Experiment No. 3

Object : *To determine the wavelength of* D_1 *and* D_2 *lines of sodium with the help of plane transmission grating.*

Apparatus Required : Plane transmission grating, spectrometer, sodium lamp, prism, reading lamp and reading lens.

Description of the Apparatus : (a) Spectrometer : The spectrometer is shown in Fig. 7. It consists of three parts : (1) the collimator, (2) the prism table, and (3) the telescope.

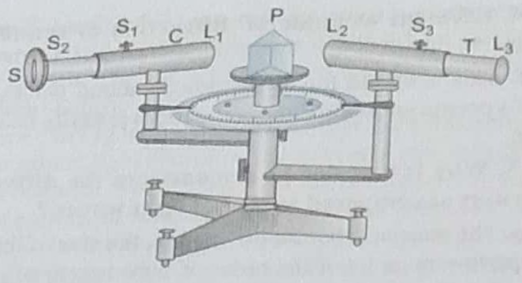

Fig. 7. Spectrometer

(1) Collimator—This part of the spectrometer is used to obtain a narrow and parallel beam of light from a light source. It consists of two cylindrical hollow metallic tubes. At one end of a tube, a slit S is attached which is kept in front of the light source. The slit can be made wide or narrow by means of a screw S_2. An achromatic convex lens L_1 is attached at the end of other tube. Both the tubes are connected by the rack and pinion arrangement S_1 such that the tube fitted with the slit can be moved inside or outside the other tube fitted with the lens, with its help. This changes the distance between the lens and the slit. It is so adjusted that the slit is in the focal plane of the lens so that the rays emerging out from the lens are parallel (Fig. 8). The collimator is mounted on a fixed stand and this stand is rigidly attached to the base of the spectrometer. The collimator rests on two screws provided below it, with which it can be made horizontal.

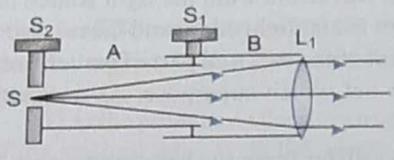

Fig. 8. Collimator

(2) Prism table—It is a metallic circular disc on which the prism is kept. The disc has straight parallel lines and also the concentric circles drawn on its surface (Fig. 9). They help in placing the prism in the correct position. This disc is provided with another parallel disc below it with three levelling screws P, Q, R to make the disc horizontal. The prism table is made horizontal with the help of these levelling screws and the spirit level. A vertical metallic thin rod passes through the centre of gravity of the prism table, by which the prism table can be raised or lowered. The prism table can be freely rotated about the axis of the vertical thin rod. The prism table can be mounted in any position as desired by means of a screw. A tangential screw is also provided so as to rotate the prism table very slowly. To locate the position of prism, on the base of the prism table there are two circular vernier scales opposite to each other (*i.e.*, at 180° angular separation).

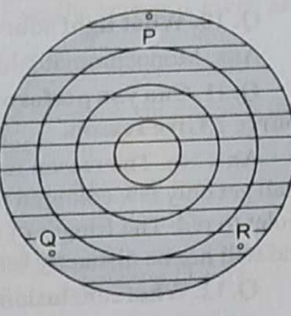

Fig. 9. Prism table

(3) Telescope—To obtain a pure spectrum by focusing the light emerging out of the prism and to take observations, telescope is used. Just like the collimator, telescope also consists of two hollow cylindrical tubes (Fig. 10). At the end of one tube (which is towards the prism), there is an achromatic lens L_2 which is called *objective lens*. At the other end of this tube, the other tube can be moved in or out of this tube by means of a screw S_3 through the rack and pinion arrangement. This tube is called eyepiece tube. On the other side of eyepiece tube, there is an eyepiece L_3 (a combination of two or more than two lenses) and cross-wires within it. Only the eyepiece can be taken out or inserted in by hand, so that the cross-wires lie at the focus of the eyepiece and are distinctly seen. By moving the eyepiece tube by means of the screw S_3, the cross-wires can be brought in the focal plane of the objective lens L_2.

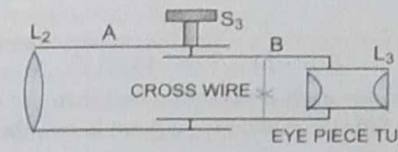

Fig. 10. Telescope

The telescope is attached to a vertical stand which can be rotated about a vertical axis passing through the centre of gravity of the prism table. The position of telescope can be read with the help of circular main scale and vernier scales. The circular main scale is rigidly attached at the base of spectrometer and the vernier scales are attached with the stand of telescope. On the stand, there is a heavy metal piece opposite to the telescope so as to balance the weight of the telescope and the telescope can easily be rotated alongwith its stand. The telescope can be clamped at any position with the help of a screw. A tangential screw is also provided for the slow movement of telescope. Just like collimator, the telescope is also provided with two screws below its tube with which it can be made horizontal.

(b) Plane transmission grating : It is an arrangement consisting of several parallel and equidistant slits, each of equal width. It was invented by the scientist Fraunhofer. It is constructed by drawing several equidistant parallel lines on an optically plane glass plate with a pointed diamond. The width of the line drawn is opaque, while the space between two consecutive lines is transparent and behaves like a slit through which light is transmitted. This is why it is also called the *transmission grating*. The distance between the centres of two consecutive slits is called the grating element. Generally the value of grating element for the grating to be used with visible light is of the order of 10^{-6} m (*i.e.*, there are nearly 10,000 lines drawn on 1 cm length of grating).

Theory : When a parallel beam of monochromatic light of wavelength λ (from the collimator) is incident normally on a grating of grating element e, by Huygen's principle each point of each slit emits out secondary wavelets in all directions which interfere and get focused in the focal plane of a convex lens (or telescope). The path difference between the diffracted waves at an angle θ from the corresponding points of two consecutive slits is $e \sin\theta$. When this path difference is equal to integer multiple of wavelength λ, the waves produce constructive interference. Hence for principal maxima

$$e \sin\theta = n\lambda, \qquad \text{where } n = 0, \pm 1, \pm 2, \ldots\ldots$$

Here n is called the order of spectra. For $n = 0$, we get zero order (or central) maxima and for $n = \pm 1, \pm 2, \ldots\ldots$ we get first order, second order, ... maxima respectively on either side of the zero order maxima.

Thus knowing the grating element e and the angle of diffraction θ in a particular order n, the wavelength λ of light can be calculated. To determine the angle of diffraction θ, spectrometer is used.

It may be mentioned here that generally on grating, the number of ruled lines per inch is labelled. If there are N lines per inch, the grating element will be $e = 2{\cdot}54/N$ cm.

Now if sodium light is made incident on a grating, there are two close wavelengths 5890 Å (D_2 line) and 5896 Å (D_1 line), so in each order the value of θ will be different corresponding to

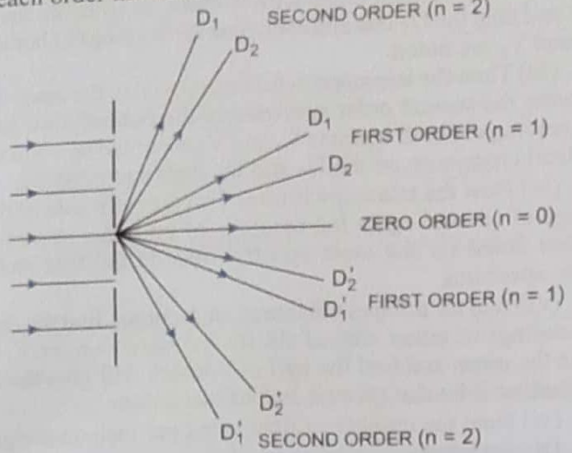

Fig. 11. Diffraction spectrum

different wavelengths present in the incident sodium light. Thus we get D_1 and D_2 lines in each order (Fig. 11). The first order ($n = 1$) principal maxima of wavelengths in the incident light form the *first order spectrum*. Similarly the second order ($n = 2$) principal maxima of wavelengths in the incident light form the *second order spectrum*.

Since angle of diffraction θ is 0° for the principal maxima of all wavelengths corresponding to $n = 0$, therefore the zero order maxima is white in the direction of incident light (on either side of which there are first order and second order spectrum).

Formula Used: The wavelength λ of a spectral line is calculated by the following formula

$$e \sin\theta = n\lambda, \quad \text{where } e = \frac{2.54}{N}$$

or
$$\lambda = \frac{1}{n} \times \frac{2.54}{N} \sin\theta$$

where e = grating element, θ = angle of diffraction, n = order of spectrum, and N = number of lines ruled per inch on grating.

Procedure : The experiment is performed in the following three steps:

(1) Adjustment of spectrometer : Before the experiment, the spectrometer is so adjusted that (i) the axes of collimator and telescope intersect each other on the vertical axis of the telescope, (ii) the prism table is horizontal, and (iii) the telescope and collimator are focused for the parallel rays.

(i) To test whether the axes of collimator and telescope intersect each other on the vertical axis of telescope or not, a vertical pin is fixed at the centre of prism table and the slit is made wide. Then taking the eyepiece out of the telescope, the pin is seen through the telescope by moving it in various angular positions. If in each position, the pin is seen in the middle of objective, the adjustment is correct, otherwise with the help of screws provided below the telescope and collimator, they are slightly raised up or lowered down so that the pin is seen in the middle of objective of telescope.

(ii) To make the prism table horizontal, the prism is kept on the prism table such that its refracting edge is at the centre of prism table and the refracting face AC is perpendicular to the line joining the two levelling screws P and Q as shown in Fig. 12 (a). Then the prism table is rotated and it is adjusted in such a position that the parallel rays incident from collimator get reflected equally from both the refracting faces AB and AC of the prism [Fig. 12 (b)]. Now the prism table is clamped and the telescope is moved to the

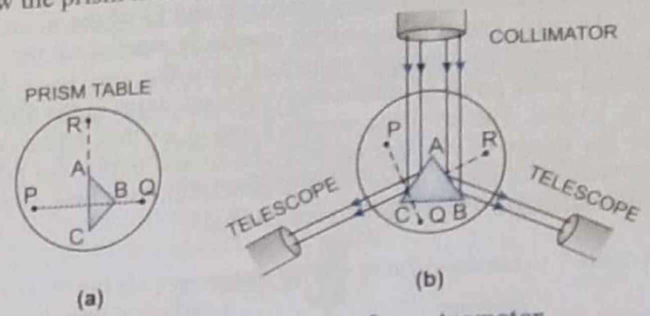

Fig. 12. Adjustment of spectrometer

left side so as to see through the telescope the image of the slit formed by the rays reflected from the face AC of the prism. Now the screws P and Q are adjusted such that the image of slit is obtained exactly in the centre of field of view. Then the telescope is turned on the other side to see the image of slit, through the telescope, formed by the rays reflected from the face AB of the prism and only the screw R is adjusted so as to bring the image of the slit again in the centre of field of view. The process is repeated several times till the image of slit is seen exactly in the centre of field of view in the telescope on either side. Now the prism table is said to be optically plane (or horizontal).

(iii) Adjustment of telescope and collimator for parallel rays by Schuster's method—For this, the prism is placed on the prism table such that its one refracting face AB is towards the collimator and other refracting face AC is towards the telescope. Then the telescope is turned to bring the spectrum in the field of view of telescope. Now the prism table is turned towards the collimator. The spectrum also begins to move in the same direction. The telescope is now turned so as to keep the spectrum in the field of view. On turning the prism table towards the collimator, a stage is reached when the spectrum begins to move in opposite direction (*i.e.*, away from collimator). This position of prism is called the *position of minimum deviation*. The prism table is clamped in this position.

Now the refracting edge of the prism is slightly turned opposite from the position of minimum deviation (*i.e.*, towards the collimator) and the collimator is adjusted with the help of its rack and pinion arrangement such that the spectrum is distinctly seen.

Then the refracting edge of the prism is slightly turned towards the telescope and the telescope is adjusted with the help of its rack and pinion arrangement such that again the spectrum is distinctly seen.

The process is repeated several times till there is no effect on the focus of spectrum when the prism is slightly turned on either side from its position of minimum deviation. At this stage, parallel rays fall on the prism from the collimator and the parallel rays emerging out of the prism are focused on the cross-wires of telescope.

(2) Adjustment of grating on the prism table : The grating is mounted in the middle of prism table such that the light incident from collimator falls normally on the grating. To obtain this condition, the following adjustments are made :

(i) The telescope is brought in the line of collimator and the image of slit is focused at the point of intersection of cross-wires with the help of tangential screw. This position of telescope on the circular scale is noted.

(ii) Then the telescope is turned exactly by 90° from this position and is clamped, so that the axis of telescope becomes exactly normal to the axis of collimator.

(iii) Now the grating is mounted on the prism table with its ruled surface at the centre of prism table and perpendicular to the line joining the two levelling screws P and Q of the prism table [Fig. 13 (a)]. Prism table is then gradually rotated till the image of slit formed by the light reflected from the grating surface is focused at the point of intersection of cross-wires in the telescope [Fig. 13 (b)]. The levelling screws P and Q are then adjusted such that the image of slit lies equally above and below the point of intersection of cross-wires. In this condition, the plane of grating makes an angle 45° with the incident light.

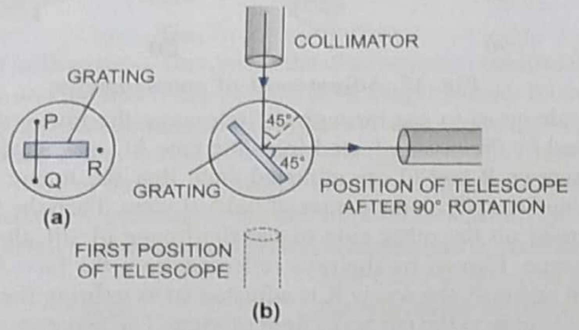

Fig. 13. Adjustment of grating

(iv) Now the grating is turned by 45° (or 135°) such that the ruled surface of grating comes towards the telescope. The light incident from the collimator is now normal on the grating. The prism table is now clamped and the telescope is unclamped so as to rotate freely.

(v) The rulings on grating are adjusted parallel to the axis of spectrometer. For this, spectrum is seen in the telescope in the first order on either side and the cross-wire is made to coincide a particular spectral line. If the middle point of the spectral line does not coincide the point of intersection of the cross-wires, the third levelling screw R of the prism table is rotated such that the centre of the spectral line coincides the point of intersection of the cross-wires.

(vi) The rulings on the grating are adjusted parallel to the slit. For this, the slit is rotated in its own plane till the spectrum becomes intense.

(3) Measurement of angle of diffraction θ : After all the above adjustments, the angle of diffraction θ in the spectrum of grating is measured as follows :

(i) First note the least count of the spectrometer.

(ii) The telescope from the position of direct image of slit is rotated towards left till the first order spectrum is seen in the field of view. Then the telescope is clamped near the D_2 line. The telescope is then gradually rotated with the help of its tangential screw and its vertical cross-wire is made to coincide the D_2 line first and then the D_1 line and each time the readings of both verniers V_1 and V_2 are noted.

(iii) Then the telescope is further moved in the same direction to bring the second order spectrum in the field of view and again the readings of both verniers V_1 and V_2 are noted by coinciding the vertical cross-wire on the D_2 and D_1 lines successively.

(iv) Now the telescope is turned on the right side of the direct image of slit and again the readings of both the verniers V_1 and V_2 are noted for the same spectral lines in the first and second order spectrum.

(v) Then for the spectral line of each colour, find the difference of readings of either side of slit for the same vernier V_1 (or V_2). Take the mean and find the half of it which will give the angle of diffraction θ for the spectral line of that colour.

(vi) Note the number of lines ruled per inch on the grating.

Observations :

Value of one division on main scale of spectrometer x = ...°

Total number of divisions on the vernier scale n = ...

Least count of vernier

$$= \frac{\text{Value of one division of main scale } x}{\text{Total number of divisions on the vernier scale } n} = ...^\circ$$

(1) For the adjustment of grating :

(i) Position of telescope for the direct image of slit.
Reading of vernier V_1 = ...°,
Reading of vernier V_2 = ...°

(ii) Position of telescope after turning it through 90°
Reading of vernier V_1 = ...°,
Reading of vernier V_2 = ...°

(iii) Position of prism table when the image of slit coincides the vertical cross-wire.
Reading of vernier V_1 = ...°,
Reading of vernier V_2 = ...°

(iv) Position of prism table after turning it through 45° (or 135°)
Reading of vernier V_1 = ...°,
Reading of vernier V_2 = ...°

(v) The number of lines ruled per inch on the given grating
N = ...

$\therefore$ Grating element $e = \frac{2.54}{N}$ cm = ...cm

(2) For the diffraction angle θ :

Order of spectrum n	Name of spectral line	Vernier no.	Position of telescope on the left of direct image			Position of telescope on the right of direct image			$2\theta = x \sim y$ (in °)	Mean θ (in °)
			Main scale reading (in °)	Vernier scale reading (in °)	Total reading x (in °)	Main scale reading (in °)	Vernier scale reading (in °)	Total reading y (in °)		
First order $n = 1$	D_2	V_1							>	
		V_2								
	D_1	V_1							>	
		V_2								
Second order $n = 2$	D_2	V_1							>	
		V_2								
	D_1	V_1							>	
		V_2								

Calculations : From $e \sin \theta = n\lambda$

In the first order ($n = 1$),

Wavelength of D_2 line $\lambda_1 = e \sin \theta =$ ....cm

Wavelength of D_1 line $\lambda_2 = e \sin \theta =$ ....cm

In the second order ($n = 2$),

$$\text{Wavelength of } D_2 \text{ line } \lambda_1' = \frac{e \sin \theta}{2} = ...\text{cm}$$

$$\text{Wavelength of } D_1 \text{ line } \lambda_2' = \frac{e \sin \theta}{2} = ...\text{cm}$$

$$\text{Mean wavelength of } D_2 \text{ line} = \frac{\lambda_1 + \lambda'_1}{2} = ...\text{cm} = ...\text{Å}$$

$$\text{Mean wavelength of } D_1 \text{ line} = \frac{\lambda_2 + \lambda'_2}{2} = ...\text{cm} = ...\text{Å}$$

(Remember that 10^{-8} cm = 1 Å)

Result : The wavelengths of D_1 and D_2 lines for the sodium lamp are given in the following table :

Name of spectral line	Observed wavelength λ (in Å)	Standard wavelength λ (in Å)	Percentage error %
D_2		5896	
D_1		5890	

Remember that percentage error

$$= \frac{\text{Observed wavelength} \sim \text{Standard wavelength}}{\text{Standard wavelength}} \times 100\%$$

$= .....\%$

Permissible Percentage error : From the relation $e \sin \theta = n\lambda$, the permissible percentage error in λ is

$$\frac{\Delta\lambda}{\lambda} \times 100\% = \{(\cot\theta)\, \Delta\theta\} \times 100\% = ...$$

where $\Delta\theta = 2'$ (if the least count of spectrometer is 1')

$$= \frac{2}{60} \times \frac{3{\cdot}14}{180} \text{ radian}$$

Precautions : (1) Before the experiment, the spectrometer should be properly adjusted.

(2) Light must fall normally on the grating.

(3) The ruled lines on grating must be parallel to the axis of rotation of the telescope.

(4) The grating should not be touched by hand.

(5) While taking the observation, the prism table should be clamped.

(6) For each observation, both verniers must be read.

Calculations : From $e \sin \theta = n\lambda$

In the first order ($n = 1$),

Wavelength of D_2 line $\lambda_1 = e \sin \theta = ...$cm

Wavelength of D_1 line $\lambda_2 = e \sin \theta = ...$cm

In the second order ($n = 2$),

$$\text{Wavelength of } D_2 \text{ line } \lambda_1' = \frac{e \sin \theta}{2} = ...\text{cm}$$

$$\text{Wavelength of } D_1 \text{ line } \lambda_2' = \frac{e \sin \theta}{2} = ...\text{cm}$$

$$\text{Mean wavelength of } D_2 \text{ line} = \frac{\lambda_1 + \lambda'_1}{2} = ...\text{cm} = ...\text{Å}$$

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Precautions : (1) Before the experiment, the spectrometer should be properly adjusted.

(2) Light must fall normally on the grating.

(3) The ruled lines on grating must be parallel to the axis of rotation of the telescope.

(4) The grating should not be touched by hand.

(5) While taking the observation, the prism table should be clamped.

(6) For each observation, both verniers must be read.

Viva-Voce

Q. 1. Differentiate between the interference and diffraction.

Ans. Interference occurs due to the superposition of two waves obtained from two different coherent light sources, while diffraction occurs due to the superposition of secondary wavelets originated from each point of the part of the incident wavefront exposed by the obstacle.

Q. 2. What do you mean by the diffraction grating ? How is it constructed ?

Ans. Diffraction grating is an arrangement consisting of several parallel and equidistant slits, each of equal width. It is