Expt - 2
GRATING SPECTROMETER

I. OBJECTIVE

To determine the wavelengths of spectral lines of mercury and the angular dispersive power of a diffraction grating

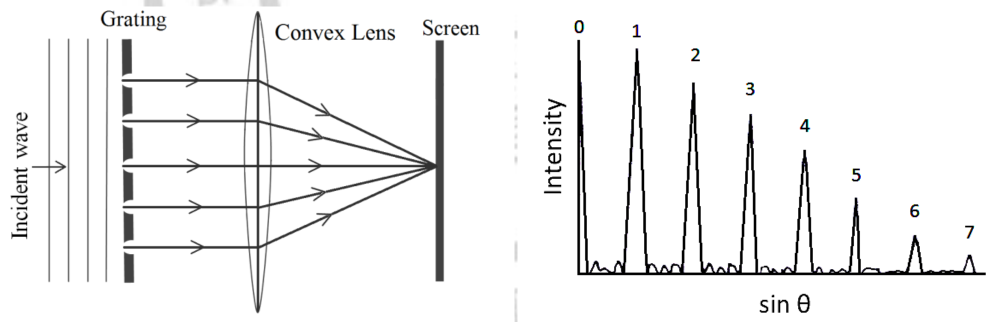
II. PRINCIPLE

An arrangement consisting of a large number of parallel slits of the same width, which are separated by equal opaque spaces is known as a diffraction grating. For N parallel silts, each having width a, separated by opaque spaces of width b, the diffraction pattern consists of diffraction modulated interference fringes. The quantity g (= a+b) is called the grating constant and N (=1/g) is the number of slits per unit length.

If monochromatic light of wavelength λ from a narrow slit (parallel to the slits/rulings of a grating) is incident normally on the diffraction grating, the diffraction pattern consists of extremely sharp narrow lines parallel to the rulings. These sharp lines are called principal maxima and are given by

$$g \sin \theta = \pm n \lambda \qquad (1)$$

where, θ is the diffraction angle and n is the order of diffraction. A grating schematic and typical, Intensity *vs.* $\sin \theta$ variation (for 5 slits) are shown in *Fig. 1*. Notice that there are weak secondary maxima in between the principal maxima of different orders.



(a) (b)

Figure 1

It is clear from *Eqn. 1* that the diffraction angle θ depends on wavelength λ. Hence if the source of light is polychromatic, then for each order of diffraction (except for n = 0), there will be as many lines in the diffraction pattern, as there are different wavelengths in the light source. Thus the diffraction grating (like a prism) enables us to observe and analyze the spectrum of a polychromatic light source and forms the basis of modern day high resolution mono-chromators and spectro-photometers.

The angular dispersive power (DP) of a grating is defined as the rate of change of diffraction angle with change in wavelength. Obtained by differentiating Eqn. 1, it is given by

$$\mathrm{DP} = \frac{d\theta}{d\lambda} = \frac{n}{g\cos\theta} \qquad (2)$$

Figure 2

III. EXPERIMENTAL SET-UP AND APPARATUS DETAILS

The experiment is performed using a conventional prism spectrometer and a mercury lamp, shown in *Fig.2*. Details of different parts of the spectrometer are described in *Fig. 3* below. The spectrometer essentially consists of a collimator (1), a telescope (2) and a prism table (3), on which a grating holder (4) is mounted. The collimator is fixed to the tripod base with its horizontal axis intersecting the central vertical axis of the spectrometer. The telescope (2), the prism table (3) and a turn-table (5), can be rotated independently about the vertical axis of the spectrometer. The grating used in this experiment consists of 600 *lines/mm*. A mercury (Hg) spectral lamp, which is housed in a covered housing, is placed near the collimator (*Fig. 2*) and is used as the source of polychromatic light.

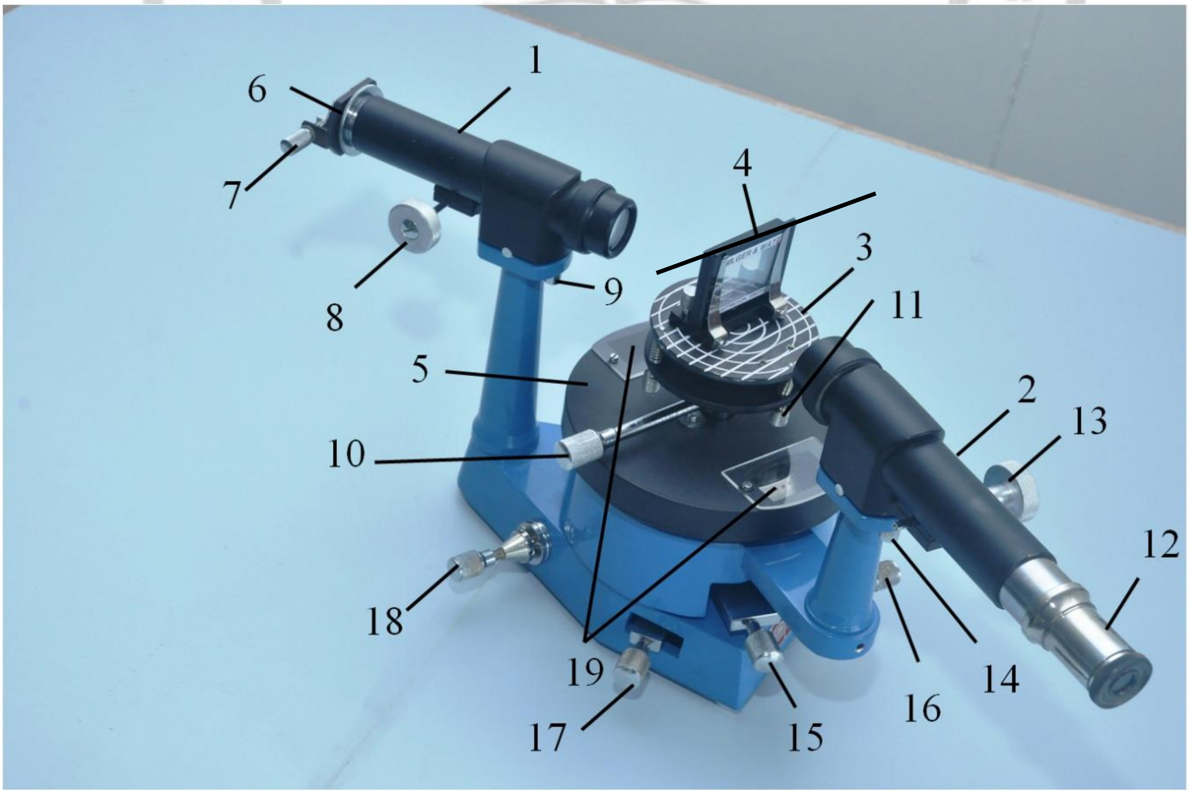


Figure 3

The collimator employs a lens at one end of a tube, at the other (free) end of which is another sliding tube, which carries a vertical slit (6). The width of the slit can be adjusted with a screw (7). There is a collimator adjustment knob (8), which can be used to slide the slit tube inside the lens tube. This arrangement can be used to position the slit to be in the focal plane of the collimating lens so that the parallel rays come out of the collimator. The collimator is also provided with two height adjustment screws (9).

The parallel beam of light from the collimator falls on the plane of the grating resting on a horizontal prism table. The prism table can be clamped in any position or height with the help of the locking screw (10). In the locked condition, it can be rotated with the turn table, independent of the telescope. The prism table consists of two circular discs. The lower disc is provided with three leveling screws, two of which are shown as (11). The three leveling screws form corners of an equilateral triangle. Concentric circles and lines parallel to two of the leveling screws are drawn on the upper disc, which assist in setting the prism/grating in a desired position and orientation on the prism table.

The diffracted beam from the grating is received by the telescope. A tube carrying the eyepiece (12) and the built-in cross-wires can slide within another tube carrying the objective lens. The position of the eyepiece can be adjusted with respect to the cross-wires by slightly moving it in or out. The distance between the plane of the cross-wires and the objective lens can be varied with the help of the telescope focusing knob (13). The telescope tube is also provided with two height adjustment screws (14). As mentioned above, the telescope tube can be rotated about the vertical axis of the spectrometer and is also provided with a locking screw (15). Coarse rotation can be imparted by hand in unlocked condition. Fine and controlled rotation can be imparted to the telescope by a tangent screw (16) after tightening the locking screw. The turn-table can also be locked by a stopping screw (17). Fine and controlled rotation can be given using a tangent screw (18). Two diametrically oppositely verniers (19) are provided on the turn-table. The verniers can be used to measure the angular position of the telescope when the turn-table is locked. The angular position of the turn table can also be measured with the verniers, when the telescope is locked.

IV. PROCEDURE

The spectrometer, collimator and the telescope are pre-leveled and do not normally require any further adjustments.

A.Adjusting the telescope for parallel rays

The telescope tube is pre-leveled to be horizontal and hence, the height adjustment screws of the telescope should not be disturbed. Focus the eyepiece of the telescope on the cross-wires by slightly adjusting its position with respect to the cross-wires. Make one of the cross-wires nearly vertical. Then, point the telescope towards a distant object (preferably outside the window) and use the telescope focusing knob to bring the distant object into focus in the plane of the cross-wires. *The telescope is now adjusted for receiving parallel rays.*

B. Adjusting the collimator for parallel rays

Make sure that the window of the Hg lamp is in front of the slit of the collimator and then switch it ON from the power board. The collimator tube is pre-leveled to be horizontal and hence, the height adjustment screws of collimator should not be disturbed. Open the slit to a reasonable width and bring the telescope arm in line with the collimator and directly view the slit. If required, adjust slit width slightly to see a sharp image of the slit. Also, make the vertical cross-wire of the telescope parallel to the slit by slightly adjusting its orientation. Check that the horizontal crosswire divides the image of the slit into nearly two halves. If not, then request the instructor to check the horizontal leveling of the collimator and telescope, which is done by adjusting the height adjustment screws of the telescope and the collimator. Next, use the collimator adjustment screw to obtain a focused image of the slit in the plane of the cross-wires of the telescope. *Now the collimator is adjusted to give parallel rays*.

C. Positioning the telescope at right angles to the collimator

First of all, lock the turntable in any position. Then, position the telescope directly in line with the collimator so that the direct image of the slit coincides with the vertical cross wire. For this, initially position the telescope arm to view the slit close to the vertical crosswire and then lock it and fine adjust with the tangent screw. Now, using one of the angular verniers, note down the main scale and vernier readings (Φ) in this setting of the telescope (see, *section F.1-2* for instructions on reading vernier scale). Next, the telescope arm is to be rotated through 90° from this position in any one direction. For this, calculate the value of (Φ+90°) or (Φ-90°), as the case may be and note it. Unlock the telescope arm and bring it and lock near the desired position and then fine adjust with the tangent screw to get to the exact angular position. *Now the axis of telescope is at right angles to that of the collimator.*

D. Positioning the grating normal to the collimator

1. Clamp the prism table at such a height that when the grating is mounted on it in the grating holder, the light from the collimator falls at its middle portion. Inspect and ensure that the two discs constituting the prism table are nearly parallel and the three levelling screws protrude well outside the upper disc, so that these can be adjusted comfortably, when required. Then level the turntable with a spirit level in two cross positions (parallel and perpendicular to the straight lines drawn on it), by using the three leveling screws appropriately. *After this step, the spirit level should NOT be used again.*

2. Fix the grating holder on the turntable in such way that the surface of the grating is parallel to the line joining two of the leveling screws and then clamp the grating in the holder. Unlock the turntable and rotate it to an orientation, such that the reflected image of the slit from the grating surface again coincides with the vertical cross-wire. For this, initially lock the turntable near this position and then fine adjust with the tangent screw to get to the desired angular position. In this position, the image of slit should be divided into nearly two halves by the horizontal cross-wire. If not, then ensure this by adjusting the TWO leveling screws parallel to which the grating is fixed on the table. These screws have to be adjusted slightly and simultaneously, if required. *The THIRD levelling screw should NOT be used in this step.*
3. Notice that in this setting, the grating makes an angle of 45^{o} with the incident rays as well as with the telescope axis. Note down the reading in one of the verniers in this position. Then, unlock and rotate the turntable through 45^{o} from this position (pre-calculate and note the final angular position), which makes the plane of the grating normal to the incident rays. For this, lock the turntable initially at an approximate position and then fine adjust with the tangent screw to get to the exact angular position. Leave the locked turntable finally in this position for the rest of the experiment. *The plane of the grating is now nearly normal to the rays from the collimator*.
4. The complete optical levelling requires that the grating lines are parallel to the vertical axis of the spectrometer. For this, unlock the telescope and rotate the telescope arm to view of the first order diffraction pattern on both sides of the direct image. If the spectral lines on both sides are not approximately divided into two equal halves by the horizontal cross-wire, then use the THIRD leveling screw on the prism table to ensure this as much as possible. *This completes the optical levelling of the grating and the plane of the grating is now normal to the rays from the collimator. The grating spectrometer is now ready for measurements.*

E. Measuring the angular positions of spectral lines

1. First of all, inspect the angular verniers. Record the value of each main scale division and calculate the least count (L.C.) of the vernier in arc minutes (1’ = 1/60 degrees).
2. Now use the telescope to measure the angular positions of all the first order spectral lines on both sides of the direct image of the slit. Any angular position is measured by using both the angular vernier windows (V_1 and V_2), whose readings differ by 180^{o}. Read the angular vernier scale with a magnifying glass to get the angular position in a manner described by the example as shown in *Fig. 4*.

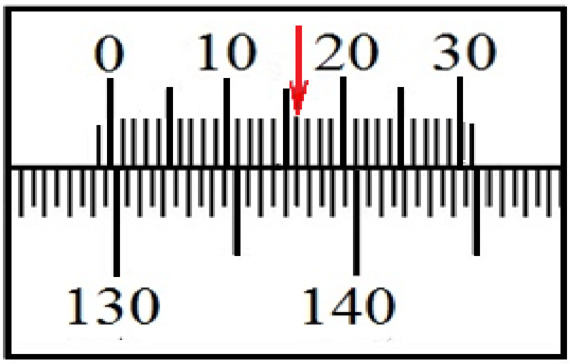


Figure 4

In this example, the least count of the vernier is 1'. As the zero of the angular vernier scale (upper scale) is between 129.5° and 130° of the main scale (lower sc ale), the angle is somewhere between these two values. You can take the main-scale reading as 129° 30' or 129.5°. Next check for the graduation on the angular vernier scale which lines up with a main scale graduation below it. In this case, it is the 16th graduation on the angular vernier scale, hence the vernier reading is 16 (≡ 0.27°). So, the required angular position is 129.77°.

3. Move the telescope arm to any one side of the direct image and make the vertical cross-wire coincide with the extreme red line of the first order spectrum. Use tangent screw to get to the exact angular position. Note down the two angle values (α_1, α_2) using V_1 and V_2, in this position.
4. In a similar manner, record the angular positions of the two lines of the yellow doublet, the green line and the violet line at the other end of the spectrum, in that sequence.
5. After crossing the direct image, continue to move the telescope arm in the same direction to measure the angular positions (β_1, β_2), corresponding to V_1 and V_2, for all the corresponding spectral lines on the other side of the direct image.

G. Closing the experiment

Switch OFF the mercury lamp. Remove the grating from its holder and keep it in its box.

V. RESULTS AND CALCULATIONS

1. Record and tabulate for all first order spectral lines, the colour, (α_1, α_2) and (β_1, β_2).

2. Calculate and tabulate separately (in degrees) for all the first order spectral lines:
$\theta_1 = \frac{\alpha_1 \sim \beta_1}{2}$, $\theta_2 = \frac{\alpha_2 \sim \beta_2}{2}$, $\theta = \frac{\theta_1 + \theta_2}{2}$ and $\Delta\theta = \left|\frac{\theta_1 - \theta_2}{2}\right|$. Take $\Delta\theta = \frac{L.C.}{2}$ if, $\theta_1 = \theta_2$.

3. Using *Eqn. 1*, calculate the wavelengths (λ) for all the spectral lines.
Take N = 600 lines/mm.
4. Estimate the uncertainties ($\Delta\lambda$) for all the λ's by using $\Delta\lambda = (\cos\theta / N)\,\Delta\theta$, where $\Delta\theta$ is in radians.

5. Using *Eqn. 2*, calculate the values of angular dispersive power (DP) for all the spectral lines and also obtain the respective uncertainties, Δ(DP) by using $\Delta(\mathrm{DP}) = (N \sec\theta \tan\theta)\,\Delta\theta$.
6. Tabulate all the values of $\lambda \pm \Delta\lambda$ and DP $\pm$ Δ(DP) in a separate Table of Results.

VI. PRECAUTIONS

1. NEVER touch the surface of the grating by hand. Always hold the grating from the sides.
2. Once the collimator and the telescope are adjusted for parallel rays (*steps A* and *B*), their focusing should not be disturbed.
3. Make sure that the telescope arm is locked while taking vernier readings at different angular positions.
4. While rotating the telescope arm from one angular position to another, if the vernier crosses over 0º (360º) on the circular scale, take the angular difference appropriately in *step* **V**.*2*.

SUGGESTED READING: *Introduction to Geometrical and Physical Optics*, B. K. Mathur