Discussions : (i) This correction of the bridge wire does not eliminate the end-errors which should be determined separately.

(ii) The jockeys should have sharp edges and they should be firmly pressed.

(iii) In every case the distance between the jockeys should be 10 cm.

Oral Questions and their Answers.

1. *What do you mean by calibration of a bridge wire?*
   The wire of a metre bridge is often assumed to be uniform in cross-section and hence its resistance per cm is constant throughout its length. In practice no such assumption should be made. By taking small segment of the bridge wire and making its resistance equal to standard ohm the variation may be avoided.
2. *What is the purpose of calibration?*
   See theory.

EXPT. 55. TO DETERMINE THE SPECIFIC RESISTANCE OF A WIRE USING A METRE BRIDGE.

Theory : In the arrangement as shown in Fig. 7.33 if X and R be the unknown and known resistances respectively

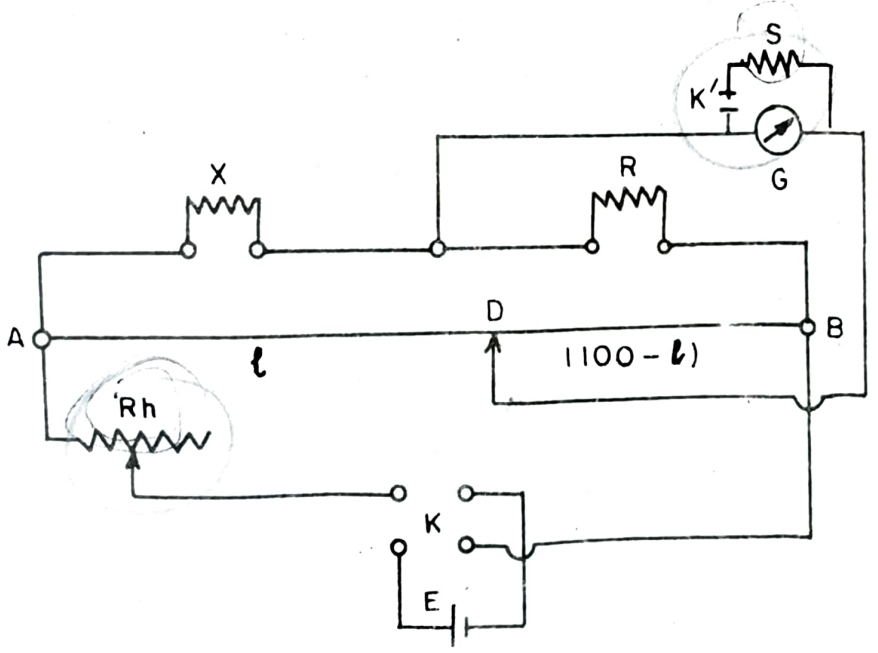

Fig. 7.33

and l be the distance of the null point measured from the left end A of the metre bridge, then by the principle of the Wheatstone's network we get

$$\frac{X}{R} = \frac{l+x}{(100 - l) + y}$$

$$\text{or, } X = \frac{R(l+x)}{(100 - l) + y} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where x and y are end-errors.

When the resistances X and R are interchanged, we get

$$\frac{R}{X} = \frac{l'+x}{(100-l')+y}$$

$$\text{or, } X = \frac{R\{(100-l')+y\}}{l'+x} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The mean of (1) and (2), after end-corrections, give the value of the unknown resistance.

If now L be the length of the experimental wire in centimetres then

$$X = \frac{\rho L}{\pi r^2}$$

$$\text{or } \rho = \frac{X\pi r^2}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where ρ is the specific resistance of the material of the wire and r is the radius of the cross-section of the wire.

Thus ρ may be determined after measuring X, r and L.

Apparatus : Metre bridge. Leclanche's cell (E), zero-centre galvanometer (G), rheostat (Rh), commutator (K), resistance box (R), the specimen wire (X), connecting wires, screw-gauge etc.

Description of the metre bridge : see Art. 7.9

Procedure : (i) Make connections as shown in Fig. 7.33. Before putting in, fold one centimetre of the specimen wire at each end at right angles to the rest of it and put the folded portion within the binding screws of the left gap. Insert 1 ohm resistance in the right gap. With 100 ohms or higher in the rheostat, move the sliding contact first to the left end and then to the right end of the bridge wire. If the deflections are on the opposite directions, the connections have been correctly made.

(ii) Move the sliding contact along the bridge wire until the galvanometer deflection is almost zero. Null point is being approached.

(iii) If the balance point seems to be far from the middle of the bridge wire, change the value of the resistance (R) in the right gap until the null point is brought very near the middle of the wire. Remove the galvanometer shunt by unplugging the key K' and find the null point accurately and note it. Reverse the current by changing the commutator plug and note the null point again (see discussion vii, expt. 56). Take the mean of the two readings, thus eliminating thermo-electric effects. From the relation (1) calculate the vlaue of X. *(When the null point is found to be very near the middle of the bridge wire, end-errors may be ignored.)*

(iv) Now interchange the positions of X and R with R in the left gap (see discussion viii, expt. 56). Find out the null point. Reverse the current and again find out the null point. Calculate the value of X from *(2)*. *(If the value of X comes out appreciably different from that obtained from the previous measurement, an unknoun resistance has been introduced in the bridge, may be, due to loose or faulty contact. This must be detected and eliminated).*

(v) With two more known resistances, repeat the operations, every time reversing the current. Then calculate the mean value of X. (If end-errors are ignored, take care to see that the null points are within 45 and 55 cm).

(vi) Carefully determine the length L of the wire between the two bends with a metre scale.

(vii) Measure the diameter (d) of the wire with a screw gauge at several places with mutually perpendicular readings at each place.

Results :

(A) Length of the wire (L).

(i) ... cm. (ii) ... cm, (iii) ... cm.

Mean L = ... cm

(B) Diameter of the wire (d).

L. C. of the screw-gauge = ... cm

	1	2	3	4	5	6	7
(a)							
(b)							

(a) and (b) are mutually perpendicular readings at the same place.

Mean diameter of the wire, d = ... cm.

(c) Readings for the balance point.

Known resistance R in ohms	Positions of		Balance point (for *l*)			100-*l*	X ohms	Mean X
	Unknown resistance x	Known resistance R	Direct	Reverse	Mean			
	Left Right	Right Left			*l* = ... *l*, = ...	100-*l* 100-*l*		
	Left Right	Right Left						

Note : *When X is in the left gap calculate its value from (1) and when X is in the right gap calculate its value from (2). Specific resistance of the material of the* given wire is given by $\rho = \frac{X\pi r^2}{L} = \frac{X\pi d^2}{4L}$ = ... ohm-cm

at the room temp ... °C.

Discussions : (i) See that the null point is not far away from the middle.

(ii) It is essential to see that none of the plugs in the resistance box R is loose.

(iii) Take care to determine the diameter (d) of the wire very accurately.

(iv) On reversing the current if the null point changes appreciably, the thermo-electric effect is too large. In such a case close the galvanometer circuit keeping the battery circuit open. The deflection of the galvanometer should be taken as the zero when looking for a null point.

(v) E.m.f. of the cell should be checked before starting the experiment.

Oral Questions and their Answers.

1. *What is meant by specific resistance and what is its unit?*
   Resistance of unit cube of the material. *i.e.*, a material having unit length and unit cross-section. Its unit is ohm-cm.
2. *On what factors does the specific resistance depend?*
   It depends on the material and its temperature. It is higher at higher temperature. It does not change with length or diameter of the wire.
3. *Why is it necessary (i) to interchange the resistances and (ii) to reverse the current?*
   (i) The pointer which indicates the null point may not be situated exactly above the fine edge of the jockey which makes contact with the bridge wire. This is known as tapping error. This is eliminated by interchanging the resistances. (ii) Reversing the current eliminates the effect of thermo-current in the circuit.
4. *While using a plug key as shunt of the galvanometer, will you use it alone or with a resistance?*
   The plug key should be used as a shunt with a resistance otherwise the galvanometer may not show any deflection when the plug is put in the key because in that case all the current passes through the shunt and no current passes through the galvanometer. When a resistance is used with the key, the galvanometer shows a deflection with the shunt and without the shunt.

EXPT. 56. TO DETERMINE THE VALUE OF AN UNKNOWN RESISTANCE AND TO VERIFY THE LAWS OF SERIES AND PARALLEL RESISTANCES BY MEANS OF A POST OFFICE BOX.

A. Determination of the value of an unknown resistance :

Theory : If P and Q are the known resistances in the ratio arms and R that in the third arm (see Figs. 7.29 and 7. 30). the unknown resistance S in the fourth arm is obtained, when there is no deflection of the galvanometer, from the relation

The shunt protects the galvanometer from damage by allowing the large proportion of the main current to flow through it, thereby reducing the current through the galvanometer.

5. *What will be the change in the galvanometer deflection for a change in the shunt resistance?*
   The galvanometer deflection will increase with the increase of shunt resistance and will decrease with decrease of shunt resistance.
6. *What should be the galvanometer deflection in this experiment and why?*
   The current is proportional to the deflection when the latter is small. This happens when the deflection is round about 10 cm.
7. *What will be the resistance of a shunted galvanometer?*
   Even less than the resistance of the shunt applied.

EXPT. 58. TO DETERMINE THE RESISTANCE OF A GALVANOMETER BY HALF-DEFLECTION METHOD.

Theory : In the arrangement shown in Fig. 7.36 if the shunt resistance S is very small compared to the galvanometer resistance G, then the potential difference (V) between the ends of the shunt resistance S remains nearly constant for all values of R_1.

Thus when $R_1 = O$, then the galvanometer current C_g is given by $\frac{V}{G} = kd$ ... ... (1)

where d is the deflection of the spot of light on the scale and k is the galvanometer constant. If now a resistance R_1 is introduced in the galvanometer circuit such that the deflection reduces to $\frac{d}{2}$,

then $C'_g = \frac{V}{G+R_1} = k\frac{d}{2}$ ... ... (2)

where C'_g is the new galvanometer current in the changed circumstances.

Dividing (1) by (2), we get

$$\frac{G+R_1}{G} = 2, \text{ or } G+R_1 = 2G$$

$$\text{or } G = R_1 \text{ ... ... (3)}$$

Hence by simply measuring R_1, G can be found out.

Apparatus : Suspended coil galvanometer, shunt box S, resistance R and R_1, commutator K, cell E, connecting wires.

Description of the apparatus :

i. Galvanometer : Art. 7.3

ii. Commutator : Art. 7.1

Procedure : (i) Make connection as shown in Fig. 7.36. Bring one sharp edge of the spot of light at the zero mark of the scale.

(ii) Insert a resistance (R) of the order of 1000 ohms in the battery circuit. Make $R_1 = 0$ by putting all the plugs in the box. Begining with the smallest value (S = 0.1 ohm) of the shunt resistance S, go on increasing S until you obtain a deflection of about 10 cm on the scale. Note this deflection.

(iii) Keeping the resistance R constant, adjust the value of the resistance R_1 until the deflection is reduced to half of the former. Record this value of R_1 which is the value of the galvanometer resistance G.

(iv) Stop the current in the circuit and examine if the same sharp edge of the spot of light is still at zero of the scale. If not, adjust the scale to bring it to zero. Make the value of R_1 zero and keep R the same. Now reverse the current with the commutator K. Repeat the whole operation to get another value of G

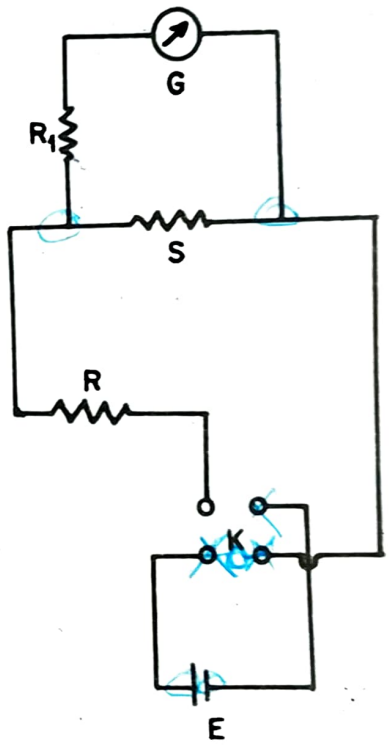

Fig. 7.36

(v) Keeping the value of the rsistance R the same, change the value of the shunt reesistance S to obtain a different deflection of round about 10 cm and similarly determine the value of G.

(vi) Repeat the operation three times with different value of R in the battery circuit and two values of S for each R.

Results : In the following table R is the resistance in the battery circuit and R_1 is the resistance in the galvanometer circuit and G is the galvanometer resistance to be determined. *Numerical values are only examples.*

No. of obs	Currents	Resistance R in ohms	Shunt resistance S in ohms	Resistance R_1 in ohms	Deflections	$G = R_1$ ohms	Mean G in ohms
	Direct	1000	0.1	0 80	10.6 5.3	80	
1	Reverse	"	"	0 81	10.4 5.2	81	
	Direct	"	0.14	0 80	10.2 5.1	80	
2	Reverse	"	"	0 79	10.4 5.2	79	
	Direct	750	0.16	0	"	"	
3	Reverse	"	"	0	"	"	
etc.							

Discussions : (i) The series resistance R should never be made equal to zero when the circuit is closed otherwise the galvanometer will be damaged.

(ii) For a steady deflection a storage battery should be used.

(iii) The position of the scale should be normal to the beam of light when no current flows through the galvanometer.

Oral Questions and their Answers.

1. *What is meant by the term galvanometer resistance?*

   The resistance of a galvanometer is the resistance of the coil of wire wound over a rectangular frame kept suspended between the pole pieces.

2. *Why do you maintain the deviation near about 10 cm?*

   If the galvanometer is not provided with concave cylindrical pole pieces the current is not proportional to the deflection and hence the deflection of the spot of light is kept small, say near about 10 cm. Even when the galvanometer is provided with concave pole pieces the current is proportional to $\tan\theta$, where θ is the angle of rotaion of the coil in radian and is small.

3. *Is the method applicable for galvanometer of any resistance?*

   The method is applicable for galvanometer of high resistance only. In case of a low resistance galvanometer, the shunt resistance becomes comparable and the method fails.

4. *How do you find the resistance of a galvanometer, when the resistance is very low?*

   In the case of galvanometer of low resistance, it is best to clamp the coil and to find its resistance by a metre bridge or P.O. Box

5. *Will you prefer a low or high resistance of a shunt?*

   Theory shows that the method gives a correct value of the galvanometer resistance when the shunt is very low. So a very low resistance of the shunt is preferred.

EXPT. 59. TO DETERMINE A HIGH RESISTANCE BY THE METHOD OF DEFLECTION.

Theory : In the arrangement of Fig.7.37, if the unknown resistance X (of the order of not less than 10^4 ohms) is included in the battery circuit by closing the gap OB_1 and if S_1 be the value of the shunt resistance S and d_1 cm be the deflection of the spot of light on the scale, then the current C_g flowing through the galvanometer is given by

$$C_g = \frac{ES_1}{X(S_1 + G) + S_1G} = kd_1 \quad (1)$$

where k is the constant of proportionality.

If now the known resistance R is introduced in the battery circuit by closing the gap OB_2 and if S_2 be the shunt resistance and d_2 be the deflection (nearly equal to d_1) of the spot of light on the scale, then the galvanometer current C_g is given by

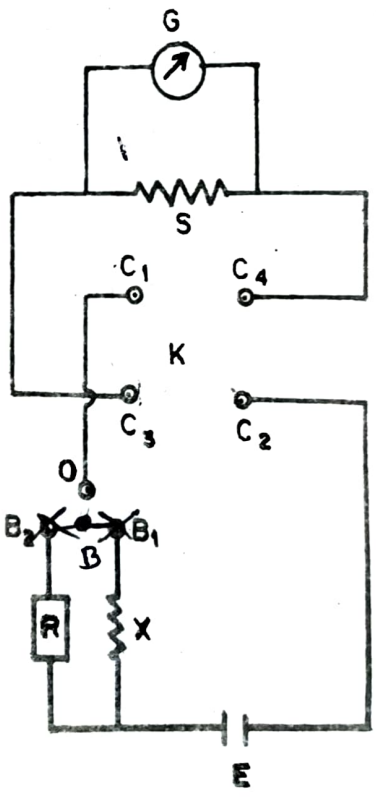

Fig. 7.37

always have a point-to-point phase relationship, *i.e.*, they are coherent. The formation of interference fringes by (i) Fresnel bi-prism, (ii) Lloyd's single mirror, (iii) Fresnel's double mirror, (iv) Rayleigh's interferometer, etc., belong to this category.

(b) Division of amplitude : In this method, the wavefront is also divided into two parts by a combination of both reflection and refraction. Since the resulting wavefronts are derived from the same source, they satisfy the condition of coherence. Examples of this class are the interference effects observed in (i) thin films, (ii) Newton's rings (iii) Michelson interferometer, (iv) Fabry-Perot interferometer, etc.

EXPT. 46. TO DETERMINE THE RADIUS OF CURVATURE OF A LENS BY NEWTON'S RINGS.

Theory : Newton's rings is a noteworthy illustration of the interference of light waves reflected from the *opposite surfaces of a thin film of variable thickness.* When a plano-convex or bi-conves lenx L of large radius of curvature is placed on a glass plate P, a thin air film of progressively increasing thickness in all directions from the point of contact between the lens and the glas plate is very easily formed (Fig. 5. 36). The air film thus possesses a radial symmetry about the point of contact. When it is illuminated normally with monochromatic light, an interference pattern consisting of a series of alternate dark and bright circular rings, concentric with the point of contact is observed (Fig. 5.37). *The fringes are the loci of points of equal optical film thickness* and gradually become narrower as their radii increase until the eye or the magnifying instrument can no longer separate them.

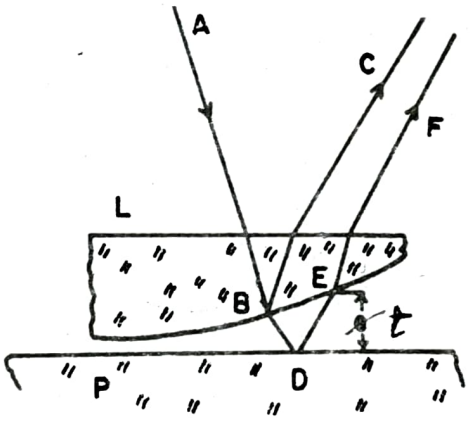

Fig. 5.36

Let us consider a ray of monochromatic light AB from an extended source to be incident at the point B on the upper surface of the film (Fig. 5.36). One portion of the ray is reflected from point B on the glass air boundary and goes upwards along BC. The other part refracts into the air film along BD. At point D, a part of light is again reflected along DEF. The two reflected waves BC and BDEF are derived from the same source and are *coherent.* They will produce constructive or destructive interference depending on their path difference. Let e be the thickness of the film at the point E. Then the optical path difference between the two rays is given by $2\mu e \cos(\theta+r)$ where θ is the angle which the tangent to the convex surface at the point E makes with the horizontal, r is the angle of refraction at the point B and μ is the refractive index of the film with respect to air.

Fig.5.37

From an analytical treatment by Stokes, based on the principle of *optical reversibility*, and Lloyd's single mirror experiment, it was established that *an abrupt phase change of π occurs when light is reflected from a surface backed by a denser medium, while no such phase change occurs when the point is backed by a rarer medium.* In Fig. 5.36 the point B is backed by a rarer medium (air) while the point D is backed by a denser medium (glass). Thus there will be an additional path difference of $\frac{\lambda}{2}$ between the rays BC and BDEF corresponding to this phase difference of π. Then the total optical path difference between the two rays is

$$2\mu e \cos(\theta+r) \pm \frac{\lambda}{2}$$

The two rays will interfere constructively when

$$2\mu e \cos(\theta+r) \pm \frac{\lambda}{2} = n\lambda$$

$$\text{or } 2\mu e \cos(\theta+r) = (2n-1)\frac{\lambda}{2} \quad \ldots (1)$$

The minus sign has been chosen purposely since n cannot have a value of zero for bright fringes seen in reflected light. The rays will interfere destructively when

$$2\mu e \cos(\theta+r) \pm \frac{\lambda}{2} = (2n \pm 1)\frac{\lambda}{2}$$

$$\text{or } 2\mu e \cos(\theta+r) = n\lambda \quad \ldots (2)$$

λ is the wavelength of light in air.

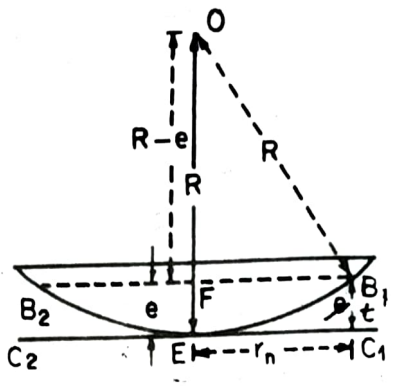

Fig. 5.38

In practice, a thin lens of extremely small curvature is used in order to keep the film enclosed between the lens and the plane glass plate extremely thin. As a consequence, the angle θ becomes negligibly small as compared to r. Furthermore, the experimental arrangement is so designed (Fig. 5.39) that the light is incident almost normally on the film and is viewed from nearly normal directions by reflected light so that cosr = 1. Accordingly eqns. (1) and (2) reduce to

$$2\mu e = (2n-1)\frac{\lambda}{2} \quad \ldots \text{ bright}$$

and $2\mu e = n\lambda$ ... ... dark.

Let R be the radius of curvature of the convex surface which rests on the plane glass surface (Fig. 5.38). From the right angled triangle OFB_1, we get the relation

$$R^2 = r_n^2 + (R-e)^2$$

$$\text{or } r_n^2 = 2Re - e^2$$

where r_n is the radius of the circular ring corresponding to the constant film thickness e. As outlined above, the condition of the experiment makes e extremely small. So to a sufficient degree of accuracy, e^2 may be neglected compared to 2Re. Then $e = \frac{r_n^2}{2R}$

Substituting the value of e in the expressions for bright and dark fringes, we have

$$r_n^2 = \frac{n\lambda R}{2\mu} \quad \ldots \quad \ldots \text{ bright}$$

$$\text{and } r_n^2 = (2n-1)\frac{\lambda R}{\mu} \quad \ldots \quad \ldots \text{ dark.}$$

The corresponding expressions for the squares of the diameters are

$$D_n^2 = 2\,(2n-1)\frac{\lambda R}{\mu} \quad \ldots \quad \ldots \text{ bright}$$

$$\text{and } D_n^2 = \frac{4n\lambda R}{\mu} \quad \ldots \quad \ldots \text{ dark.}$$

In the laboratory, the diameters of the Newton's rings can be measured with a travelling microscope. Usually a little away from the centre, a bright (or dark) ring is chosen which is clearly visible and its diameter measured. Let it be the n^{th} order ring. For an air film $\mu=1$. Then we have

$$D_n^2 = 2\,(2n-1)\lambda R \quad \ldots \quad \ldots (3) \ldots \quad \ldots \text{ bright}$$

$$\text{and } D_n^2 = 4n\,\lambda R \quad \ldots \quad \ldots (4) \ldots \quad \ldots \text{ dark}$$

The wavelength of the monochromatic light employed to illuminate the film can be computed from either of the above equations, provided R is known.

However, in actual practice, another ring, p rings from this ring onwards is selected. The diameter of this $(n+p)^{th}$ ring is also measured. Then we have

$$D_{n+p}^2 = 2(2n+2p-1)\ \lambda R \quad \ldots \quad \ldots \text{ bright}$$

$$\text{and } D_{n+p}^2 = 4(n+p)\ \lambda R \quad \ldots \quad \ldots \text{ dark}$$

Subtracting D_n^2 from D_{n+p}^2, we have

$$D_{n+p}^2 - D_n^2 = 4p\,\lambda R \ldots \quad (5)$$

for either bright or dark ring.

$$\text{or } R = \frac{D_{n+p}^2 - D_n^2}{4p\lambda} \quad \ldots \quad \ldots (6)$$

Note : *In Newton's rings experiment eqn. (5) is invariably employed to compute λ or R. The advantage of eqn. (5) over eqns. (3) and (4) lies in the fact that eqns. (3) and (4) have been derived on the supposition that the surfaces of the lens and the plate are perfect, i.e., the thickness of the air film at the point of contact is zero (e=o). This gives rise, in a reflected system, a fringe system of alternate bright and dark rings concentric with a central dark spot. In actual practice, either due to some imperfections in the surfaces in contact or due to encroachment of some dust particles between the lens and the plate, they may not be in perfect contact i.e., the thickness of the film may not be zero at the central point. The order, x, of the central ring is therefore indeterminate, i.e., it is not possible to say with certainty if the central dark ring corresponds to zero, 1st, 2nd, etc., order. The central spot may even be white. As a consequence, the order of every other bright or dark ring advances by this indeterminate nubmer x. For any one of them, the square of the diameter is not given by eqn. (3) or (4). But this indeterminacy does not occur in eqn. (5) when the difference of the squares of the diameters of the n^{th} and $(n+p)^{th}$ dark or bright rings are considered, counting the rings p, between them visually.*

Apparatus : Two convex lenses one of whose radius of curvature is to be determined, glass plate, sodium lamp, travelling microscope,etc.

Description of the apparatus:

The experimental arrangement of the apparatus is shown in Fig. 5.39. Light from an extended monochromatic source S (sodium lamp),placed at the principal focus of the convex lens C, falls on the lens and are rendered parallel. This parallel beam of light then falls on the glass plate G, inclined at an anlge of 45°, and are reflected downwards normally on to the lens L, the radius of curvature of whose lower surface is R. The lens L (see discussion v) is placed on the glass plate P which is optically worked *i.e.*, silvered at the back. A

travelling microscope M, directed vertically downwards, magnifies the system of rings. The lens C, can be fitted in the circular aperture of a screen which can be used to prevent light from the source to reach the observer's eye.

Travelling Microscope : See Art.2.5

Sodium lamp or bunsen flame soaked with NaCl sloution: See Art. 5.4.

Procedure : (i) Arrange your apparatus as shown in Fig.5.41. Level the microscope so that the scale along which it slides is horizontal and the axis of the microscope is vertical. Focus the eye-piece on the cross-wires. Determine the vernier constant of the micrometer screw of the microscope.

(ii) Carefully clean the surfaces of the lens L and the glass plate P by means of cotton moistened with benzene or alcohol. Place the glass plate P as shown in the figure. Make an ink dot-mark on the glass plate and focus the microscope on this dot. Now place the lens L on it in such a way that the centre of the lens, which is exactly above the dot, is vertically below the microscope objective.

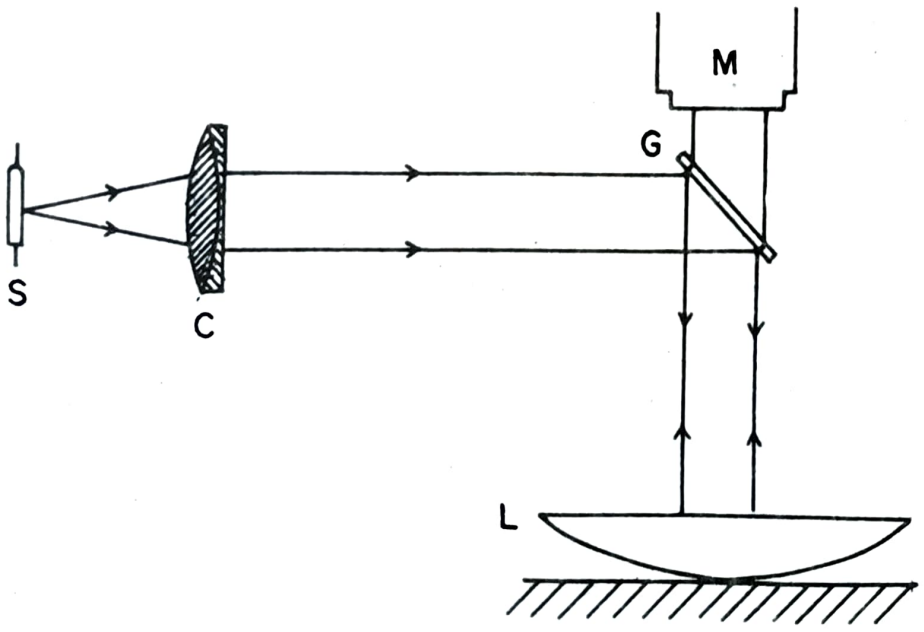

Fig. 5.39

(iii) Place the glass plate G in its position, as shown in the figure, in such a way that light from the source S, after passing through the lens C, is incident on it at an angle of approximately 45°. If you now look into the microscope, you will probably see a system of alternate dark and bright rings. Adjust the glass plate G by rotating it about a horizontal axis until a large number of evenly illuminated bright and dark rings appear on both sides of the central dark spot. Adjust the position of the lens C with respect to the flame so that a maximum number of rings are visible through the microscope. This will happen when the flame will be at the focal plane of the lens C.

(iv) After completing these preliminary adjustments, focus the microscope to view the rings as distinctly as possible and set one of the cross-wires perpendicular to the direction along which the microscope slides. Move out the microscope to the remotest distinct bright ring on the left side of the central dark spot. The cross-wire should pass through the middle of the ring and should be tangential to it. Note the reading of the microscope. Move the microscope back again. Turn the screw always in the same direction to avoid any error due to back-lash. Set the cross-wire carefully on the centre of each successive bright ring and observe the microscope reading. Go on moving the microscope in the same direction. Soon it will cross the central dark spot and will start moving to the right side of it. As before set the corss-wire on the consecutive bright rings and take readings. Proceed in this way until you have reached the same remotest bright ring as in the case of left side of the dark spot. Considering a particular ring, the difference between the left side and right side readings, gives the diameter of the ring. In this way, the diameters of the various rings are determined (see discussion)

(v) Tabulate the readings as shown below. *While tabulating the reading you should be careful about the*

number of the ring so that the left side and right side readings correspond to the same ring.

(vi) The whole experiment may be repeated moving the microscope backwards in the opposite direction over the same set of rings.

(vii) Draw a graph with the square of the diameter as ordinate and number of the ring as abscissa. The graph should be a straight line (Fig.5.40)

(viii) From the graph determine the difference between the squares of the diameters of any two rings which are separate by say about 10 rings *i.e.*, p is equal to 10. Now calculate R with the help of eqn. (6) .

Results :

Vernier const. of the micrometer screw : (Record details as in previous expts.)

Table for ring diameter

ring number	Readings of the microscope								Diameter of the ring [D=L~R]	D^2
	Left side				Right side					
	Main scale reading (S) cm	Vernier reading (V) = Ver. divn. X V.C. cm	Total reading = S+V cm	Mean (L)	Main scale reading (S) cm	Vernier reading (V) = Ver. divn. X V.C. cm	Total reading = S+V cm	Mean (R)		
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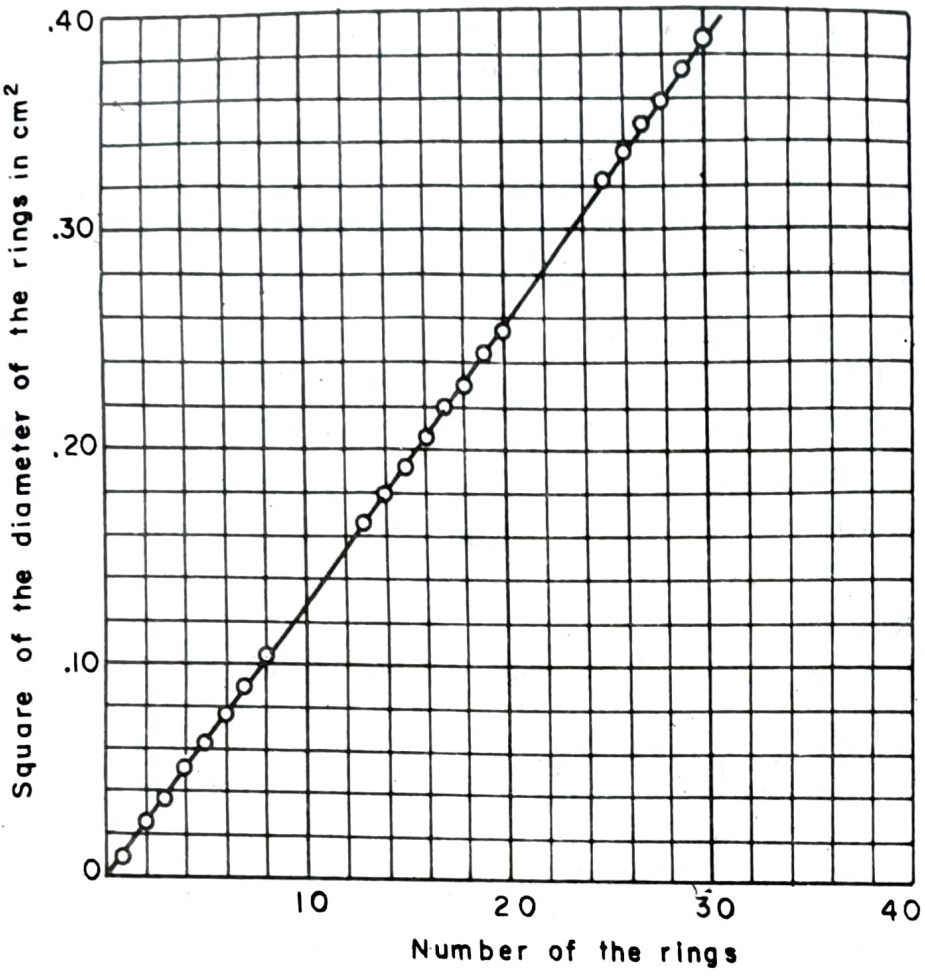

Graph (Fig.5.40)

Calculation :

Mean wavelength of sodium light (λ)=5893 A.U.= 5893×10^{-8} cm

From the graph $D^2_{n+p} - D^2_n$ = ... cm^2.

$D^2_{n+p} - D^2_n = 4p\lambda R$

$$R = \frac{D^2_{n+p} - D^2_n}{4p\lambda}$$

The radius of curvature of the lower surface of the given lens = ... cm.

Discussions : (i) The intensity of the ring system decreases as one goes from the inner to the outer rings, thus setting a limit for the selection of the outermost ring whose diameter is to be measured.

(ii) Newton's rings can also be observed in transmitted light but in that case the rings will be less clearly defined and less suited for measurement.

(iii) It may be noticed that the inner rings are somewhat broader than the outer ones. Hence while measuring the diameter of the inner rings some error may be introduced. The cross-wire should be set mid-way between the outer and inner edges of a ring. A more correct procedure is to determine the inner and outer diameters of a particular ring by setting the cross-wire tangentially at the inner and outer edges on both sides of the ring. From this the mean diameter can be found.

(iv) The first few rings near the centre may be deformed due to various reasons. The measurement of diameters of these rings may be avoided.

(v) For the purpose of the experiment a convex lens whose radius of curvature is of the order of 100 cm is suitable. Otherwise the diameters of the rings will be too small and it will be difficult to measure them.

(vi) Due account should be taken of the fact that in the present experiment, the rings which are formed in the air film in the space between the lens and the glass plate are not seen directly but after refraction through the lens. This inevitably introduces an error. However, if the lens used is thin then this error is not great.

containing a very fine micrometer screw which moves sideways between each stroke. The pitch of the screw must be constant so that the lines are as equally spaced as possible, which is an important requirement of a good quality grating. As such a grating is very costly. What is usually used in its place in the laboratory is a *photographic replica* of the same, possibly prepared by contact printing on a fine grained photographic plate. When using a replica, never try to clean or touch its surfaces at any time. Whenever it is to be handled, it must be held by the edges between the thumb and the middle finger.

The diffraction gratings are of two types : *transmission type and the reflection type*. The lines, mentioned above, act as opaque spaces and the space between any two consecutive lines is transparent to light. Such surface act as transmission gratings. If on the other hand lines are ruled on a silvered plane or concave surface, then light is reflected from the positions of the mirror in between any two lines. Such surfaces act as reflection gratings.

EXPT. 48. TO DETERMINE THE WAVELENGTHS OF VARIOUS SPECTRAL LINES BY A SPECTROMETER USING A PLANE DIFFRACTION GRATING.

Theory : If a parallel pencil of monochromatic light of wavelength λ, coming out of the collimator of a spectrometer falls normally on a plane diffraction grating placed vertically on the prism table, a series of diffracted image of the collimator slit will be seen on both sides of the direct image. Reckoning from the direction of the incident light (direct image), if θ be the deviation of the light which forms the n^{th} image and $(a+b)$ be the grating element, then $(a+b)\sin\theta = n\lambda$.

Since $a+b = \frac{1}{N}$, where N is the grating constant *i.e.*, the number of lines or rulings per cm of the grating surface, $\sin\theta = nN\lambda$. Thus $N = \frac{\sin\theta}{n\lambda}$ ...(i) and $\lambda = \frac{\sin\theta}{Nn}$....(2)

By employing sodium light of known wavelength the value of N can be determined first. Then from this knowledge of N, the wavelength λ of any unknown light can be found out with the help of equation (2).

Apparatus : Spectrometer, spirit level, a prism, plane diffraction grating, discharge tubes, etc.

Description of the apparatus : See spectrometer (Art. 5.4) and diffraction grating (Art.5.6),

Description of the apparatus : Spectrometer (See Art. 5.4).

Discharge tube : Gas discharge tubes, also known as *Geissler tubes*, are widely used in the laboratory for spectroscopic purposes. It is generally given in two shapes. The first one is a straight glass tube, the central part BC of the tube being a capillary having a length of about seven or eight centimetres and a diameter of about one millimetre. Two aluminium or platinum electrodes are sealed into this tube at the two ends A and D (Fig. 5.45 a). The tube is filled with the gas, whose spectrum is to be studied, at a pressure of 1 or 2 mm of mercury. More than 2000 volts potential is applied between the electrodes with the help of an induction coil high tension D.C. source (power pack).

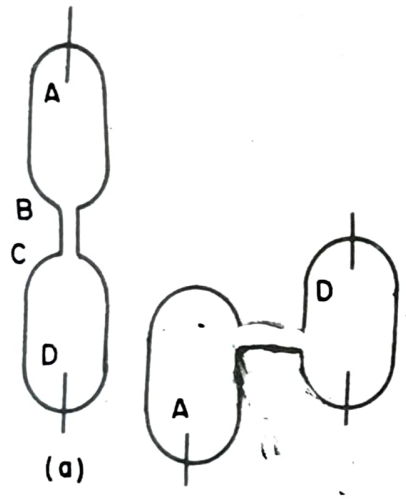

Fig. 5.43

The light comes from the positive column of the discharge and is the most intense in the capillary where the current density is the highest. The second type, as shown in Fig. 5.43 b, also works on the same principle and is of H- shape. The length of capillary tube in this design is only about 4 centimetres. Thus, it makes a source of greater intensity than the first one. The intensity is still further increased if the capillary is viewed *end on*. These tubs were used for many years for the study of the spectra of substances which could be obtain in the form of vapour or gas. They require

a high potential, still the operating current is only of the order of few milliamperes which cannot heat the electrodes sufficiently and therefore they are knwon as cold cathode tubes.

Procedure : The preliminary adjustments for this experiment are twofold (a) those of the spectrometer and (b) those of the grating.

(a) Make all the adjustments of the spectrometer including focussing for parallel rays in the usual manner as described in Art. 5.4.

The following adjustments should be made in connection with the mounting of the grating.

(1) *To make the plane of the grating vertical and set it for normal incidence :* (i) Focus the telescope towards the direct light coming through the collimator. Note the position of the telescope (direct reading). Then turn the telescope through exactly 90°and fix it there.

(ii) Place the grating, mounted in its holder, on the prism table. The grating should be so placed that the lines of the grating are perpendicular to the table and the plane of the grating, defined by the ruled surface, passes through the centre of the table so that the ruled surface, extends equally on both sides of the centre. At the same time, the grating should be perpendicular to the line joining any two of the levelling screws say E and F in Fig. 5.22.

(iii) Rotate the prism table till you get, on the cross-wires of the telescope, an image of the slit formed by reflection at the grating surface. The image may not be at the centre of the cross-wires. If so, turn one of the screws till the centre of the image reaches the intersection of the cross-wires. In this position the plane of the grating has been adjusted to be vertical. The angle at which light is now incident on the grating is obviously 45°. Read the position of the prism table, using both the verniers.

(iv) Now look carefully at the grating on the table and ascertain whether the surface of the grating which first receives the light is the one which also contains the lines. (Allow the light to be reflected alternately from both the surfaces of the grating and observe the image of the slit

through the telescope, whose axis must be kept perpendicular to that of the collimator. It will be found that the image formed by one surface of the grating is brighter than that formed by the other surface. The surface which produces the less sharp image is the one which contains the lines). If so, turn the prism table either through 135°or 45° in the appropriate direction so that at the end of this rotation the ruled surface will face the telescope, while light from the collimator will be incident normally on the grating.

If it is the unruled surface of the grating which first receives the light, then the prism table should be rotated through an angle of 45°or 135° in the proper direction to bring the grating into the position specified above. Fix the prism table in its new position.

(2) *To make the grating vertical* : In operation (1) you have made the plane of the grating vertical but the lines may not be so. The grating would require a rotation in its own plane to bring this about.

(i) Rotate the telescope to receive the diffracted image on either side of the direct image. If the lines of the grating are not vertical, the diffracted image on one side of the direct image will appear displaced upwards while that on the other side will appear displaced downwards. But actually the spectra are formed in a plane perpendicular to the lines of the grating.

(ii) Now set the telescope to receive the diffracted image in the highest possible order on one side and turn the third screw of the prism table (G in Fig.5.22) till the centre of the image is brought on the junction of the cross-wires. This screw rotates the grating in its own plane as a result of which the lines become vertical. On turning the telescope it will be observed that the centres of all the diffracted images (on both sides of the direct image) lie on the junction of the cross-wires.

This completes the adjustments required for mounting of the grating. Now proceed to take readings as follows:

(i) With sodium discharge tube placed in fornt of the collimator slit, set the telescope on, say, the first order of the diffracted image on one side of the direct image. Focus the telescope and take the reading using both the verniers.

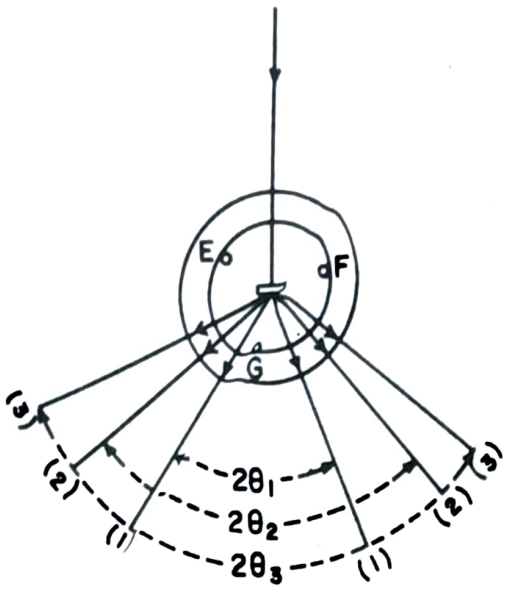

Fig. 5.4

Then focus the telescope on the diffracted image of the same order on the other side of the direct image. Again take the reading. The difference between these two readings is twice the angle of diffraction for this order of image. (Fig. 5.4). (Alternately you can take the readings of the diffracted image and the direct image. The difference is the angle of diffraction. But the previous method is to be perferred since it minimises error in observation).

(ii) Similarly measure the angle of diffractions for the second order, third order and so on. During these measurements the width of the slit should be as narrow as possible. The readings for each diffracted image should be taken at least three times for three independent settings of the telescope. The cross-wires should always be focussed on the same edge of the image of the slit.

(iii) With the help of equation (1), compute N from the known values of the wavelength for sodium-D lines and the angles of diffraction obtained for two or three of the highest orders of the spectra.

Note : *In case the Na-D (yellow) lines are not resolved then the cross-wire should be focussed on the middle of the image. In that case calculate N by assuming λ to be 5893 A.U. But if the lines D_1 (5890 A.U.) and D_2 (5896 A.U.) are resolved readings should be taken for each of these lines and N should be computed separately from each set of readings.*

(iv) Replace the sodium discharge tube by another discharge tube, say of helium, which should be mounted practically in contact with the slit. Instead of one or two lines as in the case of sodium, you will now see a large

number of spectral lines of different colours. Adjust the position of the discharge tube till the spectrum look brightest. Identify the different lines of the spectrum (see discussion) and for each line determine the angle of diffraction for as many order as possible in the manner described in operations (i) and (ii). Then from the knowledge of the grating constant N and the order of diffraction n, calculate the wavelength of each of these lines. Compare them with the values obtained from the table.

(v) Replace this discharge tube with another, say of neon. Calculate the wavelength of the prominent lines of the spectrum in the manner described above and compare them with the values given in the table.

Results :

Vernier Constants : Determine the vernier constants in the manner shown in expt.44

Direct reading of the telescope = ... ° ..... ' ..... "

Telescope rotated through 90° and set at = ... ° ..... ' ..... "

Reading of the prism table when the incidence is at 45° = ... ° ..... ' ....."

Prism table is rotated through 135° (or 45°) and set at = ... ° ..... ' ....."

Table for the determination of the grating constant

Wave length (λ) A.U	Order number (n)	Reading for the angle of diffraction θ								2θ = A~B	θ	Grating constant $N = \frac{\sin\theta}{n\lambda}$	Mean grating constant
		Left side				Right side							
		Main scale reading (S)	Vernier reading (V)	Total = S + V	Mean reading (A)	Main scale reading (S)	Vernier reading (V)	Total = S + V	Mean reading (B)				
5890	1	...	...	...	...	...	...	...	...	...	...	...	
	2	...	...	...	...	...	...	...	...	...	...	...	
	etc.	...	...	...	...	...	...	...	...	...	...	...	
5896	1	...	...	...	...	...	...	...	...	...	...	...	
	2	...	...	...	...	...	...	...	...	...	...	...	
	etc.	...	...	...	...	...	...	...	...	...	...	...	

Table for the determination of wavelengths
Helium Tube

Helium Tube

Number of order	Description of the line	Readings for the angle of diffraction θ										Wavelength $\lambda = \frac{\sin\theta}{Nn}$	Standard wavelength from Table (A.U.)	Deviation from standard wavelength
		Left side				Right side				$2\theta = A \sim B$	θ			
		Main scale reading (S)	Vernier reading (V)	Total = S + V	Mean reading (A)	Main scale reading (S)	Vernier reading (V)	Total = S + V	Mean reading (B)					
1st. order (n = 1)	Violet	...	...	...	...	...	...	...	...	...	...	...	4471	...
	Bluish green	...	...	...	...	...	...	...	...	...	...	...	4713	...
	Light green	...	...	...	...	...	...	...	...	...	...	...	4922	...
	Green	...	...	...	...	...	...	...	...	...	...	...	5016	...
	Yellow	...	...	...	...	...	...	...	...	...	...	...	5876	...
	Red	...	...	...	...	...	...	...	...	...	...	...	6678	...
2nd. order (n = 2)	Violet													
	Bluish green													
	Etc.													

Note : *Make similar tables for other discharge tubes. Tables above refer to one of the two verniers used. Similar tables may be made for the other vernier.*

Oral Questions and their Answers.

1. *What is a diffraction grating?*
   See Art. 5.6
2. *How is a grating constructed? What is a replica grating?*
   See Art. 5.6
3. *What is grating element?*
   See Art. 5.6
4. *What are corresponding points?*
   When two points in the consecutive slit are separated by a distance (a+b), the grating element, then these two points are known as corresponding points.
5. *What happens if the number of rulings per cm (N) is either increased or decreased?*

If N is increased, the order number will be few but they will be separated by a large angle. If N is decreased, the order number will be large, but separated by a small angle.

6. *Why is it necessary that the ruled surface be directed towards the telescope?*
If the ruled surface is directed towards the collimator, then the incident rays will first fall on this surface and will be diffracted. But then these diffracted rays will have to pass through a finite thickness of the glass plate and as such will be refracted again. Hence the angle (θ) measured, is not due to diffraction alone, but will be due to combined effect of diffraction and refraction.
7. *How does a grating form a spectrum?*
See a text book.
8. *How does this spectrum formed by a grating differ from that formed by a prism?*
Provided the angle of diffraction θ is not very large, then the angle of diffraction in the grating spectrum is proportional to λ but in case of prismatic spectrum, the violet end is more drawn out than the red end. Hence the spectrum formed by a grating may be regarded purer then that formed by the prism.
9. *What do you mean by ghost lines?*
If the rulings on a grating are not exactly equidistant or accurately parallel, then some additional lines appear near the real spectral lines. These additional lines are called ghost lines.
10. *What do you mean by resolving power of a grating?*
See a text book.
11. *What is meant by dispersive power of a grating?*
See art. 5.6

Art. 5.7 Polarization of light

Light is emitted in the form of wave trains by individual atoms when in an excited state. The wave trains are transverse in nature, *i.e.*, the vibrations are at right angles to the direction of propagation of the wave. A beam of natural light consists of millions of such wave trains emitted by a very large number of randomly oriented atoms and

molecules in the light source and, therefore, natural light is a random mixture of vibrations in all possible transverse directions.

Looking at such a bean end on, there should be just as many waves vibrating in one plane as there are vibrating in any other as shown in Fig. 5.47 This is referred to as perfect symmetry. As light waves are transverse in nature, each vibrations of Fig. 5.4 5 can be resolved into two component vibrations along two planes at right angles to each other and also perpendicular to the direction of propagation of light. Although these two components may not be equal to each other, the similarly resolved components from all waves will average out to be equal. Thus a beam of ordinary unpolarized light may be regarded as being made up of two kinds of vibrations only. Half these vibrations vibrate in a vertical plane , say along the plane of the paper, and are referred to as *parallel* vibrations indicated by arrow as in Fig. 5.48 (ii). The other half vibrates perpendicular to the plane of the paper and are referred to as *perpendicular* vibrations indicated by dot as in Fig. 5.48 (iii). Fig. 5.4 3 (i) will then represent a beam of ordinary unpolarized light.

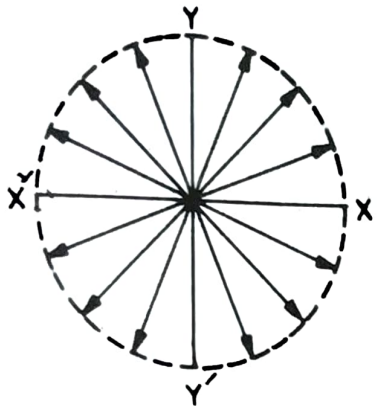

Fig. 5.4 5

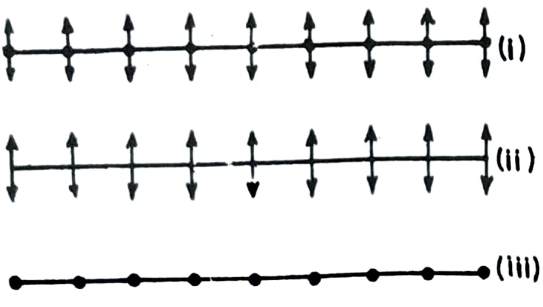

Fig. 5.4 6

If by some means the vibrations constituting the beam of ordinary unpolarized light are confined to one plane, the light is said to be plane polarized. *Polarization is, therefore, the process by which light vibrations are*

confined to one particular direction. For example, if a beam of ordinary unpolarized light is allowed to pass through a *tourmaline* crystal, only those vibrations which are parallel to a particular direction inside the crystal, will be allowed through the crystal. Hence the light emerging out of the crystal has its vibrations confined to one plane. The plane in which no vibrations occur is the *plane of polarization.* The vibrations occur in a plane which is at right angles to the plane of polarization. This is called the *plane of vibration.* In Fig. 5.47 the plane ABCD is the plane of polarization while the plane EFLH is the plane of vibration.

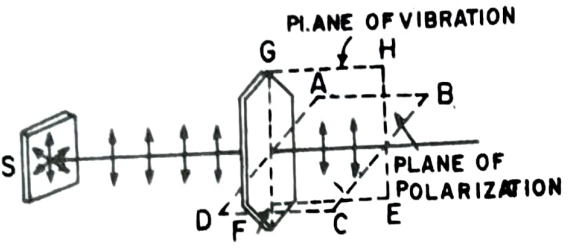

Fig. 5.47

Polarization by double refraction.

There are various methods for producing and studying polarized light. The phenomenon of double refraction is one of them. When a beam of ordinary light is incident on certain substances, such as a calcite crystal (also known as *Iceland spur* because of its availability in large quantittes in Iceland in times gone-by and chemically is hydrated $CaCO_3$ crystal), it splits into two refracted rays. This phenomenon is known as *double refraction* or *bi-refringence.* Of the two refracted rays, the one which always obeys ordinary laws of refraction (Snell's law) is called the *ordinary ray or O-ray,* while the other which does not obey the ordinary laws of refraction and behaves in quite extraordinary manner, is called the *extra ordinary ray* or *E-ray.* When tested for polarization, the two refracted rays are found to be plane polarized in mutually perpendicular directions. However, if the ordinary ray of light is incident on the calcite crystal in a direction parallel to a *particular direction* inside the crystal, the light does not suffer double refraction. This particular direction is

known as *optic axis* of the crystal. Both the *O-ray* and *E-ray* travel along this direction with same velocity. If the ray of ordinary light is incident on the calcite crystal in a direction perpendicular to the optic axis, double refraction dose not take place in this case also. But although both the *O-ray* and *E-ray* move along the same direction, they do so with different velocities this time; the E-ray moving faster than the O-ray. From the definition of refractive index it, therefore, becomes obvious that while the refractive index of O-ray (μ_o) is constant and independent of the direction of the O-ray inside the crystal, the refractive index of the E-ray (μ_e) is different for different directions. μ_e varies from a maximum value in a direction parallel to the optic axis to a minimum value in a direction perpendicular to the optic axis. *Nearly all crystalline substances like quartz, mica, sugar, topaz, selenite, aragonite, ice, etc. are known to exhibit the phenomenon of double refraction.* Calcite and quartz are particularly important because they are used extensively in the manufacture of special instruments.

Principal section and principal plane : A plane containing the optic axis and also perpendicular to the two opposite faces of the crystal, gives a section of the crystal known as *principal section*. Therefore, for every point there are three principal sections, one for each pair of opposite crystal faces. A plane drawn inside the crystal containing the optic axis and the ordinary ray is called the principal plane of the ordinary ray. This is always possible since the optic axis is merely a direction and not a particular line in the crystal. The principal plane of extra-ordinary ray is similarly defined. The two principal planes of ordinary and extra-ordinary rays coincide only when the principal section is the plane of incidence. In this case there is coincidence of principal section with these planes as well.

Nicol prism : Nicol prism is an ingenious optical device for producing and analyzing plane polarized light and is based on the phenomenon of double refraction. It may be recalled that when a beam of ordinary light is allowed to pass through a calcite crystal, two completely plane polarized beams, the O-wave and the E-wave, with vibrations in

mutually perpendicular planes are obtained. If by some means one beam can be eliminated, calcite may be used to obtain plane polarized light from natural light. William Nicol, a Scottish physicist and an expert in cutting and polishing gems and crystal, succeeded in round about 1828 in eliminating the O-wave by using the phenomenon of *total internal reflection* at a thin film of Canada balsam separating two pieces of calcite. His device has come to be known as *Nicol prism*, although in reality it is a *parallelopipedon*—not a prism.

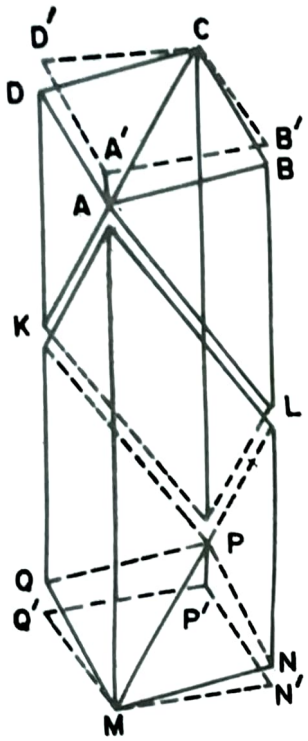

Fig. 5.48

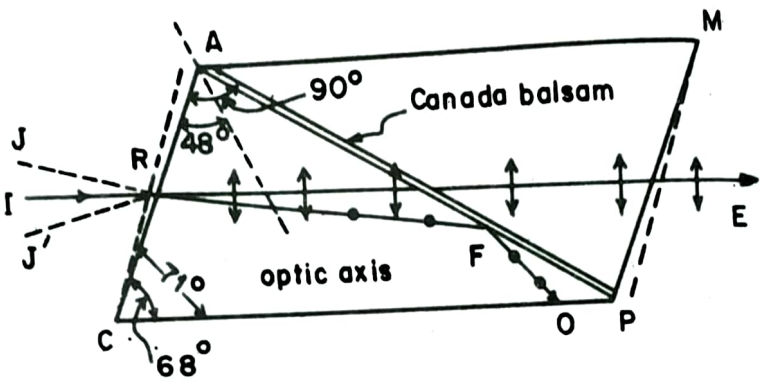

Fig. 5.49

Of the several different forms of Nicol prism, one is described here. First a calcite rhombohedron of length three times its width is produced by cleavage' from a clear natural crystal. A''B'CD'MN'P'Q' represents such a rhombohedron. A' and P' are the blunt corners of the crystal where the three obtuse angles of the three faces meet. An imaginary plane through the edges A'M and P'C contain the optic axis of the crystal; A'MP'C is therefore one of the principal section of the crystal with the angle $\angle A'CP' = \angle P'MA' = 71°$. The faces

A'B'CD' and MN'P'Q' are then grounded so as to form the new faces ABCD and MNPQ in such a way that the angles ∠ACP and ∠PMQ become equal to 68° instead of 71°. The crystal is then cut along the plane AKPL passing through A and P and perpendicular to the shorter diagonal of the end faces AC and PM (Fig. 5.18). The two cut surfaces are then grounded and polished to optical flatness and cemented together with a thin layer of *Canada balsm* which is a transparent, non-doubly refracting plaster with an index of refraction intermediate between the indices of refraction of calcite for the O- and E- rays. For sodium-D line (yellow) at mean wavelength λ =5893 A.U., the values of indices are:

Refractive index of calcite for O-ray. μ_o= 1.65863

,, ,, Canada balsam μ_B= 1.55

,, ,, calcite for E-ray μ_e = 1.48641

Action :

The action of a Nicol prism can be understood by referring to the figure 5.19 where the section ACPM of the crystal is shown. The diagonal AP represents the Canada balsam layer in the plane ALPK. A ray IR of monochromatic unpolarized light incident on the face AC splits into an O-ray and E-ray. The E- ray makes a greater angle with the optic axis than the O-ray. Since $\mu_e < \mu_B < \mu_o$, the Canada balsam acts as a rarer medium for an ordinary ray and a denser medium for the extra-ordinary ray. Therefore, at F, the O-ray is incident on a rarer (balsam) medium from a denser (calcite) medium. When the angle of incidence on the balsam is greater than the critical angle, the O-ray is totally internally reflected and is diverted along the direction FO where it is effectively absorbed by the blackened side of the prism. Now the refractive index of the ordinary ray with respect to Canada balsam is

$$\mu = \frac{\mu_o}{\mu_B} = \frac{1.658}{1.550}$$

Hence the critical angle of incidence is obtained from the relation $\sin\theta = \frac{1}{\mu}$; or $\theta = \sin^{-1}\left(\frac{1.550}{1.658}\right) = 79°$

The E-ray, on the other hand, is passing from a rarer (calcite) into a denser (balsam) medium. It is, therefore, transmitted through the balsam, simply suffering a slight deviation in its path. The E-ray finally emerges out of the prism parallel to its original direction but slightly displaced laterally. Thus if the angle of incidence of the O-ray on the balsam is greater than the critical angle, a ray of unpolarized light, on passing through the Nicol prism becomes plane-polarized.

It should be emphasized that the angular limit of the incident ray is limited to IRJ of about 14° on one side. It can be shown that for angles greater than this, the angle of incidence of the O-ray on the balsam becomes less than the critical angle. Thus some of the O-ray will also be transmitted through the balsam. On the other side, the angular limit of the incident ray should also be limited to IRJ' of about 14°; for angles greater than this, the E-ray is also totally internally reflected by the balsam surface. This happens because when the E-ray travels in a direction at right angles to the optic axis, its refractive index = 1.486. When the E-ray travels in the direction of the optic axis, its refractive index becomes 1. 658, the same as that of the O-ray. Thus, depending upon the direction of propagation of the E-ray, μ_E lies between 1.486 and 1.658. Therefore, for a particular angle of incidence of the unpolarized light, μ_E may be more than 1.55 and the angle of incidence on the balsam layer will be more than critical angle. Then the E-ray will also be totally internally reflected by the balsam layer.

Thus to avoid the transmission of the O-ray, and the total internal reflection of the E-ray, the angle between the extreme rays of light incident on the Nicol prism is limited to about 28°

Uses:

A Nicol prism can be used both for the production *(polarizer)* and detection *(analyzer)* of plane polarized light.

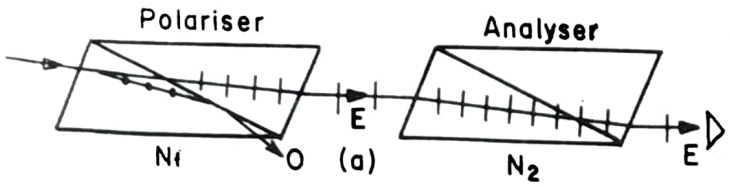

Fig. 5.50 (a) parallel position

Two Nicol prisms are frequently lined up co-axially one behind the other in an arrangement as shown in Fig. 5.50 This arrangement is frequently used in specially constructed instruments for studying the optical properties of other crystals. The first Nicol N_1 acts as the polarizer while the second Nicol N_2 acts as the analyzer.

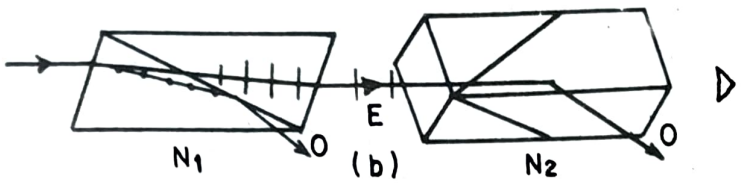

Fig. 5.50 (b) crossed position

When the two Nicols are placed with their principal sections parallel to each other as in Fig. 5.50 (a), then vibration of the E-ray which is in the principal section of N_1 is also in the principal section of N_2. This setting of the Nicols is known as *parallel position* and the intensity of the transmitted light is maximum. If the second Nicol is gradually rotated, the intensity of the transmitted E-ray goes on decreasing in accordance with Malus' law till it becomes zero when the principal sections of the two Nicols are at right angles to each other as shown in Fig. 5.50 (b). This is so because the E-ray coming out from the first Nicol becomes an O-ray for the second Nicol and is therefore, totally internally reflected. This position of the Nicol is known as *crossed position.* If I_o be the intensity of transmitted light in the parallel position of the Nicols and I_θ the intensity when the principal sections are inclined at an angle θ, then according to cosine law of Malus $I_\theta = I_o \cos^2\theta$

If N_2 is further rotated so that it has turned through an angle 180° the E-ray will again be freely transmitted and the intensity will again be maximum .

Optical activity : Certain substances like quartz, sodium chlorate, sodium bromate, etc. and also certain liquids like turpentine, sugar solution, alcoholic solution of camphor, etc. possess the property that when a beam of polarized light passes through them, a rotation of the plane of vibration occurs. This property of rotating the plane of vibration of

plane polarized light about its direction of propagation possessed by certain substances or liquids is known as *optical activity*. Substances exhibiting the phenomenon of optical activity are said to be *optically active*. It should be mentioned that the rotation of the plane of vibration occurs not on the surface of the substance but inside the body of the substance.

Optically active substances are of two types. Looking along the ray towards the source of light, if the rotation of the plane of vibration produced by a substance is to the right or colckwise, then the substance is called *right-handed* or *dextro rotatory*. Substances that rotate the plane of vibration to the left or anti-clockwise are called *left-handed* or *laevo-rotatory*. Solids are more optically active than liquids. For example the red region of the spectrum is rotated through an angle of 18° by an one millimetre thick quartz plate whereas the same thickness of turpentine produces a rotation of only twenty five minutes. Same substance may be dextro-rotatory as well as laevo-rotatory. For example, some quartz crystals are dextro-rotatory while others are laevo-rotatory. One is the mirror image of the other in their orientation. When two substances which alone would produce opposite rotations of equal magnitude are present, the result would be zero rotation. More generally if two or more active substances are present to the same extent, then the rotation, actually produced is the algebraic sum of the rotations which would be produced by the substances separately. If an active substance such as sugar is dissolved in an inactive liquid such as water, then the optical activity of the active substance is not affected.

EXPT. 49. TO CALIBRATE A POLARMETER AND HENCE TO DETERMINE THE SPECIFIC ROTATION OF A SUGAR SOLUTION BY MEANS OF A POLARIMETER.

Theory : The angle of rotation produced to the plane of vibration by an optically active substance, in solution or otherwise, is proportional to

(i) the thickness of the medium (solution)

Calculation : Modulus of rigidity

$$n = \frac{8\pi Il}{T^2 r^4} \text{ dynes/sq.cm}$$

Discussions : (i) Since the radius of the wire occurs in fourth power, it should be measured very accurately.

(ii) A large number of oscillations should be counted for determining ordinary T, the period of oscillation.

(iii) The expeimental wire should pass through the axis of the cylinder.

(iv) The pendulum oscillation of the cylinder, if any, should be stopped.

(v) Since the ratio of displacement to the acceleration is constant, the angular amplitude may have any value within the elastic limits of the experimental wire.

(vi) With the increase of the length of the wire period of oscillation increases and with the increase of the diameter of the cylinder the period decreases.

Oral Questions and their Answers.

1. *How do the length and diameter of the wire affect the period of oscillation of a torsional pendulum?*
   See 'Discussion (vi)'
2. *Does the period of oscillation depend on the amplitude of oscillation of the cylinder?*
   No. The angle of oscillation may have any value within the elastic limit of the suspension wire.
3. *How will the period of oscillation be affected if the bob of the pendulum be made heavy?*
   With greater mass, the moment of inertia increases and hence it will oscillate slowly with greater period.

EXPT. 11. TO DETERMINE THE SPRING CONSTANT AND EFFECTIVE MASS OF A GIVEN SPIRAL SPRING AND HENCE TO CALCULATE THE RIGIDITY MODULUS OF THE MATERIAL OF THE SPRING.

Theory : If a spring be clamped vertically at the end P, and loaded with a mass m_o at the other end A, then the period of vibration of the spring along a vertical line is given by

$$T = 2\pi \sqrt{\frac{m_o+m}{k}} = 2\pi \sqrt{\frac{M}{k}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where m' is a constant called the *effective mass* of the spring and k, the spring constant *i.e.*, the ratio between the added force and the corresponding extension of the spring.

How the mass of the spring contributes to the effective mass of the vibrating system can be shown as follows. Consider the knietic energy of a spring and its load undergoing simple harmonic motion. At the instant under consideration let the load m_o be moving with velocity v_o as shown in fig. 2.19.

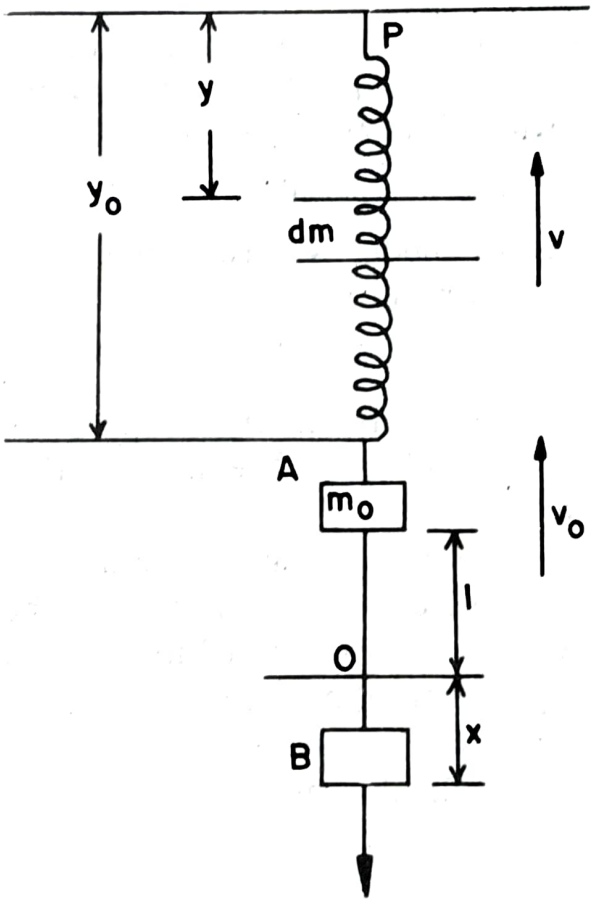

Fig.2.19.

At this same instant an element dm of the mass m of the spring will also be moving up but with a velocity v which is smaller than v_o. It is evident that the ratio between v and v_o is just the ratio between y and y_o. Hence, $\frac{v}{y} = \frac{v_o}{y_o}$ i.e., $v = \frac{v_o}{y_o} y$.

The kinetic energy of the spring alone will be $\int_0^{y_0} \frac{1}{2} v^2 \, dm$.

But dm may be written as $\frac{m}{y_0} dy$, where m is the mass of the spring.

Thus the integral equals to $\frac{1}{2} (\frac{m}{3}) v_0^2$. The total kinetic energy of the system will then be

$\frac{1}{2} (m_0 + \frac{m}{3}) v_0^2$ and the effective mass of the system is, therefore, $m_0 + \frac{m}{3}$

Hence $m' = \frac{1}{3} m$ .....(2)

where m' = effective mass of the spring and m = true mass of the spring. The applied force $m_0 g$ is proportional to the extension l within the elastic limit. Therefore $mg = kl$.

Hence $l = \frac{g}{k} m$ .....(3)

If n is the rigidity modulus of the material of the spring, then it can also be proved that

$$n = \frac{4NR^3k}{r^4} \text{.....(4)}$$

where N = number of turns in the spring, R = radius of the spring and r = radius of the wire of the spring and k=spring constant.

Apparatus : A spiral spring, convenient masses with hanging arrangement, clamp or a hook attached to a rigid framework of heavy metal rods, weighing balance, stop clock and scale. The spiral spring may be a steel spring capable of supporting sufficient loads. A cathetometer may also be used to determine vertical displacements more accurately.

Procedure : (i) Clamp the spring at one end at the edge of the working table or suspend the spring by a hook attached to a rigid framework of heavy metal rods.

(ii) Measure the length L of the spring with a metre scale. Put a scale behind the spring or make any other arrangement to measure the extensions of the spring.

(iii) Add suitable weight to the free end of the spring so that it extends to the position O (Fig. 2.18). On the reference

frame put behind the spring, read the extension l and note the position O.

(iv) Pull the load from position O to a moderately low position B and then let it go. The spring will now execute simple harmonic motion and vibrate up and down about the position O. With a stop clock take the time of 50 vibrations. Count the vibrations by observing the transits in one direction of the upper edge of the load at O across the reference line.Compute the period T in sec per vibration.

(v) Repeat operation (iii) and (iv) for at least 5 sets of loads.

(vi) Draw graphs with added loads m_o in grams (abscissa) against the extensions of the spring in cm (ordinate) and with T^2 as a function of m_o. Draw lines of best fit through the points.

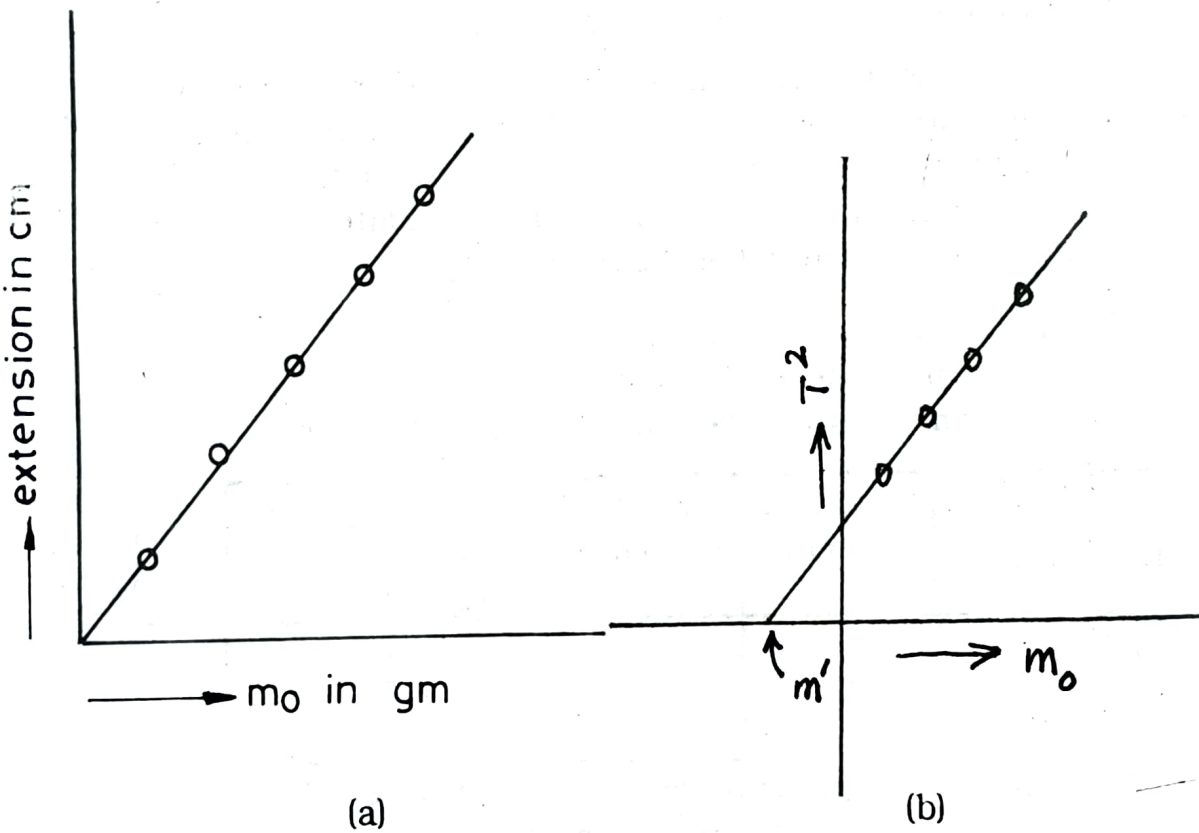

Fig. 2.20

(vii) From the first graph determine the slope of the line by choosing two points on it, one near the origin with co-ordinates x_1 cm and y_1 gm-wt and the other near the upper end of the line with co-ordinates x_2 cm and y_2 gm-wt.

The slope will be $\frac{y_2 - y_1}{x_2 - x_1}$ gm-wt/cm and the spring constant k will be this slope multiplied by g.

The second graph T^2 *vs* m_o does not pass through the origin owing to the mass of the spring which has not been considered in drawing it. The intercept of the resulting line on the mass-axis give m' the effective mass of the spring

(viii) Measure the mass m of the spring with a balance and show that the effective mass m' obtained from the graph is $\frac{1}{3}$ of it i.e., $m' = \frac{m}{3}$

(ix) Count the number of turns in the spring. Determine the radius of the spring. With the help of a slide callipers (Art. 2.1) find out the inside and outside diameters of the spring. Make several observations. Take the mean values. If D is the outside diameter and d is the inside diameter then mean radius of the spring is given by $\frac{D+d}{4}$

Also measure the radius of the wire of the spring very carefully with a screw-gauge. A number of values are to be obtained at different points and the mean value taken.

Then with the help of eqn. (4), calculate the rigidity modulus of the material of the spring.

Results :

(A) Length of the spring L = cm

(B) Determinations of extensions and time periods.

No.of obs.	Loads m_o in gms	Extension in cms.	No.of vibrations	Total time in secs	period T in sec.	T^2
1						
2						
3						

(C) Draw the graph as described in procedure (vi).

(D) Calulation of k, the spring constant and m' the effective mass of the spring as described in procedure (vii).

From Fig. 2.20a, $\frac{y_2 - y_1}{x_2 - x_1}$ = ...gm-wt/cm = M (say).

Spring constant k = Mg = ...dynes/cm

(E) Measurement of the mass of the spring, m =..... ....gms.

(F) Data for calculation of n, the rigidity modulus of the material of the spring.

(a) No. of turns N in the spring = ...

(b) Radius of the spring R:

External diameter of the spring (mean) D =.....cm.

Internal diameter of the spring (mean) d = ...cm.

Radius of the spring, $R = \frac{D+d}{4}$ .....cm.

(c) Radius of the wire of the spring (mean) r =.....cm.

Calculation : $n = \frac{4NR^3k}{r^4}$ =..... dynes/sq.cm.

From graph 1, . $\frac{y_2 - y_1}{x_2 - x_1}$ =..... gm-wt/cm. =M (say).

Spring constant k= Mg =.....dynes/cm.

From Fig. 2.20b, effective mass of spring, m'= .....gms.

Oral Questions and their Answers.

1. *What is spring constant?*

When a force is applied to the free end of a spiral spring suspended from a fixed support, the spring stretches in a normal maneer and obeys Hooke's law. The ratio of the applied force and the elongation is a constant and is known as the spring constant.

2. *What is the effective mass of the spring?*

On the period of vibrations of a spring with a load, the effect of the mass of the spring distributed over its whole length is the same as though one-third the mass of the spring is added to the load. This one-third the mass of the spring is known as the effective mass of the spring.

EXPT. 12. TO DETERMINE THE MOMENT OF INERTIA OF A FLY-WHEEL ABOUT ITS AXIS OF ROTATION.

Theory : Fig. 2.21a, shows a mass M, attached by means of a string to the axle of a fly-wheel radius r, the moment of inertia of which, about its axis of rotation, is *I*. The length of the string is such that it becomes detached from the axle when the mass strikes the floor. In falling a distance *h*, the potential energy of the mass has been converted into kinetic rotational and translation energy. If *w* be the maximum

5. *What is the physical significance of the moment inertia?*
Moment of inertia plays the same part in rotating bodies as mass plays when bodies move in straight line.
6. *What is the unit of moment of inertia?*
In C.G.S . system it is gm. cm ^{2}

EXPT. 13. TO DETERMINE THE VALUE OF g, ACCELERATION DUE TO GRAVITY, BY MEANS OF A COMPOUND PENDULUM

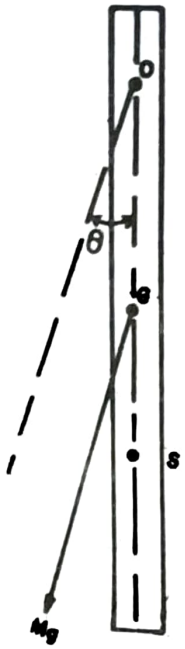

Fig.2.22a

Theory : Compound pendulum is a rigid body of any shape free to turn about a horizontal axis. In Eig. 2.22a, G is the cenire of gravity of the pendulum of mass M, which performs oscillations about a horizontal axis through O. When the pendulum is at an angle θ to the vertical, the equation of motion of the pendulum is $Iw = Mgl\sin\theta$ where w is the angular acceleration produced, l is the distance OG and I is the moment of inertia of the pendulum about the axis of oscillations. For small amplitude of vibrations, $\sin\theta = \theta$, so that

$Iw = Mgl\theta$

Hence the motion is simple harmonic, with period of vibrations,

$$T=2\pi\sqrt{\frac{I}{Mgl}}$$

If K is the radius of gyration of the pendulum about an axis through G parallel to the axis of oscillation through O, from the Parallel Axes Theorem,

$I = M(K^2+l^2)$, and so

$$T = 2\pi\sqrt{\frac{k^2+l^2}{gl}} = 2\pi\sqrt{\frac{\frac{k^2+l^2}{l}}{g}} \qquad (1)$$

Since the periodic time of a simple pendulum is given by

$T = 2\pi \sqrt{\frac{L}{g}}$, the period of the rigid body (compound pendulum) is the same as that of a simple pendulum of length

$$L = \frac{k^2 + l^2}{l} \qquad (2)$$

This length L is known as the length of the simple equivalent pendulum. The expression for L can be written as a quadratic in (l). Thus from (2)

$$l^2 - lL + k^2 = 0 \qquad (3)$$

This gives two values of l (l_1 and l_2) for which the body has equal times of vibration. From the theory of quadratic equations,

$$l_1 + l_2 = L \text{ and } l_1 l_2 = k^2$$

As the sum and products of two roots are positive, the two roots are both positiue. This means that there are two positions of the centre of suspension on the same side of C.G. about which the periods (T) would be same. Similarly there will be two more points of suspension on the other side of the C. G., about which the time periods (T) will again be the same. Thus, there are altogether *four* points, *two* on cither side of the C.G., about which the time periods of the pendulum are the same (T). The distance between two such points, assymetrically situated on either side of the C. G., will be the length (L) of the simple equivalent pendulum. If the length OG in Fig. 2.22a is l_1 and we measure the length GS = $\frac{k^2}{l_1}$ along OG produced, then obviously $\frac{k^2}{l_1} = l_2$ Or, OS = OG + GS = $l_1 + l_2$ = L. The period of oscillation about either O or S is the same.

The point S is called the centre of oscillation. The points O and S are interchangeable *i.e.*, when the body oscillates about O or S, the time period is the same. If this period of oscillation is T, then from the exprcssion $T = 2\pi \sqrt{\frac{L}{g}}$ we get

$$g = 4\pi^2 . \frac{L}{T^2}$$

By finding L graphically, and determining the value of the period T, the acceleration due to gravity (g) at the place of the experiment can be determined.

Apparatus : A bar pendulum, a small metal wedge, a beam compass, a spirit level, a telescope with cross-wires in the eye-piece, stop-watch, and a wooden prism with metal edge.

Description of the apparatus : The apparatus ordinarily used in the laboratory is a rectangular bar AB of brass about 1 meter long. A series of holes is drilled along the bar at intervals of 2-3 cm (Fig.2.22b). By inserting the metal wedge S in one of the holes and placing the wedge on the support S_1S_2, the bar may be made to oscillate.

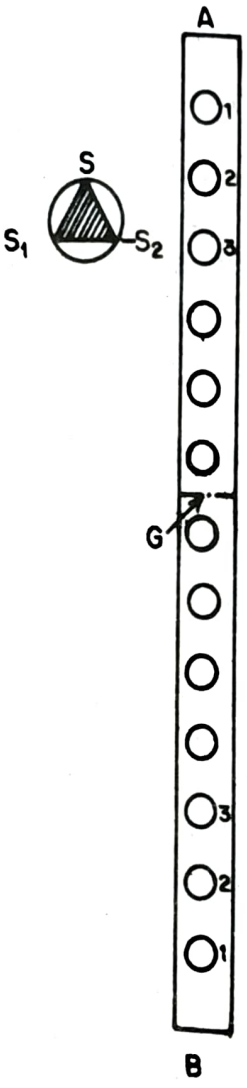

Fig.2.22b.

Procedure : (i) Find out the centre of gravity G of the bar by balancing it on the wooden prism.

(ii) Put a chalk mark on the line AB of the bar. Insert the metal wedge in the first hole in the bar towards A and place the wedge on the support S_1S_2 so that the bar can turn round S.

(iii) Place a telescope at a distance of about a metre from the bar and focus the cross-wires and rotate the collar of the tube till the cross-wires form a distinct cross. Next focus the telescope on the bar and see that the point of inter-section of the cross-wires coincides with the chalk mark along the line AB of the bar.

(iv) Set the bar to oscillate taking care to see that the amplitude of oscillations is not more than 5^0. Note the time for 50 oscillations by counting the oscillations when the line AB passes the inter-section of the cross-wires in the same direction.

(v) Measure the length from the end A of the bar to the top of the first hole *i.e.*, upto the point of suspension of the pendulum.

(vi) In the same way, suspend the bar at holes 2,3,.....and each time note times for 50 oscillations. Also measure distances from the end A for each hole.

(vii) When the middle point of the bar is passed, it will turn round so that the end B is now on the top. But continue measuring distances from the point of suspension to the end A.

(viii) Now calculate the time-period T from the time recorded for 50 oscillations.

(ix) On a nice and large graph paper, plot a curve with length as abscissa and period T as ordinate with the origin at the middle of the paper along the abscissa. (Fig.2.22c).

(x) Through the point on the graph paper corresponding to the centre of gravity of the bar, draw a vertical line. Draw a second line ABCD along the abscissa. AC or BD is the length of the equivalent simple pendulum *i.e.*, $L = l_1 + \frac{k^2}{l_1}$. $AG = l_1$ and $GC = \frac{k^2}{l_1} = l_2$, C being the centre of oscillation.

Similarly $GD = l_1$ and $GB = \frac{k^2}{l_1} = l_2$, B being the centre of oscillation. From this, $g = 4\pi^2 \frac{L}{T^2}$ can be calculated.

(xi) By drawing another line A'B'C'D' calculate another value of g

Alternate method of measuring the length of the pendulum.

Instead of measuring length from the end A to the point of suspension, length can also be measured from the point of suspension to the centre of gravity G of the bar (see Fig. 2.22b). In that case also there will be two sets of readings- one with the end A at the top and again with the end B at the top. Calculate the period T with 50 oscillations at each suspension. Now draw a graph with the centre of gravity of the bar at the origin which is put at the middle of the paper along the abscissa. Put the length measured towards the end A to the left and that measured towards the end B to the right of the origin (see Fig.2.22c). A line ABCD drawn parallel to the abscissa intersects the two curves at A B C and D.

Here also the length AC or BD is the length of the equivalent simple pendulum.

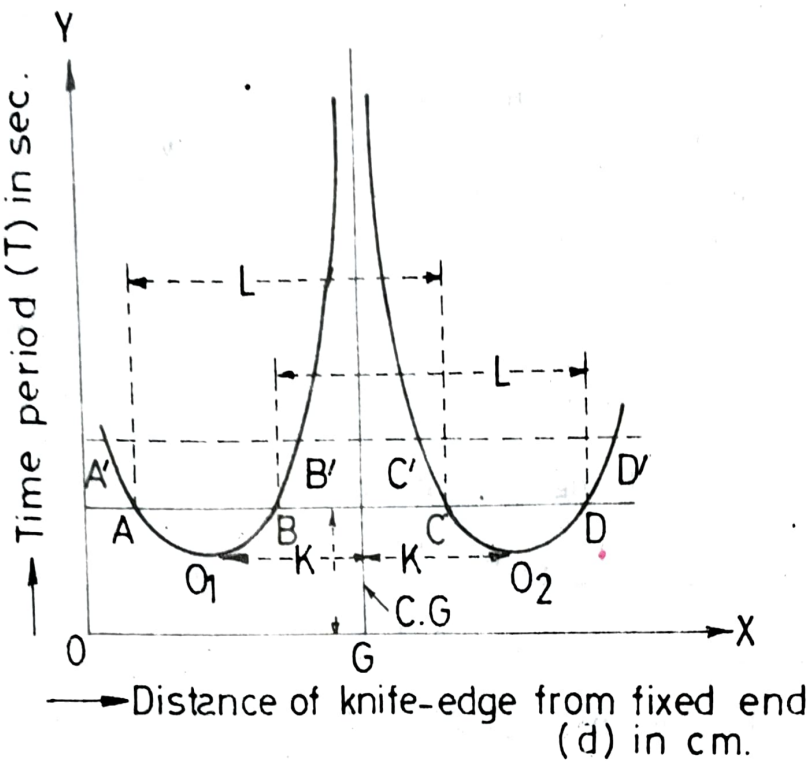

Fig. 2.22c

Results:

(A) Observation for the time period T and the distance of the point of suspension from the end A.

At the top	Hole no.	Distance from A	Time for 50 oscillations	Mean Time	Mean Period T
End A	1	=c m	(i) ....sec (ii) ...sec (iii) ...sec		
	2	= . . . cm	(i) ....sec (ii) ...sec (iii) ...sec		
	3	= . . . cm	(i) (ii) (iii) etc		
End B	1 2 3		etc	etc	

(B) Alternate method of measuring length.

Use the above table only changing the third column by "Distance from G",the centre of gravity.

(From graph)

Length AC=.....cm. Length BD =...cm.

Mean length $L = \frac{AC+BD}{2}$ =...cm

Corresponding time-period from the graph.

T =...sec. $g = \frac{4\pi^2 L}{T^2}$ =.....cm. per sec^2

Discussions: (i) Distances are to be measured from the end A or the point G, preferably from A.

(ii) In measuring time an accurate stop-watch should be used.

(iii) Oscillations should be counted whenever the line of the bar crosses the intersecting point of the cross- wires, in the same direction.

(iv) Graph paper used should have sharp lines and accurate squares and should be sufficiently large to draw smooth and large curves.

(v) Amplitude of oscillations must not be more than 5°

(vi) Error due to the yielding of support, air resistance, and irregular knife-edge should be avoided.

(vii) Determination of the position of G only helps us to understand that AG=l_1 and GC = $\frac{K^2}{l_1}$ =l_2 and is not necessary for determining the value of 'g'

(viii) For the lengths corresponding to the points A,B, C and D the period is the same.

(ix) At the lowest points of the curves P_1 and P_2 the centre of suspension and the centre of oscillation coincide.

It is really difficult to locate the points P_1 and P_2 in the graph and so K is calculated from the relation

$= \sqrt{GA.GB} = \sqrt{GB.GC}$.

PT .14. TO DETERMINE THE VALUE OF 'g' BY KATER'S EVERSIBLE PENDULUM.

Theory : In a Kater's pendulum if l_1 and l_2 be distances of two points from the centre of gravity of the bar and on opposite direction from it such that the periods of oscillations about these points are exactly equal, then period T is given by

$$T = 2\pi \sqrt{\frac{l_1+l_2}{g}} \quad \text{or } g = 4\pi^2 \frac{l_1 + l_2}{T^2} \quad \ldots \quad \ldots \quad \ldots (1)$$

But it is extremely difficult to make the periods exactly equal. It can, however, be shown in the following way that the time-periods T_1 and T_2 about these two points need not be exactly equal.

$$T_1 = 2\pi \sqrt{\frac{l_1^2+K^2}{l_1 g.}} \; . \; T_2 = 2\pi \sqrt{\frac{l_2^2+K^2}{l_2 g}}$$

or $T_1^2.l_1 g = (4\pi^2 l_1^2+K^2)$, $T_2^2.l_2 g = 4\pi^2 (l_2^2+K^2)$.

Subtracting, $(T_1^2 l_1 - T_2^2 l_2)g = 4\pi^2(l_1^2 - l_2^2)$

$$\text{or, } \frac{4\pi^2}{g} = \frac{l_1 T_1^2 - l_2 T_2^2}{l_1^2 - l_2^2} = \frac{1}{2}\left[\frac{T_1^2+T_2^2}{l_1+l_2} + \frac{T_1^2+T_2^2}{l_1+l_2}\right]$$

$$\text{or, } \frac{8\pi^2}{g} = \frac{T_1^2+T_2^2}{l_1+l_2} + \frac{T_1^2-T_2^2}{l_1-l_2}.$$

From the above relation, g can be calculated.

EXPT. 7. TO DETERMINE THE YOUNG'S MODULUS BY THE FLEXURE OF A BEAM (BENDING METHOD).

Theory : If a rectangular beam of breadth b and depth d is supported near its two ends by two knife-edges separated by a distance l and if a load of mass m acting at a point of the beam equidistant from the knife-edges produces a depression y_o, then Y, the Young's modulus of the material, is given by $Y = \frac{mgl^3}{4bd^3y_o}$ where g is the acceleration due to gravity.

Apparatus: Rectangular beam, a low power microscope or a travelling microscope, suitable weights, screw gauge, metre scale.

Description of the apparatus: Setting of the apparatus is shown in Fig. 2.14.

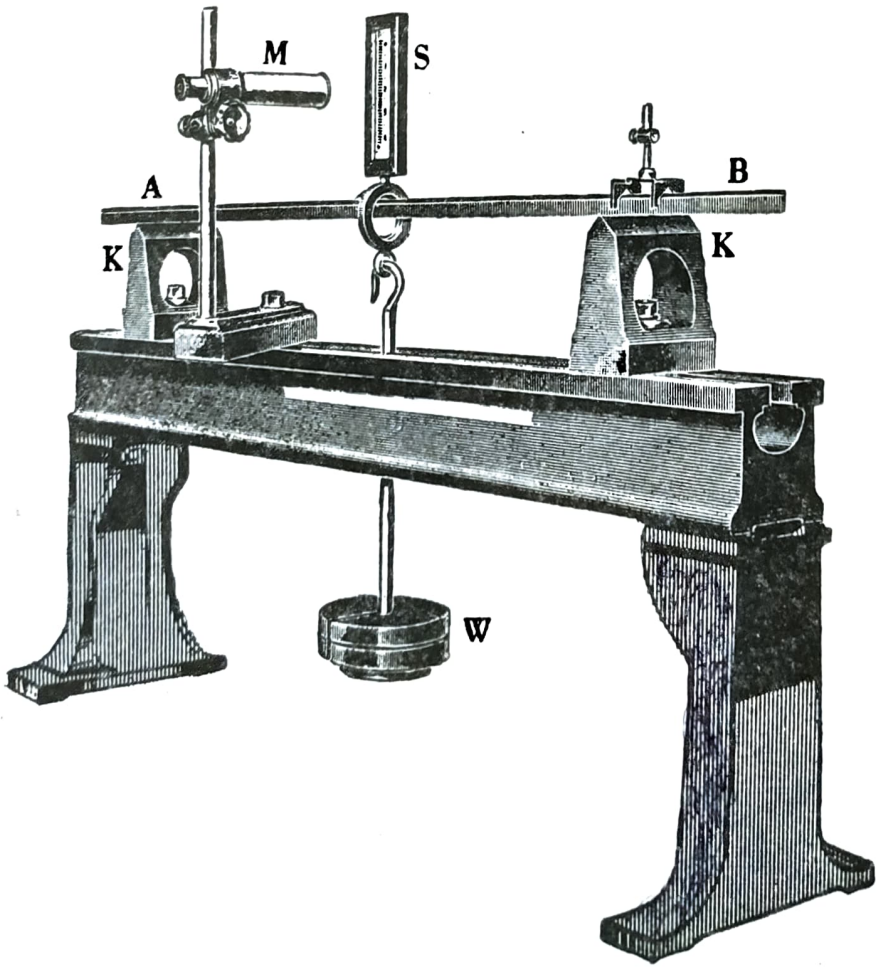

Fig.2.14

A beam AB of the experimental material about a metre long and of uniform cross-section is mounted on two strong knife-edges K,K separated by a suitable distance. A small mm scale S stands vertically on a knife-edge placed at the mid-point of the beam. A hook is attached to this knife-edge and supports a hanger on which weights are placed. A small low-power microscope M fitted with cross-wires in the eye-piece and sliding along a vertical stand is placed at a suitable distance to read the scale. Sometimes a travelling microscope is used (see Art. 2.5). It is possible to alter the distance between the supporting knife-edges.

Procedure : (i) Determine the middle point of the beam and mark on the beam distances say 30, 35, 40, 45, 50 cm from this point on either side of it.

(ii) Adjust the distance of the two supporting knife-edges so that the beam rests on them at places marked 50 cm from the middle. With the help of a spirit level placed at the mid-point make the beam horizontal. Place the knife-edge with the vertical scale and the hanger transversely at the middle point of the beam.

(iii) Place the microscope at a suitable distance to read the vertical scale. Focus the microscope so that its cross-wires are distinct.

(iv) Then focus it for one of the lines of the scale and move it vertically so that the marked line coincides with the inter-section of the cross-wires. Read the scale for this line. This is the reading for zero load on the hanger.

(v) Then place a load of, say, one kg on the hanger. The scale goes down. Another line now coincides with the inter-section of the cross-wires. Read the scale for this line. Go on increasing the load by, say, one kg, each time taking a reading for the scale until at least five readings are taken.

(vi) Repeat the procedure by decreasing load by, say, one kg and enter the results in a tabular form for increasing and decreasing loads. Take the mean values.

(vii) Measure the distance between the knife-edges with a metre scale to get length l of the beam.

(viii) Repeat the operations with the supporting knife-edges at marks 45, 40 cm etc, at either side of the mid-

point of the beam and measure each time the length l of the beam between the knife-edges.

(ix) Measure the values of b and d *i.e.* of the breadth and depth of the beam at 10 points with a screw gauge or a slide callipers and take the mean.

(x) Draw a graph with load m along abscissa and depression y_o along ordinate. Draw a line of best fit so that it passes through the (O,O) point. Choose an arbitrary point on the graph and find out the load and depression corresponding to this point and calcuate the value of Y from the formula given in the theory.

When a travelling microscope is used.

Procedure: Operations (i) and (ii) remain the same.

(iii) Find out the vernier constant of the microscope. Place it at a suitable distance to read the vertical scale. Focus the microscope so that the cross-wires are distinct.

(iv) Then focus the microscope for a marked line of the scale and move it vertically so that the marked line of the scale coincides with the inter-section of the cross-wires. Read the position of the microscope for the zero of the vernier. This is the reading for the zero load on the hanger.

(v) Now place a load of, say, one kg on the hanger. The focussed line of the scale will go down. Lower the microscope until the marked line on the scale again coincides with the intersection of the cross-wires. Take the reading for the position of the microscope. Go on increasing the load by, say one kg, each time taking a reading of the microscope position until at least five readings are taken.

(vi) Repeat the procedure by decreasing load by. say, one kg and enter the result in a tabular form for increasing and decreasing loads. Take the mean values.

Operation (vii) to (x) remain the same.

Results:

For ordinary microscope.

Data for load versus depression.

With knife-edges at 50 cm from the mid-point.

Table 1

No. of obs	Loads in kg	Reading of the vertical scale for		Mean	Mean depression y_0 in cm
		Load increasing	Load decreasing		
1					
2					
3					
4					
5					

For travelling microscope.

(A) *Vernier constant of the microscope.*

One small division of the main scale = $\frac{1}{2}$ mm

50 vernier divisions = 49 main scale divisions

1 ..... = $\frac{49}{50}$ .....

Vernier constant = 1 m.s.d - 1 v.s.d

= $(1 - \frac{49}{50}) . \frac{1}{2}$ mm

= $(\frac{1}{50} \times \frac{1}{2})$ mm = $\frac{1}{100}$ mm = 0.01 mm = 0.001 cm

(B) *Data for load versus depression.*

With the supports at 50 cm from the mid point

Table 2

No. of obs	Load in Kg	Readings for						Mean reading in cm	Mean ddepression y_o in cm
		Load increasing			Load decreasing				
		M.S	V.S.	Total in cm	M.S.	V.S.	Total in cm		
1	0							...(a)	0
2								... (b)	(b-a)
3								... (c)	(c-a)
4								... (d)	(d-a)
5								... (e)	(e-a)

Similar tables are to be made when the supports are at different distances from the mid-point.

(C) *Length of the beam l, between the two supporting knife-edges* (i) ... cm (ii) ... cm (iii) ... cm. Mean l = ... cm

(D) *Vernier constant of the slide callipers or least count of the screw gauge.*

(E) *Breadth (b) and depth (d) for the beam.*

b: (i) ... cm (ii) ... cm (iii) ... cm. Mean b = ... cm

d: (i) ... cm (ii) ... cm (iii) ... cm. Mean d = ... cm

(F) From the graph, when load m = ... kg= ...gm

depression. y_o = ... cm

$$Y = \frac{mgl^3}{4bd^3y_o} = \text{... ... dynes/sq. cm}$$

The value of Y may be calculated for other distances of the supporting knife-edges from the mid-point and mean value of Y may be determined.

Discussions : (i) The length l and depth d occur in the third power. So great care should be taken to measure them accurately.

(ii) The horizontal position of the beam must be ensured.

(iii) It is observed that for a fixed load the depression varies as l^3.

Oral Questions and their Answers.

1. *What is a cantilever?*
   A cantilever is a beam of which one end is fixed in horizontal position and the other free end is loaded.
2. *Is it necessary to use a dead load here?*
   No, because a beam of thickness of several millimetres is used and hence there is no chance of producing kinks.
3. *Does the weight of the beam affect the working formula?*
   In deducing the working formula the weight of the beam has been neglected. But if the weight produces appreciable bending, it should be considered.
4. *What is neutral surface of the bent beam?*
   When the beam of uniform cross-section is bent downward at the middle, the upper surface is compressed and the lower surface is extended. In between these two surfaces there is a layer which is neither extended nor compressed. This layer is called neutral layer.
5. *What is bending moment?*
   When a beam is fixed at one end and loaded at the other end it bends due to the moment of the applied force. Due to this

bending, different layers change in length and as a result longitudinal forces are set up. This longitudinal forces acting on a cross-section of a bar form a couple known as the bending moment which is equal and opposite to the external bending couple while the beam is in a state of equilibrium.

6. *What is flexural rigidity?*
It is defined as the external bending moment which produces a bending of unit radius of curvature. It is equal to Y AK^2 where Y is the Young's modulus and AK^2 is the geometric moment of inertia.

EXPT. 8. TO DETERMINE YOUNG'S MODULUS (Y), RIGIDITY MODULUS (n) AND POISSON'S RATIO (σ) OF A SHORT WIRE BY SEARLE'S DYNAMIC METHOD

Theory : If a wire specimen be fastened to two identical bars at their mid-points from which they are supported by threads and if the ends of the bars are drawn together and released, the bars oscillate with a period T_1. In that case Young's modulus is given by the formula

$$Y = \frac{8\pi l I}{T_1^2 r^4} \quad \ldots\ldots (1)$$

where l is the length and r is the radius of the wire. I is the moment of inertia of one of the bars about its supporting thread.

The rigidity modulus, n, is given by the formula

$$n = \frac{8\pi l I}{T_2^2 r^4} \quad \ldots\ldots (2)$$

where T_2 is the period of torsional oscillation when one of the bars is clamped horizontally so that the specimen wire hangs vertically supporting the other bar which executes torsional oscillations about the wire, and l, r and I have the same meanings as above.

From the expressions for Y and σ, it can be shown that

$$\frac{Y}{n} = \frac{T_2^2}{T_1^2}$$

But from the relation between the elastic coastants, we have

$$Y = 2n\,(1 + \sigma)$$

$$\text{or, } \frac{Y}{n} = 2\,(1 + \sigma) = \frac{T_2^2}{T_1^2}$$

Calculation :

$$K = \frac{m\,(\theta_3 - \theta_4)\,d}{A\,(\theta_1 - \theta_2)\,t} = \ldots.$$ calories per cm. per sec. per °C.

Discussions : (i) It is important that temperatures shown by the four thermometers remain constant for at least two consecutive intervals of 5 minutes each.

(ii) The conductivity of the circulating coil should be nearly the same as that of the material of the cylinder. The surface of the solid cylinder should be polished to reduce radiation loss.

(iii) During collection of water do not disturb any part of the rubber tube through which the water flows out. Otherwise a steady flow of water cannot be maintained.

(iv) Before collection of water make sure that $(\theta_3 - \theta_4)$ is of the order of 10°C. This can be arranged by adjusting the flow of water by the pinch-cock P.

Oral Questions and their Answers.

1. *Define thermal conductivity. What is its unit?*
   See page 126.
2. *What is meant by the steady state?*
   See procedure vi.
3. *Why is a constant pressure-head apparatus necessary?*
   It maintains a constant pressure difference under which water is flowing out thus keeping the rate of flow constant.
4. *Is the method suitable for bad conductor?*
   It is not suitable for bad conductor.

EXPT. 30. TO DETERMINE THE THERMAL CONDUCTIVITY OF A BAD CONDUCTOR BY LEES AND CHORLTON'S METHOD.

Theory : The thermal conductivity of a bad conductor like rubber, glass, leather, cardboard, ebonite etc. can be determined by Lees and Chorlton's method. In measuring the conductivity of such a poor conductor one must remember that a thin layer of slab of the material must be used. The difficulty then arises in maintaining the face at uniform temperature and in measuring that temperature.

Lees and Chorlton overcame this difficulty by placing a slab of a good conductor, such as brass or copper, of exactly the same diameter as the experimental slab on each side of the layer of poor conductor. In Fig. 3.14 let S be the disc of a poor conductor, such as glass or ebonite and A and B be the thick metallic discs, one on either side of S. C is a steam chamber from which heat passes to B, S and A.

When steam is passed through C, A is warmed up by the heat conducted by S. (Since the slab S is sufficiently thin, the loss of heat from the edge of the slab is small enough to be neglected in the calculation. Therefore it can be safely assumed that the flow of heat across S will be vertically downwards). After some time a steady state will be reached when the rate of flow of heat through S equals the heat lost from A by radiation and convection.

If θ_1 = temperature of B in the steady state,

θ_2 = ,, ,, A ,, ,, ,,

α = area of cross- section of the slab S.

K = thermal conductivity of the slab S.

d = thickness of the slab.

then the quantity of heat conducted per second through the poorly conducting slab S is

$$Q = \frac{K\,\alpha(\theta_1 - \theta_2)}{d} \quad \ldots\ldots\ \ldots\ \ldots\ (1)$$

In the steady state, this heat Q is radiated per second from the lower disc A. If m and s be the mass and specific heat of A and $\frac{d\theta}{dt}$ be its rate of cooling at its temperature θ_2, then the heat lost (radiated) per second from A is

$$Q = ms\frac{d\theta}{dt} \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ (2)$$

$\frac{d\theta}{dt}$ is determined by performing a subsidiary experiment.

From (1) and (2) we get

$$\frac{K\,\alpha\,(\theta 1 - \theta_2)}{d} = m\,s\,\frac{d\theta}{d}\,t$$

$$\text{or, } K = \frac{m s \frac{d\theta}{dt} . d}{\alpha (\theta_1 - \theta_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Apparatus : Lees and Chorlton's apparatus, slide callipers, thermometers, etc.

Description of the Lees and Chorlton's Apparatus : The experimental arrangement of the apparatus is shown in Fig.3.14. A brass disc A of about 10 cm in diameter is supported by means of strings from a large ring on a retort stand. The experimental material in the form of a thin circular slab (S) of uniform thickness and having the same diameter as A, is placed on it (A). A steam chamber C is placed on the slab S. The steam chamber consists of two parts- the top part is a hollow brass cylinder C of the same diameter as S, having side tubes for entry and exit of steam while the bottom part B is a thick metal plate having the same surface area as that of A. The surfaces of A and B are nickel plated to obtain uniform and good emissivity. Two thermometers T_1 and T_2 are introduced into two holes drilled in the base B and in A. The whole system is suspended horizontally from a stand by means of three threads attached to three small hooks provided symmetrically along the circumference of A.

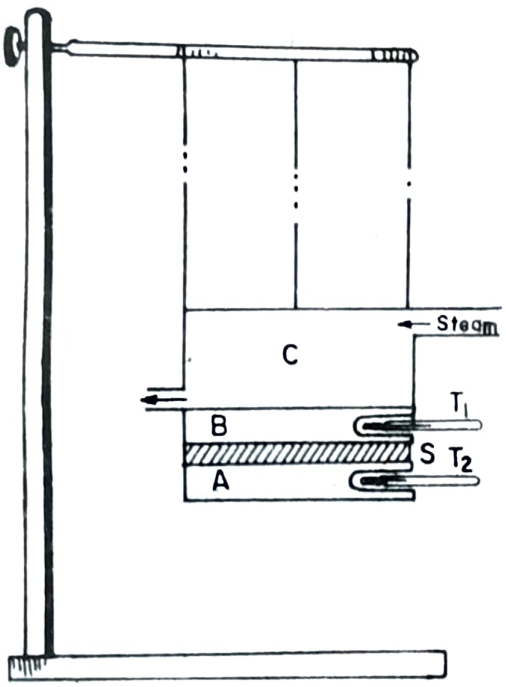

Fig 3.14

Procedure : (i) Weigh the disc A to determine its mass m. Measure the diameter (D=2r) of the disc S with a scale (the disc S is usually too big for a slide callipers). Determine

accurately the thickness d of the disc S with the help of a screw-gauge. Now arrrange the apparatus as shown in Fig.3.14. Improve the thermal contact of S with A and B by moistening it with glycerine (see discussion iii)

(ii) Pass steam from a distant boiler into C. The apparatus should be screened off from the heat of the boiler. Watch the temperatures θ_1 and θ_2 of B and A respectively. When you think they are about to become steady, record θ_1 and θ_2 at intervals of 5 minutes until they remain constant, for at least two consecutive intervals, *i.e.* for 10 minutes.

(iii) Stop the supply of steam and remove BC. With the disc S still on top of it, heat the disc A by moving a burner under it till its temperature rises about 10°C above the steady temperature θ_2. Remove the burner and allow A to cool. By keeping S on it, it is ensured that A now loses heat in the same surrounding as in the first part of the experiment when it gained heat. Note the temperature (indicated by T_2) every half minute until the temperature falls by about 10°C from θ_2.

(iv) Draw a graph with the time of cooling (t) as abscissa and the temperature (θ) of A as ordinate. Draw a tangent at a point at which the value of the ordinate is θ_2 (Fig.3.15). The slope of this tangent gives the rate of cooling $\frac{d\theta}{dt}$ at θ_2.

Results :

Mass of the disc A, m =...gm

Sp. heat of the material of A, s =.....

Diameter of the specimen disc S,, D=...cm

Area of corss-section, $\alpha = \pi \left(\frac{D}{2}\right)^2$ sq.cm

=...sq.cm.

Thickness of the specimen disc S. d=....cm.

Time-temperature records of B and A

Time in minutes	0	5	10	15	20	25	30	etc
θ_1								
θ_2								

Time-temperature record of A during its cooling.

Time in minutes	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	etc
Temp.										

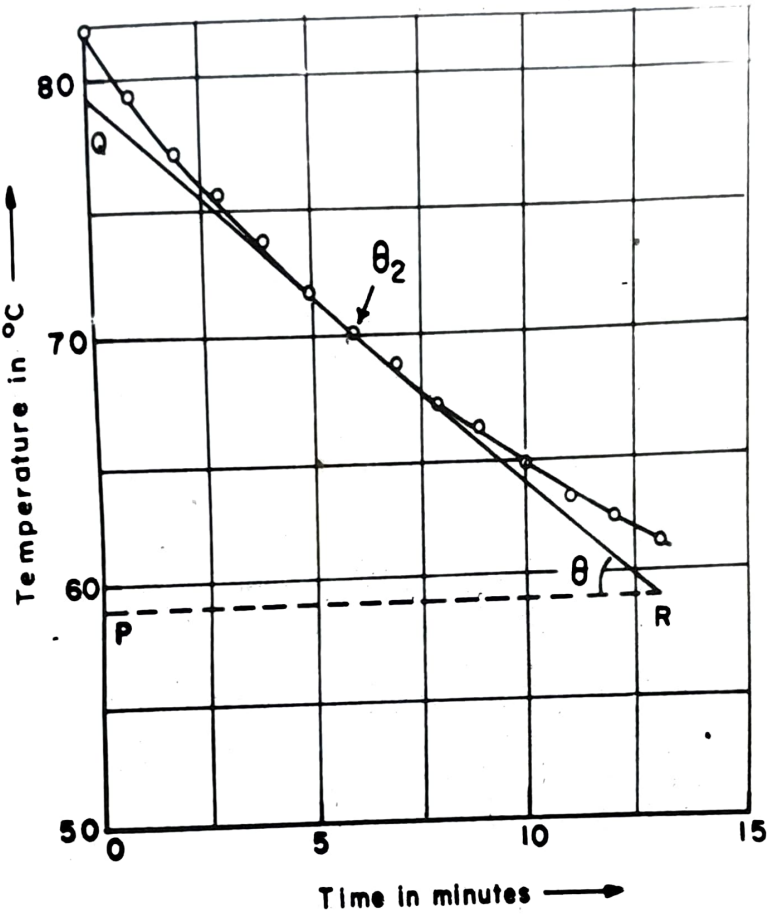

Fig.3.15.

From the cooling curve, the slope of the tangent at... in°C(θ_2),

$$\frac{d\theta}{dt} = \frac{\text{height of ordinate}}{\text{height of abscissa}} = \frac{PQ \text{ in } ^\circ C}{PR \text{ in sec}} = {}^\circ C \text{ per sec.}$$

Calculation :

$$K = \frac{ms\frac{d\theta}{dt}.d}{\alpha(\theta_1 - \theta_2)} = \ldots. \text{ calories per cm. per sec. per } ^\circ C.$$

Discussions : (i) Temperatures θ_1 and θ_2 of B and A should be noted when they remain steady for at least 10-15 minutes.

(ii) The surfaces of A and B should be nickel plated to ensure an uniform and a good emissivity.

(iii) The discs B, S and A should be tightly pressed together so that there is no air films between B and S and between S and A. Some glycerine may also be applied to the faces in contact to obtain good thermal contacts.

(iv) The thermometers should be placed close to the faces of S, one on either side.

(v) A non-luminous flame shoud be used while heating A so that the emissivity or the surface does not change by the deposition of soot on it.

(vi) The thickness of the disc S should be measured at a number of points on its surface.

(vii) During cooling, the temperature of the lower disc A should be noted every half minute or more frequently, if the rate of cooling be very rapid.

EXPT. 31. TO DETERMINE THE RATIO OF SPECIFIC HEATS AT CONSTANT PRESSURE AND CONSTANT VOLUME ($\gamma=C_p/C_v$) FOR AIR BY CLEMENT AND DESORME'S METHOD.

Theory : Clement and Desorme measured the value of γ for air by allowing it to undergo a single adiabatic expansion. In this method we shall suppose that the air occupying the volume below the dotted line (Fig. 3.16) remain in the flask all the time. Suppose the volume of the entire flask be V while that below the dotted line be V_o. If the initial pressure be P_o and that immediately after the adiabatic expansion be B, then

$$P_oV_o^{\gamma} = BV^{\gamma} \quad \ldots \quad \ldots \quad \ldots \quad \ldots (1)$$

where γ is the required ratio of the two specific heats. Since the flask is open to the air (during adiabatic expansion), B is the atmospheric pressure.

During adiabatic expansion, the temperature falls. If sufficient time is allowed, this temperature will again be equal to the temperature before the expansion. But when the temperature has become steady, the pressure will be different from B. Let this new pressure be P. We have now passed from volume V_o and pressure P_o by an isothermal process to volume V and pressure P.