PREFACE

In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. *core, discipline specific, generic elective, ability and skill enhancement* for graduate students of all programmes at Honours level. This brings in the semester pattern, which finds efficacy in sync with credit system, credit tranafer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits. I am happy to note that the University has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade "A".

UGC (Open and Distance Learning Programmes and Online Programmes) Regulations, 2020 have mandated compliance with CBCS for U. G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme.

Self Learning Materials (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English/Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisitioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs.

I wish the venture a grand success.

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Vice-Chancellor

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Under Graduate Degree Programme
Choice Based Credit System (CBCS)
Subject : Honours in Physics (HPH)
Course Code : CC-PH-05
Course : Physics Laboratory–III

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Netaji Subhas Open University

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Netaji Subhas Open University

UG : Physics
(HPH)

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Unit - 1 ❑ To find Mutual inductance by Carey Foster method using DC source

Structure

1.0 Objectives

1.1 Introduction

1.2 Apparatus used

1.3 Theory, working formula, circuit arrangement for measurement

1.4 Method of measurement

1.5 Discussion

1.6 Maximum proportional error in the present measuremnts

1.7 Summary

1.8 Model Questions and Answer

1.0 Objectives

- To determine the mutual inductance by Carey Foster method using DC sounce and a ballistic galvanometer.

1.1 Introduction

We use Carey Foster's method for the determination of mutual inductance between two coils. We use the dc source and the Ballistic galvanometer. However inductance can also be determined by using ac source and a detector by the same method.

There is also other dc method called direct method using a Ballistic galvanometer and a low resistance. Of all the methods Carey Foster's method gives a reliable and easy to operate null method for the determination of mutual inductance. We use dial type mutual inductance coil, so that angle between the primary and secondary can be noted directly.

1.2 Apparatus Used

(i) Mutual inductance coil (dial type).

(ii) A storage cell.

(iii) Tap key.

(iv) Ballistic galvanometer.

(v) A few standard capacitors.

(vi) Two non-inductive resistance boxes (1–10kΩ).

1.3 Theory, Working Formula and Circuit Used

Mutual inductance between two coils, say one primary (P) and the other secondary (S), may be defined as numerically equal to the emf induced in the secondary due to unit rate of change of current in the primary. S.I unit of mutual inductance in Henry.

Working Formula : The method consists in detecting no deflection through the Ballistic Galvanometer when the condition of balance is satisfied.

The balanced condition is obtained when no charge flows through the Ballistic Galvanometer on making or breaking contact by K.

If l be the primary current through the primary coil P_1P_2, condenser C is charged to a potential difference R_1l and when the key K is made off, the total charge CR_1I passes partly through G and partly through R. The amount of charge through G is

$$q_1 = \frac{CR_1l(R+R_S)}{R+R_S+R_G} \quad \ldots (1.1)$$

Where R_G and R_S are the resistance of the galvanometer and the secondary coil. Again when the primary current is made off the charge which flows through the secondary circuit is

$$q_1 = \frac{Ml}{R+R_S+R_G} \quad \ldots (1.2)$$

For balance the two charges given by (1.1) and (1.2) must be equal and flow through G in opposite directions. Thus

$$M = CR_1(R + R_S) \qquad \text{... (1.3)}$$

M can be determined from equation (1.3)

Determination of R_S : From equation (1.3)

$$R = \left(\frac{M}{C}\right)\frac{1}{R_1} - R_S \qquad \text{... (1.4)}$$

For a given value of ϕ, M is constant. Therefore $\left(\frac{M}{C}\right)$ is constant. Thus R versus $\frac{1}{R_1}$ curve will be a stratight line, with intercept $-R_S$ on the R-axis, from which R_S can be determined.

Circuit Arrangement :

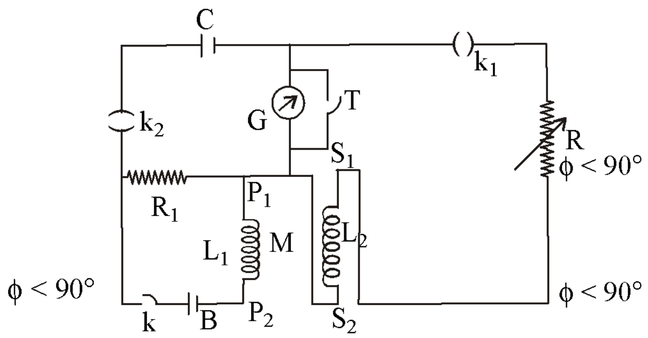


Figure 1.1

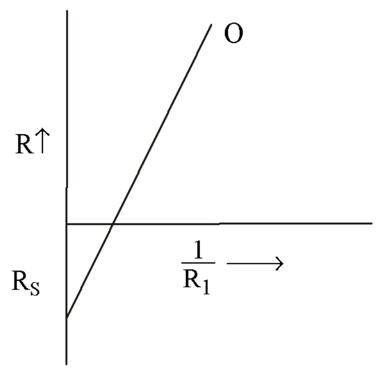


Figure 1.2

K = Tap key, P_1P_2 = Primary coil, ϕ = Angle between the two coils, primary and secondary, B = Cell, S_1S_2 = Secondary coil, K_1,K_2 = Plug keys, L_1, L_2 = Self inductance, G = Balistic galvanometer, M = Mutual inductance, R_1, R = Resistance boxes, T = Tap key parallel with B.G., C = Capacitor.

1.4 Method of Measurements

Step 1 : K_1 – open; K_2 – closed, depress K and note the direction of the deflection of the galvanometer.

Step 2 : K_2 – open, K_1 – closed, depress K and note the direction of deflection of the galvanometer which should be opposite in step 1.

Check : If this is not the case, connect one of the coil L_1 or L_2 in opposite direction i.e. interchange the connection to the terminals of L_1 or L_2 keep the angle between the two coils $\phi = 0°$ and keep k_1 and k_2 both closed.

Step 3 : Fix C (1.0 μF) and R_1 at some suitable value (say 5Ω) and vary R to obtain no deflection. Repeat the process with other two values of R_1 (say 10Ω and 15Ω)

Step 4 : Repeat step 3 for several dial readings ϕ, exclude $\phi = 90°$, Initially ϕ is changed by step of 5° for three consecutive readings. Afterwards it may be changed by step of 20° up to 160°, then again by step of 5° up to 180°. Calculated values of M for 0° and 180° must be same.

Step 5 : Draw a curve by plotting ϕ along x-axis and M anlong y-axis. The nature of the curve will be as shown below.

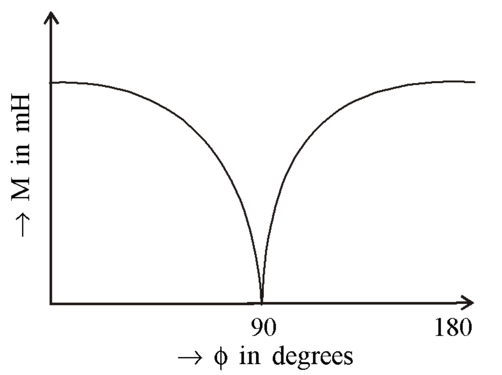


Figure 1.3

Experimental Data :

(A) Drawing data for R vs $1/R_1$ curve :

Table – 1

Angle between the coils (ϕ) in degrees	Value of R_1 in ohm	Value of $1/R_1$ in ohm^{-1}	Value of R in ohm for no deflection
0	5Ω	....	....
	10Ω	....	....
	15Ω	....	....

Values of R_S from the curve (Figure 1.2) =

(B) Data for M and ϕ curve :

Table – 2

Angle between the coils (ϕ) in degrees	Value of R_1 in ohm	Value of R in ohm for no deflection	$M = CR_1 (R + R_S)$ in mH	Mean M in mH
0	5Ω	....	....	....
	10Ω	....	....	....
	15Ω	....	....	....
5	5Ω	....	....	....
	10Ω	....	....	....
	15Ω	....	....	....
etc	etc	etc	etc	etc

1.5 Discussion

1. The ballistic Galvanometer should have large time period.
2. The value of C and R_1 should be so adjusted to make the bridge most sensitive. Sensivite of the bridge is checked as follows :

   (a) Fix C and R_1 at some suitable values and vary R to obtain no deflection in the galvanometer on closing or opening the key K.

(b) If no deflection is obtained for certain range of values of R (i.e. the bridge is less sensitive), repeat the above process with other values of R_1 and find a value of R_1 for which the bridge become more sensitive.

(c) Now change C to improve the sensitivity further.

3. The mutual inductance coils L_1 and L_2 should be connected properly to the circuit such that the charge flow caused by mutual inductive effect and that from C is no opposite directions.

1.6 Maximum Proportional Error

We have, $M = CR_1 (R + R_S)$

Therefore, $\text{In}M = \text{In}C + \text{In}R_1 + \text{In} (R + Rs)$

Therfore, $\delta M/M = \delta C/C + \delta R_1/R_1 + \delta(R + Rs)/(R + Rs)$

Assuming C and R_1 as constant value

We get $\delta M/M = (\delta Rs + \delta R)/(R + Rs)$

Where, δR_s = Resistance equal to two smallest divisions of the graph paper along R-axis.

δR = smallest range of variation of R about balance point which can produce perceptible deflection in the galvonometer.

1.7 Summary

(i) We have checked the circuit for opposite deflection and arranged for proper sensitivity.

(ii) Value of M for $\phi = 90°$ has been taken to be zero.

(iii) $M - \phi$ curve is definitely a cosine curve so its value at $\phi = 0°$ and $\phi = 180°$ is the same.

(iv) When $\phi > 90°$, connections of the L_1 and L_2 have been changed accordingly.

1.8 Model Questions and Answer

(a) What do you mean by self and mutual inductance explain ?

Ans. When current flows through a coil (closed circuit), the magnetic field lines (lines of force) cut the coil itself.

If ϕ be the flux that cuts the coil when a current i flows through it, then it absence of Ferro-magnetic material, $\phi \alpha$ i, $\phi = Li$ (1) where L is a constant*, called self-inductance of the coil. Thus self-inductance may be defined as the magnitude of flux that cut the coil per unit current through it.

Now differentiating equation (1) with respect to time t, $d\phi/dt = L\, di/dt = -e$ (2) where 'e' is the electromotive force induced in the coil due to rate of change of flux, cutting through it. From equation (2) self-inductance may be defined as the magnitude of electromotive force induced in the coil due to rate of change of unit current through it.

*(if the medium is not ferromagnetic and the circuit is rigid then L is a constant)

The SI unit of self-inductance is called Henry (H). A circuit is said to have a self-inductance of 1 henry if 1 weber of flux is linked with the circuit when 1 ampere of current flows through it. Alternatively a circuit is said to have a self-inductance of 1 henry if an emf of 1 volt is induced in he circuit when current through it changes at the rate of 1 ampere per sec.

When two loops, one primary (p) and the other secondary (S), one rigidly fixed in close proximity and a current I_p flows through the primary, it produces a magnetic field $\bar{B}_p$ at the position of the secondary. Thus some flux of $\bar{B}_p$ pass through the secondary. If now lp is varied the flux will also vary and there will be an emf induced in the secondary. This is known as mutual inductance. Thus mutual inductance refers to the induction of an emf in a circuit due to current changes in other circuits placed hereby. Therefore in the absence of ferromagnetic material.

ϕs is proportional to lp and

ϕp is proportional to I_s i.e

$$\phi s = M_{sp} Ip \text{ and } \phi p = M_{ps} I_s$$

Where ϕp and ϕs are flux through primary (P) and secondary (S) respectively due to currents I_s and Ip, the currents in the secondary and primary respectively.

The constants $M_{sp} = M_{ps}$ are called mutual inductance of the two loops. These co-efficients depend on the geometry of the circuits, their dimensions and permeability of the surrounding medium. Thus mutual inductance of two loops may be numerically defined as the flux linked in one loop due to unit current in the other loop.

The emf induced in the loop S due to current changes in loop P is given by

$$\epsilon_s = -\, d\phi/dt = d/dt\ (M_{sp} Ip) = M_{sp} \frac{dIp}{dt} \qquad (3)$$

Similarly, emf induced in the loop P due to current change in S is given by

$$\epsilon p = -d/dt\ (\phi_p) = -\frac{d}{dt}\ (M_{ps} Is) = -\ M_{ps} \frac{d}{dt} (Is) \qquad (4)$$

Thus, mutual inductance of two loops is numerically equal to the emf induced in one loop due to unit rate of change of current in the other.

The mutual inductance of two loops is said to be 1H if 1V emf is induced in one loop when current through the second loop changes at the rate of 1 ampere per second.

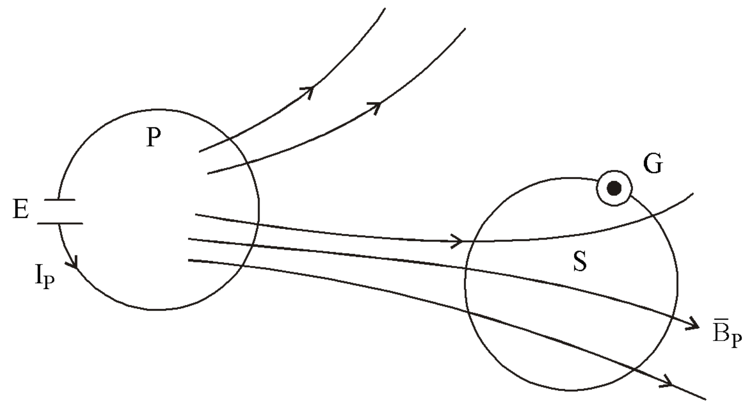


Figure 1.4

P-Primary coil containing source of emf E

Q-Secondary coil containing galvanometer G

(ii) What is the principle of operation of Carey-Foster's method?

Ans. The Charge stored in C is discharged through the Ballistic galvanometer (B.G) in a direction of opposite to the change flow caused by the induced emf in the secondary of the mutual inductance. At balance the average charge through the Ballistic galvanometer is zero.

(b) What is the co-efficient of coupling?

Ans. The mutual inductance (M) between two coils is related to their self-inductances L_1 and L_2 through a factor called co-efficient of coupling.

It may be defined as the fraction of the magnetic flux generated by one coil that gets linked up with the other. It is given by $M = KL_1L_2$ where K is called the co-efficient of coupling between the two coils. It can have values ranging from 0 to 1. It depends on the geometry of the coils and their relative positions.

Unit - 2 ❑ To measure the field strength B and its variation with distance by using a search coil

Structure

2.0 Objectives

2.1 Introduction

2.2 Apparatus used

2.3 Working formula and circuit arrangement for measurement

2.4 Method of measurement

2.5 Discussion

2.6 Maximum proportional error

2.7 Summary

2.8 Model Questions and Answer

2.0 Objectives

- To determine the strength of a magnetic field (B) with a search coil and a ballistic galvanometer.

2.1 Introduction

1. The magnetic field of an electromagnet depends on the following factors :

   (a) On the ampere-turns of the electromagnet. Field increases with increase of ampere-turns.

   (b) On the air-gap between its pole pieces. The field decreases with increases of air-gap.

   (c) On megnetic material of the pole pieces. Magnetic material of high permeability produces high magnetic field.

2. In this experiment we measure the field strength of given electromagnet and find its variation by increasing of decreasing the air-gap between the pole pieces of the electromagnet using a search coil and a ballistic galvanometer.

2.2 Apparatus Used

1. A ballistic galvanometer of large time period.
2. An electromagnet in which air-cap between its pole pieces can be changed.
3. A long solenoid acting as a primary coil, on the middle of which wound a secondary coil in close proximity.
4. A Phol's commutator.
5. One two way key.
6. Two resistance boxes.
7. One tap-key in parallel with ballistic galvanometer.
8. One milliammeter.
9. One search coil.

2.3 Working Formula and Circuit Arrangement for Measurement

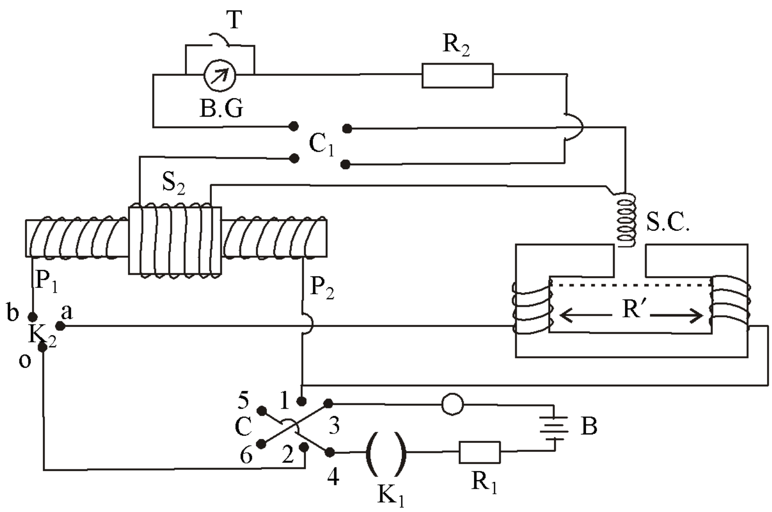


Figure 2.1

S.C : search coil; R_2 : High resistence in series with B.G greater than external critical damping resistance; B.G : Ballistic Galvanometer; S_2 : Secondary of a standard solenoid; C_1 : commutator; K_1 : plug key; T : tap key; R_1 : a variable resistance; B : A storage battery; A : Ammeter; P_1P_2 : Primary coil of a standard solenoid; R′ : Magnetising coil of electromagnet (M); K_2 : Two way key with binding screw b, a and o; C : Phol's commutator; R′ : Magnetising coil.

When the circular search coil (S.C) suddenly removed from the field B of the electromagnet to a position of zero field, the quantity of charge Q that flows through ballistic galvanometer and produces a first linear displacement (θ_0) of the spot light, is given by

$$Q = \frac{anB}{R} = K\theta_0\left(1+\frac{\lambda}{2}\right) \qquad \text{... (2.1)}$$

Where a is the area of search coil, n is its number of turns and R is the total resistance in the galvanometer circuit, λ being the log decrement of the oscillating coil of the Ballistic galvanometer, K being the galvanometer constant.

Again if primary current I is suddenly reversed, the charge Q_1 passing through the galvanometer is given by

$$Q_1 = \frac{2\mu_0 I_1 n_1 a_1 n_2}{R} \qquad \text{... (2.2)}$$

Where n_1 is the number of turns per meter of the primary coil

a_1 is the mean cross sectional area of the primary coil

n_2 is the total number of turns of the secondary coil.

If this charge Q_1 produces a linear displacement θ_1 of the spot of light on the scale, then

$$Q_1 = K\theta_1\left(1+\frac{\lambda}{2}\right) \qquad \text{... (2.3)}$$

Taking the ratio of (2.1) and (2.3)

$$\frac{\left[\frac{anB}{R}\right]}{\left[\frac{2\mu_0 l_1 n_1 a_1 n_2}{R}\right]} = \frac{\theta_0}{\theta_1}$$

$$\text{Or, } \frac{anB}{2\mu_0 l_1 n_1 a_1 n_2} = \frac{\theta_0}{\theta_1}$$

$$\text{Or, } B = \frac{2\mu_0 n_1 a_1 n_2 \theta_0 l_1}{an\theta_1} = \left(\frac{2\mu_0 n_1 a_1 n_2}{an}\right)(l_1/\theta_1)\theta_0$$

$$B = \left\{\frac{2\mu_0 n_1 n_2}{n}\right\}\left\{\frac{a_1}{a}\right\}\left\{\frac{l_1}{\theta_1}\right\}\theta_0 = N\theta_0 \quad \text{... (2.4)}$$

If d_1 and d be the mean diameters of the search coil and the primary coil or the secondary coil which is very closely wound on primary, respectively then $(a_1/a) = (d_1^2/d^2)$

$$\text{Therefore, } N = \left\{\frac{2\mu_0 n_1 n_2}{n}\right\}\left\{\frac{d_1^2}{d^2}\right\}\left\{\frac{I_1}{\theta_1}\right\} \quad \text{... (2.5)}$$

Mean (l_1/θ_1) is obtained from the graph of l_1 vs. θ_1; μ_0, n_1, n_2 n, d_1, d are all known. Hence calculating N,B can be found out from equation (2.4)

2.4 Method of Measurement

Step 1 : Constants n_1, n_2 n, d_1, d are either measured or supplied. The distance between the pole pieces of the electromagnet is measured by a slide callipers.

Step 2 : A suitable resistance R_2 is inserted in the galvanometer circuit which should be greater then the external circuital damping resistance (supplied) but which should keep the first throw of ballistic galvanometer for the maximum allowable magnetising current in the range 12 to 16 cm. This value of R_2 applied in the galvanometer circuit, is to be kept constant throughout the experiment.

Step 3 : The search coil (S.C) is hung symmetrically within the air-gap of the pole pieces of the electromagnet (M) and by eye-estimation the surface of S.C is kept at right angle to the magnetic field within the air-gap.

Step 4 : By connecting the points a and o of the two-way key K_2, the electromagnet coil (R′) is put in the battery circuit. The electromagnet is now demagnetised. After the demagnetisation operations, the rocker of the phol's commutator is kept fixed to one side and current through the electromagnet should not be reversed by any one.

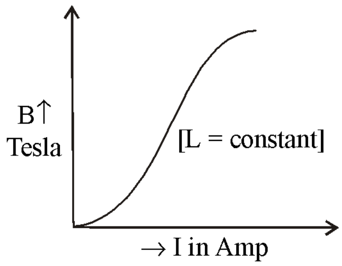


Figure 2.2

Step 5 : (a) By closing the Key K_1 and adjusting the resistance R_1 the current (l) through the electromagnet is increased from zero to a small value (say 0.5A). The search coil (S.C) is now suddenly and quickly removed well away from the pole pieces. The corresponding first throw of the galvanometer is noted.

(b) The search coil is again placed between the pole pieces, the direction of the charge flow through the galvanometer is reversed by the commutator (C_1) and after bringing the light spot to zero position with the help of the tap key T, the search coil is again quickly removed and the first throw in opposite direction is observed.

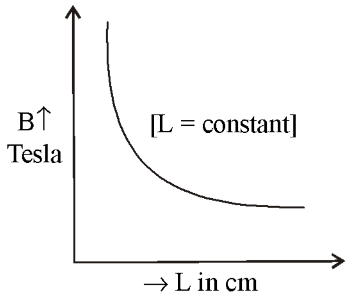


Figure 2.3

From (a) and (b), mean first throw θ_0 is noted and B is calculated from equation (2.4) for a given length (L) of the air-gap of the pole pieces.

Step 6 : For the variation of B with the magnetising current l (for a fixed length L of the air-gap between the pole pieces) then step 5 is repeated for five different values of magnetic currents upto the maximum allowable value of l. For each value of l, θ_0 is noted and B is calculated from equation (2.4) and a graph is drawn B vs. l for a fixed value of L (Fig 2.2).

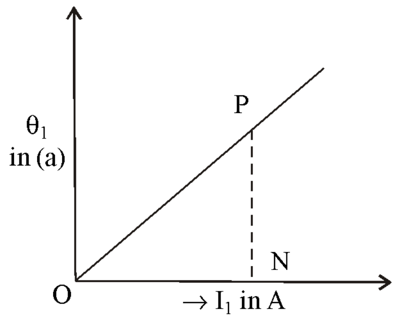


Figure 2.4

Step 7 : For the variation of B with length (L) of the air-gap between the pole pieces, for a fixed l, the magnetising current, step 5 is repeated for five different

L. However l should be relatively large to get deflections in the range 12–16 cm for the smallest gap. For each gap (L), B is calculated from equation (2.4) by noting first throw θ_0 and a graph are drawn is B vs. L for fixed value of l.

Step 8 : To find mean (I_1/θ_1), the commutator C_1 in the galvanometer circuit is kept open and connections are made between the points, b and o of the two way key K_2. By closing the key K_1 and by increasing the value of R_1 the current I_1 in the primary coil (P_1P_2) is made low (say 0.5 amps). Now by closing the commutator C_1, the primary current I_1 is now reversed from positive to negative and again from negative to positive with the help of Phol's commutator C. In each case the throw of one galvanometer is noted. The mean of these two throws give θ_1. Resistance R_2 must be kept at same value at which θ_0 was measured. The above operation is to be repeated for at least five times by increasing the value I_1 by steps of about 0.5A.

A graph is drawn by plotting I_1 along the x-axis and the corresponding mean throw θ_1 along Y-axis. The graph will be a straight line.

Taking a point P on this graph the mean value of (I_1/θ_1) is to be found out as (ON/NP) in A/m.

Experimental Data :

(A) Constants of apparatus :

Table – 1

Constants of search coil (S.C)				Constants of the solenoid (P_1P_2)		
Total no. of turns	Diameter in m			Length of P_1P_2 in m	Total no. of turns in P_1P_2	No of turns per meter of P_1P_2
	Internal	External	Mean (d)			

(B) To note the throw (θ_0) for different magnetising current :

C.D.R of the galvanometer : ....Ω

Fixed resistance (R_2) in the galvanometer circuit : ....Ω

Fixed length of the air-gap : L = m.s + v.s × v.c = ...

[By slide callipers]

Table – 2

No. of sets	Megnetising current (I)	No. of observation	Throw (θ_0) of the spot of light in cm			Grand mean of θ_0 in cm	$B = N\theta_0$ in tesla
			D.C	R.C	Mean (θ_0) in cm		
		1	......	......	......		
1	....	2	......	......	......		
		3	......	......	......		
etc.							

(C) To find throw (θ_0) for different lengths of air-gaps :

Fixed current in the electromagnet (I) .... Amp.

Table – 3

No.of Sets	Lengths of air-gap	No. of observation	Throw (θ_0) of the spot of light in cm			Grand mean of θ_0 in cm	$B = N\theta_0$ in tesla
			D.C	R.C	Mean θ_0		
		1	....	....	....		
1	....	2	....	....	....	....	....
		3	....	....	....		
etc.							

(D) To find the mean value of (I_1/θ_1) :

Table – 4

No. of observation	Current changes from $+I_1$ amp to $-I_1$ amp.	Corresponding throw (θ_1') in cm	Current changes from $-I_1$ amp to $+I_1$ amp.	Corresponding throw (θ_1'') in cm	Mean throw $\left(\theta_1 = \frac{\theta_1' + \theta_1''}{2}\right)$ in cm
1	0.5 to –0.5	....	–0.5 to +0.5	....	....
2	1.0 to –1.0	....	–1.0 to +1.0	....	....
Etc.	Etc.	....	Etc.	....	....

(E) Calculation of N :

$\mu_0 = 4p \times 10^{-9}$ N/m

n_1 = ... Per m

n_2 = ...

n = ...

d = ...

d_1 = ...

$$\frac{l_1}{\theta_1} = \frac{ON}{PN} \text{ A/m (From graph),}$$

$$N = \left\{\frac{2\mu_0 n_1 n_2}{n}\right\}\left(\frac{d_1}{d}\right)^2\left(\frac{l_1}{\theta_1}\right) = \text{........... Tesla per metre.}$$

2.5 Discussion

(1) The electromagnet is demagnetised by the following method. The resistance R_1 is adjusted to get maximum allowable current through the electromagnet. This current is reversed rapidly for some 20 times by using the rocker of the phol's commutator C. The current is reduced in small steps down to zero and in each step the current is reversed rapidly many times.

To check that the electromagnet is demagnestised, the commutator C_1 is closed and the search coil S.C is suddenly and quickly removed well away from the electromagnet pole pieces. There should be generally no first throw of the galvanometer. If there is any small throw it should be recorded.

(2) The search coil should be withdrawn quickly and suddenly from the magnetic field. This withdraw should be made several times. If the readings differ the maximum throws should be taken for calculation.

(3) It is possible to rotate the search coil in the air-gap by 180° then this should be done instead of withdrawing the coil.

2.6 Maximum Proportional Error

From equation (2.4) assuming the values of all constants of the search coil and standard solenoid are supplied.

$$\frac{\delta B}{B} = \frac{\delta \theta_0}{\theta_0} + \frac{\delta I_1}{I_1} + \frac{\delta \theta_1}{\theta_1}$$

where $\delta\theta$ = 0.1 cm (1 smallest division of the scale).

$\delta\theta_1$ = 1 smallest division of the scale or of the graph paper whichever is greater.

δI_1 = 1 smallest division of ammeter or of the graph paper whichever is greater.

Now substituting one set of observed data for θ_0, I_1 and θ_1, we can calculated the maximum proportional error in B in one set of measurements.

2.7 Summary

(1) The electromagnet is properly demagnetised and checked for any small first throw.

(2) The resistance R_2 in series with the ballistic galvanometer must be greater than the external critical damping resistance and is kept constant throughout the experiment.

(3) Variation of B with magnetising current I for a fixed value of air-gap length (l) between pole piece is studied and a graph is drawn by plotting B in tesla against I in ampere. B is measured by equation (2.4)

(4) Variation of B with the length of the air gap(l), for fixed magnetising current I is studied and a graph is drawn by plotting B in tesla against l in cm.

(5) Mean is obtained from the graph I_1 versus θ_1 by plotting I_1, the primary current, along x-axis and corresponding mean throw θ_1 along y-axis. Taking a point P on this graph the mean value of is found out.

2.8 Model Questions and Answer

1. What is other method of measuring magnetic field ?

Ans. There are two other methods.

(i) Hall Effect method and (ii) Bismuth spiral method.

In the Hall Effect method the Hall voltage V_H is proportional to the magnetic field so that by measuring V_H the magnetic field may be determined. In the bismuth spiral method the resistance of the spiral varies with the magnetic field. Thus a measurement of resistance enables the determination of an unknown magnetic field from the calibration curve.

2. What is search coil ?

Ans. A small coil containing about 50 turns of fine insulated copper wires having 1 sq. cm cross-sectional area. It is wound on a small ebonite or wooden frame and is contained in a cover of a non-magnetic non-conducting material like plastic.

3. Why is the area of cross-section of the search coil is kept small ?

Ans. There are two reasons. (i) It may remain in the uniform field between the pole pieces of the electromagnet. (ii) The air-gap between the pole pieces is also small.

4. Can you perform the experiment without withdrawing the search coil ?

Ans. Yes. The search coil may be rotated through 180° within the air-gap. It will yield double the ballistic through compared to that when the search coil is withdrawn.

5. Can you measure B by observing a galvanometer throw when magnetising current is quickly reversed ?

Ans. Ballistic galvanometer is unsuitable for this purpose. For due to the greater time constant of the electromagnet circuit, the change of flux will occur slowly and hence ballistic condition of the galvanometer will not be satisfied. A flux meter may be employed for this purpose.

6. Can you measure B by breaking the electromagnet current ?

Ans. As there is always some residual magnetism we get smaller change of flux compared to that when the search coil is withdrawn.

7. Explain the nature of I-B curve and L-B curve.

Ans. Using ampere's circuital law for the closed loop of the electromagnet, we get

$$B = \frac{\mu_0 NI}{\left\{L + \left(\frac{L_m}{K_m}\right)\right\}} \qquad (1)$$

Where N is the no. of turns of the electromagnet L and L_m is the length of the air gap and of the material of the electromagnet respectively, and I is the magnetising current. [μ_0 is the permeability of the free space and K_m is the relative permeability of the material of the electromagnet.]

(i) B vs I curve : As I increases, K_m increases at first, attains a maximum value and then falls as the core of the electromagnet approaches magnetic saturation. Hence B increases with I initially at an increasing rate till k_m is a maximum. Beyond this point, B increases with I at a slower rate since K_m decreases. Thus I vs. B curve is explained.

(ii) Equation (1) also shows that B decreases with increases L. This explain (L-B) curve.

Unit - 3 ❑ To study the variation of refractive index (μ) of the material of a prism with wavelength and to verify cauchy's dispersion formula and to find the dispersive power of the material of the prism by spectrometer

Structure

3.0 Objectives

3.1 Introduction

3.2 Apparatus used

3.3 Theory and working formula

3.4 Method of measurement

3.5 Discussion

3.6 Maximum proportional error

3.7 Summary

3.8 Model Questions and Answer

3.0 Objectives

- To draw a curve connecting refactive index (μ) of the material of a prism and wavelength (λ) of some know lines.
- To determine the dispersive power of the material of the prism.
- To verify Cauchy's dispersion relation $\mu = a + b/\lambda^2$.

3.1 Introduction

The variation of refractive index (μ) of a medium with the wavelength (λ) is known as dispersion. When the speed of a wave varies with its frequency, the supporting medium is said to be dispersive. This property arises due to dependence of the dielectric constant of the medium with frequency.

Usually ther refractive index decrease with increases in wavelength. This is known as normal dispersion. Mathematically, it may be represented by $d\mu/d\lambda$. But over a small wavelength range (absorption band) there is often increase in refractive index with increase of wavelength due to an increased absorption of radiation by the medium. This is known as anomalous dispersion.

The normal dispersion can be represented with considerable accuracy by Cauchy's empirical formula :

$$\mu = A+\frac{B}{\lambda^2}+\frac{C}{\lambda^4} \qquad \ldots (3.1)$$

Where A, B, C are constant that depend on the medium and decreases rapidly in magnitude when we proceed to the higher order terms. For some purpose the normal dispersion can be represented with sufficient accuracy by considering the first two terms only.

$$\mu = A+\frac{B}{\lambda^2} \qquad \ldots (3.2)$$

3.2 Apparatus Used

A spectrometer, a 60° prism of flint glass, discharge tube of He, Ne, H_2 or mercury vapour lamp, induction coil, and its accessories and spirit level.

3.3 Theory and Working Formula

Using a given source of light a spectrum is formed and the minimum deviation (δ_m) for each of the lines of known wavelength (λ) of the given source as well as the angle (A) of the prism are measured with the help of the spectrometer.

The refractive index of the material of the prism for those lines of known wavelength can be calculated from the relation :

$$\mu = \frac{\sin\left(\frac{A+\delta m}{2}\right)}{\sin\left(\frac{A}{2}\right)} \quad \text{... (3.3)}$$

Now taking wavelength (λ) of these lines as abscissa and corresponding (μ) of the material of the prism as ordinates, a graph is drawn which is known as the dispersion curve of the material of the prism.

Now if the Cauchy's relation given by equation (3.2) is valid for these lines in the visible region, then graph of μ vs $1/\lambda^2$ should be a straight line, which verifies Cauchy's dispersion formula.

Now by using μ vs $1/\lambda^2$ curve we can find refractive indices μ_1 and μ_2 corresponding to two specified wavelength λ_1 and λ_2 and then the dispersive power (ω) of the material of the prism with respective to these wavelengths can be calculated from the relation :

$$\omega = \frac{\mu_1 - \mu_2}{\mu - 1} \quad \text{... (3.4)}$$

Where μ is the mean of μ_1 and μ_2 i.e. $\mu = \frac{\mu_1 + \mu_2}{2}$

Usually λ_1 and λ_2 are chosen corresponding to the wavelengths of C and F lines of Fraunhofer spectrum [red and greenish-blue lines of H_2].

3.4 Method of Measurement

Setp 1 : Spectrometer is labelled; telescope and collimator is adjusted for parallel rays [see appendix A]. Vernier constants of both the verniers are determined.

Step 2 : The prism table is first levelled with the help of a spirit level and then optically.

Step 3 : Prism table is lavelled mechanically and optically so that the centre of the prism coincides with that of table. The prism table is then set to the position of minimum deviation for sodium light by altering the positions of the prism table and telescope [see appendix A]. The prism table is now made free from the spectrometer scale by making the screw attached to it loose.

Step 4 : The sodium light is now replaced by a standard source (helium discharge tube or a mercury vapour lamp) so that capillary position of source is placed just opposite to the collimator slit so that the spectral lines may be as bright as possible. At the focal plane of the telescope line spectra of helium will be seen.

Step 5 : The cross-wire of the telescope is now made coincident with the extreme red line of the spectra and the prism table is now slowly rotated by hand to make the deviation of this line minimum. When this occurs, the telescope is shifted a little to make it cross-wire coincident with this minimum deviated red line. The readings of both the verniers are now noted.

Step 6 : The operation of step v is repeated one after another for all the prominent lines of the helium until the violet light is reached.

Step 7 : Removing the prism, the telescope is shifted to receive the direst light from collimator. This position of telescope is now noted from the two verniers. The difference between this direct readings and minimum deviation reading of a particular line gives the ninimum deviation (δ_m) of the given line. In this way the minimum deviation for all the lines (both known and unknown lines) will be obtained. For each line, the mean of two minimum deviations obtained from each vernier should be taken.

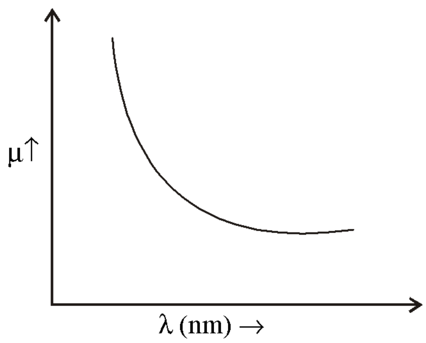


Figure 3.1

Step 8 : The prism is now placed on the prism table with its edge at the centre of the table and directed towards the collimator. The slit of collimator is now illuminated by sodium light. The parallel light from the collimator will now be reflected from the two faces of the prism [see appendix A]. Telescope is moved to receive these two reflected lights and at each position of it, the readings of its two verniers are noted. From the difference of these two readings for the two positions of the telescope the angle A of the prism will be obtained by taking half of that difference angle.

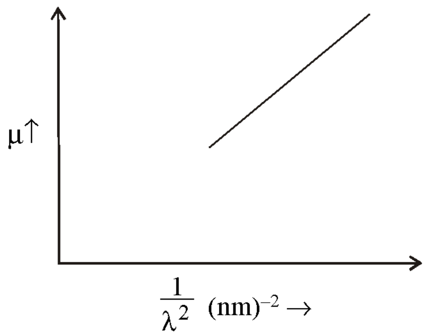


Figure 3.2

Step 9 : Now we have found δ_m and A. The refractive index (μ) of the prism for each line can now be calculated from the equation (3.3)

Step 10 : A graph is now drawn by plotting μ along y-axis λ or $1/\lambda^2$ of known lines along x-axis. The nature of the curve will be shown in Fig. 3.1 and Fig. 3.2 respectively.

From the $\mu - \lambda$ curve the refractive indices μ_1 and μ_2 corresponding to two specified wavelengths λ_1 and λ_2 are found out and then the dispersive power of the material of prism is calculated from equation (3.4) conventionally we can choose λ_1 = 486.2 nm and λ_2 = 656.3 nm which corresponds to the F and C lines of Fraunhofer spectrum respectively.

Experimental Results :

(A) To find the vernier constant (v.c) of the instrument.

Value of 1 main scale divisions = ...

Value of 1 vernier scale divisions = ...

Vernier constant : 1 main scale division –1 vernier divisions = ...

(B) Refractive indices (μ) for known lines of helium :

Table – 1

Colour of the line and its wavelength (l) in nm.	Vernier number	Readings of minimum deviation of the line of				Minimum deviation (δ_m) [taking (a) and (b) from Table-2	Mean (δ_m)
		Scale (s)	Verinier (v.r)	Total readings R=s+v.r×v.c	Mean (R)		
Red 667.8	A	....	....	....	........=(c)	(c–a) =..........	
	B	....	....	....	........=(d)	(d–b) =..........	
Yellow 587.6	A	....	....	....	........=(c)	(c–a) =..........	
	B	....	....	....	........=(d)	(d–b) =..........	

Colour of the line and its wavelength (l) in nm.	Vernier number	Readings of minimum deviation of the line of				Minimum deviation (δ_m) [taking (a) and (b) from Table-2]	Mean (δ_m)
		Scale (s)	Verinier (v.r)	Total readings R=s+v.r×v.c	Mean (R)		
Green	A						
501.6	B						
Green-blue	A						
492.2	B						
Blue (I)	A						
471.3	B						
Blue (II)	A						
447.2	B						
Violet	A						
402.6	B						

(C) Direct readings of the rays coming from the collimator :

Table – 2

Vernier number	Scale readings (s)	Vernier readings (v.r)	Total readings R = (s + v.r × v.c)	(Mean (R)
A	....	....	....	.... = a
B	....	....	....	.... = b

(D) To find the angle A of the prism :

Table – 3

Vernier no.	Readings for first images of in unit				Reading for the second image unit				Difference θ unit
	Scale (s)	Vernier (v.r)	Total= s + (v.r × v.c)	Mean	Scale (s)	Vernier (v.r)	Total= s + (v.r × v.c)	Mean	
A	....			...=R_1	....			...=R_2	**[360-(R_2–R_2)] =.......
B	....			...=R_3				...=R_4	*(R_3–R_4)

** When R_2 crosses 0° or 360°

* When R_4 does not cross 0° or 360°

(E) Data for drawing ($\mu - \lambda$) or $\left(\mu - \frac{1}{\lambda^2}\right)$ graph for helium :

Table – 4

Colour of the line	Red	Yellow	Green	Green-blue	Blue (I)	Blue (II)	Violet
λ in nm	667.8	587.8	501.2	492.2	471.3	447.2	402.6
$\frac{1}{\lambda^2}$ in nm^{-2}	......	......	......	......	......	......	......
Refractive index (μ)	......	......	......	......	......	......	......

(F) Determination of the dispersive power :

Table – 5

Specified wavelength in nm		Corresponding refractive indices		Dispersive power $w = \{\mu_1 - \mu_2\}/\{\mu - 1\}$
λ_1	λ_2	μ_1	μ_2	
.....	......	.....	......	

3.5 Discussion

1. Sometimes the zero of the vernier the zero or 360° of the scale during the rotation (θ) of telescope or of prism table. To get the correct value of the angle of rotation (θ) we are to find out (360°-difference of two readings).

2. From the $\mu - \lambda$ curve we can calculate the dispersion $\frac{d\mu}{d\lambda}$ the material for different wavelengths and hence its dependence of λ can be studied.

3. The value of the Cauchy's constant A and B can be determined. Slope of this curve gives the constant B and its intercept on the μ-axis gives the constant A.

3.6 : Maximum Proportional Error :

We have $\mu = \dfrac{\sin\left(\dfrac{A+\delta m}{2}\right)}{\sin\left(\dfrac{A}{2}\right)}$

Therefore, $\ln\mu = \ln \sin\left\{\dfrac{(A+\delta_m)}{2}\right\} - \ln \sin\left(\dfrac{A}{2}\right)$

Therefore, $$\frac{\delta\mu}{\mu} = \frac{\cos\left\{\dfrac{(A+\delta_m)}{2}\right\}}{\left\{\dfrac{\sin(A+\delta_m)}{2}\right\}}\left[\frac{\delta A}{2}+\frac{\delta(\delta m)}{2}\right] - \left\{\frac{\cos\left(\dfrac{A1}{2}\right)}{\sin\left(\dfrac{A}{2}\right)}\right\}\times\frac{\delta A}{2}$$

Therefore, $$\left(\frac{\delta\mu}{\mu}\right)_{max} = \left[\frac{\delta A}{2}+\frac{\delta(\delta m)}{2}\right]\cot\left\{\frac{A+\delta m}{2}\right\}+\left(\frac{\delta A}{2}\right)\cot\left(\frac{A}{2}\right)$$

Where δA = 1 v.c in radian since A is measured by taking difference of two readings and then dividing by $2.\delta(\delta_m) = 2 \times$ v.c, in radian, since δ_m is measured by taking difference of two readings. Now using a typical set of experimental values of different quantities we can calculate maximum proportional is μ as $(\delta\mu)$ max.

Again, $\ln\omega = \dfrac{\ln(\mu_1-\mu_2)}{\ln(\mu-1))}$

Therefore, $$\frac{\delta\omega}{\omega} = \frac{\delta\mu_1-\delta\mu_2}{\mu_1-\mu_2} - \frac{\delta\mu}{\mu-1}$$

Therefore, $$\left(\frac{\delta\omega}{\omega}\right)_{max} = \frac{(\delta\mu_1+\delta\mu_2)}{(\mu_1-\mu_2)} + \frac{\delta\mu}{\mu-1}$$

Assuming $\delta\mu_1 = \delta\mu_2 = \delta\mu = \delta\mu_{max}$ and using the values of μ_1 and μ_2 we can calculate maximum proportional error in ω.

3.7 Summary

1. Angle of the prism is measured by measuring the position of the reflected images of the slit from the two surfaces of the prism, avoiding parallax between the cross-wire and the slit image.
2. Minimum deviation positions of each colour measured and the minimum deviations of the respective colours are found out with the help of direct reading of the rays from the collimator. The direct reading is taken at the end of the experiment.
3. μ for each colour is calculated and curves $\mu - \lambda$ and $\mu - \frac{1}{\lambda^2}$ are drawn to find out dispersive power of the material of the prism and to verify Cauchy equation respectively.

3.8 Model Questions and Answer

1. What do you mean by dispersion of light ?

Ans. When a polychromatic light passes through a prism it breaks up into constituents colours. This is known as dispersion of light. The phenomenon is due to the dependence of refractive index (μ) on the wavelength (λ).

Mathematically, $\frac{d\mu}{d\lambda}$ is known as dispersion.

2. What do you mean by the term (i) normal dispersion and (ii) anomolous dispersion?

Ans. (i) Normal dispersion is that in which refractive index (μ) increases with decrease of wavelength (λ) and the dispersion $\frac{d\mu}{d\lambda}$ of the material of the prism becomes grerater at shorter wavelength. Normal dispersion will be obtained for these wavelengths of the incident light which are far away from the absorption bands of the material of the prism.

(ii) In the neighbourhood of the absorption bands of a substance the dispersion produced by the substance is anomalous because the value of μ is higher for longer wavelength than for shorter wavelengths.

3. What do you mean by dispersive power of a material ?

Ans. It measures the ability of the material to disperse various colours. It can be defined as $\omega = \frac{\mu_F - \mu_C}{\mu_D - 1}$, where F, C, D corresponds to F, C and D lines of Fraunhofer spectrum. In the laboratory the F-line coincides with hydrogen greenish-blue line, C-line with hydrogen red and D-line with sodium-yellow line.

4. What do you mean by emission and absorption spectra ?

Ans. When a substance is excited to emit light and when that light is dispersed by a dispersive substance (prism or grating) the spectrum so obtained to called emission spectrum.

But when white light from a source is made to pass through a substance in cold, the substance will selectively absorb some wavelength from the incident white light and the rest will be allowed to pass through. When this transmited light is dispersed we get a spectrum known as absorption spectrum in which the absence of some lines or bands are indicated by dark lines or bands. Solar spectrum is an example of absorption spectrum.

Unit - 4 ❑ To draw the regulation characteristics of a bridge rectifier (i) without using any filter and (ii) using C-filter. Determination of ripple factor in both cases by measuring the ripple voltage with the help of an A.C meter

Structure

4.0 Objectives

4.1 Introduction

4.2 Apparatus used

4.3 Theory and working formula

4.4 Method of measurement

4.5 Discussion

4.6 Maximum proportional error

4.7 Summary

4.8 Moden Questions and Answer

4.0 Objectives

- To draw the regulation characteristics of a bridge rectifies (i) without filter and (ii) C-filter.
- To determine the ripple factor in both cases by measuring the ripple voltage using true A.C. meter.

4.1 Introduction

Electrical power, for convenience in generation and transmission, is generated in the form of A.C. But for many applications we require D.C. which necessitates the conversion of A.C. into D.C. by using rectifiers. The performance of a rectifier can be improved by using filters.

4.2 Apparatus Used

(i) A simple step-down transformer (15V)

(ii) Four identical semiconductor diodes (usually By 125 or By 127).

(iii) A D.C voltmeter (0–30) V

(iv) A D.C mill ammeter (0–150 mA)

(v) A load resistance box or a 10KΩ turn potentiometer.

(vi) A circuit board containing several binding screws or preferably a bread board.

(vii) A filter board containing capacitors (usually electrolyte 50 μF)

(viii) An A.C millivolt meter.

4.3 Theory, Working Formula and Circuit Used

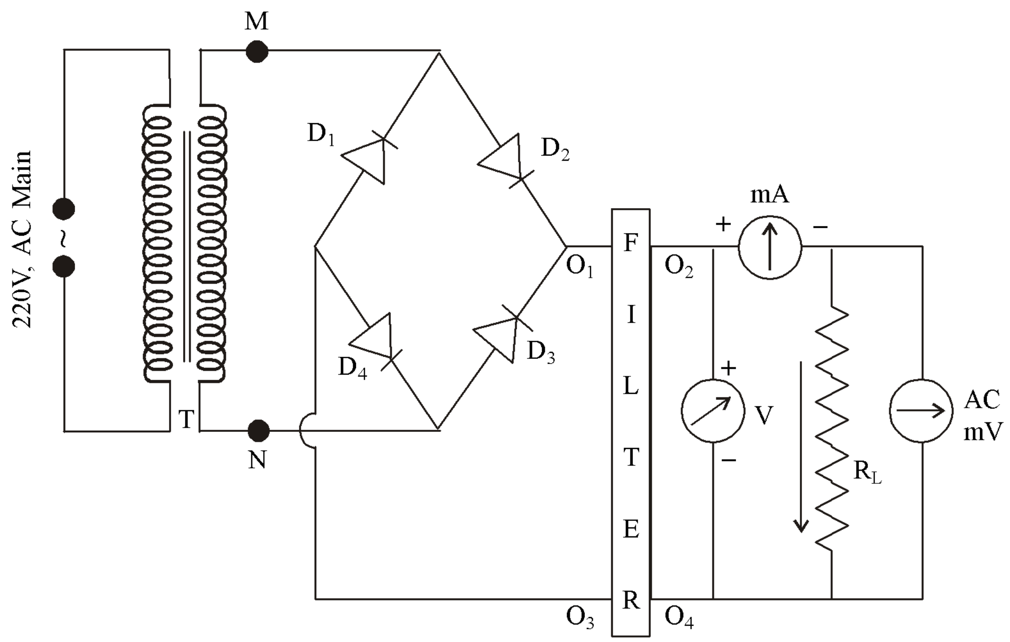


Figure 4.1

(1) AC line voltage (220V, 50 Hz) (2) T : step down transformer (15V) (3) D_1, D_2, D_3, D_4 : 4 identical diodes (By 127) (4) V : dc voltmeter (5) mA : milliammeter (dc) (6) R_L : variable load resistance (7) ac mV : ac milli voltmeter

A rectifier is a device which can convert A.C power into D.C power. A p-n junction diode conduct only when its p-side is made positive (forward bias) and practically does not conducts when p-side becomes negative (reverse bias). Thus a p-n diode can acts as a rectifier.

A rectifier using four diodes in the form of a bridge as shown in Fig. 4.1 is known as bridge rectifier.

During one half cycle of input ac, when end M is positive, the diodes D_2 and D_4 conducts. During next half cycle when the end N is positive diodes D_3 and D_1 conducts. In both the cases the direction of current through R_L is the same. So the waveform as the voltage across R_L will be of full cycle.

The variation of the D.C output load voltage V_L as function of D.C load current I_L for a given input voltage is known as load regulation curve.

The percentage regulation S_L (at any specified load current is defined by

$$S_L = \frac{(V_{NL} - V_L)}{V_L} \times 100\% \quad \text{... (4.1)}$$

Where V_{NL} = no load voltage (i.e. with $I_L = 0$ or $R_L = \alpha$)

V_L = Load voltage at any specified rated load current.

The output of the rectifier contains A.C components called ripples. A measure of this lack of smoothness is given by the ripple factor γ which is defined as

γ = (rms value of the ac components of load voltage)/(D.C value of the load voltage) ... (4.2)

The ripples in the output can be reduced by using filter networks which may be a simple large shunt capacitor. The capacitor may be connected (O_1, O_2) and (O_3, O_4) in Fig. 4.1 and again load regulation curve may be drawn, percentage regulation calculated and ripple factor determined.

4.4 Method of Measurement

Step 1 : The circuit connection (Fig 4.1) without filter network is made on a circuit board or on a bread board.

Step 2 : Main supply is made on D.C output voltage (V_{NL}) and A.C ripple voltage is noted without R_L from the voltmeter V and A.C millivolt meter respectively.

Step 3 : Load resistance R_L of suitable value is now inserted such that a load current I_L of about 10 mA flows. I_L and corresponding output load voltage V_L is noted from the miliammeter mA and voltmeter V respectively. The ripple voltage from the A.C milivoltmeter is also noted.

Step 4 : Now I_L is increased in small steps (of suppose, 10 mA) and in each case I_L, V_L and ripple voltage is recorded.

Step 5 : The load regulation curve is obtained by plotting I_L in mA along x-axix and corresponding V_L in volts along y-axis. The nature of the curve is shown in Fig. (4.2).

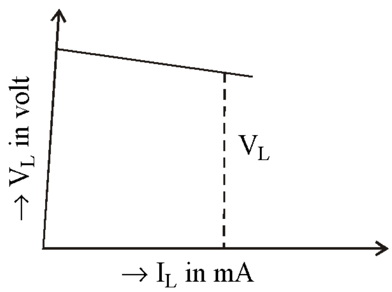


Figure 4.2

Step 6 : From the load regulation curve, output voltage V_L for a specified load current I_L is obtained and percentage of regulation S_L is calculated using equation (4.1).

Step 7 : Ripple factor γ is calculated for each load current I_L using equation (4.2). Dependence of ripple factor on load current can be shown by drawing I_L along x-axis and γ along y-axis, For simple capacitor filter γ increases with I_L.

Step 8 : Now a shunt capacitor C is inserted between O_1, O_2 and O_3, O_4. Now the steps 2 to 7 are repeated.

Experimental Data :

Type of diode = ...

Maximum allowed current through the diodes = ...A

Maximum allowed reverse voltage across the diodes = ...V

Fixed input A.C voltage across the transformer seconddary = ...V

(A) Specification of meters used :

Table – 1

Meter	Range	1 smallest division	Zero error if any
D.C voltmeter	....	....	....
D.C milliammeter	....	....	....
A.C millivolt meter	....	....	....

(B) Data for load regulation and ripple factor [without filter] :

Table – 2

No. of obs.	D.C load current I_L in mA	D.C voltage V_L in V	Ripple voltage $V_{r.m.s}$ in V	Ripple factor $\gamma = (V_{r.m.s})/V_L$
1	0	....	....	....
2	10	....	....	....
3				

(C) Data for load regulation and ripple factor [with filter] :

Table – 3

No. of obs.	D.C load current I_L in mA	D.C voltage V_L in V	Ripple voltage $V_{r.m.s}$ in V	Ripple factor $= (V_{r.m.s})/V_L$
1	0	....	....	....
2	10	....	....	....

(D) Calculation of % regulation from the curves :

Table – 4

Rectifier	No load voltage V_{NL} in V	Specified load current I_L in mA	Corresponding load voltage V_L in V	Regulation S_L
Without filter	....	....	....	....
With filter	....	....	....	....

4.5 Discussion

1. Before switch is on the A.C mains, R_L to be made sufficiently high and also it is to be kept in mind that I_L does not exceed the ratings of the diode.
2. For load regulation constancy of the input A.C voltage should be maintained.
3. To ensure better regulation with capacitor filter, capacitor having large capacitance should be used [see item no. 4]
4. Nature of the output waveform in presence of capacitor filter is as shown in below.

   In a full wave rectifier with a simple capacitor filter : $V_L = V_O - \frac{I_L}{4fC}$

   Where f is the power line frequency and C is the capacitance of the capacitor.

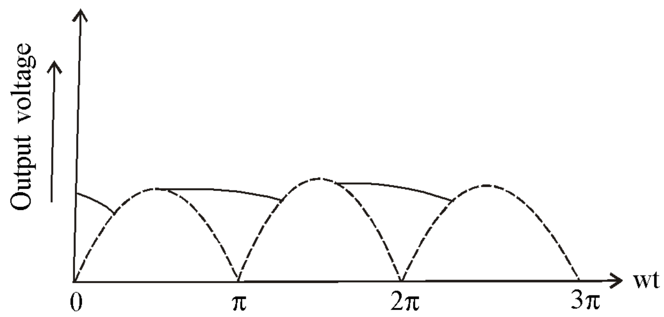


Figure 4.3

4.6 Maximum Proportional Error

We have $S_L = \frac{(V_{NL} - V_L)}{V_L} \times 100$

Maximum proportional error in S_L is $\frac{\delta S_L}{S_L} = \frac{\delta V_{NL} + \delta V_L}{V_{NL} - V_L} + \frac{\delta V_L}{V_L}$

$= \frac{2\delta V_L}{(V_{NL} - V_L)} + \frac{\delta V_L}{V_L}$ [since V_{NL} and V_L is measured by the same voltmeter and we are taking difference of the two readings] δV_L is the error in measuring V_L I.e it is the value of the smallest division of the voltmeter V.

4.7 Summary

Performance of the bridge type full wave rectifier is investigated in terms of :

(A) Study of load regulation with and without filter.

(B) Dependence of ripple factor on load current.

(C) Calculation of percentage of regulation.

4.8 Model Questions and Answer

1. What are the advantages of the bridge rectifier are a full wave rectifier ?

Ans. The output of the bridge rectifier is similar to that of the full wave rectifier but it has a number of advantages as stated below :

(i) A transformer without a centre tap can be used.

(ii) The peak-inverse voltage is equal to the peak value (V_o) of the input A.C, but for full wave circuit this is $2V_o$. The bridge circuit in thus suitable for high voltage applications.

(iii) The currents drawn in both the primary and the secondary of the input transformer are sinusoidal, and hence a smaller transformer can be used that for the full wave circuit of the same output.

2. What type of capacitor is used in a filter circuit ? What is an electrolytic capacitor ?

Ans. Electrolytic capacitor has large capacitance (5μF–1000μF). It consists of two Al-foil electrodes separated by cotton gauze soaked in an electrolyte of ammonium borate. By electolytic action a molecular thin layer of Al_2O_3 is deposited on one of the foils. This thin oxide layer acts as dielectric and have a large capacitance can be obtained with small dimensions.

The capacitor is to be used with proper polarities. Manufacturers always make positive and negative signs on its two terminals.

With reverse polarities there will be reverse electrolysis forming gases. The capacitor become hot and may even explode.

Unit - 5 ❑ To find the optical rotation of a sugar solution by a polarimeter

Structure

5.0 Objectives

5.1 Introduction

5.2 Apparatus used

5.3 Theory and working formula

5.4 Method of measurement

5.5 Discussion

5.6 Maximum proportional error

5.7 Summary

5.8 Model Questions and Answer

5.0 Objectives

- To calibrate a polarimeter.
- To determine the concentration of unknown sugar solution.

5.1 Introduction

Some crystals possess the characteristic property that when plane polarised that light passes through them along the optic axis, they rotate, as the beam propagates, the plane of polarisation through a certain angle about the direction of propagation. This property is termed rotatory polarisation or optical activity. Optically active substances can be divided into two classes. In one class, optical activity is retained in the crystalline state, in the fused state or in the dissolved state, such as lactic acid, tartaric acid, many of the sugars etc.

In another class, the activity is found in the crystalline state only. They lose their activity when they lose their structure by fusion or solution.

There are again two types of optical active substance : Dextro-rotatory and Laevo-rotatory. Those which rotate the plane of polarisation clockwise, while looking against the direction of light, are called Dextro-rotatory or right-handed. While those that rotate the plane of polarisation anticlockwise, on looking against the light, are called Laevo-rotatory or left-handed.

The optical activity of a crystal is due to its structural asymmetry. The atoms or the molecules constituting the optically active crystals are arranged on a spiral which may be left handed or right handed. Some crystals Dextro and Laevo varieties, one being the mirror image of the other. Example is quartz. While cane-sugar is Dextro-rotatory, fruit-sugar is Laevo-rotatory.

Some substance example : cane sugar show in solution the optical activity. In such cases, the activity is associated with the structural asymmetry of the molecules. While the molecules in a solution are oriented at random, their rotations however do not cancel out since the sense of rotation is the same for molecules with same type of asymmetry.

5.2 Apparatus Used

(i) Half-shade of Bi-quartz polarimeter.

(ii) Active substance (sugar-solution).

(iii) Balance and weights.

(iv) Measuring cylinder.

(v) Flask.

(vi) Distilled water.

(vii) Scale.

(viii) Sodium light source or white light source.

(ix) Filter paper.

For description of the polarimeter action of Half-shade and Bi-quartz please see the appendix A.

5.3 Theory and Working Formula

When a plane polarised monochromatic light of wavelength λ passes through a column of solution of length L cm and containing m gm of active substance per cm^3 at a given temperature, then the plane of polarisation of light is rotated through an angle θ given by

$$\theta = (sLm)/10 \qquad \text{... (5.1)}$$

Where s is the specific rotation of the solution which is defined as the rotation of the plane of polarisation of a plane polarised monochromatic light when it passes through the column of the solution of length, one decimetre and containing 1 gm of the active substance per cm^3 of the solution at a particular temperature of the solution and for the wavelength used.

If the strength of the solution be 10% by volume then m = c/100 gm per cc

Then from equation (5.1) we get $\theta = (sLc)/1000$

Here $s = (1000.\theta)/Lc$ ... (5.2)

Or, $c = (1000.\theta)/Ls$ ... (5.3)

Findings from a solution of known strength c from equation (5.2), the strength c of an unknown solution can be found out from equation (5.3).

For a given wavelength and temperature s is almost constant. Hence if θ is plotted against c a straight line curve is obtained which is known as calibration curve of the polarimeter of the active solution. From the slope of the curve we can finds. Also the curve can be used to find the unknown connection. Now the amount of substance (solute) require to prepave V cm^3 of the solution of concentration c% is given by

$$m = (cV)/100 \text{ gm} \qquad \text{.... (5.4)}$$

From the solution of a known concentration c%, a solution of lower concentration c_1% can be prepared by adding y cm^3 of water to × cm^3 of the solution of concentration c%, where

$$y = \frac{c - c_1}{c_1}.x \qquad \text{... (5.5)}$$

Sketch of Experimental Arrangement :

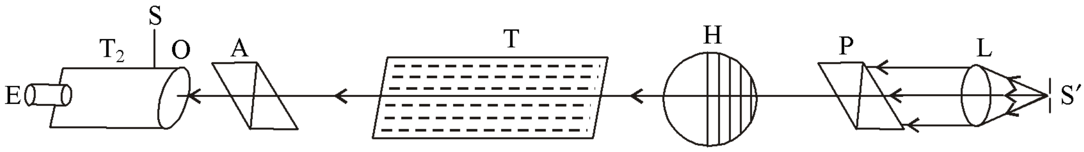


Figure 5.1

S′–adjustable slit, L–convex lens, H–biquartz, P–polarising nicol, A–analysing nicol, S–circular scale, EO–telescope, T-tube with active substance.

5.4 Method of Measurement

Step 1 : To prepare 100 cc solution of c% strength by volume, c gram of the active solid is totally dissolved in 50 cc of distilled water to make a solution and then by pouring additional distilled water slowly exactly 100 cc solution is prepared. Thus we get a solution of c% strength of volume 100 cc. The solution so prepared is filtered out.

Step 2 : The length of the tube T (Fig 5.1) is measured by a scale thrice and its mean value L cm is found out. The slit is illuminated by sodium light (for half-shade) or white light (For bi-quartz). By filling the tube T completely with distilled water (with no bubble) it is placed in its proper position. The tube T_2 is now rotated until the two-halves of the field are equally bright (for half-shade) or assume greyish violet tint (for bi-quartz). The readings R_0 and R_0' of the sacle S, as shown by the verniers V_1 and V_2 respectively are noted twice (by rotating T_2 from left to right, from right to left and finally from left to right) and their mean is taken. Note that V_1 and V_2 are 180° apart.

Step 3 : Water is the tube T is thrown away and after washing the tube T for two or three times by a little of the solution of c% strength, the whole tube is now completely filled with the solution c% strength (having no air-bubble) and it is placed in its proper position. As in step 2, the tube T_2 is rotated to make the two halves of the field equally bright (for half-shade) or equally greyish violet (for bi-quartz) and the mean of the three readings of the verniers V_1 and V_2 are noted.

If R_1 and R_1' are respectively the mean readings of verniers V_1 and V_2 then we get $\theta_1 = (R_1 - R_0)$ and $\theta_2 = (R_1' - R_0')$. Hence mean rotation of solution of c% strength is $\theta = (\theta_1 + \theta_2)/2$.

Step 4 : To dilute the solution of c% strength to other lower strengths and then to find rotations of these strengths, take × cc of the stock solution of c% strength to mix with y cc of distilled water to have c_1% strength, where y is given by equation (5.5).

By washing the tube T with a little of this new solution of strength c_1% for two or three times, the whole tube T is filled with solution of c_1% strength by avoiding any air bubble. By placing the tube T in its proper place the mean rotation of the plane of polarisation by this solution is determined as stated in step 3.

Step 5 : By following same proceduces stated in step 4, solution of other lower strengths are prepared and the mean rotation of the plane of polarisation for those are determined.

Step 6 : A graph is then drawn by plotting the strength of the solution c along the x-axis and its corresponding rotation θ along y-axis. The graph would be a straight line (Fig 5.2). Taking a point P on this graph, its co-ordinate (c, θ) are found out from which s can be obtained. However, (c, θ) should not be in the experimental data.

Step 7 : Now the tube T is washed several times by the given unknown solution and then it is finally filled with the unknown solution and placed in its position. Proceeding as in step 3, the mean rotation (θ′) for this unknown solution is determined. From the graph [Fig 5.2] the unknown concentraction c′ is obtained as the conncentration corresponding to the angle of roration θ′.

Experimental Data :

(A) To prepare solution of c% strength by volume :

Appropriate volume of water filling the tube T (V) = ...c.c

Table – 1

Volume of solution to be prepared = Vcc	Masses of			Final volume of the solution of c% = (100 m)/c
	Dry and empty flask = $m_1$gm	Flask + solid = $(m_1 + m)$ gm	Solid taken = m gm	
100 cc				100 cc

(B) To find the length of the tube T between the inner surface of its two end plates :

L = {.........+.........+..........}/3 = ...cm.

(C) To find vernier constant of verniers V_1 and V_2 :

1 m.s.d = ... v.s.d

Therefore, v.c = (1 m.s.d – 1 v.s.d)

(D) Conversion of the solution of c% strength to other lower strengths :

Table – 2

No of conversions	Volume of stock solution x cc	% strength of stock solution	% strength required	Volume of water to be added to x cc to stock solution to have next lower % strength = y cc
1st	..... = x_1	..... = c (7.5%)	= c_1(6%)	...y_1={(c–c_1)/c_1}.x_1
2nd	..... = x_2	..... = c_1 (6%)	= c_2(4.5%)	...y_2={(c_1–c_2)/c_2}.x_2
3rd	....	....	....	....

(E) Vernier readings when pure water fills the tube T :

Table – 3

No. of obs.	Reading 1st vernier V_1			Reading for 2nd vernier V_2			Mean of R_0	Mean of R_0'
	c.s.r (s)	v.r	Total (R_0) =s+(v.r)(v.c)	c.s.r (s)	v.r	Total (R_0) (R_0')=s+(v.r)(v.c)		
1	....	I→r	....	......	I→r	....	....	....
2.	....	r→I	....	......	r→I	....	....	....

[N.B : I → r rindicates vernier reading when tube T_2 [Fig 5.1] is rotated from left to right while r → I indicates vernier reading when tube T_2 is rotated from right to left].

(F) To find the rotation of the plane of polarisation when the tube T contains solutions of different unknown strengths :

Temperature of the solution = ...°c.

Table – 4

No.of obs.	% Strength of solution (c)	Vernier	Reading of vernier				Rotation of the vernier	Mean rotation θ
			Circular scales(s)	Vernier reading (v.r)	Total reading =s+v.r×v.c	Mean reading		
1	C=7.5%	First vernier (V_1)	....	I→r r→I I→r	....	..... = R_1	θ_1= (R_1-R_0)	(θ_1 + θ_1')/2
		Second vernier V_2 180° apart	....	I→r r→I I→r	....	..... = R_1'	θ_1'= (R_1'-R_0')	

(G) To find the % strength of the unknown solution :

Temperature of the solution = ...°c

Table – 5

Vrenier position	Reading of the vernier			Mean reading	Rotation of the vernier	Mean rotation $\theta'=(\theta_1+\theta_2)/2$	% strength of solution c′ from graph
	Circular scale	Vernier reading v.r	Total reading=s+v.r×v.c				
1st	....	....	....	.....= R	θ_1=R–R_0	=.....	.....
2nd (180° apart)	....	....	....	..... =R′	θ_2=R′–R_0'		

(H) To draw $(c - \theta)$ curve for known solutions :

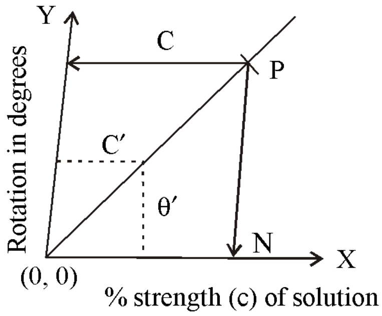


Figure 5.2

With origin (0, 0) a graph is drawn by plotting known concentrations (c%) of solution along x-axis and their corresponding rotations ($\theta°$) of the plane of polarisation along y-axis. The graph would be a straight line passing through the origin.

(I) To find the specific rotation (s) and concentration (c′) of unknown solution:

A point P is taken on the graph [Fig 5.2]. From c = ON = ...% and θ = PN = ... degree

Therefore, $s = (1000\theta)/(LC)$= .... degree. $cm^3/dm/gm$

From the same curve the unknown concentration (c′) corresponding to the angle of rotation (θ') due to unknown solution can be found out.

5.5 Discussion

1. Care should be taken so that the solutes dissolves completely in the solvent to prepare the solution. The solution should be filtered to make it dust free and the solution in the tube should be bubble free.
2. The equality of brightness or greyish violet fint of the field remains unchanged for a certain rotation of the tube T_2. Hence vernier readings should be taken thrice by rotating the tube T_2 from left to right and then from right to left and finally from left to right, to make the field equally bright as far as possible by eye-estimation.

3. Temperature of the solution should be remain constant during the experiment.

5.6 Maximum Proportional Error

We have from equation (5.2) :

$s = (1000\ \theta)/(L.c)$

Again from equation (5.4) :

$m = (cv)/100$

combining equation (5.2) and (5.4), we get

$s = (1000\ \theta \times v)/(L \times 100 \times m)$

$\delta s/S_{max} = \delta\theta/\theta + \delta L/L + \delta V/V + \delta m/m$ .... (5.6)

Again from equation (5.3), taking $c = c'$ and $\theta = \theta'$ for unknown solution.

$\delta c'/c'_{max} = \delta\theta'/\theta' + \delta L + \delta s/S$

Now $\delta\theta = \delta\theta'$ = change in the angle of rotation over which no significant change is observed in the field of view.

δV = 1 smallest division of the measuring cylinder

$\delta L = 2 \times 0.1$ cm, δm = smallest measurable weight in the balance.

Now using equation (5.6) we can calculate the maximum proportional error in s and then the error in known concentration c′ from equation (5.7).

5.7 Summary

1. Preparation of solution (sugar) of given strength by volume and subsequent conversion of strength to other lower strengths were performed.
2. Rotations of the plane of polarisation when passing through sugar solutions of different strength were measured.
3. Callibration curve of polarimeter was drawn and strength of unknown solution was found out.

5.8 Model Questions and Answer

1. What conclusions can be drawn from the phenomenon of polarisation of light?

Ans. (1) Electromagnetic wave (light) is transverse.

2. What do you mean by (i) Polarised light (ii) plane of polarisation (iii) double refraction (iv) optic axis of crystal (v) principle section of a crystal and (vi) active substance.

Ans. See and text book on wave optics.

3. What is a Nicol prism? What do you mean by parallel and crossed Nicols?

Ans. See any text book on wave optics.

4. What do you mean by Saccharimeter?

Ans. A special type of polarimeter calibrated to read directly the percentage of cane sugar in solution is known as Saccharimeter. It is used in sugar industry.

5. What is the definition of specific rotation for pure liquid and pure solids?

Ans. In pure liquid, specific rotation is the rotation produced by unit density of the liquid of one decimetre in length i.e.

S = {rotation per decimetre (dm)}/density of liquid).

For a pure solid, specific rotation is the rotation produced by solid of 1 mm thick.

6. How does optical rotation change with temperature?

Ans. The variation of 'θ' with temperature 't' is given by Gernez's relation : q = a + bt + ct^2.

For solids it increases with temperature while in liquid it decreases with temperature. For solids b and c are positive and negative for liquids.

7. Is the internal structure of a crystal responsible for its optical activity?

Ans. Yes, in the case of crystals, whose atom or molecules are arranged on a spiral, they show rotation of the plane of polarisation. The rotation is left-handed or right-handed according as the spiral is left handed or right handed.

8. What is Fresnel's explanation of the rotation of plane of polarisation?

Ans. According to Fresnel, a plane polarised light is resolved into two equal and oppositely circularly polarised light which travel with unequal speed within the substance. After emergence there will be phase difference between the two emergent circular vibrations, which will combine to form a linear vibration in a direction inclined by a certain angle with initial direction of vibration.

9. What is half-shade polarimeter? Explan in its action. [see appendix A]

10. What is a bi-quartz ? Explain in its action. [see appendix A]

11. What is the advantage of bi-quartz over half-shade?

Ans. The bi-quartz can be used with white light but the half-shade plate can be used only with a light source having the wavelength for which the quartz half serves as a half-wave plate.

Unit - 6 ❑ To find the wavelength of sodium light by Fresnel's Biprism

Structure

6.1 Objectives

6.0 Introduction

6.2 Apparatus used

6.3 Theory and working formula

6.4 Method of adjustment and measurement

6.5 Discussion

6.6 Maximum proportional error

6.7 Summary

6.8 Model Questions and Answer

6.0 Objectives

- To measure the wavelength of sodium vapour lamp by using Fresnel's biprism and optical bench.

6.1 Introduction

Two Coherent sources are necessary to produce interference. Since two independent sources in general cannot be coherent, the following methods are used to produce coherent sources in Laboratories. Usual method is to produce two sources from a single source by reflection or by refraction, using the method of division of wave front or by division of amplitude.

In case of division of wavefront, the wavefront of incident beam is divided into two or more parts by the passage through two close apparatus or by reflection, refractions etc. to produce coherent interfering beams. Fresnel's biprism serves the purpose by refraction through it.

In case of division of amplitude, the amplitude of the incident beam is divided into two or more parts by partial refraction or reflection to produce two or more coherent intersecting beams.

In Fresnel's biprism, experimental wavelength of a monochromatic light can be found out only by determining the fringe width of the interference pattern produced by it.

6.2 Apparatus Used

(i) A Fresnel biprism

(ii) A source of Monochromatic Light

(iii) A source of White light

(iv) A slit

(v) A micrometre eye-piece

(vi) A convex lens of suitable focal length

(vii) An optical bench with four stands

(viii) A plumb line

(ix) An index rod (if required)

6.3 Theory and Working Formula

A Fresnel biprism is a single prism which has one angle of 179° and the two base angles 30° each. It acts like two very thin prisms placed base to base.

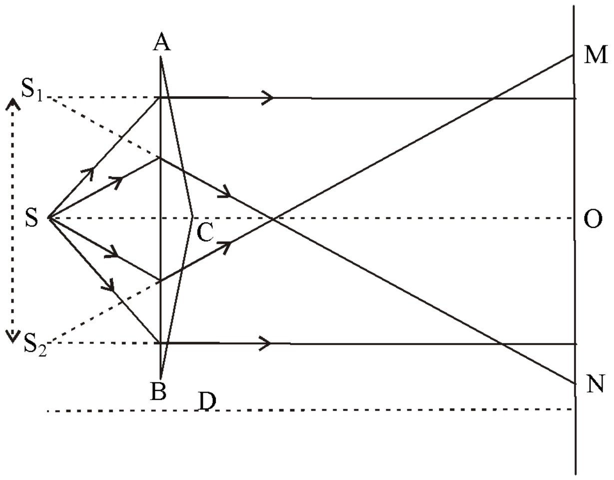


Figure 6.1

Fig. 6.1 : ABC-biprism, S-Source Slit; S_1, S_2-coherent virtual sources. D-distance between slit S and the focal plane of the eye-piece (screen)

When rays of light from slit S, (Fig. 6.1) illuminated by a monochromatic light, such as sodium light, are made to be incident on the plane face of the biprism ABC, the emergent rays from the two halves of the biprism appears to diverge from two coherent virtual sources as shown in (Fig. 6.1).

If a screen MN is placed with its perpendicular to the plane containing the slit and the common base of the biprism, the emergent beam of the light overlaps on the screen producing alternate dark and bright fringes.

If d is the distance between two virtual sources S_1 and S_2, D be the distance between the slit and the screen, and λ is the wavelength of the monochromatic radiation, then the fringe width, β is given by,

$$\beta = \frac{D}{d}\lambda \qquad \text{... (6.1)}$$

Where β is the distance between two consecutive bright and dark fringes.

If D_1 is the apparent distance between the slits and the focal plane of the eye-piece (which is the distance between two vernier readings attached to the slit stand and the eyepiece stand of the optical bench) then the fringe width β is given by,

$$\beta = \frac{D_1 + l_0}{d}\lambda \qquad \dots (6.2)$$

Where l_0 is the index error between the slit stand and eye piece stand.

When this index error l_0 is determined in the usual manner or to be supplied then λ can be found out using-

$$\lambda = \frac{d\beta}{D_1 + l_0} \qquad \dots (6.3)$$

But when the index error l_0 is unknown, it can be eliminated by nothing the fringe widths β_1 and β_2 for two apparent distances D_1 and D_2 between the slits and the forcal plane of the eye piece respectively.

$$\beta_1 = \frac{D_1 + l_0}{d}\lambda \;;\; \beta_2 = \frac{D_2 + l_0}{d}\lambda$$

$$\text{Or, } \lambda = \frac{\beta_2 - \beta_1}{D_2 - D_1}d \qquad \dots (6.4)$$

The relation (6.4) may be employed to find λ.

To determine d, a convex lens having focal length f, such that D_1 and D_2 > 4f, is interposed between the biprism and the eyepiece, so that for its two positions, real images S_1 and S_2 may be focused at the focal plane of the eye piece.

If d_1 and d_2 are the distance between the real images of S_1 and S_2 for two positions of the lens, then d will be obtained from the relation.

$$d = \sqrt{d_1 d_2} \qquad \dots (6.5)$$

6.4 Methods of Adjustments and Measurements

1. Adjustments :

STEP 1 : The slit stand is mounted near the zero of the bench scale and the slit is made vertical with the help of a plumb line and is made narrow. It is made by the middle of the bench by moving the slit-stand perpendicular to the bench.

STEP 2 : Mount the biprism on its stand with its plane face directed towards the slit and at the right angles to the optical bench. Move the stand towards the slit until it is in contact with the slit-stand. Adjust the height of briprism so that the centre of the biprism and that of slit of same height.

STEP 3 : Illuminate the slit with sodium light so that its brightest part is in front of the slit.

Place a screen with a linear aperture between the slit and the source to cut-off any stray light from reaching the eye.

On looking at the slit through the biprism along the middle line of the optical bench, turn the transverse screw of the biprism till the common base of the biprism is found to move across the slit. The place turn the transverse screw of the biprism till the common base of the biprism is found to move across the slit. This places the biprism in the middle of the bench. If there is an appreciable angle between the slit and the base of the biprism, adjust the tangent screw of the biprism till they are parallel.

STEP 4 : Place the upright carrying the eyepiece on the optical bench and close to the biprism. Adjust the height of the eyepiece so that the axis may be at the same height asthe centre of the biprism. Focus the eyepiece on the cross wires and move it perpendicular to the length of the bench until its axis passes through the centre of the biprism and the slit. Now indistinct fringes appear in the field of view. If, on looking through the eye-piece, you find neither a fringe system nor a bright patch of light in the field of view, turn the transverse screw of the biprism till it is found. Then make the fringe as distinct as possible by rotating the biprism in its own plane by the tangent screw.

STEP 5 : After getting well distinct when the bases of the slit stand and the biprism are in contact proceed to check whether d_1 and d_2 are observable.

For this purpose take the convex lens to be used for measuring d_1 and make a rough estimate of its focal length. Shift slowly the eye-piece away from the biprism and place it at a distance of about 4.5 times the focal length of the lens from the slit. While moving the eye-piece take care of the fringes never go out of the sight. To keep the fringes in the field of view, adjust the transverse screw of the biprism continuously.

Now mount the lens on the optical bench with an upright between the biprism and the eye-piece. Adjust the height and the position of the lens so that its centre is on the line joining the centre of the slit, biprism and the eye-piece. Move the lens and get real images of the two virtual sources S_1 and S_2 in the focal plane of the eye-piece for two positions of the lens.

STEP 6 : Remove the lens from the bench. Slowly shift the upright carrying the eye-piece away from the biprism and place it near the end of the optical bench. While moving the eye-piece, keep the fringes always in the field of view by adjusting the transverse screw of the biprism.

If the intensity decreases with increasing distance, adjust the slit-width, its position.

If the fringes are two broad, move the biprism slowly from the slit till the fringe width appears to be within 1–2 mm. Note that the biprism must not be moved to a distance greater than that corresponding to the position of the lens nearer to the biprism in the previous step.

STEP 7 : Place and switch a high power electric lamp to illuminate the slit. Adjust its height so that the incandescent filament is at the same height as the axis of the eye-piece. Coloured fringes with a white one at the centre is observed in the field of view. Bring the central fringe on the cross-wires by adjusting the transverse screw of the eye piece. Move the eye-piece very close to the biprism. Keeping the central fringe always on the corss wires by adjusting the micrometre screw of the eye-piece. Next move the eyepiece away from the biprism and bring it near the end of the optical bench. Keep the central fringe on the cross wires by continuously adjusting the transverse screw of the biprism. These operations are repeated till the central fringe is on the cross wires for all positions of the eye-piece.

2. Measurements

STEP 1 : Remove the white light. Determine the vernier constant for two bench stands and the least count of the micrometre screw of the eye-piece. Fix the eye-piece at a distance of about 4.5 times the focal length of the lens from the slit. Place the stand carrying the lens of the optical bench (see APPENDIX-A) between the biprism and the eye-piece, and make it co-axial with the later.

Now, on moving the lens-stand along the bench, magnified real image of the virtual source S_1 and S_2 will be seen in the field of the eye-piece. Bring the image at equal distance of the cross-wires by rotating the lens about the vertical axis. This ensures that the images of both S_1 and S_2 will appear simultaneously in focus at each of the two position of the lens. Measure the distance d_1 between the two images by shifting the eye-piece perpendicular to the bench and setting the cross-wires on the same edge (left or right) of the image. Make the measurement four times, once shifting the eyepiece from left to right, next from right to left, again from left to right and finally from right to left. The mean of these four values givesl d_1. Readjust the lens in this position and repeat the readings for two more independent seeting of the lens. Take mean of these three values of d_1.

Next move the lens towards the eye-piece keeping the later fixed in its previous position, till sharp images of the virtual sources S_1 and S_2 are seen in the field of view. Determine the distance between the two images, d_2 in a manner similar to that followed in measuring d_1. From these values of d_1 and d_2 calculated from equation (6.5).

STEP 2 : Remove the upright carrying the lens from the bench. Move the eyepiece to a suibtable distance from the biprism so that distinct fringes appear in the field of view. Do not alter the position of the slit and the biprism. Note the position of the slit, biprism and the eye-piece of the bench.

Turn the micrometre screw to shift the corss-wire of the eye-piece beyond the last distinct fringe on the side (say, the left side). Then turn the screw slowly in the opposite direction to set the cross wires in the middle of the first bright fringe as their side. Take reading of the linear and circular scales of the micrometre. Next set the cross-wire on the middle of the third and fourth bright fringe and take linear and circular scale readings. The difference between these two readings gives the width of two or three fringes. In this way, go on measuring the width for 2 or 3 fringes (or more if fringes are narrow) until the other end of the fringe system is reached. Again, starting from this side and turning the micrometre screw in the opposite direction, measure the width for three or more fringes by similarly setting the cross-wires in the middle of the bright fringes. Take as many reading as possible for width of three or more fringes and find the mean width of a single fringe.

When the index correction is to be avoided repeat the above procedure to determine the fringe width corresponding to another position of the eye-piece from the slit.

STEP 3 : When λ is calculated from the equation (6.3), index correction is required.

To find index errors, proceed as follows :

Remove the tube containing the cross-wire of the eye-piece from the socket. Also remove the biprism from the bench.

Take an index rod and put it parallel to the axis of the bench with one of its end touching the slit. Adjust the position of the eye-piece so that the other end of the rod is clearly seen through it. Take the readings of the indices attached to the slit and the eye-piece stands. The difference between these two readings gives the apparent length of the rod. Measure the actual length of the rod by a metre scale and find the difference between he actual and apparent lengths of the rod. This gives the inded error.

Experimental Results :

(A) Vernier constant of the vernier attached to the bases of stands :

1 m.s.d. = ... v.s.d.

V.C. = 1 m.s.d. – 1 v.s.d.

(B) Least count of the micrometer screw attached to the eye-piece :

Pitch of the micrometre screw = ... = p

Total circular scale division = ...

Least count = ... = (I.c.)

(C) Measurements of d_1 and d_2 and hence d :

Table – 1

Positions In cm of		Direction of eyepiece movement	Reading in micrometre screw								Distance between the images m_2-m_1 in mm	$d = \sqrt{d_1 d_2}$	Mean d in mm
			Left image (a)				Right image (b)						
Eye-piece	lens		L. scale (s) in mm	c. scale (c.r.)	Total in mm = S = c.r. × l.c,	mean of the total m_1 in mm	L. scale (s) in mm	c. scale (c.r.)	Total in mm = S = c.r. × l.c,	mean of the total m_2 in			
1st	1	1 – r											
		r – I											
	II	1 – r											
		r – I											
2nd	1	1 – r											
		r – I											
	II	1 – r											
		r – I											

N.B. : When starting from left to right fill up the column a first and then column b but when starting from right to left fill up the column b first and then a

(D) Measurement of fringe width (β) :

Position of the slit on the bench = ... cm

Position of the biprism on the bench = ... cm

Position of the eye-piece on the bench = ... cm

Table – 2

Serial no. of the fringe from left	Direction of micro-metre movement	Reading of micrometre screw				Distance between n (= 8) bands		Mean (R) in mm	Fringe width β_1/ R/n in mm
		l. scale (in mm)	C. scale (c.r.)	Total R = S + (c.r. × l.c)	Mean reading for the fringe in mm	Fringe taken from	Width of n fringer (R) in mm		
1									
2									
3									

N.B : First start from left to right and fill up the rows (l–r) and then during return from right to left fill up the rows (r–l). Make another table similar to Table D for other position of the eye-piece.

(E) Determination of wavelength λ for an unknown line :

Table – 3

Set no. of observation	Appartment distance between slit and eye-piece (in cm) D	Fringe width in mm (β)	Difference of D's in cm	Difference of β's in mm	Value of d in mm	λ in mm
1	.... = D_1	... = β_1	$D_2 \sim D_1$	$\beta_2 \sim \beta_1$		$\lambda = \frac{\beta_2 - \beta_1}{D_2 - D_1} d \times 10^5$
2	.... = D_2	... = β_2				

(F) Index error l_0 between the slit and the eye-piece (when eqn. 6.3 is used.)

Table – 4

Length of the index rod in cm (l)	Difference of bench scale reading in cm. when one end of the index rod touches the slit while the other end is sharply focussed by eye-piece (d′)	Index error for D = l_0 in cm
l = ... cm	d = (...)–(...) = ... cm	l_0 = ... cm

(G) Determination of wavelength (l) of unknown line (when equation (6.3) is used)

Table – 5

Apparent distance between the slit and the eye-piece in cm (d)	Fringe width β in cm	Value of d in mm	Index error in cm (l_0)	Corrected D + l_0 In cm	λ in nm	Mean λ in nm
D_1	β_1	...	...	...	...	...
D_2	β_2	...	...	...	...	...

6.5 Discussion

1. Fringes should be neither too wide nor too narrow. Fringe width can be made smaller by increasing the distance between the slit and the biprism. Again it can be increased by increasing the distance between the slit and the eye-piece.

2. The convex lens employed to focus he real images of the virtual sources at the focal plane of the eye-piece should be of such focal length (f) so that $D > 4f$.

3. The displacement of the lens to get the real images of the virtual sources at its two positions should be very large; otherwise proportional error in measuring d would be greater.

   For this purpose the three selected positions of eye-piece for measuring d_1 and d_2 should be near to each other. For the first nearest position of the eye-piece, D should be nearly 4.5f.

4. While using the micrometre screw, care should be taken to avoid back lash error. To do this, the eye-piece should be moved beyond the image concerned before reversing its direction of movement from left to right or vice-versa.

5. The instrument should be properly aligned so that there may not be any relative shift between the fringe and the cross-wires, as the eye-piece is moved along the bench.

6.6 Maximum Proportional Errors

We have $\lambda = \frac{\beta_2 - \beta_1}{D_2 - D_1} d$ .... (6.4)

Using $d = \sqrt{d_1 d_2}$, we get

$$\lambda = \frac{\beta_2 - \beta_1}{D_2 - D_1}\sqrt{d_1 d_2} = \frac{R_2 - R_1}{(D_2 - D_1)n}\sqrt{d_1 d_2}$$

Where R_1 and R_2 are the widths of n number of fringes.

$$\left(\frac{\delta\lambda}{\lambda}\right)_{max}=\frac{\delta R_1-\delta R_2}{R_2-R_1}+\frac{\delta D_2-\delta D_1}{D_2-D_1}+\frac{1}{2}\frac{\delta d_1}{d_1}+\frac{1}{2}\frac{\delta d_2}{d_2}$$

Since R_1 and R_2 are, measured by taking the differences between the readings of the micrometre screw of the eye-piece, the maximum error in measurement of either R_1 or R_2 would be twice the least count of the micrometre screw. Hence maximum error $\delta R_2 + \delta R_1$ is four times the least count. Similarly the maximum error measuring D_1 and D_2 may be twice the vernier constant of the vernier attached to the bench stands.

Therefore the maximum error $\delta D_2 + \delta D_1$ is four times the vernier constant. d_1 and d_2 are also measured from the difference of the readings of the micrometre screw of the eye-piece. Here the maximum error of the measurement of either d_1 and d_2 would be twice the least count.

If the vernier constants of the bench stands be 0.01 cm and the least count of the micrometre screw of the eyepiece be 0.001 cm, then the maximum proportional error is λ is given by

$$\frac{\delta\lambda}{\lambda}=\frac{4(0.001)}{R_2-R_1}+\frac{4(0.01)}{(D_2-D_1)}+\frac{0.001}{d_1}+\frac{0.001}{d_2}$$

Now substituting R_2, R_1, D_2, D_1, d_2 and d_1 from the data tables, $\left(\frac{\delta\lambda}{\lambda}\right)_{max}$ can be determined. Similarly using equation (6.3), $\left(\frac{\delta\lambda}{\lambda}\right)_{max}$ can also be determined.

6.7 Summary

1. Efforts are made to get well defined fringe system.
2. White lights should be used to make the apparatus coaxial.
3. Distances d between the two coaxial virtual sources are measured with a convex lens of suitable focal length as discussed.

4. Avoiding backlash error fringe width is determined for at least 8 to 10 fringes from the two sets of observations, one from left to right and another from right to left hence β, fringe width for a single fringe is determined.

5. Index correction if required is made.

6.8 Model Questions and Answer

1. What do you mean by interference of light ? What are the essential conditions for interference to take place ? How are these conditions fulfilled in case of biprism experiment ?

Ans. Interference is a phenomenon in which equispaced bright and dark fringes are produced by the superposition of waves from two sources having a constant phase relationship between them.

The first condition of interference between two sets of wave is that there must be a constant phase relationship between them at their origin. Hence the wave must come from two coherent sources which are derived from the same source.

The waves from the coherent source must be of equal or nearly equal amplitudes and they must be in the same of polarisation.

In case of a briprism the virtual sources are produced from the same source by refraction from the two halves of the biprism and hence the waves from the virtual sources are coherent in a position to produce interference.

2. What are the natures of the shope of the biprism fringes "

Ans. The biprism fringes are the non-localised fringes i.e. they can be obtained by holding the screen anywhere in the region where the waves of the virtual sources superpose.

These fringes in space are hyperboloids of revolution with the virtual sources as foci. As the screen is held parallel to the line joining the two virtual sources, we get straight fringes on the screen.

3. Why is it necessary that the sources must be coherent to produce sustained interference?

Ans. Light waves from two sources are to traverse a distance before they superpose on a screen. Due to the path difference of the rays from two sources at the point of interference, a phase difference is introduced between them. The point will have a maximum or a minimum intensity if the total phase difference between the rays meeting at the point be an even or odd multiple of λ. The phase difference due to the path difference remains constant at a point.

Now if the initial phase difference between the rays be constant then and only then, the point will have a maximum or minimum intensity. If the phase difference between the rays and their origin changes with time, i.e. if the source is non-coherent, the point will have alternately maximum and minimum intensity. As a result, no sustained interference pattern will be produced.

Unit - 7 ❑ To draw $\delta - \lambda$, $\delta - 1/\lambda^2$ graphs and find an unknown wavelength by a prism spectrometer

Structure

7.0 Objectives

7.1 Introduction

7.2 Apparatus used

7.3 Theory and working formula

7.4 Method of measurement

7.5 Discussion

7.6 Maximum proportional error

7.7 Summary

7.8 Model Questions and Answer

7.0 Objectives

- To draw the calibration curve for the given prism spectrometer.
- To Find wavelength of an unknown spectral line.

7.1 Introduction

Deviation of a ray of light passing through a prism depends upon (i) the angle of incidence (ii) angle of the prism and (iii) the refractive index of the material of the prism.

For a given prism, its angle is constant and for its given position with respect to the incident light, angle of incidence is constant.

Thus for a given prism for its given position, deviation depends on the wavelength λ, of the incident light used and curve drawn between deviation (δ) and wavelength (λ) of the incident light for a given position of the prism is called the calibration curve of the given prism spectrometer. Also wavelength of some unknown radiation can be determined from this calibration curve.

If a graph be drawn between $\delta - 1/\lambda^2$ then it would be appromimately a straight line from which the wavelength of unknown lines can be found out.

7.2 Apparatus Used

1. Spectrometer
2. A 60° prism of dense flint glass
3. A spirit level
4. Sodium vapour lamp
5. Discharge tubes of He, Ne, H_2 or mercury vapour lamp
6. Induction coil and its accessories
7. Reading glass

7.3 Theory and Working Formula

When a prism is placed on a spectrometer table in a standard position which is generally the position of minimum deviation for sodium light and the deviations of some lines of known wavelengths produced by the prism are found out, then a curve in which the deviations (δ) are plotted against the corresponding wavelength (λ) is called a calibration curve of the spectrometer with the given prism.

A calibration curve obtained with a given prism is a standard position, can be used to determine the wavelengths of some unknown radiations. For this purpose the deviations of the unknown lines produced by the prism in the standard position, are found out and the corresponding wavelengths are determined from the curve δ versus λ or δ versus $1/\lambda^2$.

7.4 Method of Measurements

Step 1 : Spectrometer is levelled by using the spirit level to make (i) the axis of rotation of the telescope vertical (ii) the axes of the telescope and the collimator horizontal and (iii) the top of the prism table horizontal. [See Appendix A]

Focus the eye-piece on the cross wire and make the slit narrow and vertical. Now adjust the telescope and the collimator for parallel rays [See Appendix A]

Determine the vernier constant of the circular scale and express it in minute or sound.

Step 2 : Remove the prism and take the readings of the two verniers for direct rays by setting the junction of the cross wires at the centre of the image of the slit. Take the readings three times by resetting the cross wires.

Step 3 : Place the prism on the spectrometer table with its centre coinciding with that of table. Level the prism optically and set it at the position of minimum deviation (See Appendix A). Take the reading of the two verniers. Repeat the readings by resetting the prism.

Step 4 : Replace the sodium light by a helium discharge tube. Adjust the position of the tube so that its capillary portion, where the illumination is strongest, is held just opposite to the slit. Now you will see the line spectra of helium at the focal plane of the telescope. Set the junction of the cross-wires on each of the prominent lines of the spectrum starting from red and ending in violet. Take the reading of the two verniers for each position of the telescope. Repeat the readings.

Step 5 : Repeat operation (4) with other sources you may have been provided with. Also repeat the operation for unknown lines.

Step 6 : Calculate he deviation of each line of helium by taking the difference of the readings for the direct and the deviated rays. Obtain the wavelengths of these lines from a table.

Plot the deviations (δ) against the corresponding wavelengths (l) or $\delta - 1/\lambda^2$ on a graph paper. The nature of the curve will be as shown in Figure (7.1) and Figure 7.2, respectively.

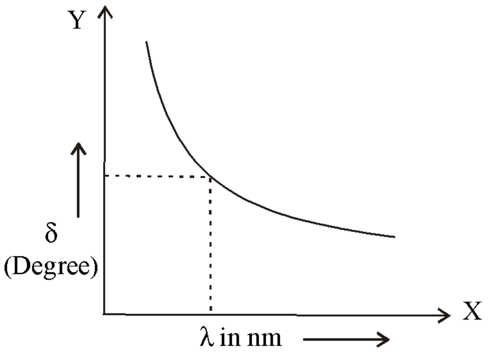


Figure 7.1

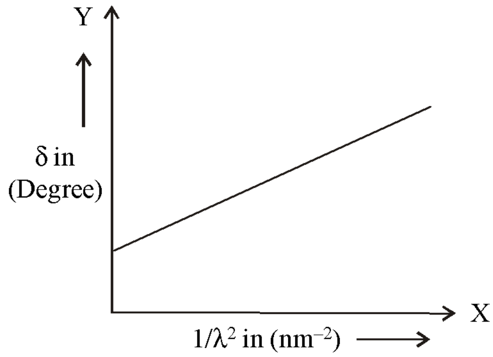


Figure 7.2

Step 7 : Calculate also the deviations of the unknown lines and determine their wavelengths from the $\delta - \lambda$ or $\delta - 1/\lambda^2$ curve obtained in step 6.

Experimental Results :

(A) Vernier constant of the spectrometer :

.....devision (say, m) of the vernier scale = ...division (say, n) of the main circular scale.

Table – 1

Value of 1 smallest main scale division (l_2) (min or sec)	Value of 1 vernier division $\left(l_2 = \frac{n}{m} l_1\right)$ (min or sec)	Vernier constant = $l_1 - l_2$ (min or sec)

(B) Readings of the telescope for direct rays :

Table – 2

Vernier No.	Main scale reading (M)	Vernier reading (V)	Total reading T = M + (V× v.c)	MeanT
1st	....	....	....	.... (D_1)
2nd	....	....	....	.... (D_2)

(C) Readings of the telescope with the prism at minimum deviation for sodium light :

Table – 3

Vernier No.	Scale reading (S)	Vernier reading (V)	Total reading $T = S + (V \times v.c)$	MeanT	Minimum deviation (D_m)
1st	....	....	....	.... $= T_1$	$T_1 - D_1$
2nd	....	....	....	.... $= T_2$	$T_2 - D_2$

(D) Determination of deviations for spectral lines of known wavelengths :

Table – 4

Spectral lines	Wave-length λ in A	Vernier no.	Telescope reading			Mean read-ing	Devia-tion	Mean deviation (δ)
			Circular scale reading (C)	Vernier reading (V)	Total reading (T) $T = C + V \times v.c.$			
Helium	6678	1st				... $= T_1$	$T_1 – D_1$	
		2nd				... $= T_2$	$T_2 – D_2$	
Helium Yellow	5876							
Helium Green	5016							
Helium Greet Blue	4922							
Helium Blue(i)	4713							
Helium Blue(ii)	4472							
Helium Violet	4026							

(E) Determination of wavelengths of unknown lines from calibration curve :

Table – 5

Unknown lines	Vernier No.	Telescope reading				Deviation	Mean Deviation (δ) in degree	Wave length (λ) in nm
		Circular scale reading (C)	Vernier reading (V)	Total reading (T)	Mean reading			
Neon red	1st				.... $= U_1$	$U_1 - D_1$		
	2nd				.... $= U_2$	$U_2 - D_2$		
Neon Orange								

(F) To draw the calibration curve (δ – λ) and (δ – $1/\lambda^2$) :

Table – 6

Wavelength (λ) In nm							
$1/\lambda^2$ in nm^{-2}							
Deviation (δ) in degree							

7.5 Discussion

(i) There should be parallax between the cross-wire and the slit image.

(ii) The slit should be made very narrow and it should be illuminated by the capillary position of the discharge tube where the intensity of the light is strongest.

(iii) The prism set at the position of the minimum deviation for sodium light must not be distributed during the whole experiment.

7.6 Maximum proportional Error

Using the straight line curve percentage error in the determination of λ can be computed.

The relation between δ and λ is given by :

$$\delta = k_1 + \frac{k_2}{\lambda^2} \quad (7.1)$$ [From Cauchy relation, using thin prism and nearly normal incidence]

From this relation we get

$$\left|\frac{\partial\delta}{\delta}\right| = \frac{\partial\left(k_1 + \frac{k_2}{\lambda^2}\right)}{k_1 + \frac{k_2}{\lambda^2}} = \frac{\left(\frac{2k_2}{\lambda^3}\right)\partial\lambda}{\delta}$$

Therefore, $$\frac{\delta\lambda}{\lambda} = \frac{\lambda^2\partial\delta}{2k_2}$$

Therefore, $$\frac{\delta\lambda}{\lambda} \times 100 = \frac{\lambda^2\partial\delta}{2k_2} \times 100 \quad (7.2)$$

Now, since δ is measured by taking the difference between the readkings for the direct and the deviated rays, the maximum error in measuring δ i.e. ∂δ is equal to the value of the two vernier constants, K_2 can be obtained from the δ versus $1/\lambda^2$ plot. Substituting the values of k_2, λ and ∂δ on the right hand side of equation (7.2), the percentage error in λ can be computed.

7.7 Summary

1. The prism is set at the position of minimum deviation for the sodium light (standard position) and the prism must not be disturbed from this position during the whole experiment.
2. Deviations of the spectral lines of known wavelengths are measured.

3. Deviations of the spectral lines for unknown wavelength are measured.
4. The graph between $\delta - \lambda$ and $\delta - 1/\lambda^2$ are drawn. $\delta - \lambda$ curve should be so drawn that it may represent a mean curve (i.e. the points should be evenly distributed on both sides of the line) so that the error in finding the wavelengths of unknown lines from the curve may be minimum.
5. The graph between δ and $1/\lambda^2$ would be approximately a straight line from which the wavelengths of unknown lines can be conveniently found out.

7.8 Model Questions and Answer

1. Can you find a relation between deviation produced by a prism for a ray of light of wavelength λ ?

Ans. A general mathematical relation giving the dependence of d upon λ is complicated. However, for a thin prism at normal incidence, a simple relation exists, which can be derived as follows :

From Cauchy's relation between μ and λ, we get,

$$\mu = a + \frac{b}{\lambda^2} \qquad (7.3)$$ where a and b are constants.

Again for a thin prism and at normal or nearly normal incidence, we have,

$$\delta = (\mu - 1) A \qquad (7.4)$$ where A is the angle of the prism.

From equations (7.3) and (7.4), we get,

$$1 + \frac{\delta}{A} = a + \frac{b}{\lambda^2}$$

Or, $$\delta = (a - 1) A + \frac{bA}{\lambda^2} = k_1 + \frac{k_2}{\lambda^2} \qquad (7.5)$$

Where $k_1 = (a - 1) A$ and $k_2 = bA$ are also constants.

Thus δ versus $1/\lambda^2$ plot will be a straight line of slope k_2 and intercept k_1 on the δ-axix.

It may be noted that this relation holds for normal incidence which is different from the minimum deviation position of the prism for sodium light.

2. Why is it necessary to place the prism in a standard position ?

Ans. The curve connecting the wavelengths of spectral lines and their corresponding deviations produced by a prism changes with the position of the prism. Hence it is necessary to place the prism in a standard position. It helps in resetting the prism if it is displaced by chance during experiment.

3. What are the factors the govern the nature of the calibration curve ?

Ans. Angle of the prism, material of the prism and its position relative to the spectrometer.

Unit - 8 ❑ To draw sinθ – λ graph with the help of a diffraction grating and find wavelength

Structure

8.0 Objectives

8.1 Introduction

8.2 Apparatus used

8.3 Theory and working formula

8.4 Method of adjustment and measurement

8.5 Discussion

8.6 Maximum proportional error

8.7 Summary

8.8 Moden Questions and Answer

8.0 Objectives

- To draw (sinθ – λ) curve for a plane tranmission grating.
- To determine the wevelength of an unknown spectral line.

8.1 Introduction

The plane transmission diffraction grating is optically a plane parallel glass plate on which equidistant, extremely close groves are made by ruling with a diamond point. If the rulings are made on a polished metal surface the grating becomes reflection grating.

A commercial grating is made by pouring properly diluted cellulose acetate on the actual grading and drying it to a thin string film. The film is attached from the original grating and is mounted between the two glass plates. A commercial grating is called replica grating.

The distance covered by a slit and an opaque space between the two slits is called the grating element or the grating constant. If be be the width of the opaque space then the distance b + c is called corresponding points.

Using Fraenhofer type of diffraction a transmission or reflection grating is used (i) to determine an unknown wavelength and (ii) to study spectra.

8.2 Apparatus Used

(i) A Spectrometer

(ii) A spirit level

(iii) A prism

(iv) A plane diffraction grating

(v) Sodium vapour lamp

(vi) Helium discharge tube or mercury vapour lamp

8.3 Theory and Working Formula

If a parallel beam of light of wave length λ, coming out of the collimator lens of a sectrometer, falls normally on the plane diffraction grating, then the diffracted rays from the greating, will form at the focal plane of the telescope number of principal maxima of different order numbers (n), on both the sides of a central maximum of zero order.

If θ be the angle of diffraction of nth order principal maximum then,

$$\sin\theta = mn\lambda \qquad (8.1)$$

Where m is the number of ruling per unit length of the grating surface.

Now for a given grating, for a given order n, $\sin\theta$ vs. λ curve will be a straight line passing through the origin as shown in Figure (8.1)

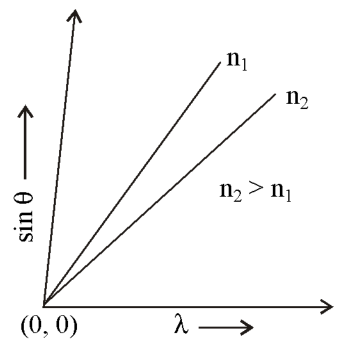


Figure 8.1

Different straight line will be obtained for different orders.

These two straight lines can be used to find the unknown wavelengths by measuring the angle of diffraction corresponding to different orders.

8.4 Method of Adjustments and Measurements

STEP I : Adjustment of Spectrometer.

The Spectrometer is levelled by a spirit level and the prism table also is lavelled by a spirit level by employing the prism and sodium vapour lamp, the spectrometer is adjusted for parallel rays [see APPENDIX A]

STEP II : Adjustment of grating :

1. To make the axis of the telescope perpendicular to that of collimator : The slit is illuminated by sodium light and the telescope is moved to receive the direct light from the collimator. By coinciding the centre of the cross-wires with that of the direct image of the slit, the reading (α) of the vernier only (say A vernier) is noted. The telescope is then rotated by 90° so that the present reading of a vernier is ($90° \pm \alpha$). By this, the axis of the telescope is made prependicular to the collimator.
2. Mounting of the grating : The grating is now placed on the prism table so that its rulings are in the vertical plane and its vertical surface passes through the diameter of the prism table which is perpendicular to the line joining

the two base screws E and F of the prism table, the grating should be so placed that the middle vertical line of the ruled portion may pass approximately through the centre of the table.

3. To make the grating surface vertical : Now the prism table, with the grating fixed on it is rotated until the light reflected from the surface of the grating enters the telescope and forms the image. If the centre of the image does not coincide with the centre of the cross wires then the screws E and F are to be rotated equally in opposite direction, until he centre of the image coincide with the centre of the centres of the cross-wires. By this the grating surface is made vertical (but this may not make the ruling of the grating surface vertical).

4. To make the grating surface normal to the rays : The reading β of the prism table is now noted and the prism table is now rotated in a proper direction

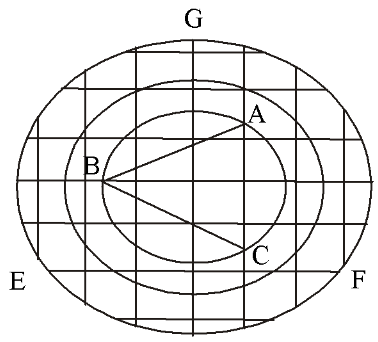


Figure 8.2

by an angle of 45° so that the rays from the collimator may fall normally on the surface of the grating and the present reading of the prism table may be (β ± 45°). This time one surface of the grating will be normal to the rays of the collimator while the other surface will be directed Fig. 8.2 (Prism table) towards the telescope. Thus the grating surface is made normal to the rays.

5. To make the ruling of the grating parallel to the slit which is kept vertical : The telescope is moved to receive the first order spectrumon both the sides

of the central band and the third screw G of the prism table is rotated until the centre of the cross-wire coincides with the centre of the first order bands on both the sides of the central band. The screw G rotates the grating its own plane and makes the ruling vertical.

6. Adjustments of collimator slits and the source : The collimator slit is made very narrow so that the diffraction fringes may be sharp. The position of the source (sodium vapour lamp) is to be adjusted to make the fringes on both sides of the central band equally bright. To increase the illumination of the slit a convex lens of short focal length may be employed to form an image of the source on the slit.

STEP III : To find 'sinθ' for different λ :

1. The sodium light is now replaced by helium light or mercury light. The highest order (say n) bright bands of different colours which are distantly visible on both the sides of the central bright band of zero order, is selected. The telescope is now moved to make its vertical cross-wires coincident with the heighest order bright band of a known colour towards extreme left. The reading of each of the two verniers are noted twice and the mean value of each vernier is obtained. The process of noting the vernier reading is continued for three or four other known colours in the same order (n) and all the above known colours in the next lower order (n-1).
2. The telescope is moved to the right side of the central bright band and the process to taking vernier for all the known colours of the order (n–1) and n is continued until the bright band of known colour in the extreme right is reached.
3. The difference of the two readings for a particular colour of known wavelength for a particular order number (one reading is for the left while another reading is for the right of the same order as in the left) when halved we get the angle of diffraction (θ) for that wavelength in the given order. This is done separately for the reading of the verniers and their mean value

is found out. θ is calculated for all the known colours in both the orders of the spectrum.

4. Sin θ vs λ are now plotted for both the orders. If the origin is taken at (0,0) graphs would be straight lines passing through the origin as shown in Fig 8.1. Since we would only work with λ in the visible range the experimental points are crowded towards the end of the straight lines. So it would be better to draw the graph by choosing the origin with the values of λ and sin θ slightly smaller than their respective smalles values. In this case the graph appears as shown in Fig 8.3.

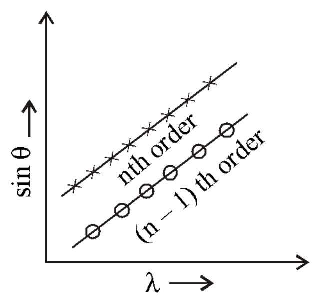


Figure 8.3

STEP IV : To measure θ of unknown lines.

1. The known light source is replaced by the unknown light.
2. The procedures adopted in step ill are repeated for the specified unknown lines and the angle of diffraction for the above orders are measured.
3. For knowledge of sin θ in a given order the wavelength λ is determined from the graph in Fig (8.3)

Experimental Data :

(A) Dtermination of the vernier constant of the spectrometer :

Same as in the experiment no (Unit 7)

(B) To set the surface of the grating normal to the rays :

(Reading of the first venier only)

Table – 1

Direct reading without grading			Telescope set at $\alpha \pm 90°$	Prism table when refracted light from the surface enters the telescope			Telescope set at $\beta \pm 90°$
Scale reading (S)	Vernier reading (v.r)	Total (α) = S + v.c. × v.r.		Scale reading (S)	Vernier reading (v.r)	Total (β) = S + v.c. × v.r.	

(C) Data for Sin θ vs λ curve :

Light source used = ...(He/Hg)

Order number (n) = ... (may be 3 or 4)

Table – 2

Spectral line λ in nm	Vernier no	Reading for spectral line with telescope								Difference of left and right reading $2q = R_1 \sim R_2$	Mean 2θ	Value of θ
		Left				Right						
		Scale (S)	Vernier (v.r)	Total = S+v.r.xv.c	Mean (R1)	Scale (S)	Vernier (v.r)	Total = S+v.r.xv.c	Mean (R1)			
He red 667.8	1st	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...
	2nd	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...
He-yellow	1st	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...
587.6	2nd	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...
		etc	etc	etc	etc	etc	etc	etc	etc	etc	etc	etc

(D) Make a table similar to Table–2 for another order of spectrum :

Table – 3

(E) Data for angle of diffraction for unknown lines :

Table – 4

Make table similar to Table–2 expecting the first column where in place of spectral line and λ in nm^3 write order no (n).

(F) To draw Sin θ vs λ :

Table – 5

Colours of the lines	Wavelength in nm	Order number.............		Order number.............	
		θ from Table-2	Sinθ	θ from Table-3	Sinθ

(G) Determination of λ of unknown line from Sin $\theta - \lambda$:

Table – 6

Order no	Angle of diffraction (θ) from Table E	Value of Sin θ	(λ) in nm from Sin $\theta - \lambda$ curve	Mean λ

8.5 Discussions

(i) The rulings of the grating must be parallel to the slit which should be kept vertical.

(ii) The grating should be so placed on the prism table that the maximum area of the ruled surface may be exposed to the incident light and the middle vertical line of the ruled portion may pass through the centre of the prism table.

(iii) The rays must be made incident to the grating surface normally otherwise the formula employed will not be applicable.

(iv) In order to spread the observed points throught the graph paper and reduce proportional error in measurement, the origin of the Sin θ vs λ curve should not be taken as (0, 0).

8.6 Maximum Proportional Error

If θ and θ' are the angle of diffraction of the lines of wavelength λ (unknown) and λ' (known) in the nth order.

Then, Sin θ = mnλ and Sin θ' = nmλ'

Combining these two equations we get, $\lambda = \frac{\sin\theta}{\sin\theta'}\lambda'$

$$\text{Therefore } \left(\frac{\delta\lambda}{\lambda}\right)_{max} = \frac{\delta(\sin\theta)}{\sin\theta} + \frac{\delta(\sin\theta')}{\sin\theta'} \qquad (8.2)$$

Where $\delta(\sin\theta) = \delta(\sin\theta')$ = 1 smallest division of graph paper along $\sin\theta$ axis.

$$\text{Also, we can write } \left(\frac{\delta\lambda}{\lambda}\right)_{max} = \cot\theta\,\delta\theta + \cot\theta'\,\delta\theta' \qquad (8.3)$$

Where $\delta\theta = \delta\theta'$ = 1 v.c. in radian

As we interested in maximum error we must use the relation (8.2) when the one smallest division of the graph is greater than that 1 v.c. in radian and the relation (8.3) when 1 v.c in radian's is greater than 1 smalles division of the graph paper.

8.7 Summary

(i) Adjustment of spectrometer and adjustment of grating is made carefully.

(ii) Angle of diffraction is measured for different known wavelengths for two different order numbers.

(iii) Also angle of diffraction is measured for different unknown wavelengths for two different order numbers.

(iv) Sin θ vs λ curve is drawn for known lines.

(v) Unknown wavelength (λ') is determined from the Sin θ vs λ curve for known wavelengths from the knowledge of Sin θ in the given orders.

8.8 Model Questions and Answer

1. In the present experiment what class of diffraction does occur and how?

Ans. Fraunhofer class of diffraction occurs, since the spectrometer is focused for parallel rays, the source and the image are effectively at infinite distance from the grating.

2. What is the effect of increasing the number of lines per cm of the grating?

Ans. The angle of diffraction, for a particular order of the spectrum increases. This results in a less number of spectra separated by a large angle.

3. How does the angular dispersive power of the grating vary with (a) the order number of the spectum (b) the number of rulings per cm of the grating?

Ans. We have grating equation

$$(b + c)\ \sin\theta = n\lambda$$

or, $\sin\theta = \frac{n\lambda}{b+c} = mn\lambda$, where m is the number of rulings per cm and is given by $m = \frac{1}{b+c}$, b + c is the grating constant.

Or, $\cos\theta\ d\theta = mnd\lambda$

Or, $\frac{d\theta}{d\lambda} = \frac{mn}{\cos\theta}$

Now (a) if the order of the spectrum n, increases the angular dispersive power $\frac{d\theta}{d\lambda}$, will also increase. (b) The angular dispersive power varies directly as the number of lines per cm or m or inversely as the grating element (b + c). Therefore the greater the spread of the spectra of a particular order. (c) Again $\sin\theta$ or θ increases with increase in wavelength λ and angular dispersive power increases with increase in θ. Thus the greating spectra are wider at the red and than at the blue end of the spectrum.

4. What will happen if the ruling of the grating are not parallel and the distance between two consecutive ruling is not constant?

Ans. The additional lines will appear near the actual spectral lines. These additional lines are called ghost lines.

5. What do you mean by resolving power of grating?

Ans. The resolving power is the capacity to separate the images of two closely spaced objects. It is given by $\frac{\lambda}{d\lambda}$, where two wavelengths λ and $\lambda + d\lambda$ are just resolved or separated in the grating spectrum. For grating of total number of rulings N the resolving power in given by $\frac{\lambda}{d\lambda} = nN$.

Unit - 9 ❑ To study response curve of a series LCR circuit and determine (a) its resonant frequency, (b) Impedance at resonance, (c) quality factor Q, and (d) Band width

Structure

9.0 Objectives

9.1 Introduction

9.2 Apparatus used

9.3 Theory and working formula

9.4 Method of measurement

9.5 Discussion

9.6 Maximum proportional error

9.7 Summary

9.8 Model Questions and Answer

9.0 Objectives

- To investigate of a series LCR circuit.
- To draw the resonance curve and to find resonant frequency.
- To determine the Q-factor of the circuit and band width.
- To study the variation of impedance of L and C with frequency.

9.1 Introduction

An alternating current or voltage (ac) is one which passes through a complete cycle of changes both in magnitude and direction at regular intervals of time. For a symmetric as the positive half cycle is exactly similar to the negative half cycle and its average over a complete cycle is zero.

Calculations in ac are usually done by considering sinusoidal variations with time. Such a voltage may be generated by rotating a coil in a uniform magnetic field. A pure sinusoidal curve can be represented by $v = v_0 \sin \omega t$ and $v = v_0 \cos \omega t$ with a suitable choice of time.

When an alternating voltage is applied to a circuit the current through the circuit also varies with time at the frequency of the applied ac voltage. The alternating current can be represented similarly as,

$i = i_0 \sin(\omega t + \phi)$ or, $i = i_0 \cos(\omega t + \phi)$

ϕ is the phase difference between the applied voltage v and the current i. It is to be noted that is steady dc circuit current and voltage remains in the same phase.

Since the average of any symmetric ac over a complete period is zero, we get the significant mean by considering over a half cycle and thus,

$$I_{av} = \frac{2I_0}{\pi} \text{ and } V_{av} = \frac{2V_0}{\pi}$$

The rms value of an alternating current is an important parameter of as since it can be related to the heating effect of ac and is given by

$$I_r = \frac{I_0}{\sqrt{2}} \text{ and } V_r = \frac{v_0}{\sqrt{2}}$$

Measuring instruments based on the heating effect of ac are generally calibrated in terms of rms value. When we speak of 220V ac supply, we mean its ram value.

Now an ac circuit containing reactance is in resonance if the voltage across the circuit is in phase with the current through it. Thus the circuit impedance is a pure resistance at resonance. The resonance occuring in a series LCR circuit is referred to as series resonance. Parallel resonance occurs in a circuit when inductance and capacitance are in parallel branches.

9.2 Apparatus Used

(i) An air corded or ferrite cored inductor (L ~ 30 mH)

(ii) A mica capacitor (C ~ 0.1 μF)

(iii) A non-inductive resistance box R (R ~ 500Ω)

(iv) An electronic ac voltmeter

(v) An audio oscillator with low (~100Ω) output imdedance and good amplitude stability.

9.3 Theory and Working Formula

Figure 9.1 shows a series resonant circuit driven by an ac source of constant output rms voltage V_i. If f be the frequency and $\omega = 2\pi f$ be the angular frequency of the source then the rms value of current (I) following through the circuit it given by,

$$I = \frac{V_i}{\left[R_i^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^{\frac{1}{2}}} \qquad (9.1)$$

Where $R_i = R + r$ (resistance of the inductor coil), neglecting internal resistance of the ac voltage source.

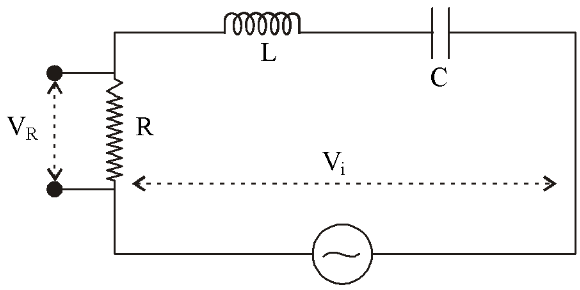


Figure 9.1

Symbols : L : inductance, C : capacitance, R : resistance, V_R : voltage across resistance, V_i : as source voltage.

I can be measured by relation, $I = \frac{V_R}{R}$ .... (9.2)

Where V_R is the rms voltage across R.

Keeping V_i fixed, if the frequency of the source is gradualy increased from a low value, I at first increases, attains a maximum value and then falls as shown in Figure 9.2.

Thus curve of current (I) versus frequency (f) is known as resonance curve. The current attains a maximum value I_0 at a frequency f_0, called resonance frequency and is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad \text{..... (9.3)}$$

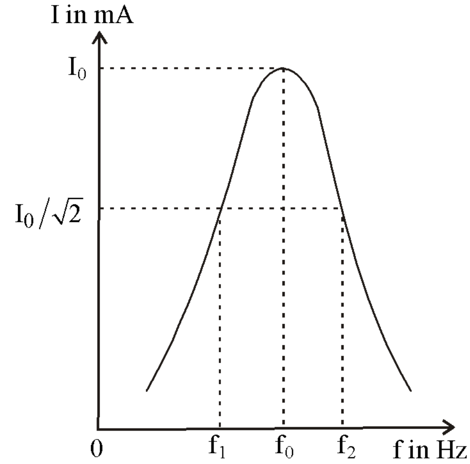


Figure 9.2

Symbols : f_0 : resonant frequency ; f_1, f_2 : half power frequencies; I_0 : current at resonance.

The response (current) falls from its maximum value of either side of f_0.

The rate of fall of response with departure of 'f' from f_0 i.e. sharpness of resonance is usually expressed in terms of Q factor. The O factor is defined by,

$$Q = \frac{f_0}{f_2 - f_1} \qquad \text{...... (9.4)}$$

Where f_1 and f_2 are the two half-power frequencies at which the current falls

$\frac{I_0}{\sqrt{2}}$. to. The Q factor can also be found out by using the relations :

$$\text{(i) } Q = \frac{\omega_0 L}{R_t} = \frac{1}{R_t}\sqrt{\frac{L}{C}} \qquad \text{..... (9.5)}$$

Where (if r is not known) R_t can be calculated from the impedance at resonance i.e.

$$R_t = \frac{V_i}{I_{resonance}} \qquad \text{..... (9.6)}$$

$$\text{(ii)}\quad Q = \frac{\text{Voltage across C in resonance}}{\text{Input voltage}} \qquad \text{..... (9.7)}$$

9.4 Method of Measurements

Step 1 : Make the circuit connections as shown in Figure 9.1. Choose a relatively low value of R (say $R = R_1 = 100\Omega$) and a suitable value of C (say $C = 0.1\ \mu F$).

Switch on the audio oscillator and adjust its output voltage V_i to a suitable value (say, 5V). Set its frequency f to a fairly low value (say, 100Hz).

Step 2 : Measure the voltage V_R across the resistance R and V_c across C by the ac voltmeter. Calculate current I by using the relation $I = \frac{V_R}{R}$.

Step 3 : Vary the frequency of the oscillator in small steps say, 100Hz over a frequency range including f_0 and in each step repeat the step 2.

The supply voltage (V_i) may change with the change in frequency. So at each step check and if necessary, adjust the supply voltage to the fixed value chosen in Step 1. The region of resonance frequency may be approximately checked before taking the final readings. Take data in smallest possible steps around the resonance frequency.

Step 4 : Draw the response curve by plotting f along x-axis and I along the y-axis. From the curve find the resonant frequency f_0, the half-power frequencies, f_1 and f_2 and then calculated Q by using relation (9.4). Measure the voltage V_c across the capacitor C at resonance and calculate Q also from relation (9.7). At half power frequencies, current I falls to of its maximum value I_0. Band width is given by $\frac{f_0}{Q}$.

Step 5 : Impedance at resonance can be calculated by

$$R + r = R_t = \frac{V_i}{I_{resonance}} = \frac{V_i}{I_0}$$

Step 6 : Repate the experiment for drawing the resonance curve and finding the Q factor, band width, impedance at resonance for a different set of values – same L, same C but a different R (say, $R = R_2 = 50\Omega$)

Step 7 : Compare the values of Q obtained by different methods and discuss the dependence of the sharpness of resonance on the values of R.

Experimental Data

(A) Data for the study of responses curve :

Set I : C = ... μF, $R = R_1$ = ...Ω, L = ...mH

rms value of input ac V_i = ...V

Table – 1

No. of Observations	Frequency in Hz of source	rms voltage		rms curren $I = \frac{V_R}{R}$ in A	Imdedance at resonance $\frac{V_i}{I_{resonance}}$ in Ω
		V_R in V	V_C in V		
1	100	....	....	....	
2	200	....	....		
....				$I = I_0 = \frac{V_0}{R}$	$\frac{V_i}{I_0}$ = ...Ω

Make another Table–2 similar to Table–1 for a different combination of L, C and R. For example, for set II : L = L, C = C, $R = R_2 = 50\Omega$

Table – 2

(B) Calculation of Q factor from response curve :

Table – 3

Set no.	Resonant frequency f_0 in Hz	Maximum current I_0 in A	The frequency in Hz at which $I = \frac{I_0}{\sqrt{2}}$		Band width $\Delta f = f_2 - f_1$ in Hz	$Q = \frac{f_0}{\Delta f}$
			Lower half power (f_1)	Upper half power (f_2)		
Set I						Q_1
Set II						Q_2

(C) Q from measurement of V_C at resonance :

Table – 4

Set no.	Oscillator set at a frequency f_0 in Hz	rms voltage V_i in volt	rms voltage across C, $V_{c\ rms}$ in volt	$Q = \frac{V_{C\ resonance}}{V_i}$
Set I	$(f_0)_1$	....	....	Q'_1 = ...
Set II	$(f_0)_2$	....	....	Q'_2 = ...

Remarks : Q_1 and Q'_1 should be nearly equal. Similarly Q_2 and Q'_2 should be nearly equal.

9.5 Discussions

(i) The voltage across C at resonance is Q times higher than input V_i. So it may be dangerously high when Q is large. So V_i should be kept small and special care should be taken during measurement of $V_{c(rms)}$.

(ii) Generally the audio oscillator is provided with a number of frequency scales of different ranges. The accuracy of callibration generally differs from ones scale to the other. So, if possible, only one scale should preferably be used.

(iii) The method of measuring Q factor by using equation (9.7) is better than equation (9.5) because r is acually the resistance of the coil which may differ significantly from the dc value measured with an ohmmeter. In fact, by measuring Q with equation (9.7), it is possible to calculate the ac resistance of the coil (r) by using equation (9.5)

(iv) Smaller the value of R, large is the value of Q and sharper is the resonance.

9.6 Maximum Proportional Effor

From equation (9.4) : $Q = \frac{f_0}{f_2 - f_1}$

Therefore, $\left(\frac{\delta Q}{Q}\right)_{max} = \frac{\delta f_0}{f_0} + \frac{\delta f_2 + \delta f_1}{f_2 - f_1}$

$$= \frac{\delta f_0}{f_0} + \frac{2\delta f}{f_2 - f_1}$$

Where $\delta f_0 = \delta f = 1$ div of the frequency scale of the audio oscillator or 1 div of graph paper which one is greater.

Again from equation (9.7), we have, $Q = \frac{V_{c\,resonance}}{V_i} = \left|\frac{V_0}{V_i}\right|$

Therefore, $\left(\frac{\delta Q}{Q}\right)_{max} = \frac{\delta V_0}{V_0} + \frac{\delta V_i}{V_i}$

Where δV_0 and δV_i are the smallest divisions of the scales used for measurement of V_0 and V_i respectively.

We get precentage error by multiplying maximum proportional error by 100.

9.7 Summary

(i) Response curve is drawn by changing the frequency of source (f) and measuring I by $\left(\frac{V_R}{R}\right)$, keeping source voltage (V_i) at a constant value.

(ii) Resonance frequency (f_0) and half power frequencies (f_1, f_2) are obtained from the response curve.

(iii) Impedance at resonance is obtained form $\frac{V_0}{I_0}$, where I_0 is the current at resonsnce frequency (f_0).

(iv) Band width is given by $\Delta f = f_2 - f_1$.

(v) Q is determined by $\frac{f_0}{\Delta f}$ and also from $\frac{V_{c\,resonsnace}}{V_i}$ and compared.

(vi) Dependence of sharpness of resonance on R and Q discussed.

9.8 Model Questions and Answer

(i) What is resonance? What is the nature of the impedance at resonance?

Ans. A circuit containing reactance is in resonance if the voltage across the circuit is in phase with the current through it. Thus, the circuit impedance is a pure resistance at resonance.

(ii) What is series and parallel resonance?

Ans. The resonance occurring in a series LCR circuit is referred to as series resonance. Parallel resonance occurs in a circuit where inductance and capacitance are in parallel branches.

(iii) What is the power factor at resonance?

Ans. Unity.

(iv) What is quality factor?

Ans. The quality factor Q of a resonant circuit is defined as the ratio of the inductive reactance at resonance to the resistance in the circuit.

(v) Why is Q referred to as an amplification factor?

Ans. The voltage V_c across the capacitance of an LCR circuit at series resonance is Q times the supply voltage V_i. As Q >>1, $V_c >> V_L$. Hence Q is referred to an amplification factor.

(vi) What do you mean by sharpness of resonance?

Ans. The current is a series LCR circuit is maximum at $f = f_0$. The current decreases on either side of the resonance frequency (f_0). The sharpness of resonance is a measure of the rate of all of response (or current) with departue of f from equality with f_0. The higher the Q of the circuit, the greater is the sharpness of resonance.

(vii) What is the bandwidth of a series resonant circuit?

Ans. The frequency reange over which the current is greater than $\frac{I_0}{\sqrt{2}}$, where I_0 is the value at resonance, is known as the bandwidth of the circuit. The bandwidth is given by $\frac{f_0}{Q}$ hertz, where f_0 is the resonant frequency.

Unit - 10 ❑ To find the resistance of a galvanometer by half deflection method

Structure

10.0 Objectives

10.1 Introduction

10.2 Apparatus used

10.3 Theory and working formula

10.4 Method of measurement

10.5 Discussion

10.6 Maximum proportional error

10.7 Summary

10.8 Model Questions and Answer

10.0 Objectives

- To measure the galvanometer resistance by half-deflection method.

10.1 Introduction

1. Most commonly used galvanometers and of moving-coil type. In moving coil (also called suspended coil) galvanometer, a movable coil is suspended in the magnetic field of a permanent magnet. When current is passed through the coil, it experiences torque—the deflection torque—due to Lorentz force and rotates the coil until the torque is balanced by the restoring torque of the suspension fibre. The angle of deflection is a measure of the current through the coil.

2. The resistance of the coil of a suspended coil galvanometer is called galvanometer resistance. The current sensitivity of a galvanometer varies as the square root of the galvanometer resistance and therefore the current

sensitive galvanometer should have high resistance of the order of 200Ω on the other hand, a voltage sensitive galvanometer should have a low of the order of 50Ω and used in null point works.

3. However the half-deflection method will give satisfactory value when the resistance of the galvanometer is high in comparison to 5 (Fig. 10.1). When the resistance of the galvanometer is low, it is best measured by clamping the coil and measuring the resistance of the coil in the usual way by employing metre bridge or a P.O. box.

10.2 Apparatus Used

(i) A storage battery B (usually one or two alkali cells in series)

(ii) A resistance box R (in which high resistance in inserted)

(iii) A commutator M, with binding screws C_1, C_2, C_3, C_4.

(iv) A suspended coil galvanometer G.

(v) A resistance box R_1 in series with galvanometer G.

(vi) A low resistance box S, calles Shunt box, containing fractional resistances.

(vii) A lamp and Scale arrangement.

10.3 Theory and Working Formula

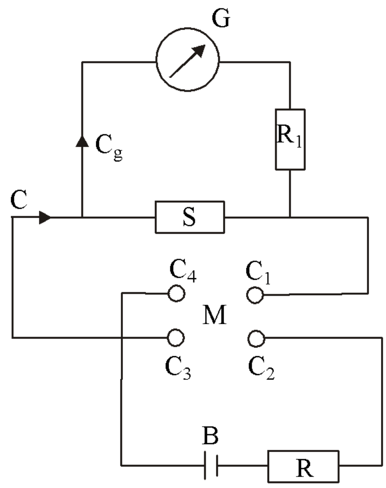


Figure 10.1

If the shunt resistance S is very low in comparison with the galvanometer resistance G (Fig 10.1), then the equivalent resistance of the parallel combination of S and (G + R) is very nearly equal to S and hence the potential difference V across the shunt resistance S is independent of the resistance in the galvanometer circuit.

Let d and d/2 be the deflections of the spot of light on the scale, when the resistance in the box R_1 of the galvanometer circuit are successively zero and R_1. If C_g and C_g' be the galvanometer currents in the two cases, then we may write,

$C_g = V/G = Kd$; and $C_g' = V/(G + R_1) = (Kd)/2$ ......(10.1)

Where K is constant. Taking the ratio of the two relations of equation (10.1), we get,

$(G + R_1)/G = 2$ or, $1 + (R_1)/G = 2$

Or, $G = R_1$ (10.2)

Equation (10.2) gives the galvanometer resistance

10.4 Method of Measurements

Step 1 : One sharp edge of the spot of light is broguht at the zero mark of the sacle and then the connections are made as shown in Fig. 10.1 with the shunt resistance as 0.1 ohm.

Keeping the resistance in box R_1 of the glavanometer circuit equal to zero, the resistance R in the battery circuit is decreased from a high value until the deflection of the spot of light on the scale lines between 8 to 16 cm. This deflection is noted.

Now keeping this value of R constant the value of the resistance in the box R_1 is measured from zero value until the deflection is reduced exactly to half of the former. This value of R_1 is then the resistance of the glavanometer.

Step 2 : The current is now made is the circuit and examined whether the same edge of spot of light, still remains at zero. If not it should be brought to zero, by adjusting the scale. The value of R_1 is now made zero and the value of R is kept the same as before.

The direction of the current in the circuit is then reversed by the commutator

M. The deflection is noted. A suitable value of R_1 is inserted to make this deflection again exactly half of that when R_1 was zero. This value of R_1 gives the glavanometer resistance with the reversed current.

Step 3 : Step 1 and Step 2 are repeated for three and four different values of R in the battery circuit and three or four different values of shunt resistance S, but maintaining the deflections in each case within the range 8 to 16 cm.

Thus for each values of R we get two values of galvanometer resistance G (are for direct and another for reversed current). Hence for three of four different values of R and S we get six or eight values of G, the mean values of which gives the galvanometer resistance.

Experiental Results :

(A) Data for galvanometer resitance :

Table – 1

No. of obs.	Currents	Resistance in the battery circuit (R) in ohm	Shunt resistance (S) in ohm	Resistance in the galvanometer circuit (R_1) in ohm	Galvanometer deflection in cm	Galvanometer resistance (G) in ohm	Mean G in ohm
1.	Direct	500 Ω	0.1	0	8.4	172	......
		"	"	172	4.2		
	Reversed	500 Ω	"	0	8.6	174	
		"	"	174	4.3		
2.	Direct	"	0.2	0	......	......	......
			"	......	......		
	Reversed	"	0.2	0	......	......	
			"	......	......		
etc	etc	etc	etc	etc	etc	etc	......
6	Direct	"	0.3	0	......	......	......
				......			
	Resersed	"	0.3	0	......	......	
				......			

Galvanometer resistance from Table–1 = ...Ω

10.5 Discussion

1. The shunt resistance S must be very low otherwise the assumption made in the theory will not be justified.
2. The cell employed must be a storage cell otherwise deflections will not remain stady.
3. The assumptions that the current would be halved when the deflection is reduced to half will not be justified unless the deflection is small (say between 8 to 16 cm).
4. The protect the galvanometer from damage a high value of R and a low value of S should be applied.

10.6 Maximum Proportional Error

We have G = R_1 therefore, $\delta G/G = \delta R_1/R_1$

Using δR_1 as the maximum resistance available in the box R_1 and one experimentally observed value of R_1 we can calculate the maximum percentage error in G as $(\delta G/G) \times 100\%$

10.7 Summary

1. Circuit arrangement as shown in Fig. 10.1 is made.
2. A suitable value of R chosen and kept it fixed through the experiment.
3. Suitable values of S are chosen and the value of R_1 is changed from zero value to make the deflection exactly half for each value of S and with direct and reversed current.

10.8 Model Questions and Answer

1. Will the galvanometer deflection increase and decrease, when the shunt resistance is increased ?

Ans. Increase. As the resistance of the alternative path of the current viz shunt,, is higher, greater fraction of the main current will flow through the galvanometer causing its deflection higher.

2. What will be the resistance of the shunted galvanometer?

Ans. Less than the resistance of the shunt applied.

3. What kind of cell do you require to perform the experiment?

Ans. A storage cell having low internal resistance and a constant emf can only send a steady current and hence this cell must be used.

Unit - 11 ❑ Measurement of charge and current sensitivity and CDR of Ballistic galvanometer

Structure

11.0 Objectives

11.1 Introduction

11.2 Apparatus used

11.3 Theory and working formula

11.4 Method of measurement

11.5 Discussion

11.6 Maximum proportional error

11.7 Summary

11.8 Model Questions and Answer

11.0 Objectives

- To measure charge and current sensitivity and CDR of a ballistic galvanometer.

11.1 Introduction

For the measurement of charge, the moving coil galvanometer is used ballistically and the glavanometer is then termed ballistic galvanometer. Here, the charge must pass through the coil before it moves significantly i.e. the time of charge flow should be very small compared to the time for coil deflection.

A galvanometer is considered sensitive if if can measure small current, small voltage or small amount of charge. Hence the sensitivity may be of three types : current sensitivty, voltage sensitivity and charges sensitivity.

The current sensitivty of a galvanometer S_i, is defined as the deflection of the spot of light in mm on a scale 1 m away from the galvanometer, produced by a current of 1 μA. If a current if i μA produces a steady deflection of d mm of a scale of 1 m away, the current sensitivity is

$$S_i = (d/i) \text{ mm}/\mu A$$

The voltage sensitivity of a galvanometer S_V, is defined as the deflection of light spot in mm on a scale 1 m away when the voltage of 1 μv is applied across the galvanometer.

If a voltage V mv produces a deflection of d mm on a scale 1 m away, the voltage sensitivity is,

$$S_v = (d/v) \text{ mm}/\mu v$$

The charge sensitivity applies to ballistic galvanometer.

The charge sensitivity or quantity sensitivity S_q, also called ballistic sensitivity, is defined as the corrected throw of spot light in mm on a scale 1 m away, when a charge of 1mc pass through the galvanometer used ballistically.

If a charge q μc scale 1 m away, the charge sensitivity is

$$S_q = (d/q) \text{ mm}/\mu c$$

Now the current sensitivity is given by $S_i = (d\theta/di) = (NAB)/C$, where N is the total no of turn in the coil of the galvanometer, A the mean cross sectional area of the coil, B is the magnetic inductin and C is the torque per unit twist of suspension.

Voltage sensitivity $S_v = (d\theta/dv) = (1/R_g)\ (d\theta/di) = (S_i/R_g)$

Where R_g is the resistance of the coil of the galvanometer.

Therefore, $S_i = S_V \times R_g$

Now the charge through the ballistic galvanometer is given by $q = (CT/2\pi NAB)\ \theta_0$ where θ_0 is the corrected throw, therefore charge sensitivity is given by

$$S_q = (d\theta_0/dq) = (2\pi NAB/CT) = (2\pi/T) \times S_i$$

Thus charge sensitivity is given by product of the current sensitivity and $2\pi/T$ where T is the time period of oscillation of the ballistic galvanometer.

The objective of the experiment is to measure the charge and current sensitivity of the ballistic galvanometer and to find its external critical damping resistance (X CDR).

There are several methods for the determination of sensitivity of a ballistic galvanometer e.g. (a) standard solenoid method (b) condenser discharge method (c) by passing steady current through the ballistic galvanometer. We will discuss here item no. (c). For other two methods see for example "An advance course in practical physics" by D. Chattopadhya, P.C. Rakshit and B Saha.

11.2 Apparatus Used

(i) A storage battery B.

(ii) Two resistance boxes R and R_1, one of which should contain high resistance of the order of 4 to 5 KΩ

(iii) a low resistance shunt S.

(iv) A commutator M_1.

(v) A lamp and scale arrangement.

11.3 Theory and Working Formula

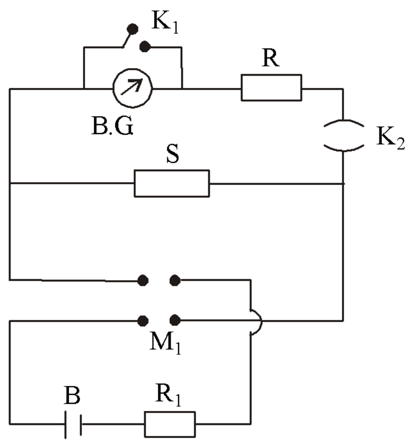


Figure 11.1

The circuit connections are shown in the Figure 11.1. If a steady current I_g ampere flowing through the ballistic galvanometer produces a steady deflection θ_s radian of the coil of ballistic galvanometer then,

$$I_g = (C/NAB)\ \theta_s \qquad \text{.... (11.1)}$$

Where N is the total no of turns of the coil of the galvanometer, B is the magnetic induction and A is the mean cross-sectional area of the coil, C is the torque per unit twist of the suspension.

If d be the deflection of the spot light on the scale placed at a distance D of the galvanometer mirror, then,

$$\theta_s = (d/2D) \qquad \text{... (11.2)}$$

Here we get

$$K = (T/2\pi)(C/NAB) = (T/2\pi)(2DI_g/d) \text{ coulomb/radian} \qquad \text{... (11.3)}$$

Where K is the constant of ballistic galvanometer given by,

$$Q = (CT/2\pi NAB)\ \theta_0 = K\theta_0 \qquad \text{... (11.4)}$$

Where Q is the quantity of charge flowing through the ballistic galvanometer, θ_0 is the corrected first through and T is the open circuit time period of the galvalometer. Therefore, K = (CT/2pNAB) as shown in the equation (11.3).

If E be the emf for the battery B, R_1 is the resistance in series with B and S be the shunt resistance across the ballistic galvanometer G, and G be the galvanometer resistance.

Then, $I_g = [E/\{R_1 + (S(G + R)/S + G + R)\}] \times (S/S + G + R)$

In practical circuit $S << G + R$ and here we can approximately write

$$I_g = (E/R_1)(S/G + R) \qquad \text{.... (11.5)}$$

Therefore,

$$K = (TD/\pi d)\{ES/R_1(G + R)\} \text{ coulomb/radian.} \qquad \text{... (11.6)}$$

Now charge sensitivity S_q of a ballistic galvanometer is defined as the number of scale devision (in mm) deflection of the first throw of the spot of light on a scale placed at a distance of 1 metre when a charge of 1μc passes through it.

Thus, $S_q = (2 \times 10^{-3})/K$ mm/μc/m ... (11.7)

And current sensitivity of the ballistic galvanometer S_i is given by,

$$S_i = (T/2\pi) \times S_q \quad \text{... (11.8)}$$

Critical Damping Resistance (CDR) :

When the galvanometer is in a closed circuit and the coil moves in the radial magnetic field there is generation of induced current which tries to oppose the motion of the coil. This is known as the electromagnetic damping. The extent of this damping can be changed by changing external resistance in the circuit. The value of external resistance for which the galvanometer becomes critically damped (i.e. the motion is reduced just oscillatory or just non-oscillatory) is called external critical damping resistance (XCDR).

11.4 Method of Measurements

Step 1 : The circuit connection are made as shown in Fig 11.1 where a storage battery B, a resistance box R_1, a low resistance shunt S and a commutator M_1 are joined in series. The ballistic galvanometer and a series high resistance R are together connected parallel to shunt S.

Step 2 : The distance D between the scale and the mirror is measured thrice by thread and its mean value is found out.

Step 3 : The emf of the battery B is measured by a voltmeter. It should also be measured at the end of the experiment to check its constances.

Step 4 : Suitable values of S (may 0.1Ω to 0.3Ω) and are choosen and R_1 is adjusted to get deflection in the range 12 cm–16 cm. This value is noted for both D.C and R.C and mean value d is found out keeping S and R fixed, R_1 is now measured in suitable steps and in each step the mean deflection d is found out.

Step 5 : A graph is now drawn by plotting R_1 along x-axis and its corresponding 1/d value along y-axis (Fig. 11.2). It would be straight line the mean value of $(1/dR_1)$ = (PN/ON) can be calculated.

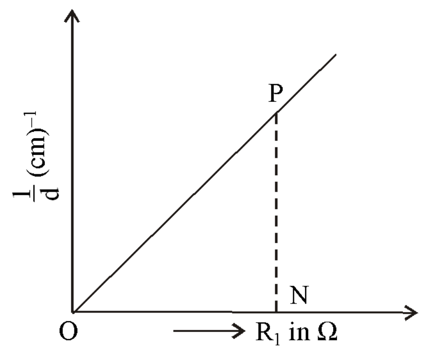


Figure 11.2

Now using the values of E, S, D, G, R and the mean value of $(1/dR_1)$

We can calculate K from eq. 11.6 provided we know T.

Step 6 : To find the open circuit time period T, galvanometer circuit after getting some steady deflection, is suddenly made off by using the key K_2. The time for its 30 complete oscillations are noted thrice and their mean is found out. This mean time be t then T = t/30.

Step 7 : When K is known, the charge sensitivity S_q and current sensitivity S_i can be determined from equations (11.7) and (11.8) respectively.

Step 8 : When galvanometer resistrance G is unknown, suitable values of S (may be 0.1Ω to 0.3Ω) and are choosen and R_1 is adjusted to get deflection in the range 12 cm – 16 cm. This value in noted for both D.C and R.C by using the commutator M_1. The mean value d is found out keeping S and R fixed, R_1 is now measured in suitable steps and in each step the mean deflection d is found out.

Step 9 : A graph is now drawn by plotting R_1 along x-axis and its corresponding 1/d value along y-axis. The nature of the graph will be shown in the Fig. 11.3 from the intercept ON of the straight line with R-axis we get the value of G.

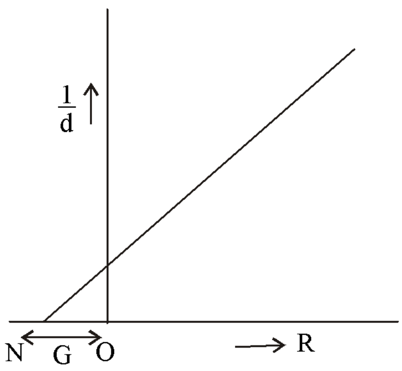


Figure 11.3

Step 10 : With slight modification on the circuit in Fig. 11.1 we can determine XCDR as follows.

We introduce a high resistance box R_0 parallel to the ballistic galvanometer as shown in Fig. 11.4 and use step 6 to find T.

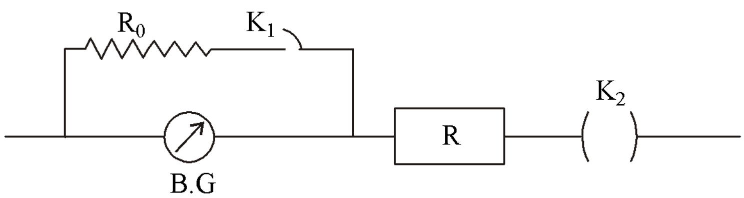


Figure 11.4

Now by trial,a suitable value of R_0 is introduced and simultaneously tap key K_1 closed to find the oscillations of the coil just stops at the zero of the scale from some steady deflection on the scale when K_2 is made open.

The value of R_0 when the oscillation just starts or just stops is the critical damping resistance (CDR).

Experimental Result

(A) E.M.F of the battery B :

Table – 1

E.M.F of the battery in volts.		Remarks
Before expt.	After expt.	

(B) Data for 1/d vs R_1 graph :
Values of S = ... Ω (fixed)
Values of R = ... Ω (fixed

Table – 2

No. of obs	R_1 in ohms.	Steady deflection in cm with			Value of 1/d in cm^{-1}
		D.C	R.C	Mean (d)	

(C) Data for open circuit time period and CDR :

Table – 3

No. of obs.	Time for 30 oscillation in sec	Mean time T is sec for 30 oscillation	Time period T = t / 30 sec	Value of R_0 to just stops the oscillations at zero of the scale in Ω
1 2 3				

(D) Data for galvanometer resistance (G) :
Value of S = ... Ω (fixed)
Value of R_1 = ... Ω (fixed)

Table – 4

No. of obs	R in ohms.	Steady deflection in cm with			Value of 1/d in cm^{-1}	Value of G in Ω from 1/d vs R graph = ON
		D.C	R.C	Mean		

(E) Distance between the scale the mirror :

D = (.......+.......+........)/3 = ...m

(F) Calculation of K, S_q, S_i :

D = ...m, T = ...s, E = ...v, S = ...Ω, G = ...Ω

R = ...Ω [from Table–2]

R_1 = ON = ...Ω, 1/d = PN cm^{-1} = PN × $100m^{-1}$

$K = (TD/\pi)(1/d)(1/R_1)(ES/G + R)$ coulomb/radian

$S_q = (2 \times 10^{-3})/K$ mm/μc/m

$S_i = (T/2\pi) \times S_q$ mm/μA/m.

11.5 Discussion

1. Theory assumes that S should be so choosen That $S << G + R$. If this condition is not satisfied, formula yield would not be valid.
2. The time period T should be measured with the galvanometer in open circuit.
3. Critical damping resistance (CDR) shoudl be measured in open circuit and by trial R_0 should be so adjusted that the coil becomes just non-oscillatory or oscillatory. This value of R_0 is called CDR.
4. Constancy of the emf of the battery should be checked before and after experiment.

11.6 Maximum Proportional Error

We have from equation (11.6) we get,

$$K = (TD/pd)\{ES/R_1(G + R)\} \qquad \text{... (11.6)}$$

Therefore, $(\delta k/k)_{max} = \delta T/T + \delta D/D + \delta d/d + \delta E/E$.

Where we assumes the face values of the resistance boxes to be correct and neglect error in the measurement of G.

Now, δE = 1 div. of voltmeter.

$\delta d = \delta D = 1$ div. of meter scales.

$\delta T/T = \delta t/t$, $\delta t = 1$div. of stopwatch. And t = time for 30 oscillations.

11.7 Summary

1. Suitable value of S and R are fixed. Now deflections d are recorded for various values of R_1 for R_1 vs 1/d curve.
2. Time period of the galvanometer coil is measured in open circuit.
3. If galvanometer resistance is unknown, then R vs 1/d curve is drawn for fixed S and R_1 and from the curve galvanometer resistance G is found out.
4. Galvanometer constant K is calculated and then charge sensitivity S_q and the current sensitivity S_i are found out.
5. Critical damping resistance is found out by adjusting R_0 in Fig. 11.4 so that the galvanometer coil is just rendered non-oscillatory or oscillatory.

11.8 Model Questions and Answer

1. Why is the name ballistic given to this galvanometer ?

Ans. It is called ballistic, for the quantity of electricity which is to be measured, should be passed through the galvanometer coil very quickly giving an impulse to the coil, so that the moving part of the galvanometer may not find time to move during the passage of the charge.

2. What should be the order of time period of ballistic galvanometer?

Ans. It should be large in the range 15-30 sec in order to satisfy the ballistic condition.

3. What is electromagnetic damping ?

Ans. As the coil oscillates within the magnetic field of the permanent magnet, an induced current will be generated in the coil when it is kept in a closed circuit.

According to lenz's law, this induced current will be reduce the amplitude of oscillation i.e. will try to damp the oscillation which is known as electromagnetic damping. This damping will be small as the resistance in the galvanometer circuit is made higher.

4. What is meant by critical damping resistance ?

Ans. To make the motion of the galvanometer coil oscillatory, the external resistance in the galvanometer circuit should be higher than a particular value which is known as critical damping resistance.

5. What is the difference between a dead beat galvanometer and a ballistic galvanometer ?

Ans. In a dead beat galvanometer, the oscillation of the coil, after the withdrawal of current stop quickly due to the generation of induced current in the conducting copper frame of the coil which oscillates in he magnetic field of the horse-shoe magnet. In ballistic galvanometer the damping of the coil is avoided by winding the coil on a non-conducting frame. Here, first throw the coilis required for the measurement of quantity of electricity and hence damping should be minimised and the correction should be made for the little damping left.

Unit - 12 ❑ To determine wavelength of sodium light using Newton's ring

Structure

12.0 Objectives

12.1 Introduction

12.2 Apparatus used

12.3 Theory and working formula

12.4 Method of measurement

12.5 Discussion

12.6 Maximum proportional error

12.7 Summary

12.8 Model Questions and Answer

12.0 Objectives

- To measure the diameters of the Newton's rings.
- To determine the radius of curvature of the lens.
- To determine the wavelength of sodium light using there two data.

12.1 Introduction

Newton's rings are example of interference by division of amplitude in a thin film of slowly varying thickness. Boyle and Hooke, independently first observed them and Newton first measured the radii of the rings and analysed them but could not explain the formation of rings. The credit of explaining the phenomenon finally by the wave theory goes to Thomas young.

When a plano-convex lens of large radius of curvature be placed with the convex surface in contact with a plane glass plate, an air film of small thickness is formed between the two. The thickness of the flim at the point of contact is zero and progressively increases onwards.

If monochromatic light be allowed to fall normally on the film and viewed normally with a low–power microscope in reflected light, a system of alternate bright and dark concentric rings around the point of contact, with their centre dark, is observed to be formed in the air film. These are called Newton's rings. These fringes are fringes of equal thickness for they are the loci of points of equal film thickness. The rings are localised in the film.

12.2 Apparatus Used

1. A combination of plano-convex lens L of large radius of curvature R and glass plate P enclosed in a cylindrical case provided with three levelling screws and a screw-cap at the top to apply suitable pressure uniformly on the rim of the lens.
2. A travelling microscope M.
3. A glass plate P_1, kept inclined 45° to the vertical.
4. A sodium vapour lamp. For arrangement see Fig. 12.2.

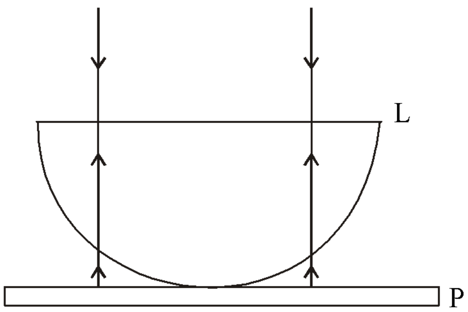


Figure 12.1

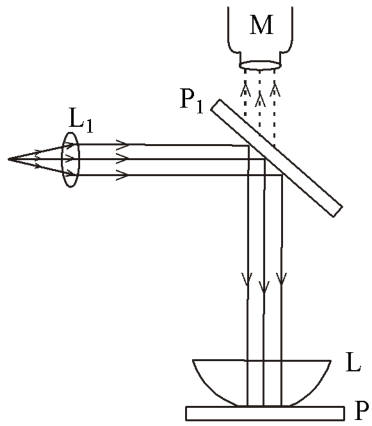


Figure 12.2

12.3 Theory and Working Formula

When a parallel beam of monochromatic light is incident nromally on a combination of a plano-convex lens L and a glass Plate P, as shown in Fig. 12.1, a part of each incident ray is reflected from the lower surface of the lens, and a part, after refraction through the air firm between the lens and he plate, is reflected back from the plate surface.

These two reflected rays are coherent. Hence the reflected rays will interfere and produce a system of alternate dark and bright rings with the point of contact between the lens and the plate as the centre. These rings are called newton's rings.

If D_m is the diameter of the m^{th} bright ring counted from the centre, we have

$$(D^2_m/4R) = (2m + 1)\ \lambda/2 \qquad \ldots (12.1)$$

Where R is the curvature of the radius of the lower surface of the lens L and λ is the wavelength of the light used.

For the $(m + n)^{th}$ bright ring from the curve, we obtain

$$(D^2_{m+n})/4R = (2m + 2n + 1)\ \lambda/2 \qquad \ldots (12.2)$$

Where D_{m+n} is the diameter of the $(m + n)^{th}$ ring. From equation (12.1) and (12.2) we get

$$D^2_{m+n} - D^2_n = 4nR\lambda \qquad \ldots (12.3)$$

λ can be calculated measuring diameter of the rings and radius of the curvature (R) of the convex surface of the lens.

12.4 Method of Measurements

Setp 1 : The base of the microscope is made horizontal by placing a spirit level on the base and adjusting the levelling screws attached to the base.

The axis of the microscope tube is made vertical and its cross-wire is sharply focused by moving the focussing lens in or out. The vernier constant of the horizontal scale is determind.

Step 2 : Taking away the glass plate P and lens L from the case the surface of P and lower convex surface of L are cleaned by a cotton pad, moistened with alcohol. The centre of the upper face of P is anyhow marked and inserted within the case. The microscope is then placed above the plate P_1 in such a way that this mark on P remains on the vertical axis of the microscope tube. By raising or lowering the microscope tube the mark on P is focussed.

Step 3 : The lens L is now placed on the glass plate so that its convex surface may remain in contact with the marked point on P. By applying the screw cap at the mouth of the case a suitable pressure is applied. The sodium light is placed at the focus of the convex lens L_1. The parallel rays from the lens L_1, after being reflected from the plate P_1 are made incidence on air-film, enclosed between L and P normally. This time, on looking through the microscope, rings will be seen. The microscope tube in then slowly adjusted until the rings are focussed as directly as possible.

Step 4 : The glass plate P_1 is then adjusted by rotating it about a horizontal axis, until a large number of uniformly illuminated rings are seen.

Then the position of the slit of the sodium vapour lamp with respect of the lens L_1 is adjusted until a large number of rings are visible.

Step 5 : The case containing a lens plate combination is slightly adjusted until the point intersection of the cross-wires coincide with the centre of the central dark ring and one of the cross-wires becomes perpendicular to the line of movement of microscope and also tangented to the bright or dark rings.

Step 6 : Counting from the first clear ring, which may be lebelled as m^{th} ring (as the first few rings are indistinct, it is difficult to know the order of number of the first clear ring), the microscope is shifted towards the left until one of its cross-wires becomes tangential to the remotest distinctly observed bright or dark ring. The ring number [say $(m + n)^{th}$ ring–counted first clear ring which was called as the m^{th} ring] of this ring is noted as well as the position of the microscope is noted from the horizontal scale and vernier. The miscroscope is then displaced towards right and the same line of the cross wire is made tangential to the next lowered numbered ring. The reading of the horizontal scale and vernier is again noted. This process of recording the ring number and the vernier readings of the horizontal scale is continued from one rihg to the next, until we arrive through the centre to the extreme distinctly observed ring whose number is $(m + n)^{th}$ is the same as was first noted on the extreme left.

Step 7 : Another set of observations may be taken, by starting from the extreme right-end ending in the extreme left-end of the same remotest distinctly observed ring as was employed in the former set. The difference of the two microscope readings corresponding to the two ends (one in the left and other in the right) of each ring will give the diameter of that rihg. Thus from two sets of observations (one starting from left and another starting from right) we get two values of diameter of each ring. The mean of these two values will give the diameter of the ring.

Step 8 : By removing the screw cap, the lens L is taken out and the radius of curvature R of the lower convex surface of the lens L is then measured by an accurate spherometer or by optical lever or by floating the lens on mercury and employing Boyle's method.

The better method of finding R is to employ sodium light first, where wavelength λ (= 5893Å) is known hence R can be calculated from equation (12.3). Knowing R, λ of a given light say red from an electric lamp obtained after the passage of the white light through a red filter can be found out from equation (12.3).

Experimental Result

(A) Measurement of the radius of curvature R of the lower convex surface of lens by a spherometer with the formula : $R = \{d^2/6h + h/2\}$

(i) Determination of the least count. (l.c) :

Smalles division on the linear scale = S = ...mm

Pitch of the screw = P = ...mm

No. of divisions on the cirular scale = N = ...

Least count. (l.c) = P/N = ...mm.

Instrumental error (e) : ±y division of circular scale = ± y × (l.c) mm.

Distance between the outer legs = d = (.....+......+.....)/3 cm

(ii) Determination of h [here the screw is moved downwards and this downward movement decreases the circular scale reading]

Table–1

No. of obs	Initial circular reading when the screw touchs the spherical surface R_1	When the screw touches the plate			Total no. of C.S.D rotated x = Nm + n	Values these divisions in mm h = x × (l.c)	Mean h in cm	$R=d^2/6 + h/2$
		No. of rorations of circular disc.m	Final circular scale reading R_2	Additional no.of C.S division rotated (n)				
1	29	3	98	31	331	.....	.....	.....
	30	3	0	30	330	.....	.....	.....
	29	3	99	30	330	.....	.....	.....

Specific values are given for illustration only

*N.B: (a) If the direction movement of the screw (downdard or upward) decreases the circular scale readings, then $n = [N - (R_2 - R_1)]$ when $R_2 > R_1$ and $n = (R_1 - R_2)$; when $R_2 > R_1$

(b) If the direction of movementof the screw (downward or upward) increases the circular scale reading, then $n = (R_2 - R_1)$; when $R_2 > R_1$, $n = [N - (R_1 - R_2)$ when $R_2 < R_1$.

(B) Determination of the diameters D of the rings :

Vernier constant of the microscope employed.

Smallest division of the main scale = ...mm

Total number of vernier division divisions (V.d) = ...mm

..... v.d = ... m.s.d

Therefore, 1 v.d = ... m.s.d

Therefore, v.c = 1m.s.d – 1v.d = ...m.s.d = ...mm = ...cm

[specific values of n are given for illustration only]

Table–2

Ring number	Obs. started from	Reading of microscope in cm for the						Diameter $D=R_1-R_2$ in cm	Mean D in cm
		(a) Left end of the ring			(b) Right end of the ring				
		Scale S	Vernier v=v.r.x v.c	Total reading $R_1=S+v$	Scale S	Vernier v=v.r.x v.c	Total reading $R_2=S+v$		
m + 19	Left (l)	....	....	....	....	....	....	....	....
m +18	Right (r)	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....

N.B: When started from left, all readings are to be noted against l, first is column of (a) and then in cloumn of (b) after crossing the centre, But when started from right, all readings are to be noted against r, first in column of (b) and then in column of (a) after crossing the centre.

(C) Determination of λ from the data of Table–2 :

Table–3

Ring number	Mean diameter in cm (D)	$D^2(cm^2)$	Value of m^{th}	Value of m	Value of n	$D^2_{n+m}-D^2_m$ for 10 rings	Mean $D^2_{n+m}-D^2m$	$\lambda = (D^2_{m+n}-D^2_m)/4Rn$
m +19	.....	....a_1)	m +19	m +9	10	....a_1-b_1	.....	λ =.....
m +18	.....	....a_2)	m +18	m +8	10	....a_2-b_2		
.....	.....	.....	.....	.....	10	.....		
m = 10					.....			
m + 9	.....	....b_1)						
m + 8	.....	....b_2)						
.....	.....	....						
m								

12.5 Discussions

1. Greatest source of error is in the measurement of R. As the radius of curvature of the convex surface of plano-convex lens is very large, spherometer method of finding the elevation h of the convex surface from its plane surface is not very accurate. Hence optical lever may be employed to find h. Knowing h by optical lever, the radius R of the convex surface of plane-convex lens can be obtained from the relation $R = \{D^2/8h + h/2\}$ where D is the diameter of the boundary of the plano convex lens. The better method of finding R is to employ a light to know wavelength (say, sodium light) and then to use this value of R to find some unknown λ.
2. As the first few rings are indistinct, it is very difficult to obtain he exact ring number of the first clearest ring.
3. In this arrangement the rings are seen after refraction through the lens and the error due to this is very small if the lens employed is thin.

12.6 Maximum Proportional Error

From equation (12.3)

$\lambda = (D^2_{m+n} - D^2_m)/4nR = y/4nR$ (say)

therefore, $(\delta\lambda/\lambda)_{max} = \delta y/y + \delta R/R$ (12.4)

Again proportional error in R can be calculated from the relation

$R = d^2/6h + h/2 \approx d^2/6h$ since, h is very small h/2 is neglected.

Therefore, $(\delta R/R)_{max} = \delta y/y + 2\delta d/d + \delta h/h$

Maximum error is measuring :

1. D is 2 v.d and hence error in D^2 is 4 v.d. The error is obtaining y is $\delta y = \delta (D^2_{m+n} - D^2_m)$ would be 8 v.d = $8 \times .001$ cm.
2. δd is 1 v.d of slide callipers = .01 cm
3. δh is 2 d.c of spherometer = $2 \times .0005$ cm

thus we can find out $(\delta\lambda/\lambda)_{max}$ from the experimental data of the concerned parameter.

12.7 Summary

1. Radius of curvature R of the convex surface of a plano-convex lens is measured by a spherometer.
2. Diameters of the newton's rings are measured with the help of travelling microscope.
3. Wavelength λ of the monochromatic light used by the formula given by equation (12.3).

12.8 Model Questions and Answer

1. Why are the interference fringes circular in this case ?

Ans. Here the film is of varying thickness and a locus of constant illumination over the face of the film is a locus of constant path difference which is a circle with the point of contact of the lens and the plate as centre. Hence, the fringes are circular.

2. Why is an extended source used in this experiment?

Ans. An extended source is used to increase the intensity of the circular rings. An entended source used so that the whole surface of the lens isilluminated. This is necessary for the interference fringes to become circular rings. With a point source only alternate dark and bright points will be seen. With an illuminated slit only a portion of the rings will be observed.

3. Why is the central spot dark?

Ans. Although the path difference between the reflected rays from the centre is zero, there is a phase change of π due to reflection from the denser medium i.e. from the glass plat. Because of theis phase change, the central spot becomes dark.

4. What would happen if white light is used instead of sodium light?

Ans. A smaller numbered of coloured rings will be seen.

5. On which factors does the diameter of a ring depend?

Ans. The diameter D of a ring depends on the radius of curvature R of the lens, wavelength λ of light, order number n of the ring, and the refractive index μ of the medium.

Unit - 13 ❑ To study the reponse curve of parallel LCR circuit and determine it's (a) Anti-resonant frequency and (b) Quality factor Q

Structure

13.0 Objectives

13.1 Introduction

13.2 Apparatus used

13.3 Theory and working formula

13.4 Method of measurement

13.5 Discussion

13.6 Maximum proportional error

13.7 Summary

13.8 Model Questions and Answer

13.0 Objectives

- To study voltage versus frequency curve of a parallel LCR circuit.
- To determine its anti-resonance frequency and Q factor.

13.1 Introduction

When an ac voltage is applied across a circuit with resistance and reactance, the circuit produce oscillations with frequency of the applied voltage. If the frequency of the applied voltage becomes equal to the natural frequency of the circuit, electrical resonance will occur.

A series resonant circuit consists of L, C and R all in series; while a parallel resonant circuit consists of a capacitor C in parallel with a series LR combination.

13.2 Apparatus Used

Same as in the experiment of unit 9 and an ac millimeter capable of measuring small current.

13.3 Theory and Working Formula

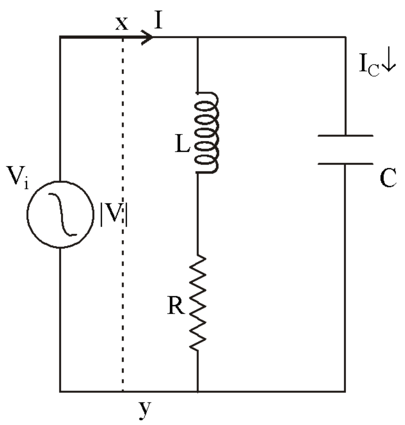


Figure 13.1

Fig. 13.1 shows a parallel resonant circuit consisting of a capacitor C in parallel with a series LR combination, driven by ac source of constant output rms voltage V_i

The impedance of the circuit at terminals x, y is $1/Z = 1/(R + jwL) + jwC$

$1/Z = (R–jwL)/(R^2 + w^2L^2) + jwC$

$= R/(R^2 + w^2L^2) + j(wC – wL/(R_2 + w^2L^2)$ .... (13.1a)

The source current and the source voltage will be in phase if the imaginary part of 1/Z venishes i.e. if $wC = wL/(R^2 + w^2L^2$ .... (13.1b)

Or, $w = w_p = \sqrt{\{1/LC - R^2/L^2\}}$ ..... (13.2)

Where w_p is called the parallel resonant angular frequency. The corresponding parallel resonant frequency f_p= $1/2\pi \sqrt{\{1/LC - R^2/L^2)}$ when R is small, $w_p = 1/\sqrt{(LC)}$ and $f_p = 1/2\pi (w_p - R/L)$

If resonance, the circuit impedance, at parallel resonace is purely resistive and is given by,

$1/Z_p$= $R/(R^2 + w^2L^2) = R/(L/C) = CR/L$

Using equation (13.3) in $Z_p = (L/CR)$ .... (13.3)

The line current at parallel resonance is given by $I_p = |V|/Z_p$ and at resonance $(I_p)_{resonance} = |V|/(L/CR)$..... .... (13.4)

The capacitor current at parallel resonance is givenby

$$I_{cp} = |V|/)1/w_pC) \quad .... (13.5)$$

$$I_{cp}/I_p = w_pCZ_p = w_pL/R \; .... \quad .... (13.6)$$

Now for high Q circuit, $w_pL >> R$ and in such a circuit, we can replace, in the neighbourhood of the resonance, w by w_p in the first term of equaion (13.1a) and we get,

$$(1/Z) = R/w^2L^2 + j\{wC - wL/(R^2 + w^2L^2)\}$$

Since $wL >> R$

$1/Z = G + j(wC - 1/wL)$

$G = R/w^2{}_pL^2 = 1/Q^2R = R/w^2L^2$ [in the neighbourhood of resonance, $w_p \approx w$]

$V = \{I/G + j(wC - 1/wL)\}$ .... (13.7)

Equation (13.7) shows that V is maximum at $w_p = 1/\sqrt{(LC)}$, when imaginary terms become zero, the voltage |V| drops on either sides of resonance as w is varied. The variation of |V| with frequency is shown is Fig. 13.2

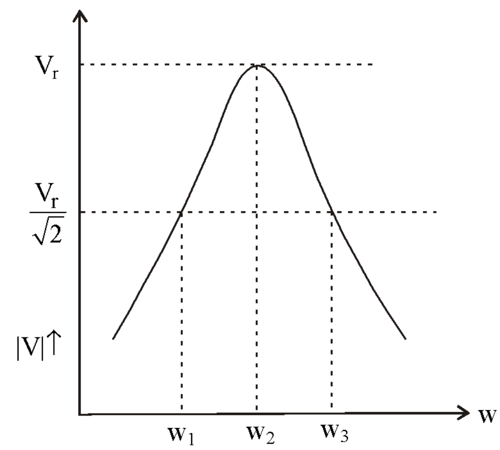


Figure 13.2

The rms voltage at parallel resonance is $V_r = I_r/G$ where I_r is the rms current. The frequency range $(w_2 - w_1)$ over which the voltage is equal to or greater than $V_r/\sqrt{2}$ is called band width of the circuit. The frequencies w_1 and w_2 are half-power frequencies and is given by $Q = w_p/(w_2 - w_1) = f_p/(f_2 - f_1)$ .... (13.8)

Where $w_p = 2\pi f_p$, $w_2 = 2\pi f_2$, $w_1 = 2\pi f_1$

13.4 Methods of Measurements

Step 1 : Make the circuit connections as shown in Fig. 13.1 choose a relatively low value of R (say $R = R_1 = 100\Omega$) and a suitable value of C (say, $C = 0.1\mu F$).

Switch on the audio oscillator and adjust the output voltage V_i to a suitable value (say, 5V). Set its frequency f to a fairly low value (say, 100Hz)

Setp 2 : Measure the voltage V across point (x, y) [Fig. 13.1] by an ac voltmeter.

Step 3 : Vary the frequency of the oscillator in small steps, say 100Hz over a frequency range including f_p and in each step repeat step 2 adjust the voltage V_i to the fixed value choosen in step 1 as it may change with change in frequency.

The region of resonant frequency may be approximately checked before taking the final readings. Take data in smallest possible steps around the resonance frequency.

Step 4 : draw the voltage resonance curve by plotting f along the x-axis and |V| along y-axix. From the curve find the resonance frequency f_p, he half-power frequencies f_l and f_l and then calculate Q by using equation (13.8). At half-power frequencies |V| falls to $1/\sqrt{2}$ of its maximum value V_r.

Step 5 : The relation (13.6) can also be used to determine Q. Set he frequency of the oscillator exactly at the resonance frequency f_p and adjust the input voltage V_i to a relatively high value.

Measure the current I_{cp} through the capacitor and the line input current I_p.

Step 6 : Repate the experiment for drawing the voltage resonance curve and finding the Q-factor for a different set of values as in C and R; same L; same C but different R ($R = R_1 = 50\Omega$).

In this case again measure |V| as a function of frequency : compare to the values of Q obtained by different methods.

Experimental Results

(A) Data for different voltages as a function of frequency :

Set 1 : C = ...μF, $R = R_1$ = ...Ω, L = ...mH

Rms input voltage V_i = ...V

Table–1

No. of observation	Frequency in Hz source	Rms voltage |V| in volt across parallel resonant circuit	Anti-resonant frequency f_p unit
1	100	....	....
2	....	....	....
3	....		
4			
5			
.			
.			
.			

Set 2 : C = ...μF, R = R_1 = ...Ω, L = ...mH make similar table as set 1

Table–2

(B) Calculation of Q-factor from voltage resonance curve :

Table–3

Set no.	Anti-resonant frequency f_p in Hz	Maximum voltage v_r in volt	The frequency in hertz at which $\|V\| = V_r/2$		$Q=f_p/(f_2-f_1)$
			Lower half power (f_1)	Upper half power (f_2)	
Set 1	$(f_p)_1$				
Set 2	$(f_p)_2$				

(C) Q from the measurement of I_{cp} and I_p at anti-resonance :

Table–4

Set no.	Oscillator set at frequency f_p in Hz	Rms current I_p in mA	Rms current I_{cp} in mA	$Q = I_{cp}/I_p$
Set 1	$(f_p)_1$			
Set 2	$(f_p)_2$			

13.5 Discussion

1. For the measurement of current I_p and I_{cp} ac milliammeter of high frequency response is required.
2. Capacitors are more or less ideal while inductors are not. Hence the current I_{cp} is measured across the capacitor and not across the inductor to find Q.

13.6 Maximum Proportional Error

For $Q = f_p/(f_2 - f_1)$ see unit 9 Art. 9.6

Again $Q = I_{cp}/I_p$

Therefore, $(\delta Q/Q)_{max} = \delta I_{cp}/I_{cp} + \delta I_p/I_p$

Where dI_{cp} and dI_p are the smallest division of ac milliammeter used in the measurement of I_{cp} and I_p.

13.7 Summary

1. Voltage response of a parallel resonant circuit is drawn to identify f_p, f_1, f_2
2. Q is also determined from $Q = I_{Cp}/I_p$ which gives the current magnification at anti-resonance.

13.8 Model Questions and Answer

1. What are the characteristics of parallel resonant circuit?

Ans. (a) The impedance decreases rapidly with change in frequency above or below the resonant frequency where it is maximum. This characteristics enables the parallel circuit to select a particular frequency and reject all other frequencies. At resonance, the circuit behaves as a pure resistive circuit.

(b) The Q-factor is measure of quality (selectivity) merit of the resonant circuit. For a parallel resonant circuit to be highly selective, the resistance of the coil should be minimum to set a sharp impedance curve.

(c) The band-width of a resonant circuit is the range of frequencies over which the circuit impedance is equal to or more than 70.7% of the maximum value.

(d) In parallel resonance circuit the circuit impedance is high at resonance and therefore current is small. Due to small current at resonance power loss (I^2R) is also small.

2. How the overall circuit behaves above and below resonant frequency? (a) In case of series resonant circuit and (b) in case of parallel resonant circuit?

Ans. (a) The circuit is capacitive below resonant frequency but inductive below it.

(b) The circuit is inductive below f_p but is capacitive above f_p.

3. What is the power factor of (a) parallel resonant circuit (b) series resonant circuit at resonance frequency?

Ans. Power factor is unity in both cases since the voltage and current are in phase at resonance.

Unit - 14 ❑ To determine refractive index of the material of the prism using sodium source

Structure

14.0 Objectives

14.1 Introduction

14.2 Apparatus used

14.3 Theory and working formula

14.4 Method of measurement

14.5 Discussion

14.6 Maximum proportional error

14.7 Summary

14.8 Model Questions and Answer

14.0 Objectives

- To determine the refractive index of the material of a prism using sodium source.

14.1 Introduction

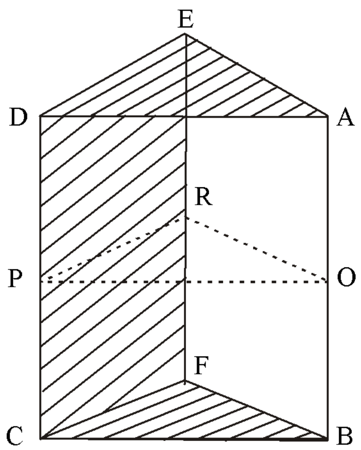


Figure 14.1

A prism may be considered to be a portion of a refracting medium with two intersecting plane boundary surfaces. These two faces are called refracting faces of the prism (faces ABCD and ABFE in Fig. 14.1) and the agnle between them is called angle of the prism. The line along which this plane intersects is the refractive edge of the prism (line AB). The refracting faces are well polished.

The prism are generally limited by a third face (CDEF) which, except in right-angled prism, is generally set at the same angle to both refracting faces. This face is the base of the prism. It is generally not polished and thus be easily distinguished from the refracting surfaces.

On the other sides of the prism. Since no refraction occurs through them they also are not polished. The prism rests on one of these end faces. A section on the prism perpendicular to the refracting edge is called a principle section (PQR). In the elementary theory of the prism the incident are the refracted rays are supposed to be confined to the same principle section.

While finding the minimum deviation we are taking the reading of the emergency rat at minimum deviation. However it is to be noted that for every incident ray on the prism there is no emergent ray. For a prism of definite angle, there is a certain range of the angle of incidence within which emergent rays are possible.

14.2 Apparatus Used

1. Spectrometer with vernier constant 20″.
2. A triangular prism principle section of which is preferably equilateral triangle.
3. A sodium vapour lamp.
4. A magnifying glass, spirit level etc.

14.3 Theory and Working Formula

If δm be the minimum deviation of a monochromatic ray of light refracted through the principle section of the prism of refracting angle A, then the refractive index of the of the material of the prism is given by

$$\mu = \{\sin(A + \delta_m)/2\}/\sin(A/2) \quad \text{... (14.1)}$$

14.4 Method of Measurements

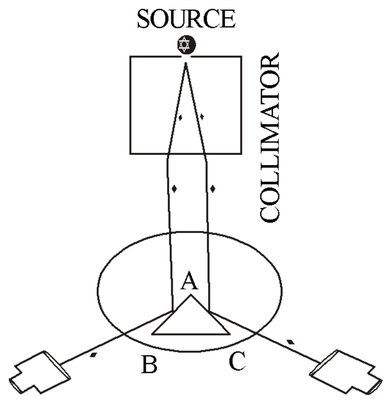


Figure 14.2

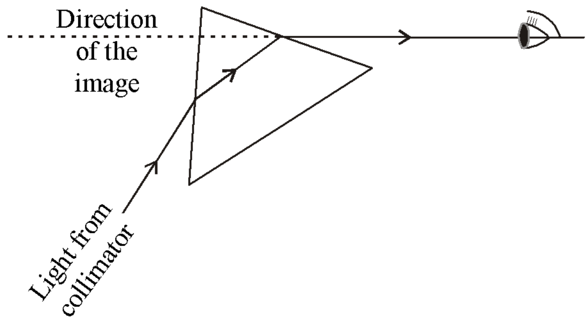


Figure 14.3

Step 1 : By a spirit level, the axis of the telescope and collimator are made horizontal and also perpendicular to the vertical axis of rotation of the prism table and the telescope. [see appendix A for adjustment]

The prism table is also levelled by a spirit level to make its upper surface horizontal and if the bottom of the prism is perpendicular to its edges then the refracting faces of the prism will be vertical when it is placed on the prism table.

Step 2 : The cross-wire in front of the eye-piece of the telescope is sharply focused by moving the focussing lens in and out. The prime table is furthered levelled by optical method so that the refracting faces of the prism, when placed on the table may be exactly vertical [see Appendix A] Then the telescope and the collimator are focused for parallel rays by Schuster's method [see appendix A].

Step 3 : To find the angle A of the prism, at first the vernier constant of both the verniers is determined and the prism is placed on the prism table so that the edge A coincides with the centre of the table.

The prism is placed in such a way that the vertical plane through the axis of the collimator will cut the base BC nearly normally [Fig. 14.2]. Parallel rays from the collimator now fall on both faces AB and AC of the prism and after reflection, from images which can be seen by looking towards these faces. The image formed by reflection from the faces AB of the prism is first seen by an unaided eye and then the telescope is taken to the position $S_1(T_1)$ of the eye to receive the image. The telescope is than moved slowly by the tangent screw until the centre of the cross-wire coincides with an edge (say right edge) of the slit image. The readings of both the verniers are noted and this is repeated for three independent settings of the telescope. The mean value of these three readings corresponding to each vernier is determined.

Next the reflected image is formed by the reflection of rays from other face AC of the prism is first received by the unaided eye and by the telescope taken at the position $S_2(T_2)$.

The entire operation as in the case of the first reflected image, is repeated by coinciding the centre of the cross-wire with the same edge of the slit-image. Again the mean value of the three readings corresponding to each vernier is determined.

Setp 4 : The difference between the two mean readings of the particular vernier for the two positions of the telescope, [$S_1(T_1)$ and $S_2(T_2)$] is determined separately for the two verniers and mean of these two differences when halved, gives us the angle A of the prism.

Step 5 : Place the prism on the prism table with its refracting edge vertical and the centre of the prism coinciding with the centre of the table. Let the light from the collimator be incident on one of the refracting faces at an angle of 45° or so to the face close to one eye, if necessary, and with the other look for the refracted beam, which is bent towards the base of the prism [Fig. 14.3] and leaves the prism horizontally. Looking into the face of the prism from which the beam emerges you will see an image of the collimator lens and in its centre the bright-yellow image of the slit.

Slightly turn the prism table first in one direction and then in other you will find the image of the slit moves. Now so turn the prism table that the image moves towards the side of lesser deviation. As you go on turning the prism table the image moves and soon reaches a position from which it turns back. This turning point is the position of minimum deviation of the image, the position of the image in which it occurs in the position of the minimum deviation of the prism.

Having got the images at minimum deviation with nacked eyes, rotate the telescope between the prism and the eye. A very small movement of the telescope this way or that will enable you to see the image of the slit in it. Adjust the prism table slowly so that the deviation is minimum. Fix the prism table.

Having got the image exactly at the position of minimum deviation, set the cross-wire at the centre of the image. Read both verniers. Take three imdependent sets of readings.

Remove the prism but don't disturb the prism table. Place the telescope in a straight line with the collimator and take the directr reading. The difference from the previous reading gives the angle δm.

Experiental Results :

(A) To find angle of the prism (A) :

Vernier constant of both verniers.

Smallest circular scale division = ...

......Vernier divisions = ... scale divisons

Vernier constant (V.C) = 1s.d – 1v.d = ... S.d = ...

Table–1

Vernier no.	Readings for first image				Readings for second image				Difference θ	Mean θ	A = $\theta/2$
	Main Scale (S)	Vernier (V)	Total R = S +V	Mean R	Main Scale (S)	Vernier (V)	Total R = S +V	Mean R			
First	....			= R_1				= R_2	= $R_1 - R_2$		
Second	....			= R_3				= R_4	= $R_3 - R_4$		

(B) To find angle of the prism (A) :

Table–2

	Readings for minimum deviation				Readings for direct rays					
Vernier no.	Main Scale (S)	Vernier (V)	Total R = S +V	Mean R	Main Scale (S)	Vernier (V)	Total R = S +V	Mean R	Minimum deviation δ_m	Mean δ_m
First	....			$= R_1$				$= R_2$	$= R_1 - R_2$	
Seco nd	....			$= R_3$				$= R_4$	$= R_3 - R_4$	

14.5 Discussion

1. Deviation of ray of light through prism depends on (a) angle of prism (b) angle of incidence (c) wavelength for a given prism and wavelength of light when the angle of incidence is equal to the angle of emergence from the prism
2. The vertical cross-wire or better the centre of the cross-wire should be made coincident with the same edge of the slit image.

14.6 Maximum Proportional Error

We have $\mu = \left\{\sin\frac{A+\delta m}{2}\right\}/\sin\,(A/2)$ from equation .....(14.1)

Therefore, $(\delta\mu/\mu)_{max} = (\delta A/2 + \delta_m/2)\cot(A + \delta_m)/2 + \delta A/2\cot\,(\delta A/2)$

Where, δA = 1 V.C in radian

$D\delta_m = 2 \times$ V.C in radian

Since A is measured by taking difference of two readings and then dividing by 2. Again dm is measured by taking difference of two readings.

Now, using the experimental values of A and δm we and calculated the maximum proportional error as $(\delta\mu/\mu)_{max} \times 100\%$

14.7 Summary

1. Angle of prism is measured with the help of two reflected image from two refracting surface of the prism using both the verniers of the spectrometer.
2. The prism is set in the minimum deviation position by the usual method and δm is measured.
3. Refractive index μ of the material of the prism is found out by equation (14.1).

14.8 Model Questions and Answer

1. How does the deviation of a ray through prism vary (a) with the angle of incidence (b) with colour of the incident light? (c) with the change of the angle of prism ?

Ans. (a) The deviation becomes minimum at a particular angle of incidence, but it always increases when the angle of incidence is either greater or smaller than that at which the deviation becomes minimum.

(b) Deviation varies inversely as the square of the wavelength. Thus, deviation is greater for violet light than red light.

(c) Deviation increases with the increase of the angle of the prism.

2. Why the telescope and collimator are adjusted for parallel rays?

Ans. When the incident rays are either divergent or convergent, the distance of the image formed by the prism will be divergent for different position of the prism (for the angles of the incident will change with the change of the position of the prism). Hence the image will remain forcused from one position of the prism but will go out of focus for another position of the prism. If the incident rays are parallel, then both the object and the image of the prism will be at infinity and the telescope are focused for the image will remain so for every position of the prism.

3. What kind of image is produced by the telescope?

Ans. The telescope produces virtual image at infinity. The objective of the telescope produces a real diminished image while the eye-piece a virtual magnified image.

Unit - 15 ❑ To determine the temperature co-efficient of resistance by platinum resistance thermometer

Structure

15.0 Objectives

15.1 Introduction

15.2 Apparatus used

15.3 Theory and working formula

15.4 Method of measurement

15.5 Discussion

15.6 Maximum proportional error

15.7 Summary

15.8 Model Questions and Answer

15.0 Objectives

- To find the resistance of the platinum coil of the platinum resistance thermometer at 100°C and 0°C by using Callendar and Griffiths bridge.
- To determine the temperature co-efficient of resistance of the platinum coil.

15.1 Introduction

Electrical resistance of some pure metals change in a reproducible manner with temperature. This property is usually used in resistance thermometers.

The precision and reliability of modern resistance thermometers are due to the work of Callender and Griffiths who, from a wide range of experiments found that the resistance of pure platinum is very accurately given by

$$R_t = R_0 (1 + \alpha t + \beta t^2) \qquad ...(15.1)$$

Where R_t and R_0 are the resistance at t°c and 0°c an α, β are constants characteristics of the specimen. When the range of temperature is small (t – 100°c), it is found $\beta << \alpha$, equation 15.1 can be written as

$$R_t = R_0 (1 + \alpha t) \qquad ...(15.2)$$

Where a is the mean temperature co-efficient of resistance between 0°c and 100°c, Therefore, $\alpha = \{R_{100} - R_0/100R_0\}$ ...(15.3)

Where, R_{100} is the resistance at 100°c

R_{100} and R_0 are measured by a platinum resistance thermometer.

15.2 Apparatus Used

1. Platinum resistance thermometer
2. A P.O box
3. a metre bridge

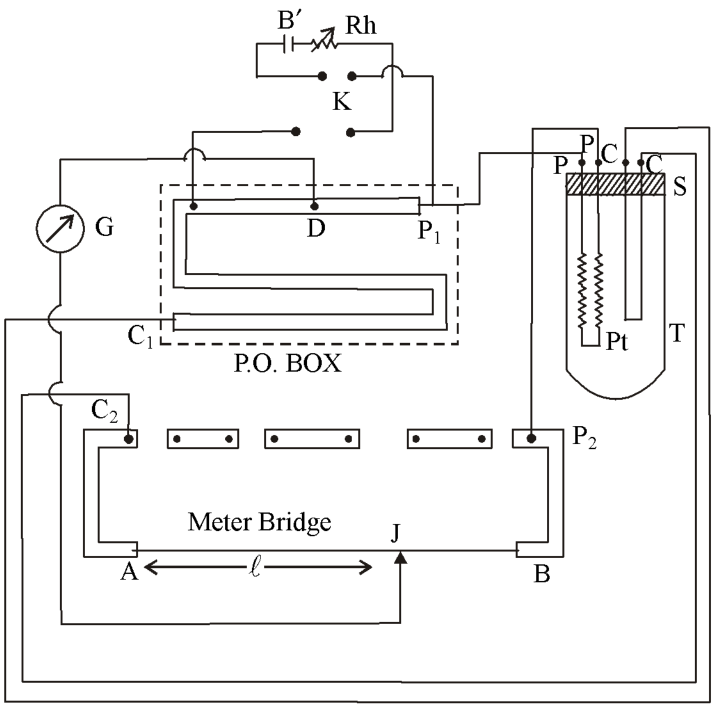


Figure 15.1

4. A battery (b′)
5. A rheoster (Rh)
6. A commutator (K)
7. A suspended coil galvanometer (G) or a table galvanometer of sensitivity 2μA/division.

Plan of connection (circuit diagram) :

Plan of connection is shown in Fig. 15.1

(a) The battery B′ is connected through the rheostat Rh. To one diagonal of the commutator (K) while the other diagonal of the commutator is connected to the ends of the ratio arms i.e 1st and 2nd arms of P.O box.

(b) The galvanometer is connected to the junction D of the 1st and 2nd arms of the P.O box and the metre bridge jokey J.

(c) From a reel of double cotton covered copper-wire four equal lengths of the wire are cut off. The wires should be sufficiently long so that they may reach from the terminals [(P, P) or (C, C)] of the thermometer, kept fixed in a position, to even the longest distance like C_1.

The first of these four wires is employed to join the beginning (P_1) of the 1st arm of P.O box with one terminal of the platinum leads (P, P) while second wire is employed to join the right end(P_2) of the metre bridge wire with the other terminal of the platinum leads (P, P) while second wire is employed to join the right end (P_2) of the metre bridge wire with the other terminal of the platinum leds (P, P). The third wire is employed to join the end C_1 of the 3rd arm of the P.O box (R-arm) with one terminal of the compensating leads (C, C) while the fourth wire is used to join the left end (C_2) of the metre bridge wire with the other terminal of the compensating leads (C, C).

15.3 Theory and Working Formula

Within a moderate range of temperature, the relation between the resistance R_0 and R_t of a pure sample of platinum wire at 0°c and t°c respectively, is approximately given by

$$R_t = R_0 (1 + \alpha t) \quad \text{... (15.2)}$$

Here α is the average temperature co-efficient of resistance between 0°C and t°C.

If R_T be the resistance of the given sample of platinum wire at the boiling point T°c of water under atmospheric pressure at the time of experiment then,

$$R_T = R_0 (1 + \alpha T) \quad \text{...(15.3)}$$

$$\alpha = (R_T - R_0)/R_0 T \quad \text{... (15.4)}$$

α is determined from the equation (15.4)

Theory of measuring resistance R_t : At room temperature, the (P, P) leads and (C, C) leads of thermometer are short-circuited.

Putting equal resistance in the 1st and 2nd arm and zero resistance in the 3rd arm of the P.O box let the balance point (electric mid-point) is obtained at a distance ℓ_0 from the left end of the bridge wire (having the resistance ρ per unit length). After removing the short-circuit between (P, P) and (C, C) let a null point is obtained at a distance ℓ from the left end of the bridge wire with a resistance r inserted in the 3rd arm of the P.O box then we have,

$$R_t = r + 2\rho(\ell - \ell_0) \quad \text{... (15.5)}$$

From equation (15.5) we can find R_t provided we know r

To find ρ : Again keeping all parts of the apparatus at room temperature, a resistance (r + m) is now inserted in the 3rd arm of P.O box to have another null point at a distance ℓ' from the left end to the bridge wire then we get

$$\rho = m/2(\ell - \ell') \quad \text{(15.6)}$$

By using equation (15.5) and (15.6), the resistance R_l of the platinum wire at any temperature t°C can be calculated.

15.4 Methods of Measurement

Step 1 : The connections are made in the manner as in Fig 15.1 and thermometer tube T is kept at the middle of a large funnel, completely filled with a thoroughly crushed pure ice in the melting state. The (P, P) and (C, C) terminals are then joined by short thick wires.

The resistance in each of the 1st and 2nd arms of the P.O box are made equal to 10 Ω while the resistance in the 3rd arm (R-arm) is kept zero (by tightly closing all plugs by by twisting them downwards). The rheostat resistance is increased to reduce the current to make sensitively 2μA per mm of the bridge wire.

Setp 2 : Null point is now determined three times, both for direct and reverse current. After the determination of each null point, the key K is to be kept open for some time and the next null point is to be determined within as minimum time as possible after closing the key K, so that heating effect of the circuit may be negligible. The mean null point is found out which is the electrical mid-point. This determination of the mid-point should also be made at the end of the experiment. The mean of these two null points (ℓ_0) would be taken as the correct electrical mid-point.

Step 3 : The short-circuting wires connecting (P, P) and (C, C) are now removed. The platinum wire has by this time assumed the temperature (0°C) of melting ice.

A suitable resistance r (say 2Ω) is inserted in the 3rd arm of the P.O box and null points are noted both for direct and reversed currents.

This nothing is continued after an interval of two minutes until the null point remains steady for atleast three consecutive intervals. Mean null point (ℓ) is found out.

This determination of mean null point is repeated for two other values of the resistance r (say 3Ω and 4Ω) in the 3rd arm of the P.O box. [sometimes depending on the resistance on the resistance of the metre bridge wire.

It may be necessary to change r by fractions of an ohm. Then a fractional resistance box may be used in series with the 3rd arm to obtain null points for three different values of r.

Each pair resistance in the P.O box and their corresponding mean null points are employed to calculate ρ (resistance per unit unit length of the bridge wire) by using the relation (15.6). Three such values of ρ will be obtained and their mean should be found out. In a similar manner mean r is to be found out when the thermometer is kept at T°C (boiling point of water). The grand mean of the two mean values of r is to be employed in calculating the resistance R_0 of platinum wire at

0°C by using the relation (15.6). Using three different values of r and their corresponding mean null points, three values of R_0 would be obtained and then the mean R_0 is to be found out.

Step 4 : The thermometer tube T is now introduced above the water level of a hypsometer in which steam at the boiling point T°c of water is produced. After sufficient time for the attainment of the temperature of platinum thermometer equal to that of steam, the noting of the null points for three different resistance (r) in the 3rd arm of the P.O box is started.

As in step 3, the null points for each resistance (r) in the P.O box are noted both for direct and reversed current ater an interval of two minutes until the null point remain steady for atleast 3 consecutive intervals.

As before, taking each resistance (r) in the 3rd arm of the P.O box and its corresponding mean null point (ℓ), the resistance R_T for platinum wire at T°C (boiling point of water) is calculated and then mean R_T is found out.

Step 5 : Calculating R_T and R_0, α is found out using relation (15.4).

Step 6 : Barometric height is noted before and after step (4) and the mean height is determined. From this mean height of barometer, the boiling point T°C of water is determined from table.

Experimental Data :

(A) Determination of electrical mid-point (I_0) :

Room temp. = ...0°C

Table–1

Stage of expt.	Resistance in P.O. box in ohm			Position in cm of null points on bridge wire with				Mean of m and n in cm	ℓ_0 in cm
	1st arm	2nd arm	3rd arm	Direct current (m)	Meam (m)	Reversed current (n)	Mean (n)		
Before expt. (at room) temp	10 Ω	10 Ω	0						
After expt. (at room) temp.	10 Ω	10Ω	0						

(B) Measurement of resistance of platinum thermometer :

Resistance in 1st arm = resistance in 2nd arm = ...ohm

Value of ρ from Table–3 = ... ohm/cm

Value of ℓ_0 from Table–1 = ... cm

Table–2

Thermometer	No. of obs.	Time in minutes	Resistance in 3rd arm in ohn (r)	Null point in cm with				Mean of m and n in cm (I)	Value of $(\ell - \ell_0)$ in cm
				Direct current (m)	Mean (m)	Reversed current (n)	Mean (n)		
Ice	1	0	2			....			
		2				....			
		4				....			
		6							
	2	0	3						
		2							
		4							
		6							
	3	0							
		2							
		4							
		6							
Steam	1	0							
		2							
		4							
		6							
	2	0							
		2							
		4							
		6							
	3	0							
		2							
		4							
		6							

(C) Calculation of ρ :

Table–3

No.of obs.	Temp of platinum thermometer	Resistance 3rd arm	Null point in cm corresponding to r (I)	ρ = m/2(ℓ – ℓ′) ohm per cm	Mean ρ	Grand mean ρ
1 2 3	0°C (ice)	2 3 4	74.4 52.1 30.5	(i) ρ = ½(74.4-52.1) = .0024 (ii) ρ = ½(52.1-30.5 = .0231 (iii) ρ = 2/2(27.4-30.5) = .0228	0.228	
1 2 3	T°C (B.P. of water)	....	....	....	....	

(D) Determination of Barometric height and B.P (T°C) of water :

Vernier constant of barometer = ... cm

Assume that a change of pressure by 27.12 mm of Hg changes the B.P of water by 1°C.

Table–4

	Reading of		Total reading in cm (H) = s + v.r × v.c	Mean barometric height (H) in cm	Change in pressure from normal value = H-76 cm of Hg	Boiling point of water (T°C)
	Scale (s) in cm	Vernier (v.r)				
Before experiment	....	....	....	....	....	....
After experiment	....	....	....	....	....	....

(E) Calculation of α :

R_0 in ohn	R_T in ohm	B.P of water T°C from Table–4	$\alpha = (R_T - R_0)/R_0T$ per °C

15.5 Discussion

(i) To avoid the presence of air between ice pieces some water is sprinkled over ice bath and the thermometer tube should be kept in the middle of the ice bath.

(ii) The thermometer tube should be kept a little above the level of boiling water or liquid so that the tube may be surrounded by the water vapour only whose temperature would be equal to the boiling point of pure water.

(iii) Due to the temperature gradient along the lead wires thermo-current will be developed. To avoid its effect the mean of the null points for direct and reversed currents should be taken.

(iv) The bull points should be noted after an interval of 2 minutes till it remains constant for three consecutive intervals indicating the constancy of temperature of platinum.

15.6 Maximum Proportional Error

We have $\alpha = (R_T - R_0)/R_0T$

$d\alpha/\alpha_{max} = \delta(R_T - R_0)/(R_T - R_0) + \delta R_0/R_0 + \delta T/T$

$$= 2\delta R/(R_T - R_0) + \delta R/R_0 \qquad (15.7)$$

Since temperature of ice and boiling point of water is assumed to be correct.

Now, $R = r + 2\rho(\ell - \ell_0) = r + 2m(\ell - \ell_0)/2(\ell - \ell') \qquad (15.8)$

From equation (15.6) and (15.8)

Thus $\delta R = \{\delta(\ell - \ell_0) \times (\ell - \ell') - \delta(\ell - \ell') \times (\ell - \ell_0)/(\ell - \ell')^2$

$$\delta R_{max} = \delta\ell/(\ell - \ell') + 2\delta(\ell - \ell_0)/(\ell - \ell')^2 \qquad (15.9)$$

where $\delta\ell$ = 1 smallest division of the metre scale. Subsituting δR_{max} from equation (15.9) in equation (15.7) we get, $(\delta\alpha/\alpha)_{max}$

15.7 Summary

(i) Electirc mid point ℓ_0 is determined.

(ii) By placing the thermometer in ice bath R_0 is determined.

(iii) By placing the thermometer in hypsometer (Boiling point of water) R_T is determined.

(iv) α is calculated from equation (15.4).

15.8 Model Questions and Answer

1. Why is platinum selected for the construction of thermometer ?

Ans. Pure platinum has a fixed resistance at a fixed temperature, whether that temperature is attained from a low or from a high value.

2. Why are two equal resistance applied in the ration arms ?

Ans. For the cancellation of the resistance of the platinum leads and compensating leads.

3. What is temperature co-efficient of resistance ?

Ans. The change in resistance per unit resistance of a material for 1°C change in temperature is called the temperature co-efficient of resistance of the material. Copper and platinum has positive temperature co-efficient while carbon, india rubber have negative temperature co-efficient.

4. Does α of a material is same for different range of temperature?

Ans. No. Temperatue co-efficient of resistance of a material is different for different range of temperature.

Apendix A

A.1 The spectrometer : This is the apparatus you will be required to handle the most in the optical laboratory. It has quite a number of parts, and requires several careful adjustments before work with it can begin. It is, therefore, necessary that you acquire a thorough knowledge of its parts and the adjustments it needs for use. These adjustments should be so thoroughly practiced that you can complete them in less than half-an-hour.

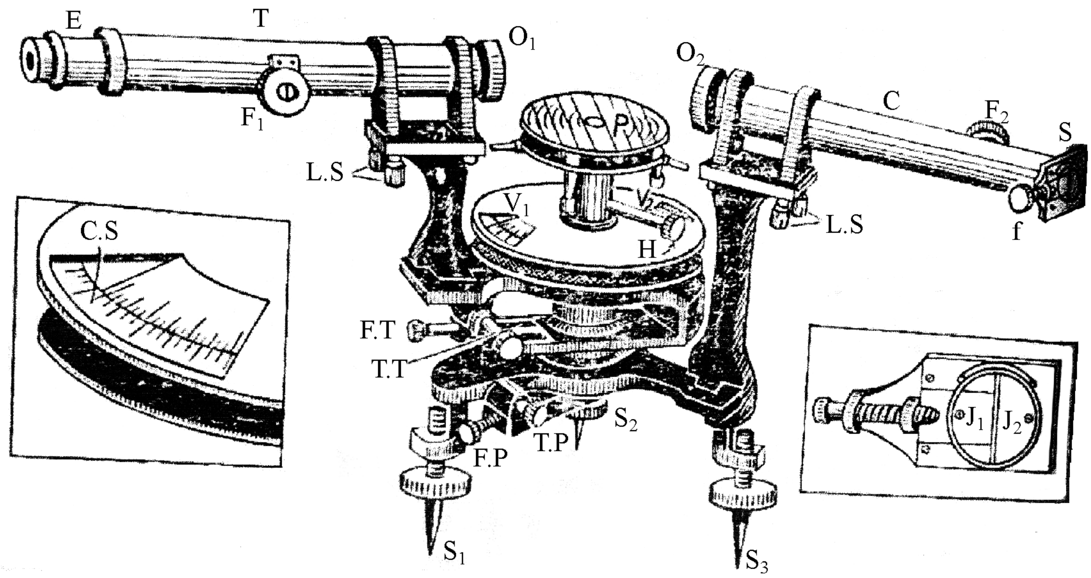


Figure A.1

T, telescope : E, eyepiece: O_1, objective: F_1, focusing screw: C, collimator: O_2, lens : F_2 focusing screw: S, slit : f, screw for adjusting width of the slit: L S, levelling screws: F.T, screw for fixing telescope: T.T. tangent screw to telescope: F.P, fixing screw for prism table : T.P, tangent screw for prism table : $S_1.S_2.S_3$, levelling screws : C.S, circular scale: V_1,V_2, vernier scales: H, screw for fixing the prism table to verniers : J_1, J_2, parallel jaws of the slit.

The essential parts of a sectrometer are

(i) the collimator (C; Fig. A.1)

(ii) the prism table (P)

(iii) the telescope (T), and

(iv) the circular scale (C.S shown separately in the left inset of the figure).

(i) **The collimator :** Its purpose is to provide a parallel beam of light. It consists of a tube with a vertical slit (S, shown separately in the right inset of Fig. A.1) of adjustable width mounted at one end of the tube, and has a converging achromatic lens (O_2) at the other. It is rigidly fixed to the main frame of the instrument. The distance between the slit and the lens can be altered by a rack and pinion or some other focusing device. In the figure, F_2 is the focusing screw.

The slit is a very important part of the experiment. It consists of metal jaws (J_1, J_2) with exactly parallel edges.

The width is adjusted by turning a screw (f). Light from a suitable source, such as sodium vapour lamp, illuminates the slit. When properly focused the slit lies in the focal plane of the collimator lens. The collimator thus gives rise to a parallel beam which falls on the prism standing on the prism table. For a properly placed source the emergent beam from the collimator has a circular section of the same diameter as the lens.

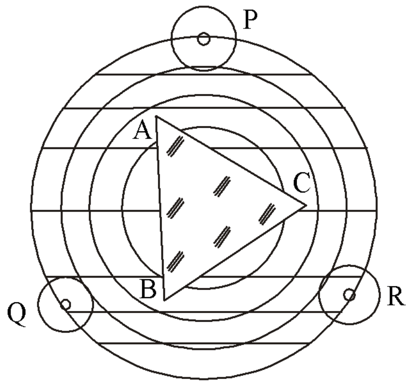


Figure A.2

(ii) The prism table has a flat top and is capable of rotation about a vertical axis. It is provided with three leveling screws. The prism is placed on the table with its refracting edge vertical.

A set of parallel, equidistant lines are ruled on the top of the prism table (Fig. A.2). These lines are rarallel to the line joining two of the leveling screws and are required for adjusting the prism. A series of circles concentric with the axis of rotation of the prism table is also ruled on the top. The circles help in placing the prism correctly. The height of the prism table can be adjusted. The screw H (Fig. A.1) fixes the prism table to the verniers and also keeps it at a given height.

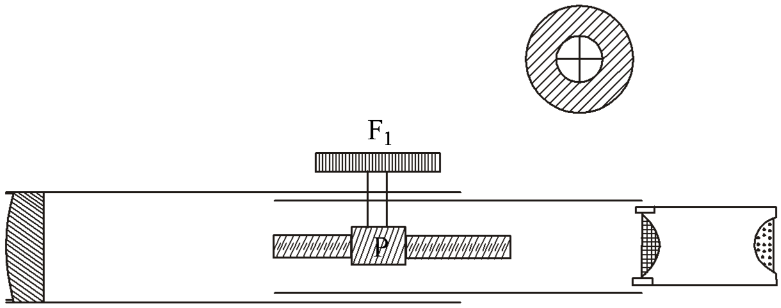


Figure A.3

(iii) The telescope (shown separately in Fig. A.3) is an astronomical telescope. The objective is an achromatic doublet. The eye-piece is of the Ramsden type and is fitted with cross-wires. The eye-piece slides in a tube which carries the cross-wires. This tube slides in another tube which carries the objective. The distance between the objective and the cross-wires can be altered by a rack and pinion or some other focusing device. (The rack and pinion arrangement (R, P) is shown in Fig. A.3. It should be understood that the device is on the outer side of the inner tube and does not obstruct the light.)

While working, the eye-piece is so adjusted that the cross-wires lie in its focal plane. The eye can then see the cross-wires without applying accommodation. The image of the cross-wires is formed at infinity. The focusing screws (F_1 Fig. A.1) is then turned till there is no parallax between the cross-wires and the image of the slit formed by the objective of the telescope. This ensures that the image of the slit has been formed in the plane of the cross-wires.

The eye-piece magnifies this image of the slit which has been formed in the plane of the cross-wires. The final image is at infinity.

The axis of the telescope (as also of the collimator) passes through the axis of rotation of the prism table. The telescope is carried on an arm which can be rotated about the above axis of rotation (but the collimator is fixed). A counterpoise balances the weight of the telescope and eliminates the strain due to this weight on the rotation axis. The telescope and collimator tubes are supported near one end on two screws, each marked L.S. in Fig. A.1. By means of these screws their axes may be made exactly horizontal.

The telescope may be fixed at a given position by means of the screw F.T.

A slow motion can then be imparted to it by the screw T.T., called the tangent screw. The prism table is also provided with similar fixing and slow motion screws (F.P. and T.P. respectively). It should be noted that a tangent screw will not function unless the corresponding fixing screw is tightened.

(iv) Circular scale : The spectrometer has a circular scale coaxial with the axis of rotation of the prism table and the telescope. It is graduated in degrees.

In some spectrometers the telescope and the prism table each carries two verniers, 180° apart, which slide along a fixed circular scale. In smaller instruments the circular scale and the telescope are rigidly attached to each other and turn together. Two verniers, 180° apart, are carried on a separate circular plate mounted coaxially with the circular scale. The prism table can be clamped to the spindle of this circular plate. When so clamped the prism table and the verniers turn together.

By means of the vernier the circular scale may be read up to a minute of arc or even less.

The purpose of having two verniers is to minimize the error due to the centre of the circular scale not lying on the axis of rotation.

A.2 Adjustments of the spectrometer : In all work with the spectrometer certain adjustments are essential. It will be advantageous to spend sufficient time over learning and practicing these adjustments so that they could be completed in at most half-an-hour. The student will then have enough time at his disposal in which to take the necessary readings.

The adjustements are the following and should be performed in the given order:

(i) Levelling of the instruments (i.e. of the telescope, collimator and the prism table)

(ii) Focussing of the crossed-wires.

(iii) Adjustment of the slit.

(iv) Focussing for parallel rays.

(i) Levelling : While working with a spectrometer it is necessary that (a) the axis of rotation of the telescope etc. shall be vertical (b) the axis of the telescope and (c) of the collimator, shall be horizontal and (d) the top of the prism table shall also be horizontal. Levelling the instruments means making these adjustments.

(a) Levelling the telescope : Place a spirit level on the telescope taking care that its axis is parallel to that of the telescope. Fix the spirit level in position by a piece of string.

Looking at the spectrometer you will find three levelling screws on which it rests. One of these is below the collimator. Call it S_3 and the other two S_1 and S_2. Imagine a line joining the screws S_1 and S_2, and place the spectrometer parallel to this line. The air bubble of the spirit-level may be found not to lie at the centre. Bring it halfway towards the centre by turning the levelling screws S_1 and S_2 (Fig. A.1) by equal amounts in opposite directions. For the other half, turn the levelling screws L.S. below the telescope by equal amounts in the same direction. (In some spectrometers there may be a third screw between the screws L.S. Its purpose is to fix the telescope tube to the arm carrying it. Where this third screw is present, it should first be unscrewed sufficiently so that the screw L.S. may move easily. After the levelling has been made, the third screw may be tightened).

Now swing the telescope so that it turns through 180° and becomes parallel to its first position. It will prehaps be found that the bubble has moved away from the centre. Bring it to the centre as before, half by S_1 and S_2, and the other half by L.S. It may be necessary to repeat the operations several times till you find that the bubble remains at the centre for both positions of the telescope. When this has been done, the axis of rotation of the telescope lies in a vertical plane perpendicular to the line joining the screws S_1 and S_2.

Note that the bubble may not be at the centre for intermediate position of the telescope. Now place the telescope in line with the collimator and take the bubble to the centre by turning the third levelling Screw S_3 below the collimator. This makes the axis of rotation vertical and the axis of the telescope horizontal. It is necessary to check the first adjustment after this second one has been made.

Summary : To remember the adjustments the students should mentally make a summary of them. The following may be helpful. The two positions in which the telescope is parallel to the line joining S_1 and S_2 may be called, respectively the first and the second parallel position, and the other one the perpendicular position. Then,

For the parallel position, adjust half by S_1, S_2 and the other half by L..S.;

For the perpendicular position, adjust by S_3.

To facilitate work, adjust S_3 whenever the telescope comes to the perpendicular position, i.e., in line with the collimator

(b) Levelling the collimator : Remove the spirit-level and place it on the collimator with the axes of the two parallel. If the bubble is not at the centre, bring if there by means of the levelling screw L.S. with which the collimator is provided. This makes the collector is horizontal.

(c) Levelling the prison table : The prism table is providing with the other levelling screws (P, O, R, Fig. A.2) just below it. On the table is ruled series of lines parallel to a line joining two of these screws. Place the spirit-level parallel to these lines and bring the bubble to the centre by turning these two in opposite direction. Now place the spirit-level perpendicular to the lines and level it by means of the third screw. This makes the table top horizontal.

(iii) Focussing the cross-wires : Turn the telescope towards an illuminated background (a small illumination will do). Look into the eye-piece without any accommodation in the eyes (i.e., look as you would do when you want to see a distant object). The cross-wires may appear blurred. Adjust the eye-piece (by moving it inwards or outwards as necessary) until the cross-wire could be seen distinctly. There cross-wire may be horizontal and vertical, or turned through 45° with respect to the horizontal.

(iv) Adjustment of the slit : Turn the telescope and bring it in line with the collimator. Looking through the telescope you will generally find a blurred image of the slit. Turn the focussing screw of the telescope (and of the collimator, if necessary) till the image of the slit appears in sharp focus. (A beginner often fails to realise the position of best focus. Remember that in this the slit appears smallest and the boundary lines are most sharply defined. It is advisable that you show the teacher-in-attendance the adjustment that you make).

If the image appears not to be vertical turn the slit in its own plane till the image is vertical. The width of the slit should be such that its image has a breadth of about one millimetre (i.e., the breadth of the lead of your pencil) when held at the least distance of distinct vision. When you have acquired more skill in handling the instrument you can make the slit narrower.

(v) Focussing for parallel rays : There are two methods available for the purpose : (a) the direct method and (b) Schuster's method.

(a) Direct method : In the direct method the telescope is turned towards a distant object (more than 60 metres away) and focused on it. There should be parallax between the image and the cross-wires. This is very important. Since the eye-piece and the cross-wires are in a separate tube and move together, the adjustment of the cross-wires is not disturbed by this focussing.

Now bring the collimator and telescope in a straight line. The image of the illuminated slit may appear blurred. Adjust the focussing screw of the collimator until the image of the slit, viewed through the telescope, appears in sharp focus. There must be no parallax error between the cross-wire and the image of the slit. To test it move the eye transversely across the eye-piece. For correct adjustment there will be no relative motion between the image and the cross-wires.

In the first operation the telescope has been adjusted to bring parallel rays to a focus. In the second operation the collimator adjusted to produce a beam of parallel rays.

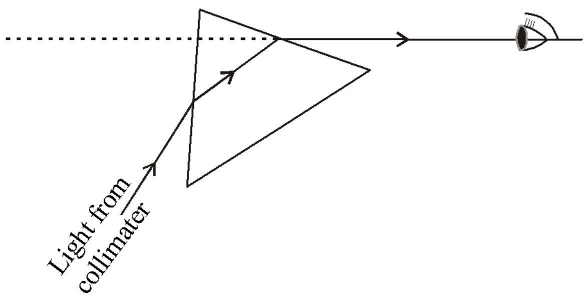


Figure A.4

(b) Schuster's method : If remote object is not available, this is the only method to be followed. Place the prism on the prism table with its refracting edge vertical. Let light from collimator be incident on one of the refracting face of an angle of 45° or so to the face. Close one eye, if necessary, and with the other look for the refracted beam towards the base of the prism (Fig. A.4) and leaves the prism horizontally. Looking into the face of the prism from which the beam emerges you will see an image of the collimator lens and in its centre the bright yellow image of the slit. To see the image properly your eye should be at the same height as the centre of the prism face. Slightly turn the prism table first in one direction and then in the other. You will find that the image of the slit moves. Now so turn the prism table that the image moves towards the side of lesser deviation. As you go no turning the prism table the image moves and soon reaches a position from which it turns back. This turning point is the position of minimum deviation of the image. The position of the prism in which it occurs is the position of minimum deviation of the prism.

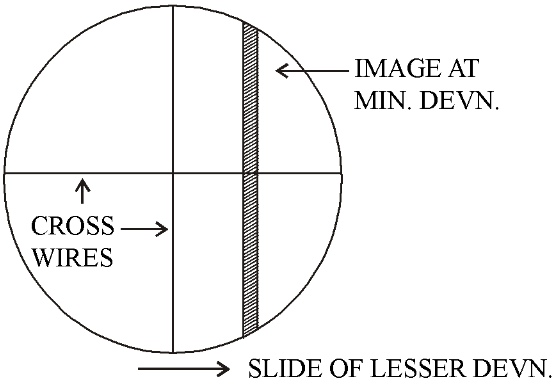


Figure A.5

Having got the image at minimum deviation with naked eyes move your head away from the prism still keeping the image of the slit in view. Then swing the telescope between the prism and the eye. A very small movement of the telescope this way or that will enable you to see the image of the slit in it. Slightly turn the prism table till on looking through the telescope, you find the image exactly at the turning point, i.e., at minimum deviation.

Displace the telescope a little towards the side of larger deviation so that the image still at minium deviation, lies about half to two-thirds the way down the field of view (Fig. A.5). Whichever way you turn the prism table now, the image moves and passes the cross-wires. Thus, there are two positions of the prism for which the image can be brought on the cross-wires. In one position the refracting edge is nearer to you than at minimum deviation. In other position it is more remote. In the former position the angle of incidence on the prism is larger; it is called the slant position of the prism.

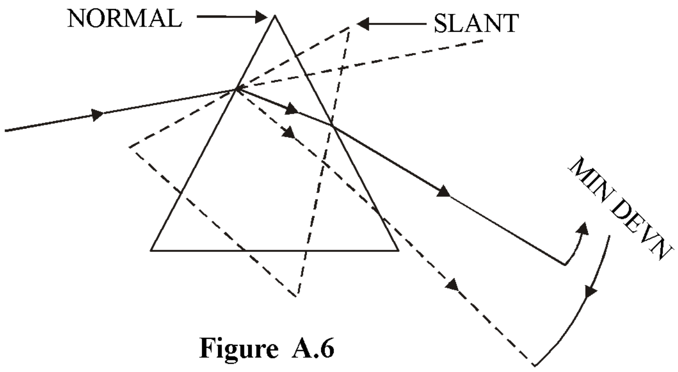


Figure A.6

In the latter position and angle of incidence is smaller; it is called the normal position (Fig. A.6).

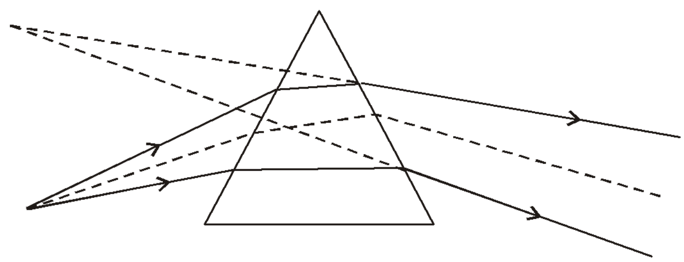
(1) Bring the image on the cross-wires. Suppose in so doing so the refracting edge has moved nearer to you than at minimum deviation. If the image is blurred focus it by the telescope, i.e., the instrument nearer to you.

(2) Now turn the prism table in the opposite direction so that the refracting edge moves away from you. The image moves towards the position of minimum deviation, turns back and reaches the cross-wires again. If the image is blurred focus it by the collimator i.e., the instrument away from you.

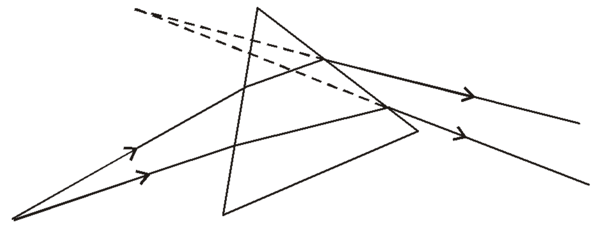
In general, it will be necessary to repeat the operation. (1) and (2) several times in succession till the image appear in sharp focus at both positions. The spectrometer is then focussed for parallel rays. In the final position, there must be no parallax between the image and the cross-wires.

MNEMONIC. It should be noticed that the focussed image is broader in the normal position and narrower in the slant position. This gives a mnemonic for Schuster's method : When the image is Broad, adjust the focus by the Collimator, or more simply, Broad-Collimator. There is also another way of remembering : adjust the focus by the instrument nearer to or away from you according as the refracting edge has moved nearer to or away from you (or more simply, near-near, away-away).

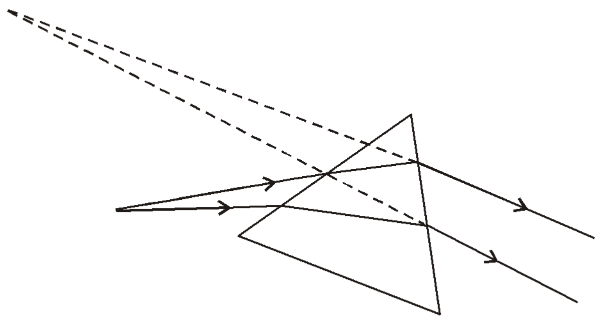
Theory of Schuster's method : When a narrow beam of light coming from a point object, is refracted through a prism, the emergent beam appears to come from a point image. If the mean ray of the beam passes through the prism at minimum deviation the distance of the image from the prism is equal to the distance of the object. But when the angle of incidence is smaller than that at minimum deviation, the image is near the object. For angles of incidence larger than that at minimum deviation, the image is farther than the object.



MIN. DEVIATION



NORMAL POSITION



SLANT POSITION

Figure A.7

Thus, for the normal position of the prism, the image of the slit formed by refraction at the prism is nearer, while for slant position it is at a greater distance (Fig. A.7).

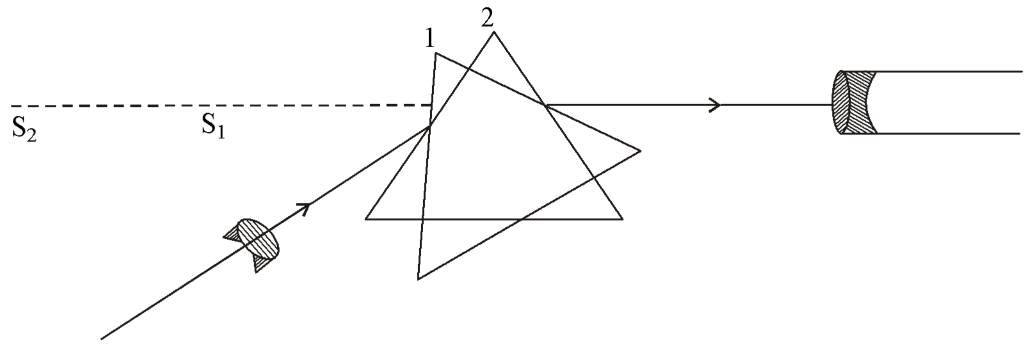


Figure A.8

Suppose the telescope is focussed on the image at (S Fig. A.8) when the prism is in the slant position. Let the prism be now turned to the normal position. Since the image moves nearer (at S), it will be out of focus in the telescope. By moving the collimator lens nearer to the slit this image at S_1 is pushed to the previous point of focus S, of the telescope. If now the prism is changed in position from normal to slant, the image moves further away. The telescope is next focussed on this more remote point.

Thus the point on which the telescope is to be focussed moves away to greater distrances with every adjustment of the collimator.

The collimator pushes the image at the normal position to the position of the image at the slant position. When finally both images are formed at a very great distances they appear to be in focus for both positions of the prism.

The magnification of the image is greater for smaller angles of incidence. Hence the image is broader in the normal position.

A.3. Optical levelling of a prism : When working with prism it is necessary that its refracting faces should be vertical. If the bottom section is perpendicular to the faces, levelling the prism table automatically brings about this adjustment. But slight differences generally remain and may be removed by optical levelling. The operation is as follows :

Place the prism on the prism table so that one of the refracting faces is at right angles to the line joining two of the levelling screws of the prism table (in Fig. A.2 the face AB is shown placed perpendicular to the line QR). It will generally be found convenient to place the apex of the prism at the centre of the table. Turn the telescope so that its axis makes an angle of about 90° with the axis of the collimator. Then turn the prism table till you see in the telescope an image of the slit produced by light reflected from the face AB (i.e., the face which is perpendicular to the line joining two of the levelling screws). If the image is not central in the field of view judged vertically bring it to the centre by turning the above levelling screws in opposite directions. Then turn the prism so that light reflected from the face AC enters the telescope. If the image is not central make it so by turning the third levelling screw of the prism table.

The first operation makes the face AB vertical. The second operation turns AB in its own plane but does not alter its adjustment, while it makes the face AC vertical. The two operations together constitute optical levelling.

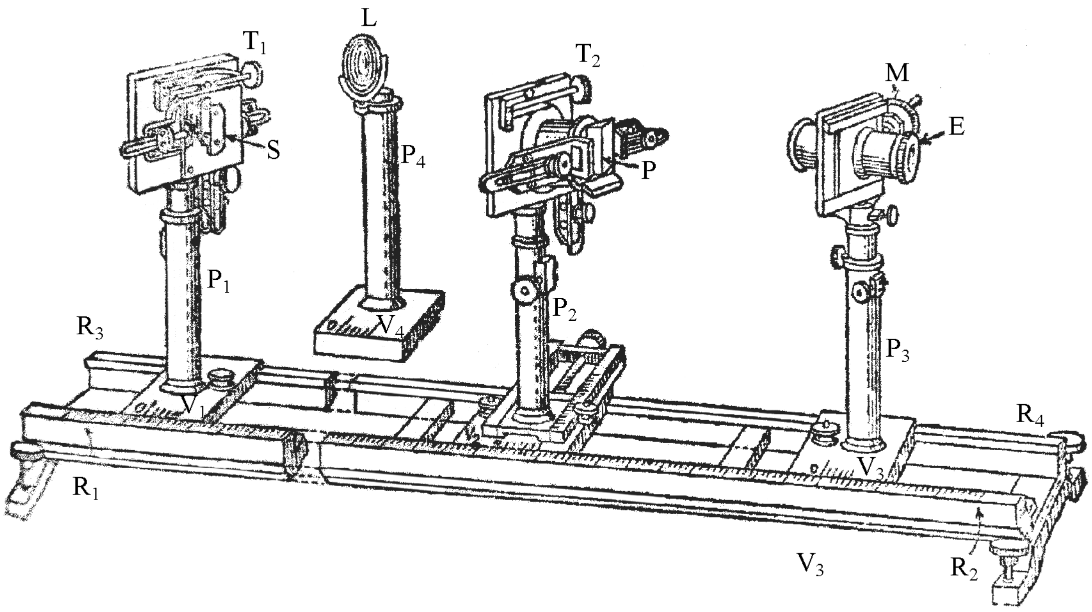


Figure A.9

A.4 Optical bench : The optical bench employed for this purpose consists of two long horizontal steel rails (R_1 R_2 and R_3R_4) maintained at a fixed distance apart (Fig. A.9). On these two rails several uprights can slide. The bases of these uprights are provided with verniers. When the uprights are shifted on the rails the verniers move over a scale (this scale is shown by arrows drawn from R_1 and R_2) graduated in mm. From this scale and verniers, the shifts of the uprights can be ascertained.

(i) The upright P_1 which carries the slit S_1 is mounted near the zero of the scale. The height of this slit from the bench can be adjusted and by a tangent screw T_1, the slit can be rotated in its own plane about a horizontal axis. The slit can also be rotated about a vertical axis. By a screw the width of the slit can be adjusted.

(ii) Next upright P_2 carries the biprism P, which is nothing but two acute-angled prism joined base to base. The plane face of the biprism should be directed towards the slit. The biprism can be rotated in its own plane about a horizontal axis by a tangent screw T_2. The biprism can also be rotated about a vertical axis. The height of the biprism from the bench can also be adjusted. The upright P_2 can be moved perpendicular to the bench.

(iii) The third upright P_3, which is mounted at a distance from the biprism, carries a micrometer eye-piece E (usually Ramsden's eye-piece provided with a cross-wire). This eye-piece can be moved perpendicular to the bench by a micrometer screw M provided with linear and circular scales. With the help of these two scales, the shift of the eye-piece perpenducular to the bench can be accurately determined. The height of the eye-piece from the bench can be adjusted and this upright can also be moved perpendicular to the bench.

(iv) Another upright P_4 carrying a convex lens L, can be mounted between the eye-piece and the prism. The height of the lens from the optical bench can also be adjusted.

A.5 The polarimeter is a piece of apparatus used for measuring the rotation of the plane of polarisation. Its essentials are a polariser, an analyser and a tube for containing the liquid placed between them. The angle through which the analyser should be turned to reduce the intensity of light again to a minimum gives the amount of rotation of the plane of polarisation.

Unfortunately, the analyser can be turned through an appreciable angle without any change in the minimum becoming detectable. This lack of sensitivity can be overcome by using special devices, of which there are several. We shall describe two of them namely, (i) the Laurent half-shade, and (ii) the biquartz.

The Laurent half-wave plate or the half-shade plate : The half-wave plate consists of a semi-circular plate of quartz cut parallel to the optic axis, and is of such thickness that it introduces a path difference of $\frac{\lambda}{2}$ between the ordinary and extraordinary rays passing perpendicular to the optic axis. It is cemented diagonally to a semi-circular glass plate which absorbs the wavelength λ to the same extent as the quartz does. The combination is placed behind the polariser, each semicircle covering half the field of view.

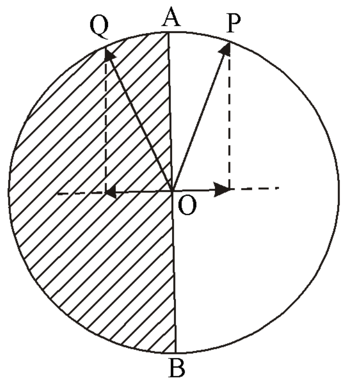


Figure A.10

In Fig. A.10, let APB be the semi-circular plate of glass and AQB and plate of quartz and AB the direction of its optics axis. If the direction of vibration of the incident light be parallel to OP, it will pass through the glass plate without any change. But in the quartz, it will be divided into two components, one parallel to OA and the other perpendicular to it. On passing through the quartz the phase of one of these is reversed w.r.t the other. The result is that in the transmitted light the direction of vibration in inclined to AB at an angle AOQ which is equal to AOP. Thus in the two halves of the field of view the vibration are along OP and QO respectively. In passing through the analyser, the light in the two halves will appear unequally bright unless the short diagonal of the analysing Nicol is parallel to AB or perpendicular to it. In either case the two halves will appear equally bright. In one position (here perpendicular of AB) the intensity of transmitted light is lower than in the other position. Since the eye can readily detect the change of about 1% in equality of illumination, the position of lower intensity is more sensitive in detecting changes of illumination. Using the half-wave plate the position provides a sensitive means of measuring the amount of rotation of the plane of polarisation. What is required to be done is to set the analyser so that the two halves of the field appears equally bright, once before the insertion of the active material, and again after insertion using the position of lower intensity.

The half-wave plate can be used only with the monochromatic light for which the plate is devised. Generally this is sodium light.

The Biquartz plate : A device which is used with white light is the biquartz. The effective wavelength is around 5600Å.

It consists of two equally thick semi-circular plates of quartz which forms a complete circle. One is right-handed quartz and the other is of left-handed, both being cut perpendicular to the optic axis. When the plane polarised beam of light passes through the plates, one of them rotates the plane of polarisation clockwise and the other anticlockwise.

The amount of rotation depends on the thickness of the plates and the wavelength. For a thickness of 3.75 mm the rotation is 90° for yellow-green light of wavelength 5600A.

Suppose the vibration of the light incident to the biquartz is parallel to AB (Fig. A.11), i.e., the short diagonal of the polarised is parallel to AB. In each half of the yellow-green light would be rotated through 90° relative to AB. Red will be less deviated, but blue more in both halves. If the analyser is set with its short diagonal parallel to AB, yellow-green light will be missing from both halves, while the components of other colours will be transmitted in equal proportions in both halves. The colour will appear to be a greyish violet and is known as the tint of passage.

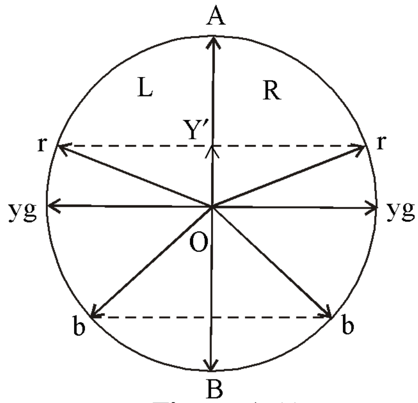


Figure A.11

If the analyser is turned slightly from this position, one half of the field will appear pink and the other a dark blue, as one half will transmit more of red and the other, more of blue. This is easy to detect an inequality of the colour in the two halves of the field. Hence, the setting of the analyser on the tint of the passage can be fairly accurate. The experiment consists in so setting it before and after insertion of the specimen.

A.6 Discharge Tubes :

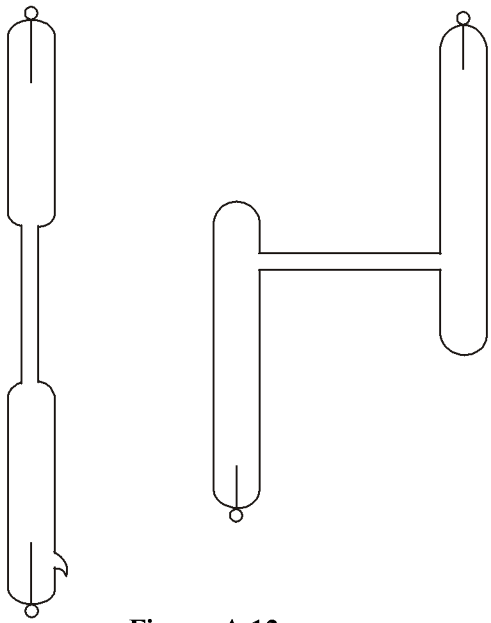


Figure A.12

Gas discharge tubes, also known as Geissler tubes, are widely used in the laboratory for spectroscopic purposes. The gas whose spectrum is to be studied fills the tube at a pressure of a few millimeters of mercury. Aluminium electrodes are sealed into the tube. The central part of the tube is a capillary. The light comes from the positive column of the discharge and is the most intense in the capillary, where the current density is also the highest. The intensity is still further increased if the capillary is viewed 'end on' as in the design represented in Fig. A.12

The voltage for running the tube is supplied by a small induction coil or a transformer.

A.7 Platinum resistance thermometer :

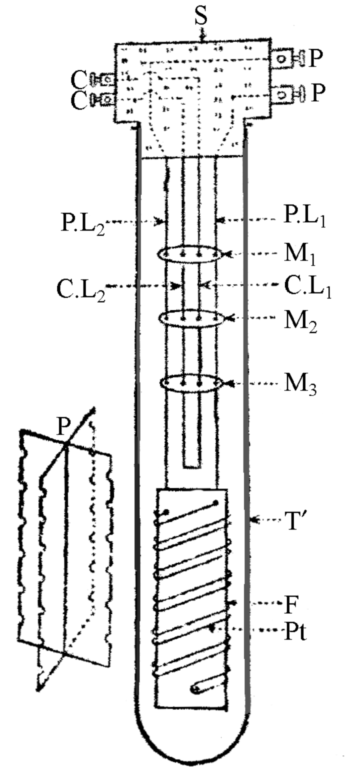


Figure A.13

Platnium resistance thermometer is shown in Fig. A.13. It consists of a mica frame F (actual arrangement of the frame is shown in the figure) on which a coil of pure platinum (Pt) is wound non-inductively. The two ends of the coil are joined to two lead wires ($P.L_1$ and $P.L_2$) which are also made of platinum and whose total resistance is c. By the side of the lead wires ($P.L_1$ and $P.L_2$) of platinum coil there are two other lead wires (C.L_1 and C.L_2) whose lowest ends inside the tube are kept jointed. These compensating lead wires (C.L_1 and C.L_2) are also made of platinum and their total resistance is also made equal to c. The compensating leads (CL_1 and C.L_2) and platinum leads (P.L_1 and P.L_2) are kept in their positions by several mica separators (M_1, M_2, M_3 etc.) through the holes of which the leads pass. The platinum coil and both the lead wires are kept in a glass or porcelain tube T, the mouth of which can be closed by an ebonite stopper S. Through this stopper, the compensating leads are connected to the binding screws C, C (fixed to the stopper S) while the platinum leads are connected to the two other binding screws P, P (also fixed to the stopper S). While the tube T′ is partially introduced into a hot bath the platinum coil is heated and its resistance increases.

Further Reading

• Advanced Practical Physics	:	D. P. Roychoudhuri
• An Advanced Course in Practical Physics (Fourth Edition)	:	D. Chattopadhyaya P. C. Rakshit B. Saha
• A Text-Book on Practical Physics FOR ADVANCED DEGREE STUDENTS (Fourth Edition)	:	K. G. Majumdar
• Advanced Practical Physics Volume II (First Edition)	:	B. Ghosh
• Advanced Practical Physics Volume I New Revised Edition	:	K. G. Majumdar B. Ghosh
• A Hand-Book on Practical Physics (Seventh Edition)	:	C. R. Dasgupta S. N. Maity
• A Text-Book of Advanced Practical Physics (Fourth Edition)	:	Samir Kumar Ghosh
• Physics through Experiment Constant and varrying 1 (Second Edition)	:	B. Saraf, et al
• Physics through Experiment Constant and varrying 2 (First Edition)	:	B. Saraf, et al