of the spectrometer telescope at right angles to its axis of rotation in the spectrometer. We shall explain the accomplishment of this setting in sec. 5.9.

5.9. The Spectrometer. The spectrometer is one of the most important optical instruments. It is usually employed for the study of the spectrum produced by the transmission of light through a dispersion producing device like a prism or a grating. Quantitatively, it is always employed for the measurement of an angle, for example the angle of a prism, the angle of minimum deviation and the angle of diffraction of light due to transmission of light through a plane diffraction grating. We shall describe the measurement of the angle of diffraction with the help of a spectrometer in the chapter 12 on *Diffraction of light—Fraunhofer Class.*

The essential parts of the spectrometer illustrated by Fig. 5.19 are

(*i*) *A collimating device* or collimator which serves the purpose of rendering parallel the rays of light to be examined by the spectrometer.

(*ii*) *A turn table* on which a dispersion producing device like a prism or a grating, can be conveniently mounted.

(*iii*) *A telescope* for examining the spectrum.

The collimator simply employs a well constructed achromatic lens at one end of a tube, and sliding within it at its other end is another tube carrying a vertical slit of adjustable width. The relative position of the two tubes can be adjusted by a rack and pinion arrangement and in this way the slit can be adjusted, as explained later with regard to the adjustment of the spectrometer,

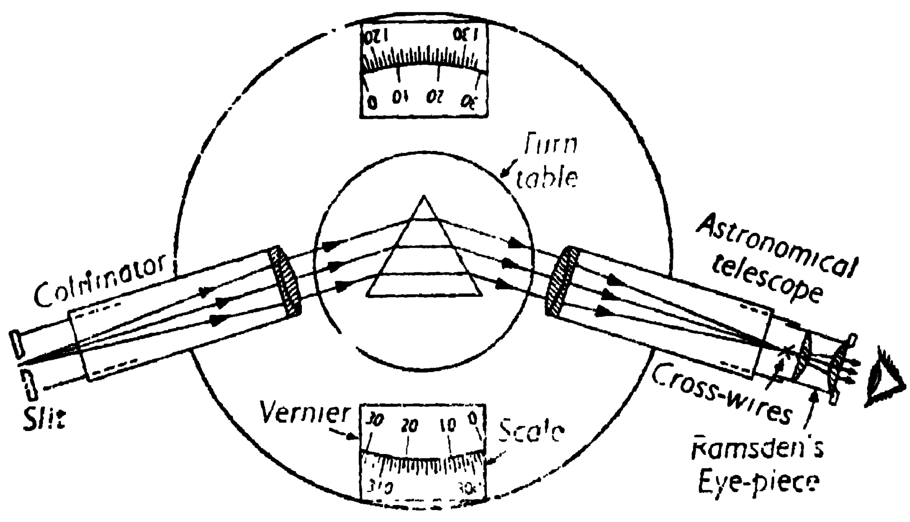

Fig. 5.19. The Spectrometer.

in the first principal focal plane of the collimating lens. In this setting of the collimator, the rays of light, under examination, after passing through the slit are rendered parallel by the collimator lens. The collimator tube is usually fixed in the instrument with its axis horizontal and intersecting the vertical axis, which passes through the centre of the circular scale, graduated in half-degree, fixed at the base of the instrument.

The parallel beam of light emerging from the collimator falls on the prism resting on a table, which can be rotated independently of the collimator and telescope, about a vertical axis which passes through its centre as well as through the centre of the circular scale. The rotation of the table can be read by the help of the diametrically positioned verniers sliding over the circular scale. The turn table can also be adjusted to any desired height and clamped. The slow rotation can be now given with a tangent screw provided at the base of the instrument. The table is provided with three screws P, Q and R, which form the three corners of an equilateral triangle. By the help of these screws the plane of the table can be made as nearly horizontal as possible. The surface of the table is usually ruled with straight lines parallel to the line joining two of the levelling screws. These lines assist in setting the prism with one of its faces normal to them.

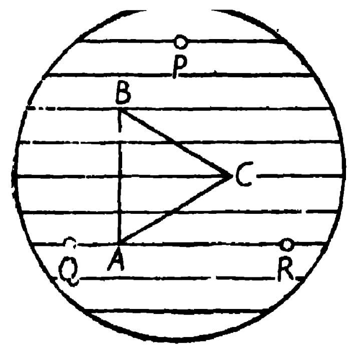

Fig. 5.20. Turn Table.

The refracted beam from the prism is examined by an astronomical telescope described in sec. 5.6 and provided with a Ramsden's eye-piece. The tube carrying the lenses which constitute the Ramsden's eye-piece can slide within the tube carrying the cross-wires. The two tubes are fixed to the third tube which slides within the tube carrying the objective. Thus the distance between the plane of cross-wires and the objective can be varied by the help of a rack and pinion arrangement. The telescope tube with its axis horizontal and pointing towards the axis of the spectrometer is fixed in a arm which can be rotated about the vertical axis of the instrument. This rotation can also be read with the help of another pair of diametrically positioned verniers which slide with the telescope arm, on the circular scale. The telescope arm can be clamped and slow rotation can be accomplished with the help of a tangent screw. The collimator and the telescope are provided with the levelling as well as the locking screws.

Adjustment of the Spectrometer. Before using the spectrometer for any experiment the following adjustments must be made in the instrument.

(a) *The axis of the telescope and that of the collimator must intersect the principal vertical axis of rotation of the telescope.* This adjustment is usually done by the makers of the instrument. However, the student may verify this adjustment by mounting a pin vertically at the centre of the prism table and observing, through a wide slit of the collimator, the image of pin formed by the collimator lens. If the adjustment of the axis of the collimator is perfect, the image must be in the centre of the field of view, but if otherwise, the collimator tube should be slightly rotated about its vertical axis till the image of the pin is visible exactly in the centre of the field of view.

After removing the eye-piece the same adjustment may be verified or made in an exactly similar way for the telescope axis.

(b) *The telescope must be focussed for parallel rays and the collimator must be adjusted for rendering the rays of light from the illuminated slit parallel.* To carry out this adjustment it is essential first to focus the eye-piece on the cross wires. This is accomplished by directing the telescope towards some non-distant white surface and moving the cross-wires tube and the eye-piece tube (Ramsden's eye-piece) relative to each other until the image of the cross-wires formed by the eye-piece is seen as distinctly as possible through it. This adjustment fixes the relative distance of the eye-piece and the cross-wires. The telescope is now focussed for parallel rays by a method given by Schuster, which also adjusts simultaneously the collimator for rendering the rays parallel.

The collimator slit is illuminated preferably with monochromatic light source and the prism is placed on the turn table and rotated to the position of minimum deviation of the refracted ray through the prism. The prism is then turned slightly by rotating the turn table so that the deviation of refracted image of the slit is slightly greater than the minimum deviation. From the shape of the i versus δ curve it is evident that any deviation other than the minimum can be obtained for two values of the angle of incidence, which correspond to two possible positions of the prism, provided the direction of the incident ray is kept fixed. In one position of the prism, shown by solid triangle in Fig. 5.22 (a) the angle of incidence i_2 is greater than i the angle of incidence of the same ray when refracted at minimum deviation. On the other hand, in the second position

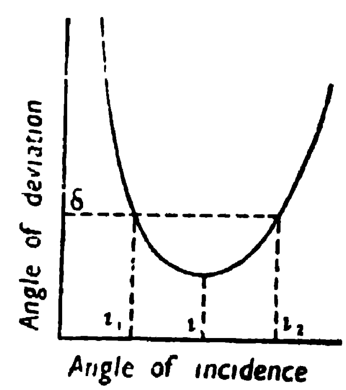

Fig. 5.21. The incidence deviation curve.

of the prism shown by solid triangle in Fig. 5.22 (*b*), the angle of incidence i_1 is less than i. The position of the prism for minimum deviation in both the figures is represented by the dotted triangle. Consequently, as proved in sec. 1.3 in the first case [Fig. 5.22 (*a*)] the incident beam becomes more parallel after refraction by the prism; on the other hand, in the second case [Fig. 5.22 (*b*)] the incident beam becomes less parallel after refraction by the prism. To apply these results to the spectrometer, let us suppose that the collimator and telescope are out of adjustment and the image is blurred. When the refracting edge of the prism is moved from the minimum deviation position towards the telescope [Fig. 5.22 (*a*)], the light falls more obliquely on the prism. Since in this setting of prism, the incident beam becomes nearly parallel after refraction, the telescope should be focussed on the image of the slit. The telescope is thus being adjusted to focus a more nearly parallel beam than that emerging from the collimator. This obviously brings the telescope near to its adjustment for focussing parallel rays. Next, the prism is rotated to the other side of the minimum deviation position, that is, the refracting edge is turned through a small angle towards the collimator, beyond its position corresponding to minimum deviation. In this setting of the prism, the parallel nature of the incident beam will be further impaired on accoun t of refraction through the prism. Therefore the parallelism of the emergent beam from the prism can be only improved by increasing the parallelism of the incident light itself. Hence the collimator must be now adjusted so that the sharp image is again seen through the telescope. This obviously brings the collimator nearer to its adjustment for rendering the rays from the slit parallel on refraction through the collimator lens. Next, the prism is again rotated to first setting [Fig. 5.22 (*a*)] and if the image of slit is not quite sharp the telescope is refocussed on the image and so on, alternatively. A few repetitions of this focussing process for the telescope and the collimator should give a good adjustment

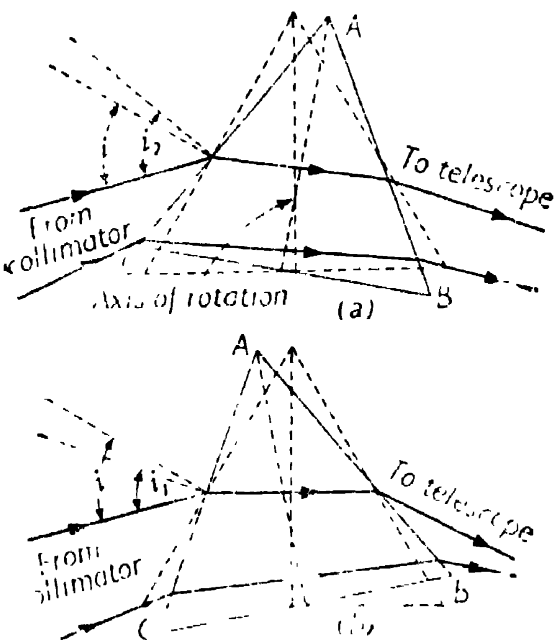

Fig. 5.22. Schuster's method of focussing telescope and collimator.

of both for parallel rays. However, if a mistake is made in the order of focussing the telescope and the collimator, the adjustment becomes rapidly and obviously worse, that is, image becomes more and more indistinct and serves as an indication of the wrong order in the focussing process.

(*c*) *The optical axis of the telescope and that of the collimator must be perpendicular to the principal axis of the instrument.* This adjustment of the optical axis of the telescope can be carried out by the help of the Gauss eye-piece. The light from a source enters the eye-piece tube through the side opening and is reflected by the glass plate as is shown in Fig. 5.23, towards the telescope objective. The reflected light illuminates the cross-wires in its path. The light emerging from the objective is allowed to fall on optically plane parallel glass plate G, mounted on the prism table. By the help of levelling screws the inclination of the plate is adjusted so as to reflect back the light along its own path. If this adjustment is perfect, the cross-wires would coincide with its own reflected image. The table is now turned through 180°, the plate now occupies the position G' in Fig. 5.23. In effect, the reflecting surface is turned through 2θ, where θ is the inclination

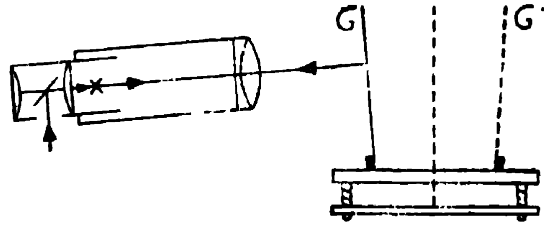

Fig. 5.23.

of the glass plate, (in the first position) to the principal vertical axis of the instrument. In the field of view, the image of the horizontal wire appears at $b\ b$ instead of in coincidence with the wire, that is, by rotating the reflecting surface through 2θ the image shifts from $a\ a$ to $b\ b$. The image is now moved half way back to the position $c\ c$ marked by arrows in Fig. 5.24 by altering the tilt of the table. This is only possible when the tilt of the table is so changed that the plate turns through θ towards its first position. Obviously the plate now becomes parallel to the principal vertical axis of the instrument. The telescope axis is now adjusted by the help of screws provided below the telescope tube until the reflected image of the horizontal wire moves from $c\ c$ to $a\ a$, that is, it coincides with the wire itself. This is possible only when the light from the telescope is incident on the glass plate normally, the reflecting surface of the plate as explained above is now

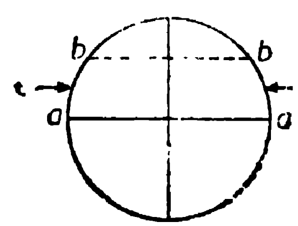

Fig. 5.24.

parallel to the principal vertical axis of the instrument. Thus the optical axis of the telescope becomes normal to the principal vertical axis of the instrument.

To adjust the axis of the collimator normal to the vertical axis, a thin wire is stretched horizontally across the middle of the slit and the inclination of the collimator tube to the vertical is altered by the help of the screws provided below it, till the image of this wire coincides with the intersection of cross-wires in the telescope.

(d) *The refracting edge of the prism, if one is employed, must be made parallel to the vertical axis of the rotation of the prism table and the telescope.* The prism is placed on the prism table with one of the faces meeting the refracting edge A, say the face AB, perpendicular to the line joining a pair of levelling screws, say the screws Q and R. The prism is turned to a position in which the light from the collimator is incident on both the faces AB and AC bounding the refracting angle A. The telescope is turned to a position to receive the light reflected from the face AB of the prism. The centre of the image of the slit, formed by reflection of light from AB, is brought at the intersection of cross-wires by adjusting the screws Q and R. Next, the telescope is turned to receive the light reflected from the face AC and the third screw P is only adjusted to bring the centre of the image again at the intersection of the cross-wires.

Measurement of the Angle of the Prism. To determine the refractive index of the material of the prism by the use of Eq. (1.2 i), it is essential to measure by the help of spectrometer the refracting angle A of the prism and the angle of minimum deviation δ_m for light of that wavelength for which the refractive index of the material is to be computed. Having made all the adjustments outlined above, the prism is placed, with its refracting edge A at the centre of the prism table, in such a way that a part of light from the collimator is incident on the face AB while the rest is incident on the face AC, the two faces under consideration bounding the refracting angle. The telescope is turned to receive the light reflected from the face AB and the cross-wires are adjusted on the reflected image of the slit. The setting of the telescope is recorded by the help of verniers which move with the telescope. The telescope is now turned to receive the light reflected from the face AC and again cross-wires are adjusted on

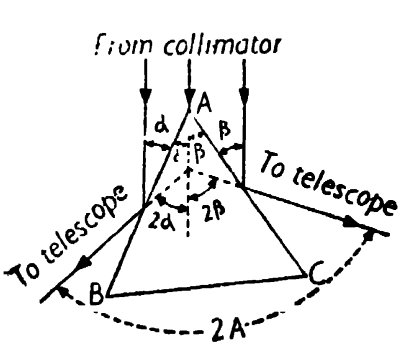

Fig. 5.25. Measurement of the angle of the prism.

the reflected image of the slit. This setting of the telescope is again recorded by the help of verniers. It is evident from Fig. 5.25 that the angle through which the telescope is turned from one position to the other is simply equal to twice the refracting angle A of the prism. Therefore, half of the difference of the readings of the same vernier for the two settings of the telescope gives the refracting angle of the prism.

Measurement of the Angle of Minimum Deviation. The prism is placed on the prism-table with the centre of its base in coincidence with the centre of the table. The refracting edge of the prism is turned to-wards the right and the refracted image of the slit is seen through the telescope. The prism table is now turned in such a direction that the deviation of the refracted ray decreases. The refracted image of the slit during the rotation of the table moves in one direction and it begins to retrace its path from a certain point, although the rotation of the table is continued in the same direction. The setting of the prism at which the image becomes momentarily at rest corresponds to minimum deviation of the incident ray due to refraction through the prism. By trial the telescope is adjusted to a position in which the image of the slit during its movement just touches the intersection of the cross-wires and then retraces its path due to rotation of the turn table. The setting of the telescope is recorded with the help of the telescope verniers. Now the prism table is turned to bring the refracting edge to the left and again the telescope is adjusted in such a way that when the prism table is rotated the image of the slit just touches the intersection of cross-wires and then retraces its path. This setting of the telescope is again recorded with the help of telescope verniers. The difference of the two readings recorded by the same vernier gives twice the angle of minimum deviation and hence half of this difference gives the angle of minimum deviation.

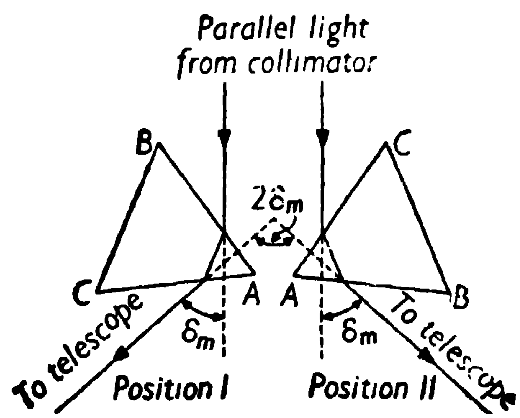

Fig. 5.26. Determination of angle of minimum deviation.

It should be emphasised that the axis of rotation of the telescope and the turn-table may not pass exactly through the centre of the divided circular scale To compensate for this slight off centering, if any present, the average of both verniers should be used in recording the position of the telescope and that of the turn-table.

The angle of minimum deviation δ_m and the refracting angle A of the prism so determined when substituted in the formula

$$\mu = \frac{\sin \frac{1}{2}(A+\delta_m)}{\sin (A/2)}$$

lead to the refractive index μ of the material of the prism for that wavelength for which δ_m was determined.

Problems—Chapter 5

1. What is an eye-piece and what is its advantage over a single lens ? Give with a neat sketch, the theory of Ramsden's eye-piece. How does it differ from the Huygens' eye-piece ? Mention their relative merits. [*Rajputana, 1956*]

2. Calculate the positions of the focal and equivalent points of Huygens' eye-piece. Hence find the position of cross-wires when the final image is seen by parallel rays. [*Rajputana, 1954*]

3. Distinguish between a *positive* and a *negative* eye-piece and show that in Huygens' eye-piece both chromatic and spherical aberrations are reduced to a minimum. [*Banaras, 1946*]

4. Explain the defects noticed in a telescope or a microscope if the eye-pieces consist of a single lens. Describe and explain the construction of an eye-piece where these defects are minimised and with which cross-wires can be used. [*Nagpur, 1950*]

5. What is an aplanatic lens ? Explain clearly its use in the construction of a high power microscope objective. [*U. P. C. S., 1953*]

6. Prove that when two lenses are separated by the algebraic sum of their focal lengths, the linear magnification is independent of the position of the object, and is equal to the reciprocal of the angular magnification for the case of an object at infinity.

7. A telescope with an objective of focal length F and an eye-piece of focal length f is focussed on an objective at a finite distance d from the objective. Calculate it magnifying power and show that it varies upto the limiting value. [*Allahabad, 1956*]

8. A distant star is seen with relaxed accommodation through an astronomical telescope fitted with Huygens' eye-piece. Use the diagram to explain that the eye-piece is *negative*. [*Agra, 1951*]