of the two verniers. The above measurements, in this method, would appear as follows :

	On First Face	On Second Face
Vernier A	335° 5′ 20″	95° 7′ 10″
Vernier B	2 20	6 40
Mean	335° 3′ 50″	95° 6′ 55″
Angle	120° 3′ 5″	

The method of averaging the entire readings of the two verniers for each setting should be avoided, as it is more cumbersome.

CVII. ANGLE OF A PRISM WITH THE SPECTROMETER

Measure the angle of a prism with the spectrometer by three methods.

174. Adjustment of Prism. *Mounting the Prism.* — Before beginning the work with the prism, the spectrometer should have been completely adjusted, as described in the preceding exercise. These adjustments must not be disturbed while placing the prism in its proper position.

Mount the prism on a support with three leveling screws, place it upon the spectrometer table with one face towards the telescope, and level the prism by inspection. For convenience it is desirable that the angle between the two lines joining one of the leveling screws in the base of the prism holder to the two other screws, should be the same as the angle between the two faces of the prisms. When this is true so place the prism on its support that each of its two edges shall be perpendicular to one of these lines joining the leveling screws. Then (Fig. 89) the face AB can be leveled by the screw D without disturbing the level of the face AC; and the face AC may be leveled by the screw F without disturbing the face AB.

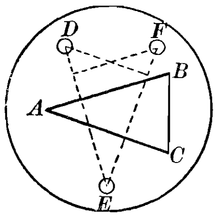

Fig. 89. Position of Prism on Stand

Before beginning the adjustment of the prism, it will be well to turn the table and telescope into all the several positions

which they will later occupy in making the measurements, to observe whether it will be possible to read the two verniers of the divided circle for each of the settings. Sometimes one vernier may come under the collimator or telescope and be inaccessible. This difficulty may usually be obviated by altering the direction in which the prism stands on the table.

It should also be noticed whether in these positions the prism faces are in the most advantageous relations to the objectives of the collimator and telescope. The best position is not always that in which the prism holder is centrally placed on the spectrometer table.

To adjust the Prism. — The two prism faces must be parallel to the vertical axis of the spectrometer table (or of the telescope). Arrange the collimating eyepiece and light to observe the reflected image of the cross wires from the first face of the prism, as described in Art. 172. By turning the spectrometer table and by altering the leveling screws in the prism support only, bring the reflected cross into coincidence with the direct image. The first face is then in position. Turn the spectrometer table till the cross wires are seen reflected from the second face of the prism, and by the principle illustrated in Fig. 89 adjust the second face. This should not have disturbed the first face; but reobserve the cross in the first face, correcting any displacement which may have occurred. Continue thus until the reflected image from either face coincides with the direct image, when the prism will be in adjustment.

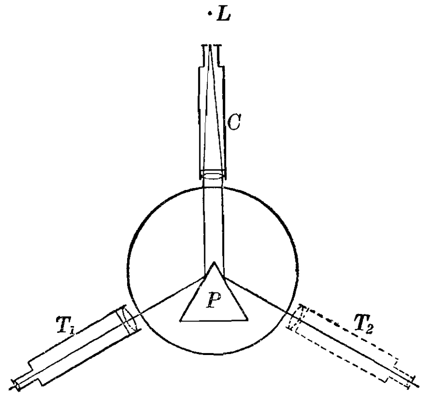

Fig. 90. Angle of Prism — Method I

175. Angle of Prism; First Method. *Without Collimating Eyepiece; Table fixed, Telescope movable.*— Place a light, L (Fig. 90), to illuminate the slit. Turn the prism P with its refracting edge toward the collimator C, dividing the beam of light, part falling on one face of the prism and part on the other. The exact position of the prism is not important. Clamp all the movable parts of the spectrometer except the telescope. Set the telescope in the position T_1, on the image of the slit reflected from the first prism face. Read the two verniers of the divided circle, as explained in Art. 173. Turn the telescope to the position T_2, and set on the image of the slit reflected from the second face.

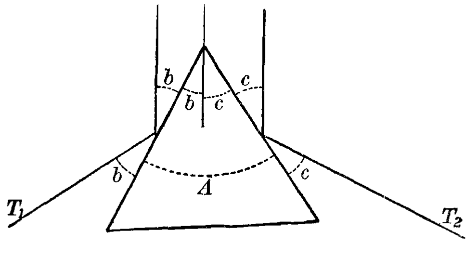

FIG. 91. RELATION OF ANGLES — METHOD I

The angle through which the telescope has been turned is twice the prism angle. For (Fig. 91) it has moved through the angle $b + A + c$. It is evident that the three angles b are all equal, and the same is true of the three angles c; also $b + c$ is equal to A; therefore $b + A + c = 2A$, twice the prism angle.

176. Angle of Prism; Second Method. *Without Collimating Eyepiece; Table movable, Telescope fixed.* — Turn the telescope of the spectrometer as near to the collimator as is convenient, and clamp all parts except the table. Illuminate the slit. Rotate the table until the image of the slit, reflected from one face of the prism, is set on the cross wires of the telescope (Fig. 92). Read the two verniers, as described in Art. 173. Rotate the table to bring the second prism face into position to reflect the image of the slit to the cross wires.

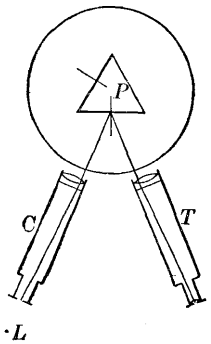

FIG. 92. ANGLE OF PRISM — METHOD II

The angle through which the table has been turned is the supplement of the prism angle; for in the first position the normal to one face bisects the angle between the axes of the telescope

and collimator, and in the second position the normal to the other face is turned to this same direction. The angle between the normals is the same as the angle between the two faces (Fig. 93), but the table has clearly been turned through the supplement of this angle.

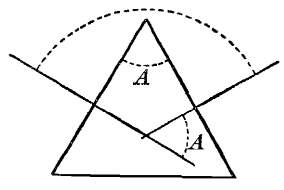

FIG. 93. RELATION OF ANGLES — METHODS II AND III

177. Angle of Prism; Third Method. *With Collimating Eyepiece; either Telescope or Table fixed, the other being movable.* — Clamp the telescope, and arrange a light, the collimating eyepiece, and the prism, to obtain the direct and reflected images of the cross wires (Fig. 94), as described in Art. 172. Secure coincidence between the two images by rotating the table only, which is possible if the adjustments have not been disturbed. Read the verniers; rotate the spectrometer table till coincidence between the direct and reflected images of the cross wires is secured with the second prism face, and again read the verniers.

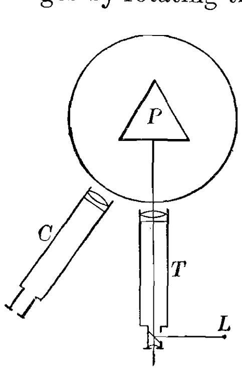

FIG. 94. ANGLE OF PRISM — METHOD III

From Fig. 93 it is clear that the table has been turned through an angle which is the supplement of the prism angle.

If the table is fixed, the telescope may be turned from one coincidence to the other, in which case the light must also be moved; or the spectrometer may be turned on its base, the telescope being held during the motion. This will avoid moving the light, and may keep the telescope in a more convenient position. This third method for measuring the angle between two reflecting surfaces is the most precise one.

CHAPTER XVI

INDEX OF REFRACTION

CVIII. INDEX OF REFRACTION BY MINIMUM DEVIATION

Find the index of refraction of a prism for sodium light.

178. Index of Refraction. — Light moves with different velocities through different media. The ratio of its velocity in vacuum, in which its velocity is greatest, to its velocity in any other medium is the *absolute index of refraction* of this medium. It is not practicable to compare these velocities directly. When light passes from one medium into a second, its direction of propagation in the second medium as compared with its direction in the first is a function of the angle of incidence upon the bounding surface and of the indices of refraction of the two media. If i is the angle of incidence, r the angle of refraction, n_1 and n_2 the indices of refraction of the two media, then

$$\sin r = \sin i \frac{n_1}{n_2}.$$

In laboratory measurements the first medium is usually air; if the index of refraction of air is taken as unity, the *relative index of refraction* of the second medium is

$$n = \frac{\sin i}{\sin r}.$$

In the particular case of light passing through a prism in the direction of minimum deviation, the relative index of refraction of the prism is

$$n = \frac{\sin \frac{1}{2}(A + D)}{\sin \frac{1}{2} A},$$

where D is the angle of minimum deviation (Art. 179) and A is the refracting angle of the prism (Art. 175).

The index of refraction of a liquid may be determined by this method, the liquid being contained in a hollow prism having sides of plane-parallel plates which will have no deviating effect.

If the index of refraction of a second medium relative to the first is multiplied by the absolute index of refraction of the first medium, the result is the absolute index of refraction of the second medium. The absolute index of refraction of air at 20° under normal pressure is 1.0002773.

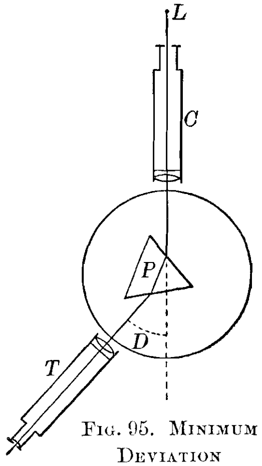

Fig. 95. Minimum Deviation

179. Angle of Minimum Deviation. — The spectrometer and prism are to be completely adjusted by the methods described in Arts. 172–174. Illuminate the slit with the kind of light for which the index of refraction is desired, and so place the prism and telescope (Fig. 95) that the spectrum is visible in the telescope. For finding the spectrum, a luminous flame is desirable, as it gives a bright, continuous spectrum. Even when the sodium spectrum is to be examined it is not necessary to use the Bunsen flame; a borax bead, placed in the luminous gas flame, gives bright yellow sodium lines in the continuous spectrum, which are very convenient for observation.

Having found the spectrum in the telescope, rotate the prism, following the motion of the spectrum with the telescope, in such a manner as to cause the deviation D, of the light by the prism, to have the least possible value. This position of the prism is a definite one, and is readily found by trial; a rotation of the prism in either direction from this point causes the deviation to increase. Set the telescope on the sodium line when the prism is at this turning point of minimum deviation.

Turn the prism (not the divided circle) on the table so that it produces deviation on the opposite side, as indicated in Fig. 96, and set the telescope on the sodium line when the prism is adjusted for minimum deviation as before.

The angle between the two positions of the telescope is twice the angle of deviation D. In making the circle readings, use the two verniers as described in Art. 173.

Instead of finding the deviation on the second side, the prism might have been removed after the first setting, and the telescope sighted directly on the slit through the collimator. Then the angle between the two positions of the telescope is the angle of minimum deviation. The first method is preferable.

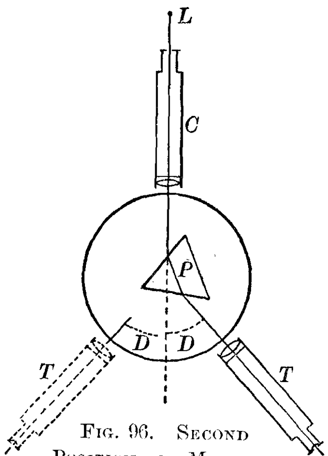

FIG. 96. SECOND POSITION FOR MINIMUM DEVIATION

CIX. INDEX OF REFRACTION WITH A MICROSCOPE

Determine the index of refraction of a piece of plate glass, and of water, alcohol, and carbon bisulphide, using a microscope.

180. Index of Refraction with a Microscope. — Any transparent substance which can be put in the form of a plane-parallel plate of suitable thickness may have its index of refraction determined with an ordinary microscope, with an accuracy giving two or three decimal places in the result. The objective of the microscope must have such a focal length (working distance) as to permit an object to be seen through the plate. The accuracy of the result is increased by using a plate of the greatest possible thickness together with a microscope objective of the shortest focal length that will permit observation through the thick plate.

Let c (Fig. 97) be any object, as a fine scratch on a piece of glass, over which is placed the plate of thickness t whose index of refraction is desired; and let cam be the path of a ray of light through the plate and air to the microscope when the

latter is accurately focused. The light enters the microscope as though it had come from the point b; that is, the plate has apparently elevated the object from c to b, represented by e. The angles of incidence and refraction are represented by i and r respectively. From the figure it is evident that, in the triangle abc,

$$\frac{ac}{ab} = \frac{\sin i}{\sin r} = n,$$

the desired index. But in actual microscopic observation the distance ao is very small as compared with ab and ac, and

$$\frac{ac}{ab} = \text{(approximately)}\ \frac{oc}{ob} = \frac{t}{t-e};$$

to this degree of approximation, then,

$$n = \frac{t}{t-e}.$$

The thickness, t, may be measured with calipers, and the apparent elevation, e, of the object by the plate is measured by noting the difference between the two positions of the microscope body when it is focused on the object uncovered and on the object covered by the plate. For measuring this distance a scale may be fastened with wax to the stand of the microscope, and a needle for a pointer to the body tube; or the fine focusing screw, if of known pitch, may be used. If the pitch is unknown, both the thickness of the plate and the elevation may be determined in terms of turns of the screw, giving the index of refraction as before. The thickness may be measured, in the first case, by focusing upon the uncovered object and then

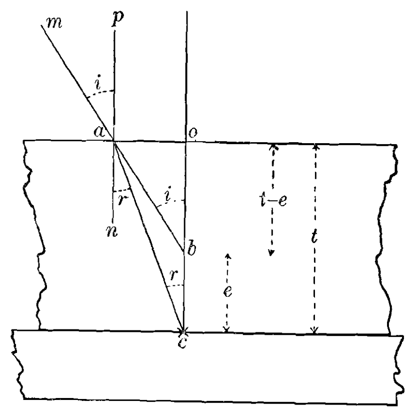

FIG. 97. INDEX OF REFRACTION WITH A MICROSCOPE

upon the upper surface of the plate when it is in position, in contact with the object.

If the plate has scratches or other marks on both surfaces, and the thickness t has been measured with calipers or otherwise, it is only necessary to focus upon the top surface and upon the lower surface through the plate, noting the depression d of the microscope. Then the index of refraction of the plate is

$$n = \frac{t}{d}.$$

In determining the index of refraction of liquids, a crystallizing dish is convenient for the receptacle. Make a fine mark on the inside of the bottom of the dish. Focus upon this, and let the scale reading be r_1; pour in the liquid to a depth as great as will allow the mark to be seen through the liquid, focus, and let r_2 be the reading; focus upon the upper surface of the liquid, which may be indicated by some floating particle, and let r_3 be the scale reading. Then the index of refraction is, as before,

$$n = \frac{r_1 - r_3}{r_2 - r_3}.$$

CX. INDEX OF REFRACTION BY DISPLACEMENT

Determine the index of refraction of a thick plane-parallel disk of glass.

181. Index of Refraction by Displacement. — A thick plate with two plane-parallel surfaces, such as a glass disk, may have its index of refraction determined by the following displacement method. The measurements may be made with simple or with more elaborate apparatus, according to circumstances and the precision required.

Let a telescope be set to view a divided scale, S, in the direction VS (Fig. 98). Set the plate whose index is desired between the telescope and scale, with its plane faces perpendicular to the line of sight. This condition is secured with sufficient accuracy by observing with the telescope that there is no apparent displacement of the scale seen through the plate. Let S be the

point of the scale under the cross wires. Rotate the plate about an axis perpendicular to the plane containing the line of sight and the scale; the scale will appear displaced, the point x now being seen under the cross wires. Let d be the amount of this displacement, t the thickness of the plate, and i the angle through which the plate has been turned. The angle of incidence of the light on the plate is i, and the angle of refraction, r, is to be found. Without detailed explanation it is evident that the following equations are true.

$$\tan r = \frac{eb}{t} = \frac{cb - ce}{t} = \frac{t \tan i - \dfrac{fe}{\cos i}}{t}$$

$$= \tan i - \frac{d}{t \cos i}.$$

The index of refraction of the plate is

$$n = \frac{\sin i}{\sin r}.$$

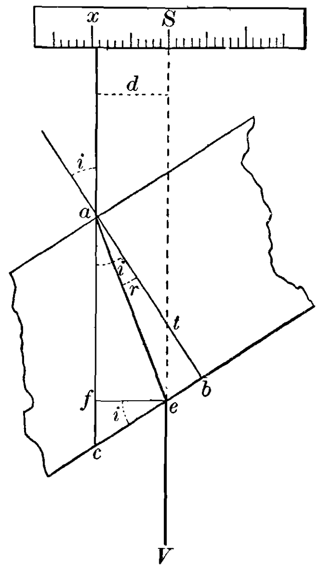

Fig. 98. Displacement by Refraction

The rotation of the plate may be measured with a protractor, or by placing the plate on an engineer's transit, or on the table of a goniometer or spectrometer.

CXI. INDEX OF REFRACTION BY TOTAL REFLECTION

Determine by Kohlrausch's method the index of refraction of a crown glass plate immersed in carbon bisulphide, of turpentine in a glass box, of a drop of Canada balsam, and of water by the immersion of an air-filled box.

182. Total Reflection. — Light moving in one medium whose index of refraction is N to the surface of another medium of