applicable to minerals in thin sections.

§ See further, Groth, Phys. Kryst. (also Pogg. Ann., **144**, 34, 1871).

‖ These figures, also Figs. 516, 517, 544, are taken from the catalogue of R. Fuess, Steglitz, Berlin.

section under examination placed on a plate at *k*. This plate can be revolved through any angle desired, measured on its circumference. The upper tube

514. 515.



contains the converging system *oo*, the lens *t*, and the analyzing prism *q*. The arrangements for lowering or raising the tubes need no explanation, nor indeed the special devices for setting the vibration-planes of the nicols at right angles to each other.

The accompanying tube (Fig. 515) shows the arrangement for observations in parallel light, the converging lenses having been removed. In this form it

is especially used for stauroscopic measurements, as later explained. In some forms of polariscope of the above type the place of the analyzer is taken by a pair of black glass mirrors set at the proper polarizing angle.

329. Polarization-Microscope.—The investigation of the form and optical properties of minerals when in microscopic form has been much facilitated by the use of microscopes* specially adapted for this purpose. First arranged with reference to the special study of minerals as seen in thin sections of rocks, they have now been so elaborated as largely to take the place of the older optical instruments. They not only allow of the determination of the optical properties of minerals with greater facility, but are applicable to many cases where the crystals in hand are far too small for other means.

A highly serviceable microscope, for general use, is that described by Rosenbusch in 1876 and later much improved. A sectional view of one form is shown in Fig. 516, and a later and improved pattern is given in Fig. 517. The essential arrangements of Fig. 516 are as follows: The tube carrying the eyepiece and objective has a fine adjustment-screw at *g*; the coarse adjustment is accomplished by the hand. The screw-head *g* is graduated and turns about a fixed index attached to the tube *p*; by this means the distance through which the tube is raised or lowered can be measured to 0·001 mm. The polarizing prism is placed below the stage at *r*, in a support with a graduated circle, so that the position of its vibration-plane can be fixed. The analyzing prism is contained in a cap, *ss*, which is placed over the eyepiece; this may be revolved at pleasure, its edge being graduated. When both prisms are set at the zero mark, their vibration-planes are crossed ($\perp$); when either is turned 90°, the planes are parallel ($\parallel$). The stage is made to rotate about the vertical axis, but otherwise (in this simple form) is fixed; its edge is graduated, so that the angle through which it is turned can be measured to $\frac{1}{2}°$. Three adjustment-screws, of which one is shown at *n*, *n*, make it possible to bring the axis of the object-glass in coincidence with axis of rotation of the stage (see, further, the detailed drawing at the side).

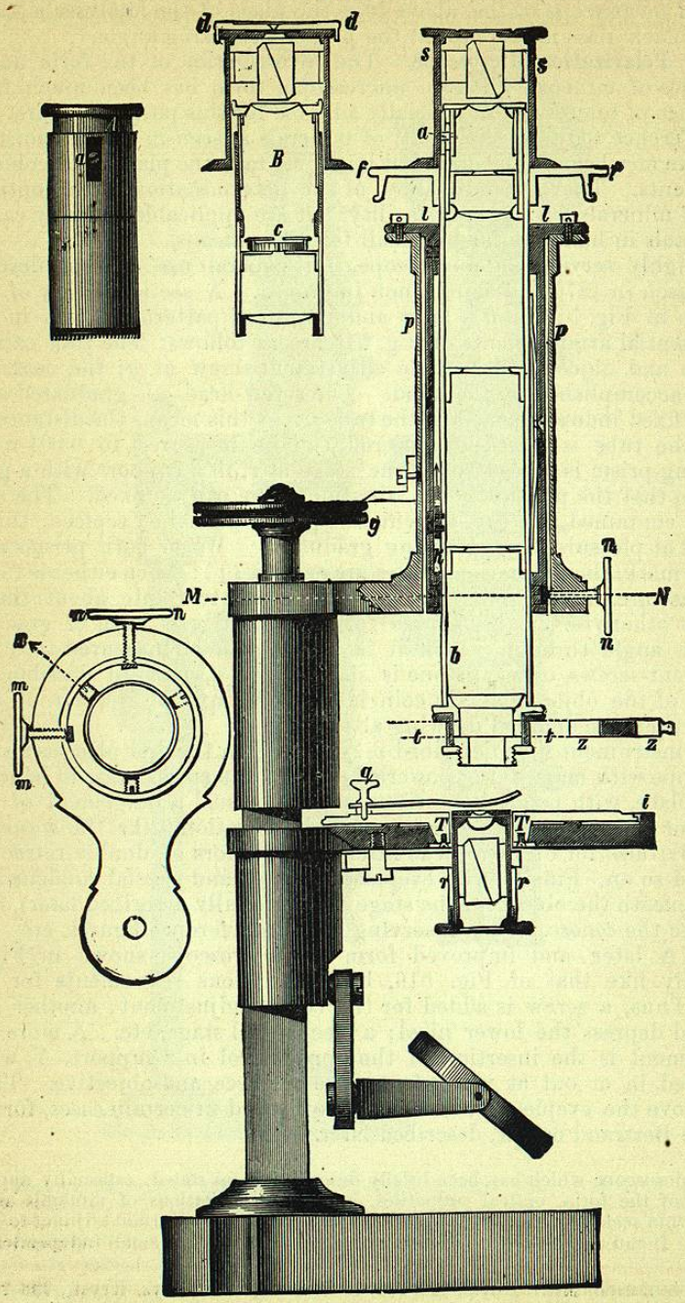
The instrument here described may be used in the first place as an ordinary microscope with magnifying power adapted to the special case in hand. In the second place, with polarizing prisms and the usual arrangement of lenses, it serves for determining the planes of light-vibration (like the *stauroscope* of Art. **328**); also for observing the interference-colors of doubly refracting sections and so on. Finally, with eyepiece removed and special condensing lenses added beneath the object on the stage (as more fully described later), it may be used, like the *conoscope*, for observing axial interference-figures, etc.

330. A later and improved form of microscope shown in Fig. 517 is essentially like that of Fig. 516, but has various refinements for accurate work. Thus, a screw is added for the coarse adjustment; another screw to raise and depress the lower nicol; a mechanical stage, etc. A more essential improvement is the insertion of the upper nicol in a support, *N*, which can be pushed in or out at will *between* the eyepiece and objective. The upper nicol above the eyepiece is, however, also needed in certain cases, for example with the Bertrand ocular, described later.

The microscope which has been briefly described is, as stated, especially applicable to the study of the form, optical properties, and mutual relations of minerals as they are found in thin sections of rocks; it has therefore become an important adjunct to geological research. It can also be used to great advantage in the study of small independent crystals

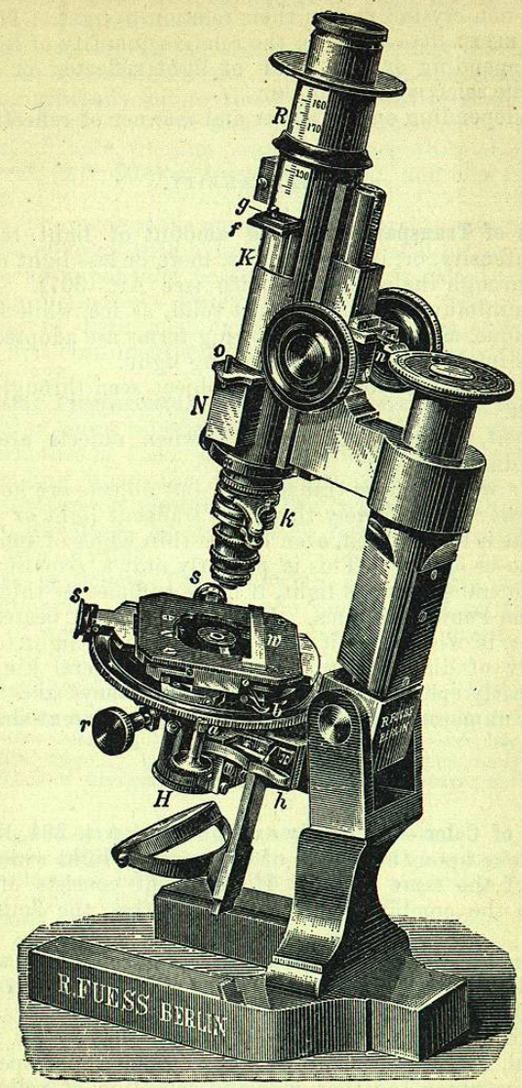
*See Rosenbusch, Mikr. Phys., 117–130, 1892; also Groth, Phys. Kryst., 733–756, 1895.

516.



and crystalline sections or fragments. The more important points to which the attention is to be directed, more particularly in the case of minerals in sections of rocks, are: (1) crystalline form, as shown in the outline; (2) direction of cleavage-lines; (3) refractive

517.



index; (4) light-absorption in different directions, *i.e.*, dichroism or pleochroism; (5) the isotropic or anisotropic character, and if the latter, the direction of the planes of light-vibration—this will generally decide the question as to the crystalline system; (6) position of the axial plane and nature of the axial interference-figures; (7) the strength and character (+ or −) of the double refraction; (8) inclusions, solid, liquid, or gaseous. The explanation in regard to the special optical points mentioned is deferred to later pages.