Autumn Semester

Instruction Manual

PH 110 PHYSICS LABORATORY

Department of Physics

Indian Institute of Technology Patna

CONTENTS

I. Introduction

Experiments provide a way of scientific enquiry and probing nature through observations. A physics laboratory course gives exposure to this. Physics experiments have also led to important technological applications. Therefore any educational program in science and technology cannot be complete without a good experience in laboratory work.

As scientist and technologist you will be dealing with instruments and apparatus of various kinds throughout your carrier. You will be greatly benefited from the beginning if you take a serious and enthusiastic attitude towards experimental work. There is no substitute for the experience that you gain by conducting laboratory experiments and measurements.

In addition to improve understanding basic physics, a laboratory course would expose you to the philosophy of measurement, use of basic instruments and methodology of data analysis and the scientific documentation. Moreover it offers the student a unique opportunity of learning science by doing rather than by reading.

II. Specific Instructions for Students

1. Assessment in the course is based on
    (i) Your performance in the laboratory class
    (ii) Your laboratory report and
    (iii) The semester examination.
2. **A prior study about the experiment is essential for good performance in the class.** Read the instruction manual carefully before coming to the lab class. If you come unprepared to the lab; your performance would be affected accordingly.
3. **In a laboratory class, you should perform the experiment, complete the calculations & data analysis, and submit the report of the experiment on the same day within the laboratory slot assigned for it**.
4. You must bring with you the following material to the lab:
    a) Report sheets (A4 size paper),
    b) pen, pencil, small scale,
    c) instruction manual,
    d) graph sheets,
    e) Scientific calculator and
    f) A file cover and any other stationary item required.
5. **Submit the file cover in the laboratory on first experiment day. Write down your Name, Roll No. and Group on the file cover.** You should file your record regularly in your file. **You are not allowed to take your reports back.** You will be given your file and records back before the end semester examination of the laboratory course.
6. **At least one set of observation should be signed by the instructor.**

7. **Following is the format of the report**:
    i. Title Page: Consisting of Name, Roll No., date, lab group and title of the experiment.
    ii. Objective of the experiment, Figures related to the experiment, working formula only (you might have to derive it starting from the expressions given in the instruction manual particularly for the linear fit to the data.), meaning of symbols and the schematic diagram of the experimental setup. DO NOT WRITE THE THEORY OF THE EXPERIMENT.
    iii. Experimental specifications: apparatus/instruments used in the experiment.
    iv. Least count of all the equipments, constants if any to be used and the well tabulated observations. Observation tables should be **neat** and **self-explanatory**. (Typical tabular columns have been given for some of the experiments. You may make your own format). ALL PHYSICAL QUANTITIES IN THE TABLE SHOULD HAVE SUITABLE UNITS.
    v. Relevant substitutions, calculations and maximum possible error analysis.
    vi. Graph/graphs if applicable.
    vii. Results along with the error estimates.
    viii. Sources of error(s)/suggestion(s)/comment(s).

(Your lab report should be ready with (i) and (ii) above before coming to the lab. Some marks are allocated for this initial preparation.)

8. Each graph should be well documented:
    (a) The title of the graph should be stated on the **top of each graph paper**.
    (b) Abscissa and ordinate along with the units should be mentioned clearly.
    (c) The scale for x-axis and y-axis should be mentioned preferably at the top right corner in the following manner:
    X-axis: 1 smallest division = …….. (Unit)
    Y-axis: 1 smallest division = …….. (Unit)
    (d) If the nature of graphs shows any maxima/minima, vertical and horizontal lines should be drawn from the point (of maxima/minima) meeting the x-axis and y-axis respectively. Write coordinates at the point on the axes where these two lines meet.
    (e) Plot the graph for linear regression line (where ever applicable).
9. You are expected to give a careful thought on the precautions to be observed in handling any equipment and conducting the experiment. In case of any doubt you should feel free to interact with the instructors.

10. Tentative scheme for evaluation:

a. Day to day performance in the lab			50 Marks
	i. Initial preparation	10 Marks	
	ii. Viva voce	10 Marks	
	iii. Observations & Graph	20 Marks	
	iv. Calculation of result	05 Marks	
	v. Error Analysis	05 Marks	
b. End Semester examination			50 Marks

[Note: Damage of instrument or its component rendering the instrument useless, would amount to a total of ZERO marks for that experiment]

III. Introduction to Error Analysis

All physical measurements are subject to various types of error. It is important to reduce the effect of errors to a minimum. In order to know the uncertainty in measurement or to know the deviation from the true value of a measured quantity, it is important to have an idea of the sources of error as well as estimates. Error involved in any measurement may be broadly classified as (a) systematic error and (b) random error.

(a) Systematic error

Errors that are not revealed through an entire set of measurements are termed systematic errors. Systematic errors may arise because of instrumental defect or experimental bias.

(i) Instrumental errors

Zero offset (instrument does not read zero when input is zero) or incorrect calibration of the instrument or changes of calibration conditions (due change in temperature, pressure or any other environmental changes) are the example of instrumental errors. Zero error can be detected before hand and all the observations are corrected accordingly. For the purpose of this course it can be assumed that the given instrument is calibrated correctly.

(ii) Experimenter's bias

This is a common source of error arising from some bias of the experimenter and is difficult to eradicate. For example parallax error in reading an analog meter is often encountered if care is not taken to view the indicator needle perpendicular to the meter face. Systematic errors are hard to handle. They are best identified and eliminated.

(b) Random errors

Fluctuations in the recording of data or in the instrumental measuring process result in random errors. The effect of random errors can be minimized by appropriate data processing techniques.

(c) Maximum possible error

Most of the experiments involve measurement of several different quantities which are combined to arrive at the final deduced quantity y. Measurement of each of these quantities is limited in accuracy by the least count of the instrument. These errors give rise to a maximum possible error. It can be estimated in the following manner. Suppose the physical quantity, y, is given by the relation

$$y = C\,x_1^{m}\,x_2^{n}$$

Where, C, m and n are known constants. Experimental determination of y involves measurement of x_1 and x_2. The overall maximum uncertainty or maximum possible error in y is given in terms of errors Δx_1 and Δx_2 in the quantities x_1 and x_2 respectively, by

$$\frac{\Delta y}{y} = |m|\left(\frac{\Delta x_1}{x_1}\right) + |n|\left(\frac{\Delta x_2}{x_2}\right)$$

Note that both contributions add up to give the maximum possible error in y, irrespective of whether m or n is positive or negative. This can be illustrated with the help of the following example. The electrical resistivity of a wire of circular cross section is given by

$$\rho = (\pi r^2 V) / (l I)$$

Where, r is the radius and l is the length of the wire, V is the voltage and I is the current flowing through the wire. The maximum possible error in the measurement of resistivity ($\Delta\rho/\rho$) depends on the fractional uncertainties in the voltage ($\Delta V/V$), current ($\Delta I/I$), etc. and is given by

$$\Delta\rho/\rho = 2\,(\Delta r/r) + (\Delta l/l) + (\Delta V/V) + (\Delta I/I)$$

(d) Least Squares Fit/Linear Regression

When the data (x_i, y_i) are linearly related by, $y = ax+b$ the best estimates for the slope a and intercept b of the straight line are obtained as follows: If y is the true value as defined by the above equation, then one should minimize the quantity $[\sum(y - y_i)^2 = \sum(y_i - ax_i - b)^2]$ with respect to a and b. By differentiating this expression w.r.t. a and b, setting them to zero and solving the two simultaneous equations, we get the best estimates of a and b as

$$a = \frac{\{N\sum(x_i y_i) - (\sum x_i)(\sum y_i)\}}{\{N\sum x_i^2 - (\sum x_i)^2\}}$$

$$b = \frac{\{(\sum y_i)(\sum x_i^2) - (\sum x_i)\sum(x_i y_i)\}}{\{N\sum x_i^2 - (\sum x_i)^2\}}$$

After obtaining the values of ***a*** and ***b***, plot the straight line $y = ax + b$ using those values. Plot the observed points too on the same graph. See how well the data are clustered around this straight line. Quite often you may be able to reduce the equation to the linear form by a suitable rearrangement. For example if $y = ce^x$, then $ln(y) = ln c + x$,so a plot of $ln(y)$ vs x would be a straight line.

References

1. J. R. Taylor, *An Introduction to Error Analysis*, University Science Books (1997).

Experiment No. 1

Decay of Current in a Capacitive Circuit

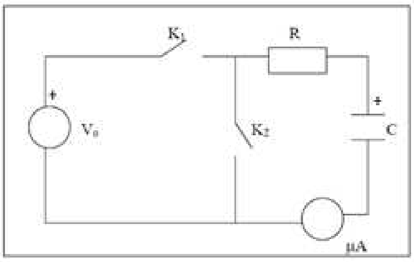
1. Objective

To study the decay of current with time in RC circuit and to determine the time constant of the circuit.

2. Theory

A capacitor can be used to store the energy by accumulation of charges and a charged capacitor can be used to deliver the energy by discharging it through a load. Both charging and discharging are not instantaneous. It can be shown that the charging and discharging times depend on the value of capacitance and total resistance of the circuit.

Fig. 1.1



(a) Charging

For the circuit (Fig 1.1), (with switch $K1$ closed and $K2$ open) containing a capacitance C, a resistance R and a source of constant voltage V_o, the equation for the potential (neglecting the source resistance and resistance of the ammeter) is

$$V_o = iR + (q/C)$$

Where i is the current in the circuit and q is the charge accumulated on the capacitor. Both i and q may be functions of time. Since $i = dq/dt$ we get the equation for q as

$$V_o = R\, dq/dt + (q/C)$$

The solution of this equation is, $q(t) = CV_o\,(1 - e^{-t/\tau})$

Where $\boldsymbol{\tau}$ is the time constant of the circuit and is equal to RC. The current $i(t)$ is given by

$$i(t) = dq/dt = (V_o/R)\, e^{-t/\tau} \qquad (1)$$

The voltage across C is given by, $v(t) = V_o\,(1 - e^{-t/\tau})$ (2)

Equations (1) and (2) describe the decay of current in the circuit and growth of voltage on the capacitor, respectively, during the charging of a capacitor.

Taking natural logarithm on both side of equation (1),

$$ln i = ln(V_o/R) - t/\tau$$

which is a straight line equation.

(b) Discharging

When key K_1 is open and K_2 is closed, with the capacitor charged to a voltage V_o, discharging of the capacitor through the resistance R is described by the following relations:

$$q(t) = CV_o\, e^{-t/\tau}$$
$$i(t) = -dq/dt = (V_o/R)\, e^{-t/\tau} \quad (3)$$
$$v(t) = V_o\, e^{-t/\tau} \quad (4)$$

Equations (3) and (4) describe the decay of current in the circuit and decay of voltage across C, respectively, during the discharging process.

Taking natural logarithm on both side of equation (3),

$$\ln i = \ln(V_o/R) - t/\tau$$

which is a straight line equation.

3. Procedure

i. Assemble the circuit as shown in Fig 1.1. **The experiment is to be performed for only one value of R.**

ii. Set the source voltage V_o (from the power supply) between 2 to 4 V such that the largest (initial) current (V_o/R) has a reasonable value (of the order μA)

iii. Set the ammeter (shown as μA in Fig. 1.1) in an appropriate range (estimate the range from V_o and R).

iv. **Decay of current during charging:** Complete the charging circuit by closing the key K_1 (keeping K_2 open) and simultaneously start a stopwatch. Measure the current i as a function of time at convenient intervals (say 10 seconds).

v. **Decay of current during discharging**: After charging C to the full voltage, discharge it through R. For this purpose disconnect the power supply by opening key K_1. Close the Key K_2 and start the stopwatch. Again measure the current as a function of time at convenient intervals (say, 10 seconds).

vi. Plot ln i (for charging and discharging circuits) as a function of time.

vii. Using the linear regression technique fit the data obtained for the two cases to Eq. (1) and (3), respectively, and draw the best-fit line on the respective graphs.

viii. Determine the time τ constant in both cases and compare it with the theoretically calculated values. Also estimate the maximum possible error.

4. Observation

Least count of Ammeter =

Least count of stop watch =

S. No.	t (s)	I (μA)	ln I

5. References

1. E. M. Purcell, *Electricity and Magnetism* (Berkley Physics Course - Volume 2), Tata McGraw-Hill (2008).
2. D. Halliday and R. Resnick, *Physics* II, Wiley Eastern Limited (1966).

Experiment No. 2

Q-factor of a LCR circuit

1. Objective

To study forced damped oscillations using LCR circuit and determine the Q-factor of the circuit

2. Theory

Any ideal oscillating system would keep on oscillating once disturbed from its equilibrium position since such systems do not have any energy dissipating element present. For example a hypothetical pendulum whose point of suspension does not offer any resistance would keep on oscillating in perfect vacuum forever. However, in reality, the presence of resistive elements could not be ignored and thus practical systems are all damped systems. Nonetheless, it is possible to keep such damped systems in the state of oscillations by pumping energy to the system from a source that provides harmonic driving force. When a damped system is subjected to such forced oscillation, the amplitude of oscillation reaches its maximum when the frequency of harmonic driving force is equal to the natural frequency of the undamped system. This condition is known as Resonance.

In electrical regime, a combination of L and C, known as tank circuit, constitute a oscillating system that shows simple harmonic oscillations, but real life inductors and capacitors contain a resistive element within it, therefore a practical tank circuit is a damped system. To show exclusively the damping nature of the system, one could put a resistance R in series with L and C in the circuit and study the damping nature of the circuit. To keep the system in state of oscillation, the circuit could be excited with and oscillating voltage source, as shown in Fig.1. The resonance (natural) frequency for this circuit is given by

$$\omega_o = 1/(LC)^{1/2}$$

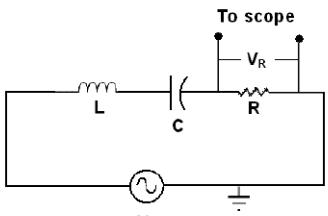


Fig. 2.1

If the voltage applied from the function generator is given by,
$v_s(t) = V_o \sin\omega t$

Then Kirchoff's Voltage Law along the loop yields:

$$L\,di/dt + Ri + (1/C)\int i\,dt = v_s(t)$$

One could solve for $i(t)$ and obtain the general solution. The amplitude of current for such a forced oscillating LCR circuit is given by the expression.

$$I_o = V_o/[R^2 + \{L\omega - 1/C\omega\}^2]^{1/2}$$

From the above expression, it is easy to see that the current is maximum when $\omega = \omega_o$

An important parameter that measures the damping in such oscillatory systems is Q factor of the system. It is defined as

$$Q = \omega\,(\text{energy stored})/(\text{average power dissipated})$$

It can be shown that, $Q = \omega_o/\Delta\omega = \nu_o/\Delta\nu = (1/R)(L/C)^{1/2}$

Where $\Delta\omega$ (= R/L) is the full width at half maxima of the resonance curve for **power.** In this experiment you are expected to plot V_R as a function of frequency and therefore instead of

FWHM, $\Delta\omega$ ($\Delta\nu$), take the full width τ, of the resonance curve between V_R **and** ω, **where** V_R **drops to** $1/\sqrt{2}$ **of its maximum value** as shown in Fig 2.2.

3. Procedure

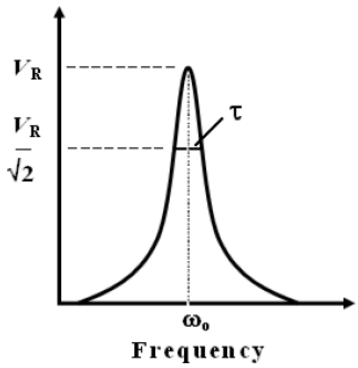


Fig .2.2

i. Assemble the circuit as shown in Fig 2.1.
ii. Set the function generator for sinusoidal signal and adjust the amplitude of the signal to some suitable value (around 1 to 2 V peak to peak) and keep it constant throughout the experiment. The ammeter shows the RMS value of current, so set the signal accordingly.
iii. Record the voltage drop across the resistance R as a function of frequency in a suitable step. Make sure that you should have sufficient data point on either side of the resonance frequency (so as to measure the value of τ).
iv. Plot the graph between frequency and the amplitude of voltage V_R.
v. Mark the Resonance frequency and the width τ on the plot.
vi. Find the resonance frequency from the plot and Q factor (from Eq. (2.10)).
vii. Repeat the experiment by changing the resistance R.
viii. Compare the Q factor for two different values of R.
ix. Estimate the maximum possible error in the measurement of Q.

4. Observation

Least count of Function Generator =
Least count of Voltmeter =
Value of Peak voltage for source =

S. No.	f (kHz)	v_R (V)

5. References

1. D. Halliday and R. Resnick, *Physics* II, Wiley Eastern Limited (1966).

Experiment No. 3

Study of Hall Effect

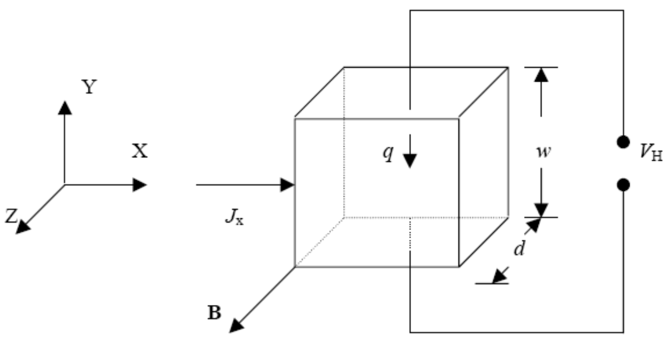
1. Objective

To study Hall Effect in extrinsic semiconducting samples and determine the type, density and mobility of majority charge carriers.

2. Theory

Consider a rectangular slab of semiconductor with thickness *d* kept in XY plane (see Fig. 3.l). An electric field is applied in *x*-direction (E_x) so that a current *I* flows through the sample. If *w* is width of the sample and *d* is the thickness, the current density is given by, $J_x = I/(wd)$.

Fig. 3.1



Now a magnetic field *B* is applied along positive Z - axis (Fig. 3.1). The moving charges are under the influence of magnetic force $q(\boldsymbol{v} \times \boldsymbol{B})$, which results in accumulation of majority charge carriers towards one side of the material (along *Y*-direction in the present case). Since charge cannot leave the top or bottom of the semiconductor slab, a vertical charge imbalance builds up in the slab. This process continues until the electric force due to accumulated charges (qE_y) balances the magnetic force. So, in a steady state the net Lorentz force experienced by charge carriers will be zero. The potential thus developed across *Y*-direction is known as Hall voltage V_H (perpendicular to both current and the magnetic field directions) and this effect is called Hall Effect. Thus the Lorentz force acting on the charge carriers is:

$$\vec{F} = q(E_x\hat{i} - E_y\hat{j}) + q(v_x\hat{i} \times B_z\hat{k}) \qquad (1)$$

where, v_x is the drift velocity of charge carriers, E_x is the electric field component along x-axis that drives the current in the slab, E_y is the perpendicular electric field induced by the charge accumulation at the top and bottom of the semiconductor slab due to the deflection of charge carriers by the magnetic Lorentz force $q(v_x\hat{i} \times B_z\hat{k})$.

Now the equation of motion can be written as

$$\left(\frac{dv_x}{dt} + \frac{1}{\tau}v_x\right)\hat{i} = \frac{q}{m}(E_x\hat{i} - E_y\hat{j}) + \frac{q}{m}(v_x\hat{i} \times B_z\hat{k}) \qquad (2)$$

At steady state $\frac{dv_x}{dt} = 0$, which implies

$$\frac{1}{\tau}v_x = \frac{q}{m}(E_x\hat{i} - E_y\hat{j}) + \frac{q}{m}(v_x\hat{i} \times B_z\hat{k}) \qquad (3)$$

$(3) \times \tau q n \Rightarrow$

$$qnv_x\hat{i} = \frac{q^2\tau n}{m}(E_x\hat{i} - E_y\hat{j}) + \frac{q^2\tau n}{m}(v_x\hat{i} \times B_z\hat{k})$$

$$qnv_x\hat{i} = \frac{q^2\tau n}{m}(E_x\hat{i} - E_y\hat{j}) + \frac{q^2\tau n}{m}v_x B_z\hat{j} \qquad (4)$$

Where, n is the charge density and q is the charge of each carrier, and τ is the relaxation time

From Ohm's law, we have the current density, $\vec{J} = J_x\hat{i} = qnv_x\hat{i} = \sigma E_x\hat{i}$, where $\sigma = \frac{nq^2\tau}{m}$ is the conductivity of the material. Now equating the components of equation (4) gives

$$qnv_x = \sigma E_x \qquad (5)$$

and

$$\begin{aligned} -E_y + v_x B_z &= 0 \\ E_y &= v_x B_z \end{aligned} \qquad (6)$$

In the present case Eq. (6) can be written as, $E_y = vB_z = \left(\frac{J_x}{nq}\right) B_z$ (7)

Where, n is the charge density and q is the charge of each carrier. The ratio $\frac{E_y}{J_x B_z}$ is called the Hall co-efficient R_H . Thus,

$$R_H = \frac{E_y}{J_x B_z} = \frac{V_H \mathrm{d}}{IB} \qquad (8)$$

Where V_H is the measured Hall voltage and d is the thickness of the sample along the current flow direction.(see Fig 3.1)

From Eq. (7) and (8), the Hall co-efficient can also be written as,

$$R_H = \frac{1}{nq}$$

Charge density,

$$n = \frac{1}{R_H q} \qquad (9)$$

Mobility, μ of either charge can be obtained by

$$\mu = \sigma R_H \qquad (10)$$

Procedure

i. Switch on the gauss meter and set it Zero. Set the hall probe of gauss meter in the stand and keep it in between the poles of electromagnet. Set the distance between the poles as 1 cm.

ii. Connect the electromagnet to constant current supply. Switch on the electromagnet and set suitable magnetic field density (< 0.3 Tesla) by varying the current by Constant current supplier to the electro-magnet. Very slowly and carefully increase the current of Constant current supplier to increase the value of magnetic field. Measure this value of magnetic field using the Gauss meter. Find out the direction of magnetic field using the magnetic compass. **DO NOT CHANGE THE MAGNETIC FIELD AND PERFORM STEPS (iii) TO (vii) WITH THIS VALUE ONLY.**

iii. Connect the leads from the sample to the "Hall effect Set-up" unit. A pair of green colour leads is provided for current and that of red colour for Hall voltage.

iv. Insert the sample between the pole pieces of the electromagnet such that the direction of magnetic field is perpendicular to the direction of current and the line connecting the Hall voltage probes.

v. Connect the positive terminal (red) of current lead to positive terminal (red) in Hall Effect set up and positive terminal (red) of voltage to positive terminal (red). This combination of connection is +I and +V for +B.

vi. From the direction of current and magnetic field estimate the direction of accumulation of majority carriers and observe the reading in voltmeter. From this determine the type of the sample.

vii. Record the Hall voltage as a function of sample current. Collect eight sets of readings: V_1(+B+V,+I), V_2(+B,-V,+I), V_3(+B+V,-I), V_4(+B,-V,-I), V_5(-B+V,+I), V_6(-B,-V,+I), V_7(-B+V,-I) and V_8(-B,-V,-I); (here positive or negative signs shows the direction only). Note that field direction of the electromagnet can be changed by changing the direction of current through the constant current power supplier. The Hall voltage V_H is obtained by,

$$V_H = \frac{|V_1|+|V_2|+|V_3|+|V_4|+|V_5|+|V_6|+|V_7|+|V_8|}{8} \quad (5)$$

Thus the stray voltage due to thermo-emf and misalignment of Hall voltage probe is eliminated.

viii. Plot a graph of V_H vs I. From the slope of graph calculate Hall Coefficient R_H and hence charge carrier density n and charge mobility μ.

ix. Estimate the maximum possible error in the measurement of Hall coefficient.

Note: Write down the sample number in the beginning of the Observations.

3. Observation Table

Least Count of Ammeter = 		Least Count of voltmeter =

Least Count of Gaussmeter = 		Least count of Vernier caliper =

Dimension of crystal = ____mm (Length) ×____mm (Breadth)

Thickness of sample and Crystal no.=

Value of constant magnetic field intensity =

S.no.	I (mA)	+B (left → right)				-B (right → left)				V_H
		V_1(+V,+I)	V_2(+V,-I)	V_3(-V,+I)	V_4(-V,-I)	V_1(+V,+I)	V_2(+V,-I)	V_3(-V,+I)	V_4(-V,-I)	
1										
2										
3										
.										

. .										
14										

4. Precautions

i. Do not exceed the current above 7mA from Hall Effect set-up, it may damage the sample.
ii. Current should be increased very slowly from constant current power supply to electromagnet as is it a high current supplier.
iii. Switch off the power of the constant current supply to electromagnet before the changing the polarity.
iv. After changing the polarity in constant current supply to change the direction of magnetic field, do check the magnetic field by the Gauss meter.
v. Handle the leads of wire of the sample with care. With rigorous use it breaks.
vi. When you are leaving the table switch off the constant current power supply.

5. References

1. C. Kittel, *Introduction to Solid State Physics*, John Wiley & Sons (1996).
2. D. J. Griffiths, *Introduction to Electrodynamics*, Prentice-Hall (1999).

Experiment No. 4

Determination of Speed of Sound in Air

1. Objective

To determine the speed of sound in air at room temperature using a cathode ray oscilloscope.

2. Theory

If two sinusoidal inputs, say, $y_1 = a_1\sin(\omega t - \alpha_1)$ and $y_2 = a_2\sin(\omega t - \alpha_2)$ are fed to the x-plates and y-plates of a cathode ray oscilloscope (CRO), the superimposed wave obtained in the screen of the CRO would have the form (*look up the method of superposition of sinusoidal waves in Ref. 1*), $\sin^2(\alpha_1 - \alpha_2) = y_1^2/a_1^2 + y_2^2/a_2^2 - 2(y_1y_2/(a_1a_2))\cos(\alpha_1 - \alpha_2)$ (1)

where a and α represent the amplitude and phase of the two sinusoids respectively. If the phase difference between these two waves $S = (\alpha_1 - \alpha_2)$ is set to be an even multiple of π, i.e., $S = \pm 2n\pi$, then the above expression reduces to: $\sin^2(\alpha_1 - \alpha_2) = \sin^2(2n\pi) = 0$

$\Rightarrow y_1^2/a_1^2 + y_2^2/a_2^2 - 2(y_1y_2/(a_1a_2))\cos(2n\pi) = 0$

$\Rightarrow (y_1/a_1 - y_2/a_2)^2 = 0$

$\Rightarrow y_1 = (a_1/a_2)y_2$ (2)

which is the equation for a straight line. It can be shown that for $S = \pm (2n + 1)\pi$ (i.e, for odd multiples of π), Eq. (8.1) reduces to $y_1 = - (a_1/a_2)y_2$ (3)

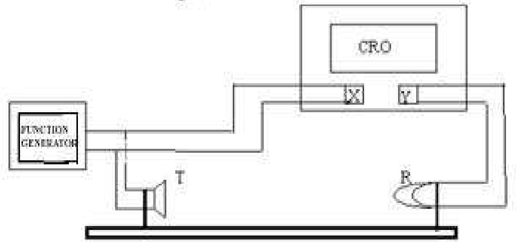
which is again the equation for a straight line with a negative slope as compared to Eq. (2).

Suppose that one of the two electrical signals, x, is derived from the audio generator which is simultaneously connected to a transmitter T (speaker), as shown in Fig.4.1 and the second one '*y'* is that of from the receiver R (microphone) placed in front of the transmitter (at a certain distance). The transmitter will be emitting the sound waves of frequency that of applied from the audio generator. The emitted sound waves propagating in air is received by the receiver. In this case phase difference between the two signals ϕ will depend on the path length traveled by the sound (in air) between transmitter and receiver. If the path length is $n\lambda$ (where λ is the wavelength of the sound wave travelling in air) then the slope of the line displayed on the oscilloscope will be positive (Eq.2) and if it is $(2n + 1)\lambda/2$ then the display will be a straight line with negative slope (Eq.3). Therefore path difference between any two successive straight line is $\lambda/2$.

3. Procedure

i. Wire-up the circuit as shown in Fig. 4.1.
ii. Set the frequency of the audio oscillator between 1-3 kHz. Obtain the sinusoidal wave forms of speaker and microphone on the CRO screen.
iii. Set the oscilloscope in ***xy*** mode by pressing the ***xy*** button on the CRO.
iv. Adjust the amplitude of the sinusoidal input such that an ellipse is obtained on the screen of the scope.

Fig: 4.1



v. Keeping one speaker (T) fixed, move the microphone (receiver R) until the ellipse collapses into a straight line. Note the distance between T and R.
vi. Move receiver R again and obtain the immediately next position for which a straight line (having slope of opposite sign) is obtained on the CRO screen. The distance between such successive positions of the receiver corresponds to half-wavelength ($\lambda/2$) of the sound wave.
vii. Take an average of many such $\lambda/2$ values and then obtain the wavelength corresponding to the particular frequency.
viii. Repeat observation for three more frequency values.
ix. Plot λ vs $1/v$ and obtain the velocity of sound from the graph.
x. Estimate the maximum possible error in the measurement of velocity for each frequency separately.

4. Observation Table

Least Count of Function Generator =

Least Count of meter scale of guide rail =

S. No.	v (Hz)	$1/v$	l_1 (cm)	l_2 (cm)	$l_2 \sim l_1 = \lambda/2$ (cm)	λ (cm)	Mean λ (cm)
1.							

5.							

3. References

1. F. A. Jenkins and H. E. White, *Fundamentals of Optics*, McGraw-Hill (1981).

Experiment No. 5

Determination of '*g*' by a Compound Pendulum

1. Objective

To determine the value of acceleration due to gravity 'g' by a compound pendulum.

2. Theory

The time period of oscillation of a body constrained to rotate about a horizontal axis for small amplitudes is given by expression:

$$T = \left\{\frac{I}{mgd}\right\}^{\frac{1}{2}} \qquad (1)$$

Where, m is the mass of the body, d is the distance between centre of gravity (CG) and the axis of oscillations and I is the moment of inertia (MI) about the axis of oscillations. If I_o is the MI of a body about a parallel axis through CG, then by parallel axis theorem

$$I = I_o + md^2 \qquad (2)$$

Let K be the radius of gyration (i.e. $I_o = mK^2$), then

$$T^2 d = \left(\frac{4\pi^2}{g}\right)(K^2 + d^2) \qquad (3)$$

By observing period of oscillation T by varying d we can obtain the values of gravitational acceleration g as well as moment of inertia I_o of the body.

The plot of T vs d, shows a minimum $T_{\min}$ at $d = K$ given by,

$$T_{min} = 2\pi\left(\frac{2K}{g}\right)^{1/2} \qquad (4)$$

3. Experimental setup

In this experiment the rigid body consists of a long rectangular bar with a series of holes drilled at regular interval to facilitate suspension at various points along its length. A screw type knife-edge can be fitted to the bar these points. The knife-edge can be rested on a wall-mount so that bar is free to move in a vertical plane. The radius of gyration for this bar is

$$K^2 = (l^2 + b^2)/12 \qquad (5)$$

Where l and b are the length and breadth of the bar respectively.

4. Procedure

(i) Determine the centre of mass of the bar by balancing it on a knife-edge.
(ii) Suspend the bar by means of knife-edge.
(iii) Measure d from the sharp-edge of the knife (***and not from the centre of the hole***) to the location of CG of the bar for each hole (point of suspension) in the bar.
(iv) Measure time for around 20 oscillations for different d (only on one side of CM). Repeat each observation ***thrice***.
(v) Plot T vs d. Calculate K and hence g from this graph. Calculate the maximum possible error in the measurement of g in this case.
(vi) Plot T^2d vs d^2. Calculate K and g from the graph.

(vii) Compare values of g obtained from two graphs above.

5. Observation Table

Least count of meter scale=
Least count of stop watch=
Length of bar =
Breath of the bar =
Mass of the bar = 3.2 kg

S. No.	Time period for 20 oscillations			t_{mean}	$T = t_{mean}/20$	d	d^2	$T^2 d$
	t_1 (s)	t_2 (s)	t_3 (s)	(s)	(s)	(cm)	(cm^2)	(cm s^2)

6. References

1. D. Kleppner and R. J. Kolenkow, *An Introduction to Mechanics*, McGraw-Hill (1999).
2. C. Kittel, W. D. Knight, M. A. Ruderman, C. A. Helmholz and B. J. Moyer, *Mechanics* (Berkley Physics Course - Volume 1), Tata McGraw-Hill (2008).

Experiment No. 6

Speed of Light in Glass

1. Objective

To determine the speed of propagation of light waves in glass.

2. Theory

Light travels with the speed $c = 2.998 \times 10^8$ m/s in vacuum. In a material medium its speed (v) is less. As a result, light waves undergo refraction at the interface of two media. In this experiment, we take the material of the medium in the form of a glass prism. A parallel stream of waves travelling from a medium 1 (here air) is incident on the interface of air and glass (of the prism), at incidence angle θ_1. The angle of refraction is θ_2 Snell's law connects the two by the relation:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (1)$$

where n_1 and n_2 are the refractive indices of the two media 1 and 2 respectively. Since the medium 1 here is air ($n_1 \cong 1.000$), the speed of light in the second medium is given by

$$v = c(\sin\theta_2 / \sin\theta_1) \qquad (2)$$

We know that for a certain direction of incidence, the ray travels parallel to the base of the prism and the angular displacement of the final ray that emerges from the second interface of the prism has the lowest possible value. For this minimum angular deviation, δ_m, and the corresponding incidence angle θ_1, the geometry of symmetric propagation inside the medium leads to the equation for v.

$$v = \frac{c\sin\left(\frac{\alpha}{2}\right)}{\sin\left[\frac{(\alpha+\delta_m)}{2}\right]} \qquad (3)$$

Where, α is the angle of the prism and δ_m is the minimum deviation angle. Thus, from a measurement of the angle of the prism and the value of the minimum deviation angle , the speed of light in the material can be determined.

3. Procedure

A spectrometer is used to measure the necessary angles. The spectrometer consists of three units: (1) collimator, (2) telescope, and (3) prism table. The prism table, its base and the telescope can be moved independently around their common vertical axis. A circular angular scale enables one to read angular displacements (together with the two vernier scales located diametrically opposite to each other. In this experiment, we need to produce a parallel beam of rays to be incident on the prism. This is done with the help of the collimator. The collimator has an adjustable rectangular slit at one end and a convex lens at the other end. When the illuminated slit is located at the focus of the lens (Fig. 5.1), a parallel beam of ray emerges from the collimator. There are three major steps in the setting up the experiment.

(a) Mechanical levelling of Spectrometer
(b) Setting of telescope and collimator
(c) Optical levelling

These procedural steps are elaborated below:

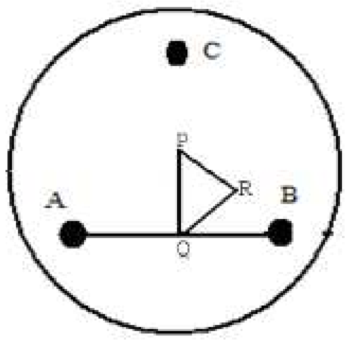
i. **Mechanical leveling of spectrometer:** Place the spirit level near at the centre of prism table parallel to the line joining the two leveling screws of the base. Next, rotate the spirit level by 90^o. Bring the bubble to the centre by rotating the two leveling screws in identical direction and in equal amounts. Rotate the spirit level by 90^o once again so that it is parallel to the imaginary line joining the two leveling screws. Check the balance. If the bubble is out of centre, repeat step 3.1.

ii. **Setting the telescope and collimator**

   a) **Setting the telescope:** Focus the telescope onto a distant (infinity!) object. Test for the absence of a parallax between the image of the distant object and the vertical crosswire. *Parallax effect (i.e. separation of two things when you move your head across horizontally) exits, if the cross-wire and the image of the distant object are not at the same distance from your eyes*. Now the telescope is adjusted for receiving parallel rays. Henceforth do not disturb the telescope focusing adjustment.

   b) **Setting the collimator:** Use the telescope for viewing the illuminated slit through the collimator and adjust the collimator (changing the separation between its lens and slit) till the image of the slit is brought to the plane of cross-wires as judged by the absence of parallax between the image of the slit and cross-wires.

iii. **Optical leveling:** The telescope is set to receive the direct rays by bringing the intersection of the cross-wire of the telescope over the image of the slit seen through it. The telescope is then rotated 90^o.



   a) The prism is then placed over the prism table with its refracting edge upon the centre of table, and a reflecting face of the prism perpendicular to the line joining two leveling screws (A & B) of the prism table. If one of the three leveling screws is attached to the prism table then the face should be place perpendicular to the line joining this screw and an adjustable screw.

   b) Now the prism table should be rotated allowing the refracting edge P to be on the axis of the collimator to receive the light reflected by the face PQ. If the image of the slit received by the telescope is not in the middle of the field of view of the telescope, the two leveling screws A and B should be adjusted one after another until the center of the image as seen through the telescope coincide with the intersection of the cross wires.

   c) The prism table should now be rotated to enable the telescope to receive the image of the slit formed by reflection from the face PR. The third leveling screw C should now be adjusted to bring the center of the image at the intersection of the cross wires. After this adjustment the refracting face of the prism is now parallel to the axis of rotation of the prism table.

   d) It is advised to repeat operation (3.4.3) after operation (3.4.4) to ensure that the image remains in the centre of the field of view after operation 4 has been made.

iv. **Finding the angle of the prism (α):** With the slit width narrowed down sufficiently and prism table leveled, lock the prism table and note the angular position of the telescope when one of the reflected images coincides with the cross-wires. Repeat this for the reflected image on the other side (without disturbing the prism and prism table). The difference in these two angular positions gives 2α (see Fig. 5.2).

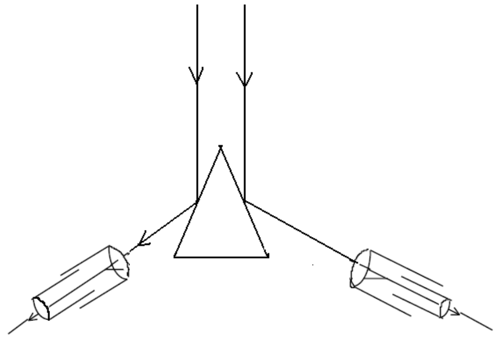


Fig. 5.2 Experimental setup for measuring α

v. **Finding the angle of minimum deviation (δ_m):** Unlock the prism table for the measurement of the angle of minimum deviation. Locate the image of the slit after refraction through the prism as shown in Fig. 5.3. Keeping the image always in the field of view, rotate the prism table till the position where the deviation of the image of the slit is smallest. **At this position, the image will go backward, even when you keep rotating the prism table in the same direction.** Lock both the telescope and the prism table and to use the fine adjustment screw for finer settings. Note the angular position of the prism. In this position the prism is set for minimum deviation. Without disturbing the prism table, move the prism and turn the telescope (now unlock it) towards the direct rays from the collimator. Note the scale reading of this position. The angle of the minimum angular deviation, viz, δ_m is the difference between the readings for these last two settings.

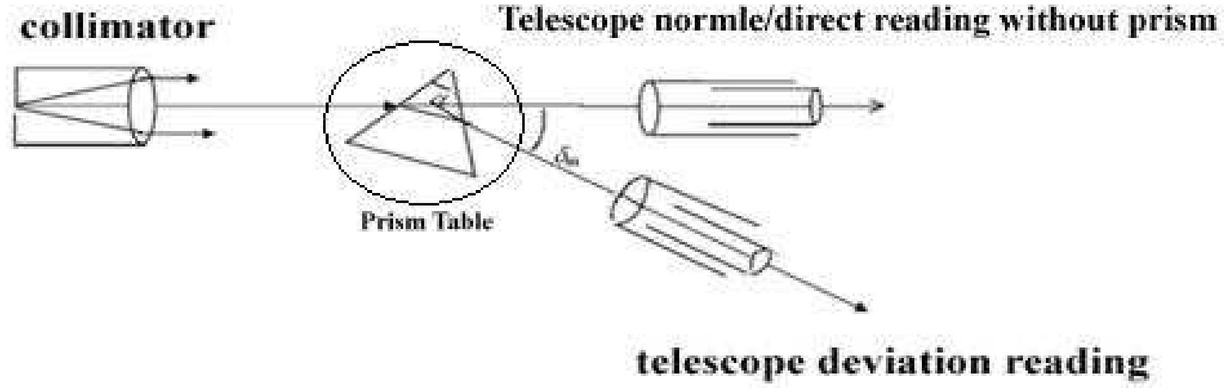


Fig 5.3 Minimum deviation geometry

4. Observation tables

Least count of spectrometer
30 V.S.D coincides with 29 M.S.D
Each M.S.D is 0.5^{o}
Therefore, 30VSD=29MSD
Or, 1VSD= 29/30MSD
Therefore, Vernier Constant= 1MSD-1VSD
= (1-29/30) MSD
=1/30 MSD =1/30 x 0.5degree
=1/60degree =1min

For angle of prism α

Left reflected Ray (L)						2α $L_A \sim R_A$	Right reflected Ray (R)						2α $L_B \sim R_B$	Mean 2α	Mean α
Vernier A			Vernier B				Vernier A			Vernier B					
MSR	VSR	Total	MSR	VSR	Total		MSR	VSR	Total	MSR	VSR	Total			

Readings for Deviation Angle δ_m

Vernier A							Vernier B							Mean
Normal(c)			Deviation(d)			c-d= δ_m	Normal			Deviation			c-d= δ_m	
MSR	VSR	Total	MSR	VSR	Total		MSR	VSR	Total	MSR	VSR	Total		

5. References

1. F. A. Jenkins and H. E. White, *Fundamentals of Optics*, McGraw-Hill (1981).
2. E. Hecht, *Optics*, Pearson Education (2002).
3. A. Ghatak, *Optics*, Tata McGraw-Hill (2005).

Experiment No. 7

Determination of e/m

1. Objective

To measure the *e*/*m* ratio by Thomson's method.

2. Theory

When the electrons are accelerated through the potential V, they gain kinetic energy equal to their charge times the accelerating potential. Therefore,

$$eV = m\frac{v^2}{2}$$

The final (non-relativistic) velocity of the electrons is therefore

$$v = \left(\frac{2eV}{m}\right)^{1/2} \tag{1}$$

When these electrons pass through a region having a magnetic field B, they are acted upon by a force, called the Lorentz force, given by $e\vec{v} \times \vec{B}$ .If the electrons are initially moving along x-axis and the magnetic field is along z-axis, the electrons describe a circular path in the xy-plane with the centripetal force balancing the Lorentz force,

$$evB = m\frac{v^2}{r}$$

Or,

$$v = \frac{eBr}{m} \tag{2}$$

Eliminating v between Eqs.(1) and (2), we get

$$\frac{eBr}{m} = \left(\frac{2eV}{m}\right)^{1/2} \tag{3}$$

Where, *d* is diameter of the circular path. This result assumes that the magnetic field B is uniform. This in the apparatus is produced by a pair of Helmholtz coils (separated by a distance equal to their radius). If n is number of turns in a coil and a its radius, then the magnetic field B, midway between the coils is given by

$$B = 2\,x\,\frac{\mu_0 In}{2\left(\frac{5}{4}\right)^{3/2} a} = 2\,x\,\frac{2\pi In}{\left(\frac{5}{4}\right)^{3/2} a}\,x\,10^{-7}$$

when a current of I amp is flowing in the coils. μ_0 is permeability of free space and is given by

$\mu_0 = 4\pi \, x \, 10^{-7} \; N/A^2$. This field is uniform in the region where the electrons move. Putting the value of B in Eq.(3), we get

$$\frac{e}{m} = \left(\frac{125a^2}{128\pi^2 n^2} x \; 10^{14}\right)\frac{V}{I^2 d^2} \tag{4}$$

The coils in this apparatus have 160 turns each and their radii are 0.14 m. using these values

$$\frac{e}{m} = \left(7.576 \; x \; 10^6\right)\frac{V(volt)}{I^2(amp)^2 d^2(m)^2} \tag{5}$$

3. Description of the Apparatus

The ratio e/m, the charge to mass ratio of the electron, can be measured with a very simple set-up based on Thomson's method. The e/m-tube is bulb-like and contains a filament, a cathode, a grid, a pair of deflection plates and an anode. The filament heats the cathode which emits electrons. The electrons are accelerated through a known potential applied between the cathode and the anode. The grid and the anode have a hole through which electrons can pass. The tube is filled with helium at a very low pressure. Some of the electrons emitted by the cathode collide with helium atoms which get excited and radiate visible light. The electron beam thus leaves a visible track in the tube and all manipulations on it can be seen. The tube is placed between a pair of fixed Helmholtz coils which produce a uniform and known magnetic field. The socket of the tube can be rotated so that the electron beam is at right angles to the magnetic field. The beam is deflected in a circular path of radius r depending on the accelerating potential V, the magnetic field B and the charge to mass ratio e/m. This circular path is visible and the diameter d can be measured and e/m obtained from the relation

$$\frac{e}{m} = \frac{8V}{B^2 d^2} \,.$$

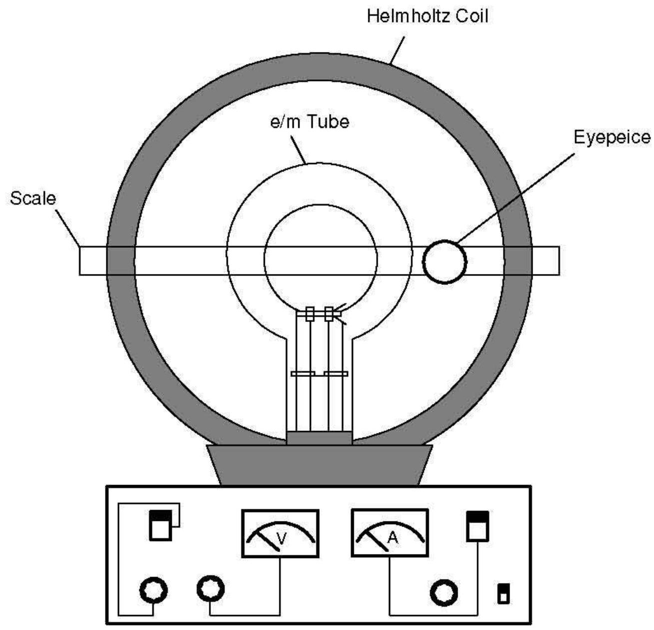


Fig. 1: e/m Experiment, EMX-01

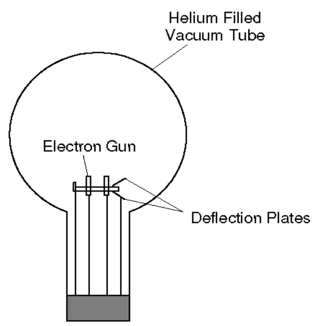


Fig 2: e/m Tube

This set-up can also be used to study the electron beam deflection for different directions of the magnetic field by varying the orientation of the e/m-tube.

The deflecting plates play no role in the experiment. They are interesting for a visual observation of how the electron beam gets deflected when a potential difference is applied between the deflecting plates.

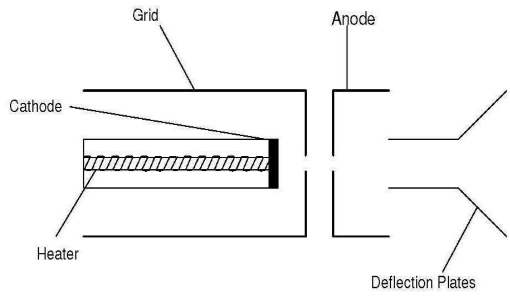


Fig. 3: Electron Gun

The central part of the set-up is the e/m-tube. This is energized by
(i) Filament current supply,
(i) Deflection plates voltage supply,
(ii) Continuously variable accelerating voltage supply to the anode.

The tube is mounted on a rotatable socket and is placed between a pair of Helmholtz coils. The tube can be rotated about a vertical axis, varying the orientation of the electron beam with respect to the Helmholtz coils. This allows magnetic deflection of the beam to be demonstrated. Circular, helical or undeflected paths can be seen. The direction of the current to the Helmholtz coils can be changed. The magnetizing current I and the accelerating voltage V are respectively measured by an ammeter and a voltmeter mounted on the front of the panel. For the measurement of e/m, the socket of the tube is rotated so that the electron beam path at right angles to the magnetic field. The beam is deflected in a circular path. The diameter of the electron beam path is measured by a detachable scale mounted in front of the bulb of the tube. This scale has a slider with a hollow tube (fitted with cross wires at its both ends) to fix the line of sight while making the measurements of the beam path diameter. Base of the unit contains the power supply that provides all the required potentials and the current to the Helmholtz coils. The entire apparatus is contained in a wooden case for convenient storage.

4. Procedure

(i) Turn the power switch to ‘ON’. The indicator lamp will glow.
(ii) Wait a little for the cathode to heat up.
(iii) Turn the accelerator voltage adjust knob clockwise to increase the voltage. Rectilinear electron beam emerging from the cathode will be visible. Adjust the accelerator voltage at about 200 volt.
(iv) It should be clear that the electrons themselves in the beam are not visible. What is observed is the glow of the helium gas in the tube when the electrons collide with the atoms of the gas. We actually see the glow of gas atoms which have been excited by collisions with electrons.
(v) Rotate the *e*/*m* -tube so that the electron beam is parallel to the plane of the Helmholtz coils. Do not take it out of its socket.
(vi) Earth’s magnetic field interferes with the measurements. However this magnetic field is weak compared to the field generated by the Helmholtz coils and we could ignore its effect as a first approximation.

(vii) Slowly turn the current adjust knob clockwise to increase the current for the Helmholtz coils. The electron beam will get curved. Increasing the current will increase the curvature of the beam.
(viii) In case the electron beam does not make a complete (closed) circle and the circular path is skewed, rotate the socket of the tube until the path is a closed circle. This happens when the tube pointer is set at about 90^o.
(ix) Measure the diameter of the electron beam. This measurement has been facilitated by fixing a hollow tube (fitted with cross wires at its both ends) on the slider of the scale. This tube fixes the line of sight during measurements.
(x) Note the ammeter reading for the current to the Helmholtz coils and the voltmeter reading for the accelerating voltage.
(xi) Decrease the accelerating voltage by a small amount (20 volt, say) and measure the diameter of the electron beam path.
(xii) Carry on the observations. **The voltmeter reading should not be increased beyond 250 V. A value lower than 90 volt is also not advisable. Similarly the current to the Helmholtz coils should not be more than 2 A.**

5. Observation Table

Least Count of length scale =
Least Count of Ammeter =
Least Count of Voltmeter =

S.No.	V (Volt)	I (A)	D (cm)	Mean D (cm)	D^2 (cm^2)
1.					

and so on and so forth till 10th serial no.

6. Sources of Error/ Precautions

(i) Before the power is switched to 'ON', make sure all the control knobs are at their minimum position.
(ii) Do not leave the beam ON for long periods of time.
(iii) The main source of error in this experiment is the velocity of the electrons. There is a hole in the anode to allow the electrons to pass through it. This makes the velocity of the electrons non uniform and slightly less than the theoretical value. Further the collisions of the electrons with the helium gas in the tube decrease their velocity a little bit. The effect of these errors can be minimized by measuring the outside radius of the electron beam path and by not using low values of the accelerating voltage.
(iv) Other source of error is in the measurement of the diameter of the electron beam.

Experiment No. 8

Interference of Light: Newton's Ring

1. Objective

To study the interference of light by division of amplitude using the method of Newton's rings and determine the radius of curvature of the lens.

1. Theory

Interference effects are observed in a region of space where two or more coherent waves are superimposed. Depending on the phase difference, the effect of superposition produces variation in intensities, which vary from a maximum of $(a_1 + a_2)^2$ to a minimum of $(a_1 - a_2)^2$ where a_1 and a_2 are the amplitudes of the two individual waves. For the interference effect to be observed, the two waves should be **coherent**. One way of realizing two coherent waves is to derive them from a single wave front. In this experiment, splitting of single wave front into two portions is done by the amplitude division.

Figure 8.1 shows the Newton's ring assembly with a Plano – convex lens placed over a plane glass plate with the curved surface of the lens facing towards the glass plate. An air film is formed between the lower face of the lens L and the glass plate G. The thickness of the air gap is zero at the point of contact and increases radially outward from the centre. The system is illuminated by the light reflected from another glass plate G1 which is illuminated from a sodium vapour lamp as shown in Figure 8.1. Interference fringes are formed due to the superposition of light reflected by the upper and the lower boundaries of the air film. Loci of constant air gap of thickness d will be concentric circles around the point of contact. Therefore fringe pattern in this case will be circular. A fringe of minimum intensity is obtained if the separation satisfies the relation:

$2nd \cos\phi = 2m\ (\lambda/2)$ (1)

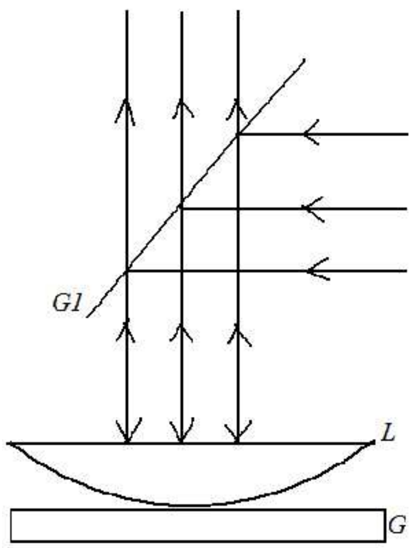


Fig. 8.1

where n is the refractive index of the medium (here air), λ is the wavelength of the light used, and ϕ is the angle of refraction at the glass air interface. For normal incidence, $\phi = 0$, and so

$2d = m\lambda$ (2)

The centre of the ring corresponds to d = 0, and this condition is satisfied with m = 0. At a small distance away from the centre, where the air thickness is $\lambda/2$, we have the first dark ring. When $d = m\lambda/2$, we have the mth. dark ring. Midway between successive dark rings, we have rings of maximum intensity corresponding to the relation.

$d = (2m + 1)\ \lambda/4$ (3)

If R is the radius of curvature of the convex surface, then from figure 8.2

$\rho^2 = R^2 - (R - d)^2$, where ρ is the radius of the ring.

For small d,

$d \cong \rho^2/(2R)$ (4)

This gives the radius of mth. dark ring,

$\rho_m^2 = m\lambda R$ (5)

$$R = \frac{\rho_m^2}{m\lambda}$$

$$R = \frac{Slope}{\lambda}$$

And for bright fringe, $\rho_m^2 = (2m + 1)\,\lambda R$ (6)

2. Procedure

(i) Switch on the light source and obtain the Newton's fringe pattern with good contrast by adjusting the tilt of the mirror G1.

(ii) Focus the microscope on to the lens – plate system to view the fringes. The microscope must be focused so that there is no parallax between cross wire and the image of the rings. Rotate the cross wire so that the horizontal wire passes through the diameter of the ring system and the vertical wire should be tangential to the ring. Move the microscope along the horizontal scale till the vertical cross wire coincides with different successive rings.

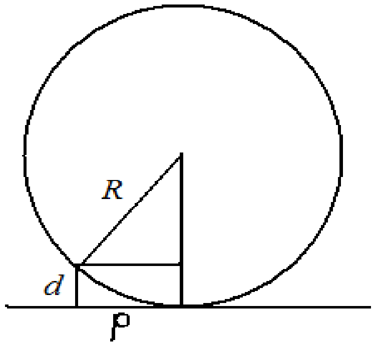


Fig. 8.2

(iii) Measure the diameter (2ρ) of around 20 dark rings (Newton's ring) in the following manner. First take the reading of the 20th dark ring on the left side, then move the microscope to the right and take the reading of 19th ring, then the 18th. And in this way reach the 20th dark ring to the right. OR You can start from the 20th dark ring of the right side and move towards left.

(iv) Plot a graph between order m and ρ_m^2.

(v) Determine R from the least square fit of the data. Estimate maximum possible error in the measurement of R.

3. Observations

Pitch of circular scale of travelling microscope =

MSR = Main Scale Reading; CSR = Circular Scale Reading; TR = Total Reading

m^{th} ring no.	LHS (mm)			RHS (mm)			D = RHS – LHS (mm)	$D/2 = \rho_m$ (mm)	ρ_m^2 (mm^2)
	MSR	CSR	TR	MSR	CSR	TR			
1.									
2.									
3.									
20.									

4. Precautions

i. Avoid parallax error.
ii. Start taking readings from extreme left or extreme right 20^{th} dark fringe to avoid backlash error.

5. References

1. F. A. Jenkins and H. E. White, *Fundamentals of Optics*, McGraw-Hill (1981).
2. E. Hecht, *Optics*, Pearson Education (2002).
3. A. Ghatak, *Optics*, Tata McGraw-Hill (2005).
4. B. K. Mathur, *Principles of Optics*, New Gopal Printing Press (1993).

Experiment No. 9

Surface Tension of Water by Method of Capillary Ascent

1. Objective

To measure the surface tension of water by method of capillary ascent.

2. Theory

If a clean narrow-bore glass tube is placed vertically with one end below the surface of a liquid, the liquid would rise inside the. The height h of this capillary ascent may be calculated by considering the forces maintain the elevated liquid column. If h is measured vertically from the bottom of the meniscus to the horizontal part of the free surface, the weight of a cylinder of liquid of height h, density ρ and radius r which is the internal radius of the capillary tube is balanced by the surface tension acting around the contact circle, whose radius is also equal to r. If the angle of contact is θ, the equation for equilibrium is

$$2\pi rS\, cos\theta = \pi r^2 h\rho g$$

Or, $S = \frac{rh\rho g}{2\cos\theta}$

This ignores the weight of the liquid in the meniscus above the horizontal part. As a first approximation the meniscus is a hemisphere of radius r, and the weight of the liquid above the horizontal tangent to the meniscus is $\frac{1}{3}\pi r^3 \rho g$. The corrected formula is

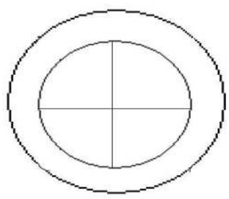
$$S = \frac{r\rho g}{2\cos\theta}\left[h + \frac{r}{3}\right]$$

Thus the correction becomes appreciable only if, within the limits of an experiment, $\frac{1}{3}r$ is comparable to h. the approximate formula may be used with a very narrow capillary tube.

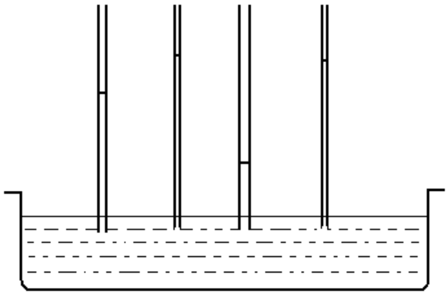
A further simplification occurs for liquids such as water, alcohol, chloroform, etc, whose contact angle is usually assumed to be zero. In such cases

$$S = \frac{r\rho g}{2}\left[h + \frac{r}{3}\right]$$

3. Procedure



(i) Set two to three capillary tubes on a glass slide. Arrange the set up so that the travelling microscope is focused on the inner diameter (i.d.) of the tubes.
(ii) Take readings for both horizontal and vertical inner radius.
(iii) After completion of set the glass slides in such a manner that the capillary tubes touches water in the jar. Then water will rise in the tube. Take readings for height of ascent of water in the capillary tubes.
(iv) Take the readings for water level in the jar also.
(v) Take all the readings thrice.



(vi) Determine the surface tension and also calculate maximum possible error analysis.

4. Observation Table

Least Count of Travelling Microscope =

Readings for Radius of Capillary Tube

S/no	Horizontal diameter – H1							Vertical diameter –V1							Mean of e and f (final inner diameter
	LHS(a)			RHS(b)			Diff = b-a=e	Upward(c)			Downward (d)			Diff = d-c=f	
	MSR	VSR	TOTAL READING	MSR	VSR	TOTAL READING		MSR	VSR	TOTAL READING	MSR	VSR	TOTAL READING		
	3 readings should be taken							3 readings should be taken							

Reading for Ascent in Tubes

S/No	Readings for A				Readings for B				Rise, C=B-A
	Water Level			Mean A	Rise in Capillary tube			Mean B	
	MSR	VSR	TOTAL READING		MSR	VSR	TOTAL READING		
	3 readings should be taken				3 readings should be taken				

5. Precautions

i. Avoid parallax and backlash error.

Experiment - 10

Determination of Planck's Constant

1. Objective

To Determine the Planck's constant

2. Theory:

It was observed as early as 1905 that most metals under influence of radiation, emit electrons. This phenomenon was termed as photoelectric emission. The detailed study of it has shown.

1. That the emission process depends strongly on frequency of radiation.
2. For each metal there exists a critical frequency (v_0) such that light of lower frequency is unable to liberate electrons, while light of higher frequency always does.
3. The emission of electron occurs within a very short time interval after arrival of the radiation and member of electrons is strictly proportional to the intensity of this radiation.

The experimental facts given above are among the strongest evidence that the electromagnetic field is quantified and the field consists of quanta of energy $E = hv$ where, v is the frequency of the radiation and h is the Planck's constant. These quanta are called photons.

What does the critical frequency (v_0) below which no electrons are emitted mean? It implies that there is a minimum energy ϕ for an electron to escape from a particular metal surface or else electrons would pour out all the time. This energy is called the work function of the metal and is related v_0 by the formula

$$\phi = h v_0$$

It then follows that if the frequency of the light is such that $hv > \phi$ it will be possible to eject photoelectron, while if $hv < \phi$, it would be impossible. In the former case, the excess energy of quantum appears as kinetic energy of the electron, so that

$$hv = \frac{1}{2} m v^2 + \phi \tag{1}$$

which is the famous equation for Photoelectric Effect formulated by Einstein in 1905.

The energy of emitted photoelectrons can be measured by simple retarding potential techniques as is done in this experiment. Retarding potential at which the photo current stop, called as stopping potential V_s and is used to measure kinetic energy of electrons E_e, we have,

$$E_e = \frac{1}{2} m v^2 = eV_s$$

Or

$$V_s = \frac{h}{e} v - \frac{\phi}{e}$$

So when we plot a graph V_s as a function of ν, the slope of the straight line yields $\frac{h}{e}$ and the intercept of extrapolated point $\nu = 0$ can give work function ϕ.

3. Procedure

1. Insert the red colour filter (635 nm), set light intensity switch at strong light, voltage direction switch (14) at `-', display mode switch at current display.
2. Adjust the de-accelerating voltage to 0 V and set current multiplier at x 0.001.
3. Increase the de-accelerating to decrease the photo current to zero. Take down the decelerating voltage (V_s) corresponding to zero current of 635 nm wavelength. Get the V_s of other wave lengths, in the same way.

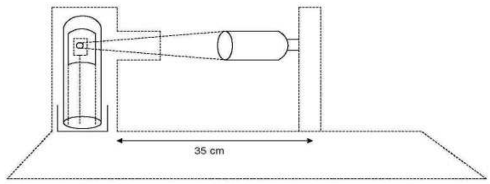


Fig. 1

4. Observation Table

Least Count of Voltmeter =

Least Count of Nano-ammeter =

S.no.	Filter Wavelength (nm)	ν (sec^{-1} x^{14})	Stopping voltage (V_s)			Mean V_s

5. Precautions

a. This instrument should be operated in a dry, cool indoor space.
b. Phototube particularly should not be exposed to direct light, particularly at the time of Installation of phototube; the room should be only dimly lit.
c. The instrument should be kept in dust proof and moisture proof environment, if there is dust on the phototube, color filter, lens etc. clean it by using absorbent cotton with a few drops of alcohol.
d. The color filter should be stored in dry and dust proof environment.
e. After finishing the experiment remember to switch off power and cover the drawtube with the lens cover provided. Phototube is light sensitive device and its sensitivity decreases with exposure to light, due to ageing.

Reference:

Arthur Beiser, Concepts of Modern Physics, 6th Edition (McGraw-Hill publications)