Indian Institute of Technology Guwahati
Department of Physics

PH 110
Physics Laboratory
(online mode)

Instruction Manual: 2021-22

Index

Instructions to Students

Introduction: A few simple experiments are designed to demonstrate some laws of Physics that you already know. In this course we expose you to the simple instruments, handling of these instruments, acquiring data from the instruments, measurements, and methodology of data analyses. Interpretation of results, error analysis and writing a scientific report are other learning steps of this course. PH110 is a unique opportunity of learning physics by doing hands on experiments rather than by reading a book.

However, this time this course is going to be online. It will be conducted online through MS teams. A laboratory group will be subdivided into six small divisions. For example, **PH110_L10_Div1, PH110_L10_Div2, …., PH110_L10_Div6** will be the name of the MS team groups for Lab group **L10**. Such divisions will be made for all lab groups **L1** to **L5**. The sub-group you belong to will be informed to you. Students are supposed to join the corresponding MS team group upon invitation. An Instructor/TA will present an online demonstration of a designated experiment. A pre-recorded data set will be provided to you. You need to do the calculations using the data, perform error analysis, plot graphs (if required). A viva will be taken by MS team call by your instructor during the session. Your calculation, graphs, error analysis, and final result with error bars will be verified by your instructor during the lab class. Then you submit a report.

Specific Instructions:

1. Assessment in the course is based on (i) your day to day activity in the lab class and (ii) a final quiz involving all the experiments.
2. Read the instruction manual carefully before joining the lab class. A prior study about the details of the experiment is essential for good understanding and finishing the calculations in time.
3. You must be ready with the following materials: paper, pen, pencil, scale, graph sheets, calculator and this instruction manual.
4. You are expected to complete the calculations, data analyses, plotting of graphs, error analysis and writing the report of every experiment within class duration.
5. Each graph should be well documented; abscissa and ordinate along with the units should be mentioned clearly. The scale used for abscissa and ordinate should be mentioned on the graph paper. The title of the graph should be stated on the top of each graph paper.
6. The maximum possible error of the results should be estimated.
7. **During the laboratory hours, a one to one interactive session will be held during the lab class which includes verification of your calculations, graph plotting, error analysis, final result and a viva. There is 10 marks (6 for report and 4 for viva) for each lab session.**

8. Following is the format of the report*:*
    a) Cover page: Experiment number, title of the Experiment, Name, Roll no, and date. (Be ready with this page before joining the class).
    b) Objective of the experiment, working formula (you might have to derive it starting from the expressions given in the instruction manual particularly for the linear fit to the data.), explanation of the symbols and diagrams/figures (if required). (Be ready with this page before joining the class).
    c) After demonstration, you will be asked to download a data set. Note the data set number in your report.
    d) Least count of all the equipment, 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 in the manual. You may make your own format).
    e) Relevant substitutions, calculations and error analyses.
    f) Graph/graphs if applicable.
    g) Results along with the error estimates.
    h) Remarks/suggestion/comments if any.
9. After you finish writing the report, you need to scan it (or take a photo of it) and make a single file by the name Rollno_Expn.pdf. For example, a student with roll No. 200122005 performed experiment1, then the file name should be **200122005_Exp1.pdf**.
10. Upload the report file in the MS team by 12:30 pm on the same day of the lab. Closing time is 5:30 pm of the same day. One could make a late submission during 12:30-5:30 pm with justification which will be verified by the instructor for consideration. For submission during 12:30-5:30 pm without justification, there will be deduction of one mark for every half an hour delay.
11. Zero marks will be awarded if report is not submitted.
12. After performing the experiment as per schedule one must upload/submit at least five reports to fulfil 75% attendance criterion, Without five reports no final grade will be awarded.
13. Final mark out of 100 will be calculated by adding marks of (Lab1 + Lab2 + ----- + Lab6) each of 10 marks and Quiz mark (out of 40).

For details, please consult the PH110 webpage

https://www.iitg.ac.in/phy/ph110.php

Introduction to Error and Data Analysis

All physical measurements are subject to various types of errors. It is important to reduce the effect of errors to a minimum. In order to know the uncertainty in a 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 their estimates. Errors 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 examples of instrumental errors. Zero error can be detected beforehand and all the observations are to be 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's 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 minimised by appropriate data processing techniques.

(c) Probable error

It is known from experience that the repetitive measurement of a single quantity *x* shows up fluctuating deviations from the average value. The probability of occurrence of these deviations is expressed by the normal distribution,

$$P(x)dx = \frac{1}{\sqrt{2\pi\sigma^2}}\ exp\left[-\frac{(x-\bar{x})^2}{2\sigma^2}\right]dx \qquad (1)$$

where $P(x)dx$ is the probability that the observation lies in an interval x to $x+dx$, $\bar{x}$ is the mean and σ is the standard deviation. The mean and the standard deviation are given by

$$\bar{x} = \int_{-\infty}^{+\infty} xP(x)dx \quad and \quad \sigma^2 = \int_{-\infty}^{+\infty} (x-\bar{x})^2 P(x)dx \qquad (2)$$

where σ is a measure of spread of observations about $\bar{x}$. For a discrete set of data they are given by the expressions,

$$\bar{x} = \frac{1}{N}\sum_i x_i \qquad and \quad \sigma^2 = \frac{1}{N-1}\sum_i (x-\bar{x})^2 \qquad (3)$$

where N is the total number of observations. Standard error is defined as

$$e_r = \frac{\sigma}{\sqrt{N}} \qquad (4)$$

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

$$y = Cx_1^m x_2^n \qquad (5)$$

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

$$\frac{\Delta y}{y} = |m| \frac{\Delta x_1}{x_1} + |n| \frac{\Delta x_2}{x_2} \qquad (6)$$

Note that both contributions add up to give the maximum possible error in y, irrespective of whether m or n is +ve or -ve.

This can be illustrated with the help of the following example:

The electrical resistivity of a wire of circular cross section is given by

$$\rho = \pi \frac{r^2 V}{l\, I} \qquad (7)$$

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

$\left(\frac{\Delta\rho}{\rho}\right)$ depends on the fractional uncertainties in the voltage $\left(\frac{\Delta V}{V}\right)$ current $\left(\frac{\Delta I}{I}\right)$ etc. and is given by

$$\frac{\Delta\rho}{\rho} = 2\frac{\Delta r}{r} + \frac{\Delta l}{l} + \frac{\Delta V}{V} + \frac{\Delta I}{I} \qquad (8)$$

Data analysis

From experiments, one usually collect *N* data points (x_i, y_i) where $i = 1, \cdots, N$. Using such raw data, new quantities need to be estimated. During such estimates one must consider propagation of errors and keep data up to right decimal points.

Very often it is found that the data follow a linear relationship. Fitting of a straight line through the data points is required to estimate the slope and constant of the linear equation. This is usually done by linear least square fitting of the data points as discussed below.

Least squares fit

When the data (x_i, y_i) are linearly related by

$$y = ax + b \qquad (9)$$

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 equation (9), then one should minimise the quantity

$$\chi^2 = \sum_{i=1}^{N} (y_i - ax_i - b)^2$$

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

$$\frac{\partial \chi^2}{\partial a} = 0 \qquad\qquad \frac{\partial \chi^2}{\partial b} = 0$$

$$a = \frac{N\sum_i x_i y_i - \sum_i x_i \sum_i y_i}{N\sum_i x_i^2 - \left(\sum_i x_i\right)^2} \quad \text{and} \quad b = \frac{\sum_i y_i \sum_i x_i^2 - \sum_i x_i \sum_i x_i y_i}{N\sum_i x_i^2 - \left(\sum_i x_i\right)^2} \qquad (10)$$

After obtaining the values of a and b, plot the straight line $y = ax + b$ using these 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 $lny = lnc + x$, so a plot of ln(y) vs x would be a straight line.

Reference

1. John R Taylor, *An Introduction to Error Analysis*, Second ed, University Science Book (1996).

Exp.1: Fly Wheel

Objective

To determine the moment of inertia of a flywheel about its own axis of rotation.

Apparatus:

Flywheel, meter scale, Vernier calliper, stop watch, inextensible thread, weights and a pan.

Theory:

In order to find the moment of inertia of the fly wheel about the fixed axis of rotation, a mass m (including the mass of the weight hanger) is attached to the axle of the flywheel by a thread which is fixed at the other end with P and wrapped several times (say in n_1 turns) over the axle of the fly wheel. If the mass m is left free, it would descent under the gravity freely setting the fly wheel in rotation. The height h of the mass m from the floor level before it starts descending is so adjusted so that when it strikes at the floor, the thread leaves the axle.

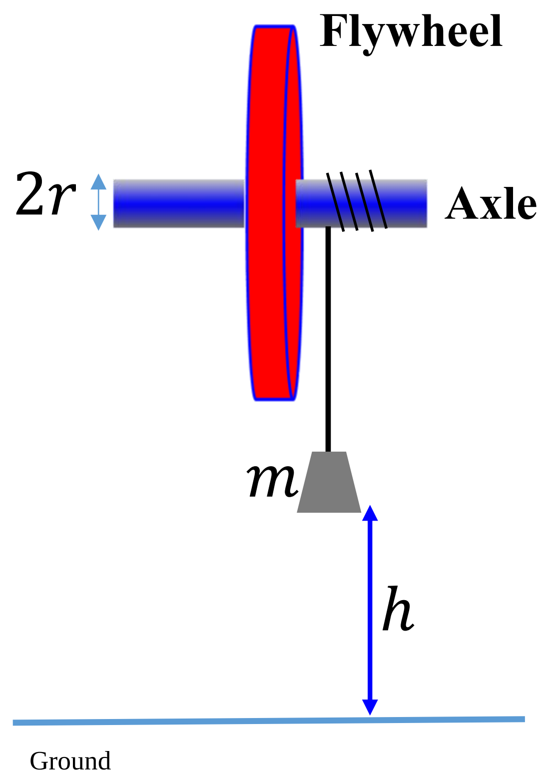

Fig.1

From the principal of conservation of energy,

$$mgh = \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2 + n_1 f \qquad (1)$$

where n_1 is the number of revolutions fly wheel makes till the instant mass m is detached from the axle, v is linear velocity of mass m, ω is angular velocity of the wheel at the instant when thread leaves the axle, f is the energy used in overcoming the frictional forces during one rotation and I is the moment of inertia of the wheel and axle about the fixed axis of rotation.

Angular velocity of the fly wheel is measured by counting the number of revolutions n_2 made by the wheel and correspondingly recording the time t. It is given by

$$\omega = \frac{4\pi n_2}{t} \qquad (2)$$

Let's assume that the fly wheel completes n_2 rotations in order to come to rest after the thread leaves the axle. Thus,

$$\frac{1}{2}I\omega^2 = n_2 f \qquad (3)$$

Substituting Eq. (3) into Eq. (1) gives,

$$mgh = \frac{1}{2}I\omega^2\left(1+\frac{n_1}{n_2}\right)+\frac{1}{2}mv^2 \tag{4}$$

Further, if the radius of the axle of the fly wheel is r, then v = $r\omega$. Thus, moment of inertia of the fly wheel is given by

$$I = \frac{mght^2}{8\pi^2 n_2(n_1+n_2)} - \frac{mr^2 n_2}{(n_1+n_2)} \tag{5}$$

Procedure: Adjust the length of the thread so that when mass *m* touches the floor, the other end of the thread remains just attached to the axle. Use the following procedures step-by-step:

1. Attach a mass to one end of the thread. Wrap the other end of the thread n_1 (an integer) rounds on the axle without any overlap. Ensure that the fly wheel makes around 40-50 rotations once the thread leaves the axle.
2. Measure the height (*h*) of the weight hanger from the floor.
3. Release the flywheel. The pin P slips off from the peg when the weight hanger just touches the ground. By this time, the flywheel would have made n_1 rotations.
4. Just when the thread gets detached from the axle after n_1 turns, start the stop watch. Count the number of revolution n_2 before the flywheel comes to rest. Stop the stop watch at this moment. Thus n_2 and *t* are known.
5. Repeat "steps 1-5" for at least three different values of *m*.
6. With the help of a Vernier calliper, measure the diameter of the axle at several points in one direction as well as for the points in the corresponding perpendicular directions. Measure the length of the wrapped thread with the help of meter scale.

Observations: Determination of n_1, n_2 and *t*:

Least count of the stop watch =

Least count of the meter scale

S No	Total mass hanged *m* (kg)	Height above the ground *h* (m)	n_1	n_2	Time for n_2 revolutions, *t* (sec)	Mean n_2	Mean *t* (sec)	$\omega = \frac{4\pi n_2}{t}$ rad/sec
1								
2								

Determination of radius of the axle: Least count of the Vernier caliper =

Zero error of the Vernier caliper =

S No	Reading along any direction			Reading along Perpendicular Direction			Axle diameter, (X+Y)/2 cm	Mean axle radius $r = d/2$ cm
	Main Scale	Vernier Scale	Total X cm	Main Scale	Vernier Scale	Total Y cm		
1								
2								
3								

Radius of the axle =

Calculation:

Following procedures should be adopted for the calculation of I:

1. Calculate I for every m and h combinations using Eq. 5. Find out the average value of I.
2. Consider identical h for all m in the first table. Plot $2gh/\omega^2$ vs $\frac{1}{m}\left(1+\frac{n_1}{n_2}\right)$ graph by least squares fitting. Calculate I and r from the graph.
3. Compare the value of I and r obtained from the graph and from step 1.
4. Determine maximum possible error in the measurement of I.

Reference:

1. Resnick & Halliday, *Fundamentals of Physics*, John Wiley & Sons (1981).
2. B. L. Worshnop and H. T. Flint, *Advanced Practical Physics*, Khosla Pub House (1991).

Exp.2: Jaeger's Method

Objectives:

To determine the surface tension of a given liquid by Jaeger's method.

Apparatus:

Jaeger's apparatus, travelling microscope, adjustable stand.

Theory:

The apparatus used by Jaeger is depicted in Fig. 1. This apparatus consists of a bottle B to which a funnel F is attached in order to pour liquid into it. Another glass tube containing the manometer M and a capillary tube C is attached to the bottle B. The end of C is drawn into a fine capillary tube with a circular orifice and is dipped to a depth h into the liquid whose surface tension is to be determined. Liquid rises in the capillary tube up to a certain height. Now if the liquid is allowed to slowly enter into the bottle B from the funnel though the stop-cock S_1, an equal amount of air is pushed out of the bottle into the tube with the manometer and capillary tube C, thereby compressing the liquid in C. The liquid column in C is pushed down and the air escapes in the form of a bubble at the end of C. The radius of the bubble gradually decreases with increasing pressure inside it and finally reaches a minimum value, which is equal to the radius (r) of orifice at the open end of C. Two external pressures act on the bubble at this stage. When the two pressures are equal, the bubble becomes hemispherical. Any slight increase of the inner air pressure at this stage upsets the stability of the bubble and it gets blown out of the end of C. Let us consider equilibrium of the air bubble just before its detachment from the orifice of C. If P is the atmospheric pressure, then the pressure acting from inside the air bubble is

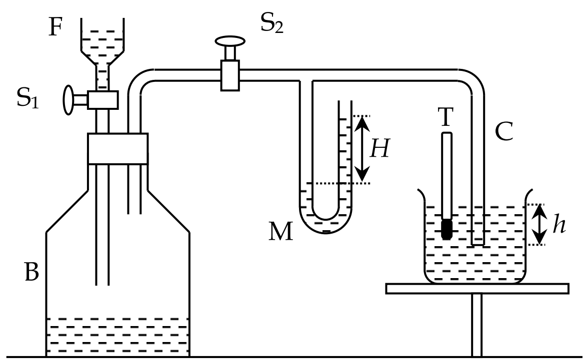

Figure 1: Experimental set-up for Jaeger's method.

$$P_{in} = P + H\rho g \qquad (1)$$

where H is the maximum difference in the level of liquid in the manometer and ρ is the density of the liquid in the manometer. At the same time pressure outside the bubble is

$$P_{out} = P + h\sigma g \qquad (2)$$

where σ is the density of the liquid for which surface tension is to be measured. The excess pressure inside the bubble over the outside is

$$P_{excess} = (P + H\rho g) - (P + h\sigma g) \qquad (3)$$

But the excess pressure within the air bubble in a liquid is $2T/r$. Hence,

$$T = \frac{1}{2} r g (H\rho - h\sigma) \qquad (4)$$

The unit of surface tension is "Newton/meter".

Procedure: Measurement of orifice radius of the capillary tube using the travelling microscope

In order to measure orifice radius, following procedures have to be executed step-by-step:

1. Clamp the capillary tube on the holder in horizontal position.
2. Arrange microscope in horizontal position and in line with the horizontal axis of the capillary tube.
3. Focus microscope on the orifice of the capillary tube.
4. Now adjust the microscope in such a way that the vertical crosswire coincides with the left end of the orifice of the capillary tube (Fig. 2). Note down the reading.
5. Bring the vertical crosswire on the right end of the orifice of the capillary tube. Note down the reading.
6. Now adjust microscope so that the horizontal crosswire becomes tangent to the lower end of the orifice. Note down the reading.
7. Bring the horizontal crosswire on the upper end of the orifice of the capillary tube. Note down the reading.

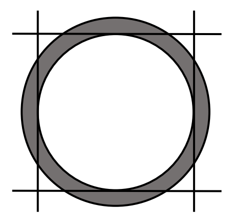

Figure 2: Measurement of orifice radius.

From the observations you will get two values of diameter, one for vertical and one for the horizontal. Repeat the diameter measurement at least thrice for both the directions. Be careful to avoid backlash error and move the microscope in one direction for both measurements.

Measurement of surface tension by Jaeger's method: Referring to Fig. 1, first ensure that the bottle B is tightly closed and there is no leakage of air from any point where rubber tubes/cocks are used to connect glass tubes/capillary. Now, in order to carry out the experiment, following procedures have to be executed step-by-step:

1. Fix the capillary tube "C" so that it stands vertically as shown in Fig. 1. Dip it inside the liquid whose surface tension is to be measured. The immersed height should be ~3-4 cm.
2. Measure h with the help of the microscope. For this, the travelling microscope should be first focused on the lower end of the capillary tube "C" with horizontal crosswire coinciding with the lower end of the capillary tube. Note down the reading. Now, focus in a way that the horizontal crosswire coincides with the water level. Note down the reading. Difference of these two readings leads to h. Be careful to avoid backlash error and move the microscope in one direction for both measurements.
3. Open S_1 slightly so that the liquid falls into the bottle B. Adjust S_1 & S_2 so that a sufficient gap is maintained in the formation of successive air bubbles at the immersed end of the glass capillary C. Using the travelling microscope, record maximum difference in the height of the liquid in the two arms of the manometer just when bubble attains a radius equal to the radius of the orifice of the capillary tube.
4. Repeat "step 3" at least five times for same h and then several times by varying h.

Observations: Measurement of radius of the orifice of the capillary tube:

Least count of the microscope =

S. No.	Microscope reading in one direction			Microscope reading in perpendicular direction			Mean dia (cm)	Mean radius (cm)
	One End (cm)	Other End (cm)	Diameter (cm)	One End (cm)	Other End (cm)	Diameter (cm)		
1								
2								
3								

Measurement of H and h:
Room temperature =
Density (ρ) of the liquid in the manometer at room temp =
Density (σ) of the liquid for which surface tension is to be measured at room temp =

S. No.	r (cm)	h (cm)	Manometer reading		H (cm) ($y - x$)	Mean H (cm)
			Lower end (x) (cm)	Upper end (y) (cm)		
1						
..						

Average H =

Calculation:

Following procedures should be adopted for the analysis:

1. Calculate T using Eq. (4) for room temperature for the given liquid. Compare the obtained value from the theoretical value for the given liquid.
2. Estimate maximum possible error in the measurement made by both the methods.

Reference:

1. Resnick & Halliday, *Fundamentals of Physics*, John Wiley & Sons (1981).
2. B. L. Worshnop and H. T. Flint, *Advanced Practical Physics*, Khosla Pub House (1991).

Exp.3: Magnetic field along the axis of a circular coil

Objective:
To measure the magnetic field along the axis of a circular coil in the presence of the Earth's magnetic field.

Apparatus: Stewart and Gee galvanometer, constant current supply, commutator, plug key, spirit level.

Theory:
In this experiment, the coil is oriented such that the plane of the coil is vertical and parallel to the magnetic north-south direction. The axis of the coil and the field produced by the coil are parallel to the east-west direction (Figure 1). The net field at any point x along the axis, is the vector sum of the fields due the coil B(x) and earth B_E. The ratio of the two is given by

$$\tan\theta = \frac{B(x)}{B_E}$$

$$B(x) = B_E \tan\theta \qquad (1)$$

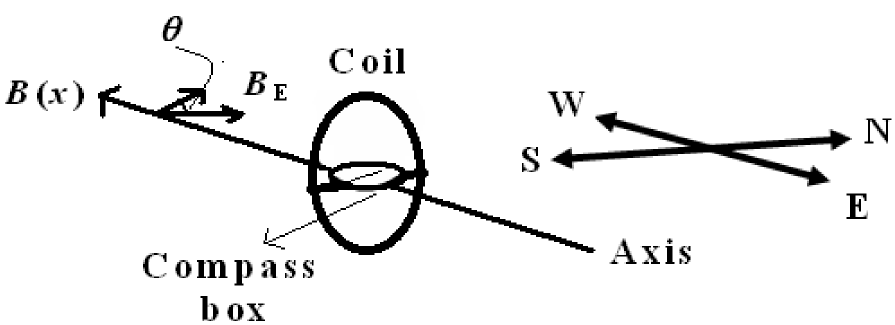

Fig 1

For a circular coil of n turns, carrying a current I, the magnetic field along its axis is given by

$$B(x) = \frac{\mu_0 n I R^2}{2} \frac{1}{\left(R^2 + x^2\right)^{\frac{3}{2}}} \qquad (2)$$

where R is the radius of the coil.

Procedure:

1. The apparatus consists of a coil mounted perpendicular to the base. A sliding compass box is mounted on graduated aluminium rails so that the compass is always on the axis of the coil.
2. Orient the apparatus such that the coil is in the north-south plane using the orientation of the magnet in the compass box. (You may use the red dot on the bar magnet as reference). Adjust the levelling screws to make the base horizontal. Make sure that the compass is moving freely.
3. Place the compass box at the centre of the coil.
4. Connect the circuit as shown in the figure 2.

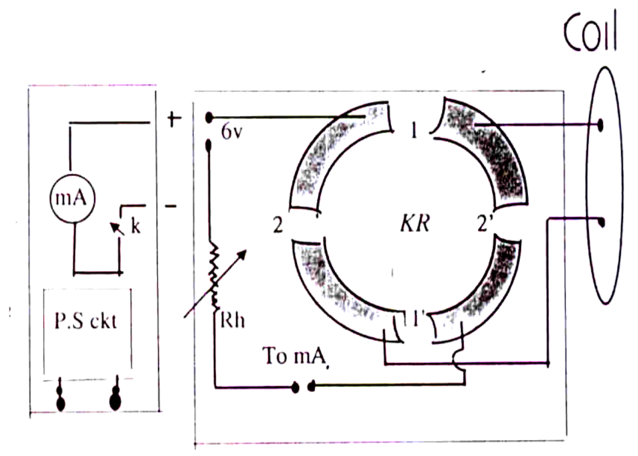

Fig. 2

5. Place the compass box at the centre of the coil and rotate it so that the pointer (needle) indicate 0-0.
6. Close the keys K and KR (make sure that you are not shorting the power supply) and adjust the current with the potentiometer, Rh so that the deflection of the pointer is between 50 to 60 degrees. The current will be kept fixed at this value for the rest of the experiment.
7. Note down the readings θ_1 and θ_2. Reverse the current by suitably connecting the keys of KR and note down θ_3 and θ_4. All θ values should be in suitable units.
8. Repeat the experiment by moving the compass box at intervals of 2cm along the axis until the value of the field drops to 10% of its value at the center of the coil.
9. Repeat the procedure by moving the compass box on the other side of the coil.
10. Plot $B(x) = B_E \tan\theta$ against x.
11. Identify the values of B for x = 0, 10 cm & 20 cm from the graph and compare with the theoretical value calculated from eqn(2).
12. Estimate the maximum possible errors in B at these positions

Observation

No of turns of the coil, n =.........

Radius of the coil, R = 10cm

Current in the coil, I =.........

Permeability of air, $\mu_0 = 4\pi \times 10^{-7}$ N/A^2

Earth's magnetic field, $B_E = 0.39\times10^{-4}$ T

x	θ_1	θ_2	θ_3	θ_4	θ *avg*	Tan θ

Reference:

1. Resnick & Halliday, *Fundamentals of Physics*, John Wiley & Sons (1981).
2. D. J. Griffiths, *Introduction to Electrodynamics*, Prentice Hall (1995).

Exp.4: LCR Circuit

Objective: To determine the resonant frequency and the quality factor for a given *LCR* circuit.

Apparatus: Signal generator, Cathode Ray Oscilloscope, wish board and passive electronic components (resistors, inductor, capacitor).

Theory

Let us consider a simple harmonic driving force given by $F(t)=F_o \cos(\omega t)$ on a damped oscillator. The equation of motion for such a system can be written as

$$\frac{d^2x}{dt^2} + 2\mu\frac{dx}{dt} + kx = \frac{F_o}{m}\cos(\omega t) \qquad (1)$$

where, 2μ is the damping coefficient, k is the spring constant and ω is the angular frequency of the driving force.

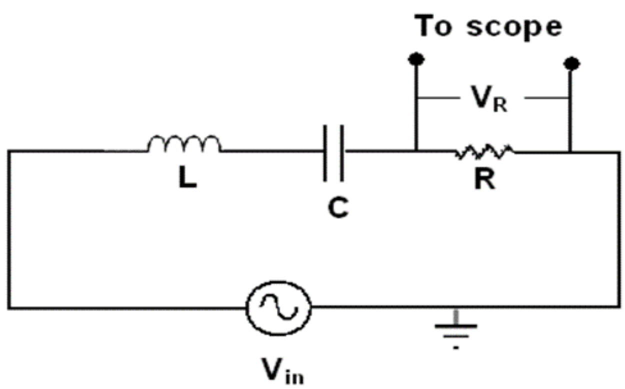

Figure 1

At steady state, the instantaneous displacement is given by

$$x = A\cos(\omega t + \delta) \qquad (2)$$

where δ is the phase difference between the displacement and the driving force given by

$$\tan\delta = \frac{-2\mu}{\omega^2 - \omega_o^2} \qquad (3)$$

ω_o is the natural frequency of oscillations and A is the maximum amplitude of oscillations given by

$$A = \frac{F_o}{m}\left[\frac{1}{\left(\omega^2 - \omega_o^2\right)^2 + 4\mu^2\omega^2}\right]^{1/2} \tag{4}$$

From Eq. 4, the amplitude of oscillations will be maximum at the resonance, when the frequency of driving force is equal to the natural frequency of oscillation, $\omega = \omega_o$. A very good example of the physical system described by Eq. 1 is a series LCR circuit connected to a sinusoidal voltage source (function generator) as shown in Fig. 1. The resonance (natural) frequency for this circuit is given by

$$\omega_o = \frac{1}{\sqrt{LC}} \tag{5}$$

If the voltage applied from the function generator is given by

$$V_{(in)} = V_{o(in)} \sin \omega t \tag{6}$$

then the equation governing the current in such a circuit is given by

$$L\frac{dI}{dt} + RI + \frac{1}{C}\int i dt = V_{o(in)} \sin \omega t \tag{7}$$

Differentiation of Eq. 7 will give an equation similar to Eq. 1. Hence the circuit of Fig 1 can be treated as a forced damped harmonic oscillator whose amplitude of current given by

$$I_o = \frac{V_{o(in)}}{\sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}} \tag{8}$$

From the above equation, the current in the circuit will be maximum corresponding to the resonance frequency of the circuit given by Eq. 5. A typical graph, with the applied frequencies as abscissa and the current amplitude as ordinate, is shown in Fig. 2. As can be observed, the current is maximum at $\omega = \omega_0$. Furthermore, as the resistance in the circuit decreases, the curves get narrower and taller. The sharpness of curves is usually described by a dimensionless parameter known as the quality factor (or Q-factor), denoted by

$$Q = \frac{\omega_0}{\Delta\omega} \tag{9}$$

where $\Delta\omega$ is the width of the curve measured between the two values of ω at that current falls to the $1/\sqrt{2}$ of its maximum value and termed as bandwidth or full-width-at-half-maximum (FWHM). One can also determine Q from the graph plotted with the applied frequencies as abscissa and the V_R as ordinate. Physically, Q is defined as

$$Q = 2\pi \frac{Energy\ stored\ in\ the\ system}{Energy\ lost\ per\ cycle\ from\ the\ system} \tag{10}$$

Maximum energy stored in the inductor is $LI^2/2$ with $I = I_{max}$. At this instant, I and V_C are 90^o out of phase, and hence, no energy is stored in the capacitor. The energy lost in one cycle is $I^2_{rms}R\times 2\pi/\omega_0 = I^2_{max}R\times\pi/\omega_0$. Using Eq. (10),

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} \tag{11}$$

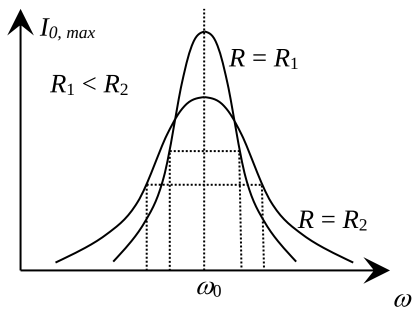

Fig. 2

Procedure

1. Assemble the circuit as shown in Fig. 1.
2. Set the function generator for sinusoidal signal and adjust the amplitude of the signal to some suitable value (around 1 to 2 V) and keep it constant, throughout the experiment for each reading.
3. Record the voltage drop across the resistance R as a function of frequency in a suitable step. Make sure that you have sufficient data points on either side of the resonance frequency (so as to measure the value of τ).
4. Plot the graph between frequency and the amplitude of voltage V_R.
5. Find the resonance frequency and the FWHM τ from the plot.
6. Find the Q factor.
7. Estimate the maximum possible error in the measurement of Q.

Observation:

Least count of Signal generator=
Least count of CRO=
L=
C=
R=

S. No.	Frequency f (kHz)	$\omega = 2\pi f$	Input voltage (V)	Voltage across R (V)
1	2.5			
2	3.0			
3	3.5			
..				

Reference:

1. Resnick & Halliday, *Fundamentals of Physics*, John Wiley & Sons (1981).
2. H. J. Pain, *Physics of Vibrations and Waves*, Wiley (2006).

Exp.5: Study of Hall Effect

Objective:

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

Apparatus: Hall effect set-up, constant current supply, Electromagnet, Gauss meter with Hall probe, Digital milli-voltmeter, bar magnet.

Theory:

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

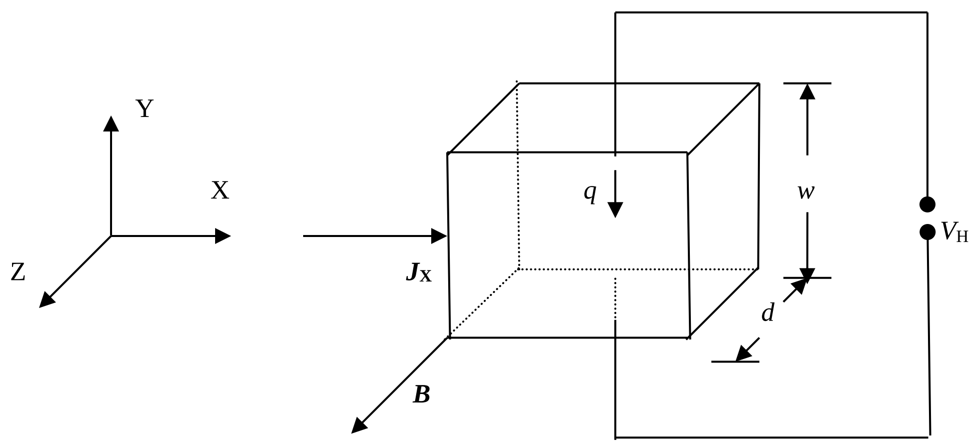

Fig. 1

Now a magnetic field *B* is applied along positive Z- axis (Fig. 1). Appearance of voltage difference in the mutually perpendicular direction under such conditions is called as Hall effect. The moving charges are under the influence of magnetic force $q\left(\vec{v} \times \vec{B}\right)$, which results in accumulation of majority charge carriers towards one side of the material (along Y-direction in the present case). This process continues until the electric force due to accumulated charges (qE) balances the magnetic force. So, in a steady state, the net Lorentz force experienced by charge carriers will be zero and there will be a Hall voltage V_H perpendicular to both current and the field directions. Thus under steady state condition,

$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right) = 0 \qquad (1)$$

where $\vec{v}$ is the drift velocity of charge carriers. In the present case eq. (1) can be written as,

$$E_y = vB_z = (J_x/nq)B_z \qquad (2)$$

where n is the charge density. The ratio (E_y/J_xB_z) is called the Hall co-efficient R_H. Here n is the density of charge carriers and 'q' is the charge of each carrier. Thus

$$R_H = E_y/J_xB_z = V_Hd/IB \qquad (3)$$

From equation (2) and (3) the Hall co-efficient can also be written as

$$R_H = 1/nq \qquad (4)$$

From the equation (4) it is clear that the type of charge carrier and its density can be estimated from the sign and the value of Hall co-efficient R_H. It can be obtained by studying the variation of V_H as a function of I for a given B.

Experimental Set-up:

Sample in the form of a thin rectangular slab is mounted on a sun mica sheet with four spring type pressure contacts. A pair of green colour leads is provided for current and another pair of red colour for Hall voltage. Note the direction of current and voltage measurement carefully. Do not exceed current beyond 8 mA.

The unit marked "Hall Effect Set-up" consists of a constant current source (CCS) for supplying current to the sample and a digital milli voltmeter to measure the Hall voltage. The unit has a single digital display used for both current and Hall voltage measurement.

For applying the magnetic field, an electromagnet with a constant current supply is provided with a toggle switch to choose either. It is capable of generating a magnetic field of upto 0.75 tesla for 10mm gap between its pole pieces. The magnetic field can be measured using the gauss meter along with the given Hall probe.

Procedure:

1. Connect the leads from the sample to the "Hall effect Set-up" unit. Connect the electromagnet to constant current supply.

2. Switch on the electromagnet and set suitable magnetic field density (<0.3 tesla) by varying the current supplied to the electro-magnet. You can measure this magnetic field density using the Hall probe. Find out the direction of magnetic field using the given bar magnet.

3. Insert the sample between the pole pieces of the electromagnet such that I, B and V are in proper direction (Fig.1).

4. From the direction of current and magnetic field, determine the direction of accumulation of majority carriers. Connect the one of the Hall voltage probes into which charge carriers are expected to accumulate to the positive side of the milli voltmeter. Connect the other Hall voltage probe to the negative side of the milli voltmeter. Don't change this voltmeter connection throughout your experiment.

5. Record the Hall voltage as a function of sample current. Collect four sets of readings: V_1(B,I), V_2(B,-I), V_3(-B,I) and V_4(-B,-I) for each current; V_1 is for positive (initial) current and field, V_2 is for the reverse current, V_3 is for reverse field, V_4 is for reverse field and current. Note that field direction can be changed

by changing the direction of current through the electromagnet. The Hall voltage V_H is obtained by,

$$V_H = [V_1(B,I) - V_2(B,-I) - V_3(-B,I) + V_4(-B,-I)] /4 \qquad (5)$$

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

6. Plot V_H vs I graph by least squares fitting. Calculate R_H and majority charge carrier's density from this graph.
7. Determine the type of majority charge carriers.
8. Estimate maximum possible errors in the measurement of Hall co-efficient.

Observation Table

S. No.	Sample current I (mA)	$V_1(B,I)$ (mV)	$V_2(B,-I)$ (mV)	$V_3(-B,I)$ (mV)	$V_4(-B,-I)$ (mV)	Hall voltage V_H (mV)
1						
2						
3						
..						

Reference:

1. Resnick & Halliday, *Fundamentals of Physics*, John Wiley & Sons (1981).
2. D. J. Griffiths, *Introduction to Electrodynamics*, Prentice Hall (1995).

Exp.6: Newton's Ring

Objective:

To determine the radius of curvature of a Plano-convex lens by means of Newton's rings method.

Apparatus:

Lens, glass plate, beam-splitter, Sodium lamp, travelling microscope.

Theory:

Optical interference corresponds to the interaction of two or more light waves yielding a resultant irradiance that differs from the sum of the component irradiances in the space. There are two ways to observe interference. These are "*division of wavefront*" and "*division of amplitude*". One of the elegant ways to experience the interference phenomena employing "*division of amplitude*" is Newton's rings method as depicted in Fig. 1.

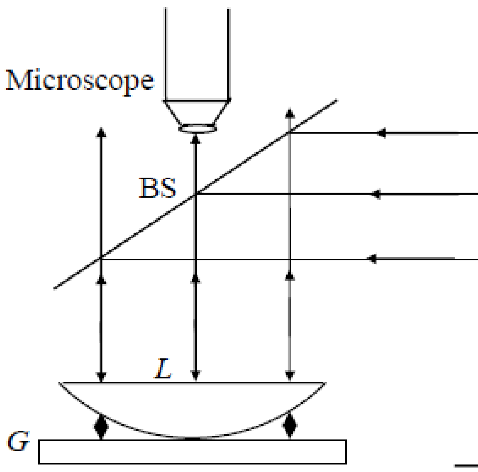

Fig. 1 (a)

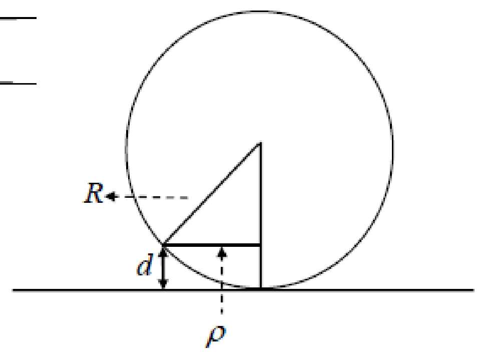

Fig. 1(b)

Here a plano-convex lens L (it can also be a convex lens) is placed over an optical flat (plane glass plate G). In this arrangement, a thin air film is formed in between the curved surface of the lens and the optical flat. Thickness of the air film is zero at the point where the lens touches the optical flat (with no dust) and gradually increases while moving radially outward towards the circumference of the lens. This system is illuminated at normal incidence with monochromatic/quasi-monochromatic (such as sodium vapour lamp) light through a beam-splitter (BS) as shown in Fig. 1. Light waves reflected from upper and lower surfaces of the air-film trapped between L and G interfere. Under normal illumination, at a fixed r (i.e., at a fixed d) the optical path length between the two reflected light wave beams would be $2n_f d$ where n_f is the refractive index of the film trapped between L and P. If the film is of air, n_f is 1. Interference minima will occur at this point if this optical path length is equal to the wavelength of the light λ. It's worth mentioning that the film thickness d will be constant over a circle, hence, this interference minimum will be circular in shape. In general, where ever the following condition would be satisfied

$$2n_f d_m = m\lambda \tag{1}$$

a family of concentric minima would be observed. In between the interference minima, there would be interference maxima, where the film thickness will be in accord with the relation

$$2n_f d_m = \left(m + \tfrac{1}{2}\right)\lambda \tag{2}$$

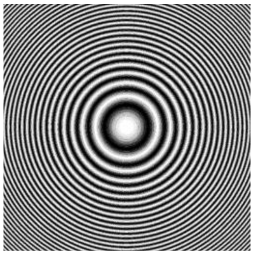

Figure 2: Newton's rings.

Such rings in the interference pattern depicted in Fig. 2 are known as Newton's ring (as it was Issac Newton, who first measured fringe radii). Refereeing back to Fig. 1, r and d can be related as

$$r^2 = R^2 - (R - d)^2 = 2Rd - d^2 \tag{3}$$

Here, R is the radius of curvature of the plano-convex lens. Since $R >> d$, Eq. (3) reduces to

$$r^2 = 2Rd \tag{4}$$

Using Eq. (1) and Eq. (4), radius of m^{th} dark ring comes out as

$$r_m = \sqrt{m\lambda R / n_f} \tag{5}$$

Procedure:

In order to carry out the experiment, execute the following procedures step-by-step:

1. Mount the glass plate P and fix the beam-splitter BS in the slots provided in the experimental set-up. Maintain BS at an angle of 45^o from vertical in order to achieve normal illumination. As the rings are viewed with the help of travelling microscope, focus the microscope at the top surface of the plate P. For this, keep a small piece of paper with a cross marked by pen on the plate P and focus microscope in a way that a very clear image of the cross is seen through the microscope.
2. Remove the paper. Mount the lens L in a way that the spherical surface of the lens comes into the contact with G. Maintain the flat surface of L in the horizontal plane. Newton's rings will be immediately observed through the microscope.
3. Rotate the cross-wires in the microscope in a way that one cross wire is tangential to the ring and the other passes through the center of Newton's ring. Move the microscope along the horizontal scale till the tangential cross wire coincides with the

11th ring from the center. Moving back, bring the cross wire in a tangential position to the 10th ring. Record the main and Vernier scale readings.

4. Now while moving in same direction, record the main and Vernier scale readings for 9, 8, ……, 1, -1, -2, ……, -10th ring; that is, on both the sides of the central fringe.
5. Plot D_m^2 versus m.
6. Estimate $R = n_f D_m^2 / 4m\lambda$ by least squares fitting to data points.
7. Calculate error in R for both the methods and make a comparative analysis of your experimental findings.

Observations:

Least count of the travelling microscope =

Average wavelength of the light = 589.3 nm

Ring No (m)	Microscope reading						Rings diameter D_m = $R - L$ (cm)	D_m^2
	LHS (L)			RHS (R)				
	Main scale	Vernier scale	Total (cm)	Main scale	Vernier scale	Total (cm)		
10								
9								
..								
..								
2								
1								

Reference:

1. E. Hecht, *Optics*, 3nd Ed, Addison-Wiley (2008).
2. A. Ghatak, *Optics*, 4th Ed, McGraw-Hill, (2009).