Expt-2
Grating Spectrometer

Aim To determine the wavelength of polychromatic light and the angular dispersive power of a diffraction grating.

Apparatus Spectrometer, prism, diffraction grating, polychromatic light source.

Theory

An arrangement consisting of a large number of parallel slits of the same width (e) and separated by equal opaque spaces (b) is known as diffraction grating. It is usually made by ruling equidistant, extremely close fine grooves with a diamond point on an optically plane glass plate. The quantity (e+b) is called the grating element and N (= 1/ (e+b)) is the number of slits per unit length. For a large number of slits, the diffraction pattern consists of extremely sharp lines called principal maxima and are given by

$$(e+b)sin\theta = \pm m\lambda \qquad (1)$$

where, θ is the diffraction angle and m is the order of diffraction. A schematic of intensity vs. sinθ is shown in Fig 1.

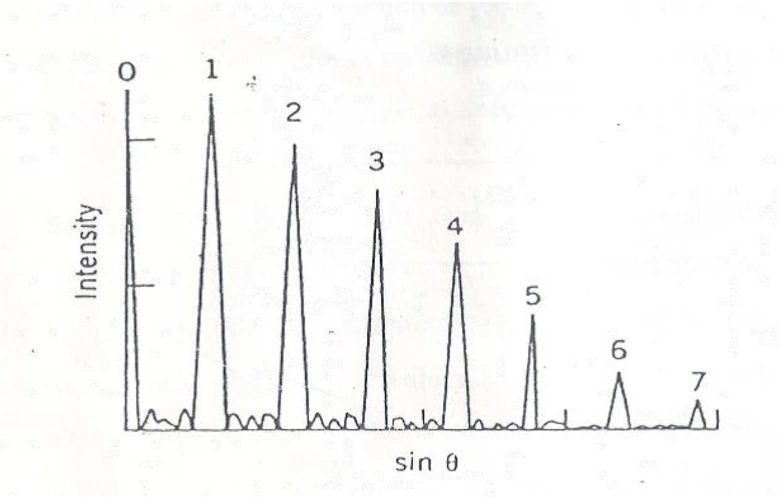

Fig. 1

Where, m is the order of principal maximum and θ is the angle of change of diffraction. The angular dispersive power of the grating is defined as the rate of angle of diffraction with the change in wavelength. It is obtained by differentiating Eqn. 1 and is given by

$$\frac{\delta\theta}{\delta\lambda} = \frac{m}{(e+b)\cos\theta} \qquad (2)$$

Experimental Setup:

Fig. 2.

The experiment is performed using a conventional prism spectrometer and mercury lamp, shown in Fig.2. The spectrometer essentially consists of three parts, namely, a collimator, a turntable and a telescope. The collimator employs an achromatic lens at one end of a tube, sliding within which at the other end, there is another tube carrying a vertical slit of adjustable width. A collimator focusing knob is provided to change the relative positions of the two tubes. If the slit is positioned to be in the principal focal plane of the collimating lens, the rays of light are rendered parallel by the collimating lens. The collimator tube is rigidly fixed to the spectrometer base, with its horizontal axis intersecting the central vertical axis of the spectrometer. The parallel beam of light from the collimator falls on the plane of the prism/grating resting on the turntable, which can be rotated independent of the telescope about the vertical axis of the spectrometer. The rotation of the table can be read with the help of diametrically positioned verniers (at windows A and B) which slide over a circular scale having its centre on the vertical axis of the spectrometer and which rotates with the telescope arm. The turntable can be adjusted to any desired height and clamped. The rotation of the table can be locked and a fine rotation can be given with a tangent screw provided at the base. The table is also provided with three leveling screws, which assists in setting of the prism/grating to a desired position and orientation on the turntable.

Fig. 3

The refracted beam from the prism or the diffracted beam from the grating is received by a telescope. The tube carrying the eyepiece and the crosswire can slide within the tube carrying the objective. Thus the distance between the plane of the cross wires and the objective can be varied with the help of a telescope focusing knob. The telescope tube with its axis horizontal is fixed in an arm, which can be rotated about the vertical axis of the spectrometer. A circular scale rotates with the telescope arm relative to the two verniers attached to the turntable. Thus, by fixing the turntable, the angular position of the telescope can be measured on the circular main scale using the vernier. Any angular position is measured by taking two readings at the vernier windows A and B. The telescope arm can be locked and its fine rotation can be accomplished with the help of a tangent screw. Both the telescope and the collimator are also provided with levelling screws.

Procedure:

(A) (1) The base of the spectrometer, collimator and the telescope are pre-levelled and these adjustments as well as the position of the spectrometer should not be disturbed. Focus the eyepiece of the telescope on the crosswire and make one of them vertical. Open the slit to a reasonable width and bring the telescope arm in line with the collimator and directly view the image of the slit with the telescope. See that the horizontal crosswire cuts the image of the slit approximately into two equal parts. If necessary, adjust the telescope knob and slit width to get a sharp image of the slit.

(2) Clamp the turntable at such a height that when the prism is kept on it, the light from the collimator falls at the middle portion of the prism. Now place the prism on the turntable such that the light is reflected from both faces. See that the reflected slit is approximately cut into two equal parts by the horizontal crosswire. If not, adjust the three leveling screws.

(3) Now place the prism at the centre of the turntable in such a way that each face of the prism is parallel to the line joining any two leveling screws. Unlock and rotate the turntable and position it such that light from the collimator falls on one of the refracting faces and you can see the spectrum with naked eye, through the other face. Just ensure that in this position of the prism table, the line joining the two verniers A and B is roughly perpendicular to the collimator so that, the verniers can be conveniently read. Leave the prism table in this position.

(4) Rotate the telescope and position it to see the spectrum in its field of view. Focus telescope to obtain sharp spectral lines (a well resolved yellow doublet is a good indication of this). Now, the next step is to bring in minimum deviation position. For this, slowly rotate the turntable and the telescope arm simultaneously observe the movement of the spectrum. You may concentrate on the green line whose direction of motion should get reversed, when the turntable (which is being rotated in one direction) crosses over the position of minimum deviation. Ascertain this position by fine movement of the turntable with tangent screw and lock the turntable in this position.

(5) Now the collimator is to be adjusted to give a parallel beam of light and the telescope is to be adjusted to bring the parallel beam to a sharp focus on the cross wire. This is done by Schuster's method, as described below.

Schuster's Method

Position the telescope to bring the yellow doublet line at the centre of its field of view and lock it. Rotate the turn table slightly using tangent screw such that the refracting edge turns towards the collimator. Notice that the spectral lines get defocused. Focus the collimator to get the sharp spectral lines again. Next rotate the prism slightly to the other side of minimum deviation position (refracting edge turns towards telescope). If the spectral lines get defocused again, this time focus the telescope to obtain sharp spectral lines again. Repeat this process of alternatively focusing the collimator and the telescope until the rotations of the prism do not cause the spectral lines (concentrate on yellow doublet) to get defocused. In this situation, the rays entering and leaving the prism are parallel. <u>It is important that the focusing of the collimator and the telescope must not be disturbed throughout the rest of the experiment, since the spectrometer has been adjusted for parallel rays.</u>

(B) (1) Now remove the prism from the turntable. The next step is to adjust the grating on the turntable so that its lines are vertical, that is parallel to the axis of rotation of the turntable. Moreover, the light from the collimator should fall normally on the grating. To achieve these adjustments the following procedure is adopted.

(2) The telescope is brought directly in line with the collimator so that the centre of the direct image of the slit falls on the intersection of the cross-wires. In this setting of the telescope, its vernier reading is taken; let it be Φ. The telescope is now turned through 90° from this position in either direction so that the reading of the vernier becomes (Φ+90°) or (Φ-90°). Now the axis of telescope is at right angles to the direction of rays of light emerging from the collimator. The telescope is clamped in this position. The grating is then mounted on the grating holder, which is fixed on the turntable in such a way that the ruled surface of the grating is perpendicular to the line joining two of the leveling screws. The table is now rotated in the proper direction till the reflected image of the slit from the grating surface coincides with the intersection of the cross-wires of the telescope. By the help of two leveling screws perpendicular to which grating is fixed on the table, the image is adjusted to be symmetrical on the horizontal cross-wires. The plane of the grating, in this setting, makes an angle of 45° with the incident rays as well as with the telescope axis. The reading of vernier is now taken and with its help, the turntable is rotated through 45° from this position so that the ruled surface becomes exactly normal to the incident rays. The turntable is now firmly clamped.

(3) The final adjustment is to set the lines of the grating exactly parallel to the axis of rotation of the telescope. The telescope is rotated and adjusted to view the first order diffraction pattern. The third leveling screw of the prism table is now worked to get the spectral lines symmetrically positioned with respect to the horizontal cross-wire. If this adjustment is perfect, the centers of all the spectral lines on either side of the direct one, will be found to lie on the intersection of the cross-wires as the telescope is turned to view them one after another. The rulings on the grating are now parallel to the axis of rotation of the telescope. The grating spectrometer is now fully adjusted to make the measurements.

(4) Now use the telescope to measure the angular position of all the first order spectrum lines both sides of the central bright fringe. Record the value of main scale division and the least count (L.C.) of the vernier. Any angular position is measured by using both the vernier windows (A and B),whose readings differ by 180°. You must always note down the main scale and vernier readings separately and then add them to get the angular position.

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Rotate the telescope using tangent screws to coincide the vertical cross wires with all the first order spectral lines one by one, on one side of the central bright fringe. Note down the two angular positions (α_A,α_B) for each spectral line using both the vernier windows A and B. Rotate the telescope to other side of the central bright fringe and measure the corresponding angular positions ($\alpha_{A'}$,$\alpha_{B'}$).

Results And Calculations

1. Tabulate for all first order spectral lines, the colour, (α_A,α_B), ($\alpha_{A'}$,$\alpha_{B'}$)
   $\theta_A = \left(\frac{\alpha_A - \alpha_{A'}}{2}\right)$, $\theta_B = \left(\frac{\alpha_B - \alpha_{B'}}{2}\right)$, $\theta = \left(\frac{\theta_A + \theta_B}{2}\right)$ *and* $\Delta\theta = \left(\frac{\theta_A - \theta_B}{2}\right)$

$$\text{Take } \Delta\theta = \frac{L.C.}{2} \;\; for \;\; \theta_A = \theta_B$$

2. Using Eqn. (1), calculate the wavelengths ($\boldsymbol{\lambda}$) for all spectral lines.

   Take N =15,000 lines per inch.

3. Estimate the uncertainties ($\Delta\boldsymbol{\lambda}$) for all the $\boldsymbol{\lambda}$s using

   $\Delta\boldsymbol{\lambda}$ = (d cos θ) $\Delta\theta$

4. Tabulate all the values of ($\boldsymbol{\lambda} \pm \Delta\boldsymbol{\lambda}$) in the above table.

5. Calculate the angular dispersive power of the grating near the extreme ends of the first order spectrum using Eqn. 2.

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Precautions

1. Once the collimator and the telescope are adjusted for parallel rays, their focusing should not be disturbed throughout the experiment.

2. Once the grating, is properly adjusted on the turntable, it should be locked.

3. While taking measurements at different positions of the telescope, it must always be in locked condition.

4. While rotating the telescope arm from one angular position to another, if the vernier crosses over 0° (360°) on the circular main scale, take the angular difference appropriately.

References

(1) B.L. Worsnop and H.T. Flint, Advanced Practical Physics for Students.
(2) B.K. Mathur. Introduction to Geometrical and Physical Optics.