Department of Physics
Indian Institute of Technology Bhilai

B. Tech. Laboratory Manual

Course code IC107

(For Internal Circulation ONLY)
(last updated 06012019)

Disclaimer

General safety instructions

The students in the physics lab are expected to exercise common sense when working with laboratory equipment. When personal experience does not help to identify and avoid safety hazards, the student should exercise extra caution and consult with instructor for assistance. Safety is more important than pride; questions about safety will be answered promptly by the instructor.

Students are expected to listen and follow ALL instructions, precautions and guidelines given by the laboratory instructor.

1. Wear shoes that will protect your feet from electric shock.
2. Food, beverages, and chewing gum are NOT permitted in the laboratory.
3. Read the entire theory and experiment before entering the lab.
4. Keep work areas and apparatus clean, rearrange apparatus in an orderly manner, and report any damaged or missing items during/after finishing the experiment.
5. DO NOT look directly at LASER source. This may cause permanent eye damage. Avoid looking at bright light sources.
6. LASER, power supply or other electrical equipment should NOT to be left unattended when turned on. Always turn these items off when not in use.
7. Observe the warning signs and labels on the walls and instruments.
8. DO NOT modify or damage the laboratory equipment in any way unless advised by the instructor. This does not include the changing of a lab setup as prescribed by the procedures in carrying out of measurements.
9. NEVER leave your experimental set up unattended while it is in operation. DO NOT fiddle around with apparatus. Handle the instruments with care.
10. Never work in the lab unless an instructor is present and aware of the experiment that you are doing.
11. Report any accident or injury to the instructor immediately, no matter how trivial it may appear.
12. Return all materials and apparatus to the corresponding places designated by your instructor. Follow your instructor directions for disposal of any waste materials. Keep the work area clean.
13. Know the locations of the exits (of the room and the building). Know the location of the fire extinguishers. If fire occurs your job is to leave the lab with your partner immediately. Try informing the instructor.

Safety instructions while handling glassware

1. If a thermometer breaks, inform your instructor immediately. Do not touch either the mercury or the glass with your bare hands.
2. Do not heat glassware that is broken, chipped, or cracked. Use tongs or a hot mitt to handle heated glassware. Allow all equipment to cool before storing it away.
3. If a bulb fuses, notify your instructor. Do not remove bulbs from socket.

Electrical safety instructions

1. DO NOT switch ON your circuit until it has been inspected by your instructor. NEVER open, rewire or adjust any elements inside of the electrical casing.
2. NEVER work with electricity with wet hands or near water. Be sure the floor and all work surfaces are dry.
3. DO NOT work with any batteries, electrical devices, or magnets other than those provided by your instructor.
4. When you have finished your work, check that the electric circuits are DISCONNECTED.

Cautious clothing

1. Tie back long hair, secure loose clothing, and remove loose jewellery to prevent their getting caught in moving or rotating parts in the equipment.
2. Remove ALL reflective surfaces from hands which include jewellery, wrist watches etc while working with LASER.

How to record in Laboratory report sheet?

Title: Write the title of the Experiment with date in the margin on the first page.

Aim / Objective of the experiment: Write down the aim of the experiment.

Apparatus: Write the apparatus / items required to perform the experiment.

Circuit diagram: Sketch the circuit diagram wherever it is necessary.

Recording the observations: Write full details of each measurement in the order of observation.

Measurements: Record all measurements (with units) in tabular format.

Formulae: Write the formulae to be used.

Calculation: Show the calculations step by step. Report all the measured values with appropriate units.

Error Analysis: Estimate the possible errors.

Graph: If a graph is plotted, choose scales in such a way that as much as possible the entire graph paper is used. Label the two axes and give the units. Mark the points plotted with crosses X or dots and mark circles. Use a sharp pencil to plot a graph. Show error bar.

Result and conclusion: Give the result to a sensible order of accuracy. It must consist with the units.

Precautions: Write the precautions taken while doing the experiment.

About the cycle of experiments

1. Each one of you is required to complete ALL of the NINE experiments during the semester.
2. ONE experiment has to be completed within one laboratory session.
3. Laboratory manual summarizing all the experiment is available on the website: -------------The online manual is provided for reading and planning the experiment prior to the laboratory session.
4. A copy of the manual for the experiment is also kept with each set of the experiment for reference in the laboratory. **DO NOT TAKE IT OUT OF LABORATORY**.
5. **RECORD ALL OBSERVATIONS DIRECTLY IN THE RECORD BOOK / LAB RECORD SHEET.**
6. Show first observation to the instructor and get it signed by her/him.
7. Every student must bring her / his own **CALCULATOR** to the laboratory class and take it back without fail.
8. Calculations **MUST** be completed and the record should be shown to the instructor for evaluation on the same day.
9. Consider all possible errors carefully. Estimate them and evaluate the overall errors in the results.
10. Each experiment has a number and this number has to be entered along with the title in the record book.
11. Each student is expected to write his/her own conclusions about the results.
12. **STUDENTS ARE NOT PERMITTED TO TAKE THE RECORD BOOK OUT OF THE LABORATORY**

Best of luck
Coordinators and laboratory staff.

List of experiments

0. Error analysis

"To err is human; to evaluate and analyse the error is scientific".

I Introduction

Every measured physical quantity has an uncertainty or error associated with it. An experiment, in general, involves

1. Direct measurement of various quantities (primary measurements), and
2. Calculation of the physical quantity of interest which is a function of the measured quantities.

An uncertainty or error in the final result arises because of the errors in the primary measurements (assuming that there is no approximation involved in the calculations). For example, the result of an experiment to determine the velocity of light (Phys. Rev. Lett. **29**, 1346 (1972)) was given as

$$c = (299,\ 792,\ 456.2 \pm 1.1)\ \text{m/sec.}$$

The error in the value of 'c' arises from the errors in primary measurements, viz., frequency and wavelength.

Error analysis, therefore, consists of

i. **Estimating** the errors in all primary measurements, and
ii. **Propagating** the error at each step of the calculations.

This analysis serves two purposes. First, the error in the final result (±1.1 m/sec in the above example) is an indication of the precision of the measurement and, therefore, an important part of the result. Second, the analysis also tells us which primary measurement is causing more error than others and thus indicates the direction for further improvement of the experiment.

For example, in measuring 'g' with a simple pendulum, if the error analysis reveals that the errors in 'g' caused by measurements of l (length of the pendulum) and T (time period) are 0.5 cm/sec^2 and 3.5 cm/sec^2 respectively, then we know that there is no point in trying to devise a more accurate measurement of l. Rather, we should try to reduce the uncertainty in T by counting a larger number of periods or using a better device to measure time. Thus, error analysis **prior to the experiment** is an important aspect of planning the experiment.

Nomenclature

i. 'Discrepancy' **denotes the difference between two measured values of the same quantity.**

ii. 'Systematic errors' **are errors which occur in every measurement in the same way-often in the same direction and of the same magnitude- for example, length measurement with a faulty scale. These errors can, in principle, be eliminated or corrected for.**

iii. 'Random errors' **are errors which can cause the result of a measurement to deviate in either direction from its true value. We shall confine our attention to these errors, and discuss them under two heads: estimated and statistical errors.**

II Estimated Errors

Estimating a primary error

An estimated error is an estimate of the maximum extent to which a measured quantity might deviate from its true value. For a primary measurement, the estimated error is often taken to be the least count of the measuring instrument. For example, if the length of a string is to be measured with a meter rod, the limiting factor is the accuracy in the last count, i.e. 0.1 cm. However, it should be kept in mind that

a. What matters really is the **effective least count** and not the nominal least count. For example, in measuring electric current with an ammeter, if the smallest division corresponds to 0.1 amp, but the marks are far enough apart so that you can easily make out a quarter of a division, then the effective least count will be 0.025 amp. On the other hand, if you are reading a Vernier scale where three successive marks on the Vernier scale (say, 27th, 28th, 29th) look equally well in coincidence with the main scale, the effective least count is 3 times the nominal one. Therefore, **make a judicious estimate of the least count.**

b. The estimated error is, in general, to be related to the **limiting factor** in the accuracy. This limiting factor need not always be the least count. For example, in a null-point electrical measurement, suppose the deflection in the galvanometer remains zero for all values of resistance R from 351 Ω to 360 Ω. In that case, the uncertainty in R is 10Ω, even though the least count of the resistance box may be less.

Propagation of estimated errors

How to calculate the error associated with f, which is a function of measured quantities a, b and c? Let

$$f = f(a,b,c). \qquad (1)$$

From differential calculus (Taylor's series in the 1st order)

$$df = \frac{\partial f}{\partial a}da + \frac{\partial f}{\partial b}db + \frac{\partial f}{\partial c}dc \quad . \qquad \textbf{(2)}$$

Eq. (2) relates the differential increment in f resulting from differential increments in a, b, c. Thus, if our errors in a, b, c (denoted as δa, δb, δc) are small compared to a, b, c, respectively, then we may say

$$\delta f = \left|\frac{\partial f}{\partial a}\right|\delta a + \left|\frac{\partial f}{\partial b}\right|\delta b + \left|\frac{\partial f}{\partial c}\right|\delta c \quad . \qquad (3)$$

where the modulus signs have been put because errors in a, b and c are independent of each other and may be in the positive or negative direction. Therefore, the maximum possible error will be obtained only by adding absolute values of all the independent contributions. (All the δ's are considered positive by definition). Special care has to be taken when all errors are not independent of each other. This will become clear in special case (e) below.

Some simple cases

a) For addition or subtraction, the absolute errors are added, e.g.,

$$\begin{aligned} &if \quad f = a + b - c \quad , \quad then \\ &\qquad \delta f = \delta a + \delta b + \delta c \quad . \end{aligned} \qquad (4)$$

b) For multiplication and division, the fractional (or percent) errors are added, e.g.,

$$\begin{aligned} &if \quad f = \frac{ab}{c} \quad , \quad then \\ &\left|\frac{1}{f}\right|\delta f = \left|\frac{1}{a}\right|\delta a + \left|\frac{1}{b}\right|\delta b + \left|\frac{1}{c}\right|\delta c \quad . \end{aligned} \qquad (5)$$

c) For raising to constant powers, including fractional powers, the fractional error is multiplied by the power, e.g.,

$$\begin{aligned} &if \quad f = a^{3.6} \quad , \quad then \\ &\left|\frac{1}{f}\right|\delta f = \left|3.6 \times \frac{1}{a}\right|\delta a \quad . \end{aligned} \qquad (6)$$

d) In mixed calculations, break up the calculation into simple parts, e.g.,

$$if \quad f = \frac{a}{b} - c^{\frac{3}{2}} \quad , then$$

$$\delta f = \delta\left(\frac{a}{b}\right) + \delta\left(c^{\frac{3}{2}}\right) \quad .$$

(7)

Note that the same result could have been derived directly by differentiation.

(e) *Consider* $f = \frac{ab}{c} - a^2$.

The relation for error, **before** putting the modulus signs, is

$$\delta f = \left(\frac{b}{c}\right)\delta a + \left(\frac{a}{c}\right)\delta b - \left(\frac{ab}{c^2}\right)\delta c - 2a\delta a \quad .$$

Note that the δa factors in the first and fourth terms are **not** independent errors. Therefore, we must **not** add the absolute values of these two terms indiscriminately. The correct way to handle it is to collect the coefficients of each independent errors **before** putting modulus signs, i.e.,

(8) $$\delta f = \left|\frac{b}{c} - 2a\right|\delta a + \left|\frac{a}{c}\right|\delta b + \left|\frac{ab}{c^2}\right|\delta c \quad .$$

III. Statistical Errors

Statistical distribution and standard deviation

Statistical errors arise when making measurements on random processes, e.g., counting particles emitted by a radioactive source. Suppose we have a source giving off 10 particles/sec on the average. In order to evaluate this count rate experimentally, we count the number of particles for 2 seconds. Shall we get 20 counts? Not necessarily. In fact, we may get any number between zero and infinity. Therefore, in a measurement on a random process, **one cannot specify a maximum possible error**. A good measure of uncertainty in such a case is the standard deviation (s.d.) which specifies the range within which the result of any measurement is "most likely" to be.

The exact definition of "most likely" depends on the distribution governing the random events. For all random processes whose probability of occurrence is small and constant, Poisson distribution is applicable, i.e.,

$$(9) \quad P_n = \frac{m^n}{n!} e^{-m} ,$$

where P_n is the probability that you will observe a particular count n, when the expectation value is m.

It can be shown that if an infinite number of measurements are made, (i) their average would be m and (ii) their standard deviation (s.d.) would be $\sqrt{m}$, for this distribution. Also, if m is not too small, then 68% or nearly two-thirds of the measurements would yield numbers within one s.d. in the range m $\pm\sqrt{m}$.

In radioactive decay and other nuclear processes, the Poisson distribution is generally valid. This means that we have a way of making certain conclusions without making an infinite number of measurements. Thus, if we measure the number of counts only once, for 100 sec, and the number is, say 1608, then (i) our result for average count rate is 16.08/sec, and (ii) the standard deviation is $\sqrt{1608}$ = 40.1 counts which corresponds to 0.401/sec. So our result for the count rate is (16.08 ± 0.40) sec^{-1}. The meaning of this statement must be remembered. The actual count rate need not necessarily lie within this range, but there is 68% probability that it lies in that range.

The experimental definition of s.d. for k measurements of a quantity x is

$$(10) \quad \sigma_x = \sqrt{\sum_{n=1}^{k} \left(\frac{\delta x_n^2}{k-1} \right)} ,$$

where δx_n is the deviation of measurement x_n from the mean. However, since we know the distribution, we can ascribe the s.d. even to a single measurement.

Propagation of statistical errors

For a function f of independent measurements a, b, c, the statistical error σ_f is

$$(11) \quad \sigma_f = \sqrt{\left(\frac{\partial f}{\partial a} \sigma_a \right)^2 + \left(\frac{\partial f}{\partial b} \sigma_b \right)^2 + \left(\frac{\partial f}{\partial c} \sigma_c \right)^2} .$$

A few simple cases are discussed below.

i. For addition or subtraction, the **squares of errors** are added, e.g.

$$\begin{aligned} &if \quad f = a + b - c \\ &then, \; \sigma_f^2 = \sigma_a^2 + \sigma_b^2 + \sigma_c^2 . \end{aligned}$$

ii. For multiplication or division, the **squares of fractional errors** are added, e.g.

$$if \quad f = \frac{ab}{c},$$

$$(13) \quad then \left(\frac{\sigma_f}{f}\right)^2 = \left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2 + \left(\frac{\sigma_c}{c}\right)^2 .$$

iii. If a measurement is repeated n times, the error in the mean is a factor $\sqrt{n}$ less than the error in a single measurement, i.e.,

$$(14) \quad \sigma_{\bar{f}} = \frac{\sigma_f}{\sqrt{n}} .$$

Note that Eqs. (11-14) apply to any statistical quantities a, b, etc, i.e., primary measurements as well as computed quantities whereas

$$(15) \quad \sigma_m = \sqrt{m}$$

applies only to a directly measured number, say, number of α-particle counts **but not to computed quantities like** count rate.

IV Miscellaneous

Repeated measurements

Suppose a quantity f, whether statistical in nature or otherwise**, is measured n times. The best estimate for the actual value of f is the average of** $\bar{f}$ **all measurements. It can be shown that this is the value with respect to which the sum of squares of all deviations is a minimum. Further,** if **errors are assumed to be randomly distributed, the error in** the mean value **is given by**

$$(16) \quad \delta_{\bar{f}} = \frac{\delta_f}{\sqrt{n}} ,$$

where δ_f is the error in one measurement. Hence one way of **minimising random errors** is to repeat the measurement many times.

Combination of statistical and estimated errors

In cases where some of the primary measurements have statistical errors and others have estimated errors, the error in the final result is indicated as a s.d. and is calculated by treating all errors as statistical.

Errors in graphical analysis

The usual way of indicating errors in quantities plotted on graph paper is to draw error bars. The curve should then be drawn so as to pass through all or most of the bars.

Here is a simple method of obtaining the best fit for a straight line on a graph. Having plotted all the points, (x_1, y_1)........(x_n, y_n) plot also the centroid $(\bar{x}, \bar{y})$.

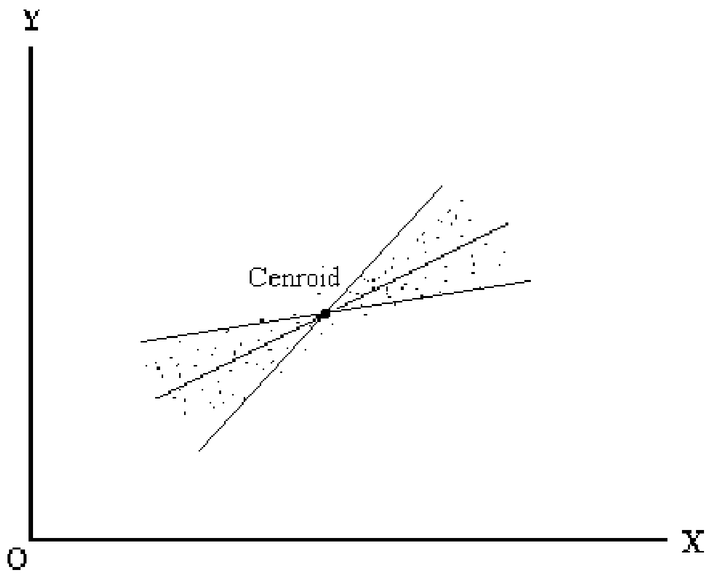


Fig. 1

Then consider all straight lines through the centroid (use a transparent ruler) and visually judge which one will represent the best mean.

Having drawn the best line, estimate the error in slope as follows. Rotate the ruler about the centroid until its edge passes through the cluster of points at the 'top right' and the 'bottom left'. This new line gives one extreme possibility; let the difference between the slopes of this and the best line be Δm_1 .Similarly determine Δm_2 corresponding to the other extreme. The error in the slope may be taken as

$$(17) \quad \Delta m = \frac{\Delta m_1 + \Delta m_2}{2} \cdot \frac{1}{\sqrt{n}} ,$$

where n is the number of points. The factor $\sqrt{n}$ comes because evaluating the slope from the graph is essentially an averaging process.

It should be noted that if the scale of the graph is not large enough, the least count of the graph may itself become a limiting factor in the accuracy of the result. Therefore, it is desirable to select the scale so that the least count of the graph paper is much smaller than the experimental error.

Significant figures

A result statement such as f = 123.4678 ± 1.2331 cm contains many superfluous digits. Firstly, the digits 678 in quantity f do not mean anything because they represent something much smaller than the uncertainty δf. Secondly δf is an **approximate** estimate for error and should not need more than two significant figures. The correct expression would be f = 123.5 ± 1.2 cm.

V Instructions

1. Calculate the estimated/statistical error for the final result. In any graph you plot, show error bars. (If the errors are too small to show up on the graph, then write them somewhere on the graph).
2. If the same quantity has been measured/calculated many times, you need not determine the errors each time. Similarly, one typical error bar on the graph will be enough.
3. In propagating errors, the contributions to the final error from various independent measurements must be shown. For example

$$
\begin{aligned}
&if \quad f = ab; \quad \frac{\delta f}{|f|} = \frac{\delta a}{|a|} + \frac{\delta b}{|b|} \quad , \\
&\qquad a = 10.0 \pm 0.1, \quad b = 5.1 \pm 0.2 \\
&then, \quad \delta f = 51.0\left[\frac{0.1}{10.0} + \frac{0.2}{5.1}\right] \\
&\qquad = 0.51 + 2.0 \\
&\qquad \approx 2.5 \\
&Therefore, \quad f = 51.0 \pm 2.5 \quad .
\end{aligned}
$$

Here the penultimate step must not be skipped because it shows that the contribution to the error from δb is large.

4. Where the final result is a known quantity (for example, e/m), show the discrepancy of your result from the standard value. If this is greater than the estimated error, this is abnormal and requires explanation.
5. Where a quantity is determined many times, the standard deviation should be calculated from Eq.(10). Normally, the s.d. should not be more than the estimated error. Also the individual measurements should be distributed only on both sides of the standard value.

VI Mean and Standard Deviation

If we make a measurement x_1 of a quantity x, we expect our observation to be close to the quantity but not exact. If we make another measurement, we expect a difference in the observed value due to random errors. As we make more and more measurements we expect them to be distributed around the correct value, assuming that we can neglect or correct for systematic errors. If we make a very large number of measurements, we can determine how the data points are distributed in the so-called **parent distribution**. In any practical case, one makes a finite number of measurements and one tries to describe the parent distribution as best as possible.

VII. Method of Least Squares

Our data consist of pairs of measurements (x_i, y_i) of an independent variable x and a dependent variable y. We wish to fit the data to an equation of the form

$$y = a + bx \tag{18}$$

by determining the values of the coefficients a and b such that the discrepancy is minimized between the values of our measurements y_i and the corresponding values $y = f(x_i)$ given by Eq. (18). We cannot determine the coefficients exactly with only a finite number of observations, but we do want to extract from these data the most probable estimates for the coefficients.

The problem is to establish criteria for minimizing the discrepancy and optimizing the estimates of the coefficients. For any arbitrary values of a and b, we can calculate the deviations δy_i between each of the observed values y_i and the corresponding calculated values

$$\delta y_i = y_i - a - bx_i \quad . \tag{19}$$

If the coefficients are well chosen, these deviations should be relatively small. The sum of these deviations is not a good measure of how well we have approximated the data with our calculated straight line because large positive deviations can be balanced by large negative ones to yield a small sum even when the fit is bad. We might however consider summing up the absolute values of the deviations, but this leads to difficulties in obtaining an analytical solution. We consider instead the sum of the squares of deviations. There is no unique correct method for optimizing the coefficients which is valid for all cases.

1. Characteristics of microwaves

Aim: (a) To study the klystron characteristics and (b) to determine the frequency and wavelength in a rectangular waveguide working in TE_{10} mode.

Apparatus: Klystron power supply, klystron tube with klystron mount, Isolator frequency meter, variable attenuator, detector mount, wave guide stand, VSWR meter or multimeter, BNC cable.

Theory: The Reflex Klystron makes the use of velocity modulation to transfer a continuous electron beam into microwave power. Electrons emitted from the cathode are accelerated and passed through the positive resonator towards negative reflector, which retards and finally, reflects the electrons and the electrons turn back through the resonator. Suppose and RF-field exists between the resonators the electrons travelling forward will be accelerated or retarded, as the voltage at the resonator changes in amplitude. The accelerated electrons leave the resonator at an increased velocity and the retarded electrons leave at the reduce velocity. The electron leaving the resonator will need different time to return, due to change in velocities. As a result, returning electrons group together in bunches, as the electron bunches pass through resonator, they interact with voltage at resonator grid. If the bunches pass the grid such a time that the electrons are slowed down by the voltage, then energy will be delivered to the resonator; and Klystron will oscillate. The frequency is primary determined by the dimension's cavity. Hence, by changing the volume of resonator, mechanical tuning of klystron is possible. Also a small frequency change can be obtained by adjusting the reflector voltage. This is called Electronic tuning.

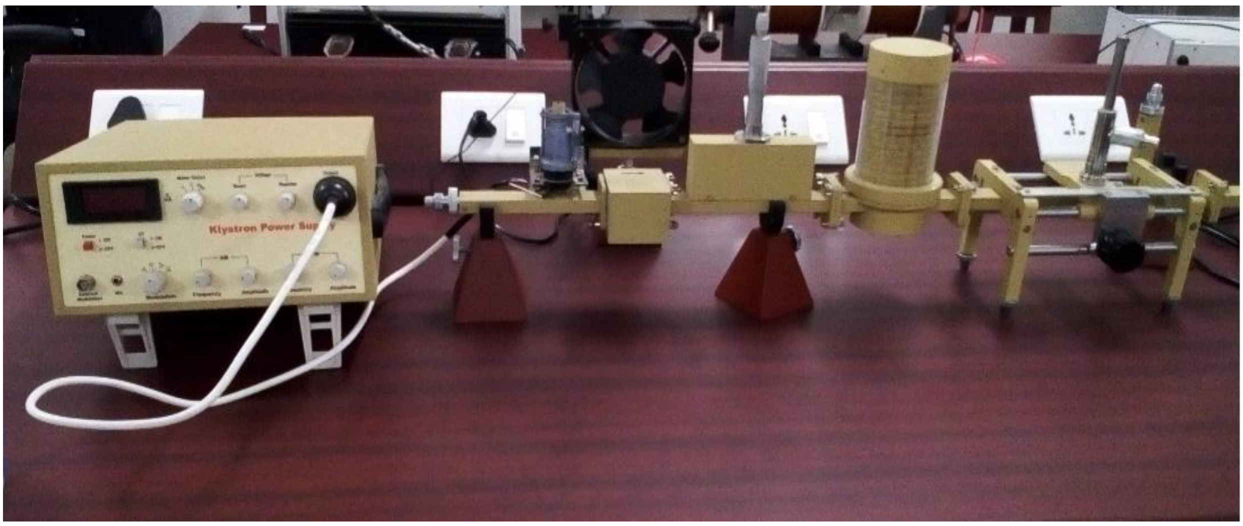


Figure 1: Experimental setup

Procedure

(a) Measurement of Frequency and output voltage with variation in repeller voltage.

1. Connect the equipment and components as shown in figure.
2. Set the variable attenuator at maximum position (at no attenuator).
3. Switch ON the Klystron power supply and cooling fan.
4. Change the meter switch of klystron power supply to beam voltage position and set beam voltage to 250 V using beam voltage control knob.

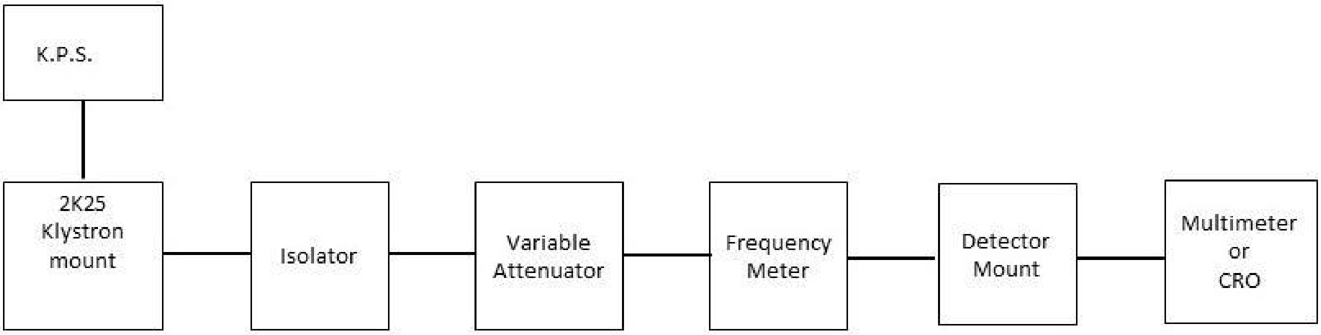


Figure 2: Block diagram of microwave test bench

5. Now, set modulation to AM which applies an internal 1 kHz square wave to the reflector along with DC reflector voltage approximately 150 volts. Adjust modulation amplitude and repeller voltages to obtain a good square wave on the oscilloscope. If the output is small, tune the detector and also reduce the attenuation.
6. Adjust the repeller voltage to maximum negative value and increase it gradually to get maximum output voltage on multimeter at this point measure the corresponding reflector voltage, output frequency and output voltage.
7. Repeat above procedure for different maximum output voltage till reflector voltage reaches 80 V.
8. Plot the graph between output voltage and frequency with respect to repeller voltage.

Observations

S.No.	Repeller voltage	Output voltage	Frequency (Ghz)
1			
.			
.			
15			

Calculation

Knowing mode top voltage of two adjacent modes, number of the modes may be computed from equation below.

$$\frac{N_2}{N_1} = \frac{V_1}{V_2} = \frac{(n+1)+\frac{3}{4}}{n+\frac{3}{4}} \quad \text{(find } n \text{ from here)}$$

where, V_1 and V_2 are reflector voltages for two successive modes at maximum power points.
t_1 and t_2 is time of two successive point.

(b) Measurement of frequency and wavelength in a rectangular waveguide working in TE_{10}.

1. Connect the equipment and components as shown in figure 3.

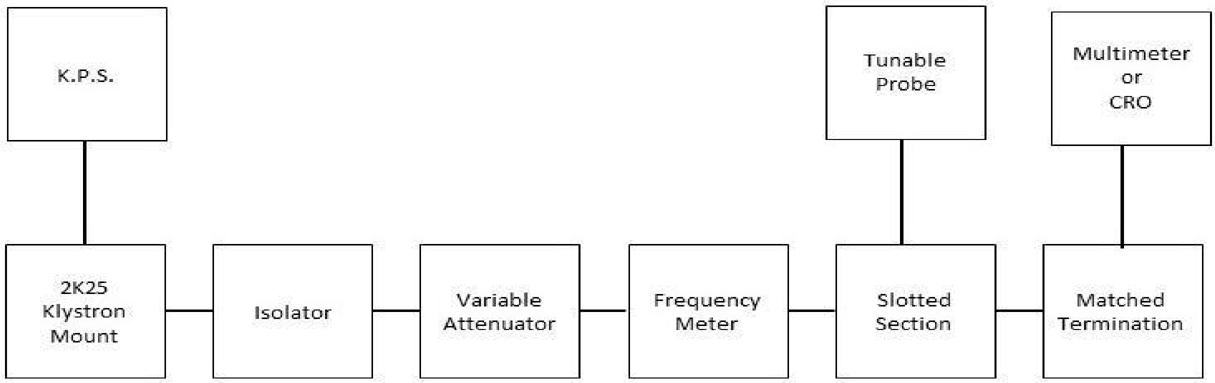


Figure 3: Block diagram of microwave test bench

2. Initially set the variable attenuator for maximum attenuation (for no attenuation).
3. Turn the meter switch of power Supply to beam voltage position and set beam voltage at 300 V with the help of beam voltage knob, current around 15 to 20 mA.
4. Adjust the reflector voltage to get some reading in multimeter.
5. Maximum the reading with AM amplitude and frequency control knob of power supply.
6. Tune the plunger of klystron mount for maximum reading.
7. Tune the reflector voltage knob for maximum reading on multimeter.
8. Tune the frequency meter to get a 'dip 'on multimeter reading and note down the frequency directly from frequency meter and detune the) DRF (Direct Readout Frequency) meter.
9. Move the tunable probe along with the slotted line to get the reading in multimeter.
10. Move the tunable probe left side to a minimum position and record the probe position distance i.e. d_1
11. move the probe to next minimum right side position and record the probe position distance i.e. d_2
12. Calculate the guide wavelength as twice the distance between two successive minimum position obtained as above.

$$\lambda = 2(d_1 - d_2)$$

13. Measure the wave-guide inner broad dimension 'a' which will be around 22.86mm for X band and calculate.

$$\lambda_c = 2a$$

For TE_{10} mode

14. Calculate the frequency by following equation:

$$f = \frac{c}{\lambda_0} = c\sqrt{\frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}}$$

where, $c = 3x10^8$ m/sec (velocity of light)
15. Verify with frequency obtained by frequency meter.

Observations

least count of Vernier scale……….cm

S.No.	Repeller voltage	Vernier scale on d1 minimum (Left)	Vernier scale on d2 minimum (Right)	Frequency(MHz)
1				
.				
.				
15				

Results

1. The frequency of microwave signal………in GHz

Questions

1. Explain the operation of the reflex klystron tube.
2. What is the basic principle involved in microwave tubes?
3. What is the difference between velocity modulation and current density modulation?
4. What happens to the power output as the repeller voltage increases?
5. What are the various modes of operation in the reflex klystron?
6. How bunching is achieved in reflex klystron?
7. What is the wavelength of 1 GHz radiation in nm?
8. How slotted line technique is used to measure frequency and wavelength?
9. What is the purpose of slotted line in the microwave bench?
10. What is meant by guide wavelength?
11. Find relationship between the guide wave length and cut of wavelength?
12. Which technique is preferable for the measurement of frequency?
13. How waveguide acts as a high pass filter?

Precaution

1. Klystron power supply should be constant.
2. BNC cable should be connected properly.
3. Do not touch the klystron mount in switch ON mode.

Reference

1.

Appendix

Appendix: Microwave experiment

(ii) Description of various parts, refer to line diagram in the manual

1. Klystron power supply

The model Klystron Power Supply is general purpose laboratory power supply specially designed, highly regulated and low ripple, for use in reflex klystron tubes of S to X band frequency range. It has built in modulation facilities of amplitude and frequency modulation. It is source of D.C. Voltages needed to operate reflex klystron tube such as beam, heater and reflector voltage.

2. Klystron tube 2k25
The klystron tube is a single cavity variable frequency microwave generator of low power and low efficiency. Figure 1 in manual, consists of an electron gun, a filament surrounded by cathode and a focusing electrode at cathode potential. The electrons emitted by the cathode travel towards the reflector through an anode kept at higher potential compared to the cathode. The electrons approaching the anode form bunches and the bunches ultimately return towards the anode cavity after traveling a small distance towards the reflector. The power is taken from the anode reentrant cavity.

3. Isolator
It allows power flow only from the generator towards the load and suppresses any reflected power. It is a two port device which provides very small amount of attenuation for transmission from port 1 to port 2 and provides maximum attenuation for transmission from port 2 to port 1.

4. Variable Attenuator
This is a wave- guide piece having a groove on the lateral side. By rotating the screw, the depth of penetration of resistive pad changes, there by introducing some attenuation. Variable attenuator provide continuous or step wise variable attenuation.

5. Frequency meter
Also called a wave meter. It consists of a cylindrical cavity mounted on a shaft. By rotating the shaft the volume in the cavity is changed and it becomes resonant and gives minimum impedance at the resonant frequency. The scale is calibrated; a dip in the output meter corresponds to the resonant frequency, which can be directly read from the scale.

Theory
The reflex klystron makes use of velocity modulation to transform a continuous electron beam into microwave power. Electrons emitted from the cathode are accelerated and passed through the positive resonator towards negative reflector, it retards and finally reflects the electrons towards the resonator. The accelerated electrons leave the resonator with increased velocity and the retarded electrons leave at reduced velocity. As the electrons bunch pass through resonator, they interact with voltage at resonator grids. If the bunches pass the grid, at such time, that the electrons are slowed down by the voltage, energy will be delivered to the resonator and the klystron will oscillate.

Applications
This is most widely used in applications where variable frequency is required, for example, radar receivers, local oscillator in microwave receivers, signal source in microwave generator of variable frequency, and pump oscillator in parametric amplifier.

MICROWAVE FREQUENCY MEASUREMENT
Various components used have already been discussed.

Theory:
There are two ways to measure microwave frequency.

1. Electronic Techniques: These techniques are more accurate but expensive. Frequency counters are used. The unknown frequency is compared with harmonics of a known lower frequency, by use of a low frequency generator, as harmonic generator and a mixer.

2. Mechanical Technique: These are slotted line and cavity meter techniques.

The operation and accuracy depends on the physical dimensions of mechanical devices.

Slotted-Line Technique: A slotted line is a piece of transmission line so constructed that the voltage and current along it can be measured continuously over its length.

For measuring the frequency, the distance between maxima (or) minima is measured on the slotted line horizontal scale from the above setup.

$$\lambda_g/2 = (d_1 - d_2)$$

For TE_{10} Mode, λ_C = 2a where **'a'** is the waveguide dimension **(22.86mm)**.

The frequency so measured is not very accurate.

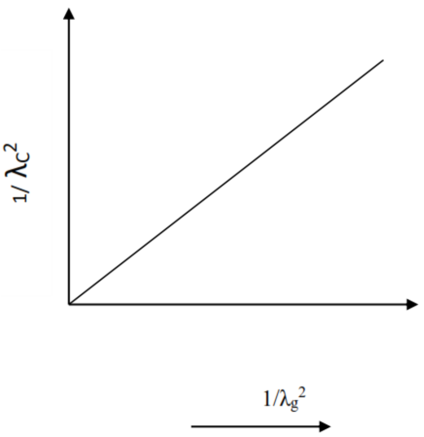
Calculations

$$f = \frac{c}{\lambda_0} = c\sqrt{\frac{1}{\lambda_g^{\,2}} + \frac{1}{\lambda_c^{\,2}}}$$

$\lambda_g = 2(d_2 - d_1)$ cm

$\lambda_C = 2a$ where a = 2.286 cm.

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-(\frac{\lambda_0}{\lambda_c})^2}}$$



2. Newton's rings

Aim: To study the phenomenon of interference and measurement of wavelength of light by observing Newton's rings.

Apparatus: Plano-convex lens of relatively larger focal length, glass plate, monochromatic light source (sodium vapor lamp) and travelling microscope.

Theory: Newton's rings result from interference of light from two surfaces which follow lines of equal thickness. It is interesting to note that these interference fringes demonstrate the wave nature of light. In fact, Newton was the chief proponent of the corpuscular theory that suggests the wave nature of the light.

The schematic of the experimental setup is shown in Figure 1. A plano-convex lens is placed on an optically flat glass plate. Light from the sodium lamp strikes a glass plate that is placed an angle of 45°. A part of the light is reflected at the lower convex lens surface and a part at the glass plate. These two reflected light rays interfere and form fringes. As a result, the interference pattern is concentric circular rings around the point of contact. These rings are referred to as Newton's rings. Since the air film is symmetric about the point of contact, the fringes, which follow lines of equal thickness, will be concentric rings with their center at this point. They are called fringes of equal thickness. This is an example of interference fringes produced by division of amplitude. If these two rays are in same phase they undergo constructive interference, the resultant rings are bright rings and vice-versa. Detailed theory is given in the following.

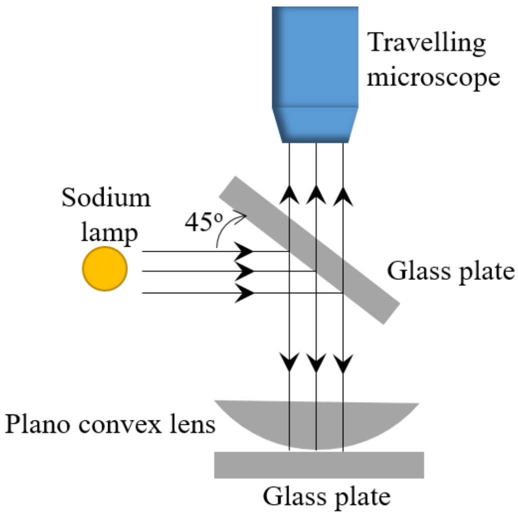


Figure 1: Newton's ring setup

Consider a ray of light incident on the air film at a point where its thickness is 't' as shown in Figure 2. The fact that the wave is reflected from air (rare medium) to glass (denser medium) surface introduces a phase shift of $\lambda/2$. Therefore, we observe constructive and destructive interference where the conditions of bright and dark fringes are satisfied.

The optical path difference (OPD) between two reflected rays = $(2\mu t\cos r + \lambda/2)$.

For normal incidence (r =0) and for air film μ= 1; and hence in this case,

OPD = $(2t + \lambda/2)$.

At the point of contact t = 0, and hence

OPD = $\lambda/2$ which is the condition of minimum intensity. Thus, the central spot is dark.

This expression shows that a maximum of a particular order n will occur for a constant value of ‘t’. For a case like ours where ‘t’ remains constant along a circle, the maximum is in the form of circle. For different values of ‘t’, different maximum will occur. In a similar way, this can be shown that minimum is also circular in form. Therefore, for bright ring (constructive interference), we have 2t = (n+1/2) λ, where n -order of rings = 1, 2, 3, 4, 5, 6...etc.
and 2t = (n) λ (destructive interference or dark rings) where n = 0, 1, 2, 3, 4 ...etc.

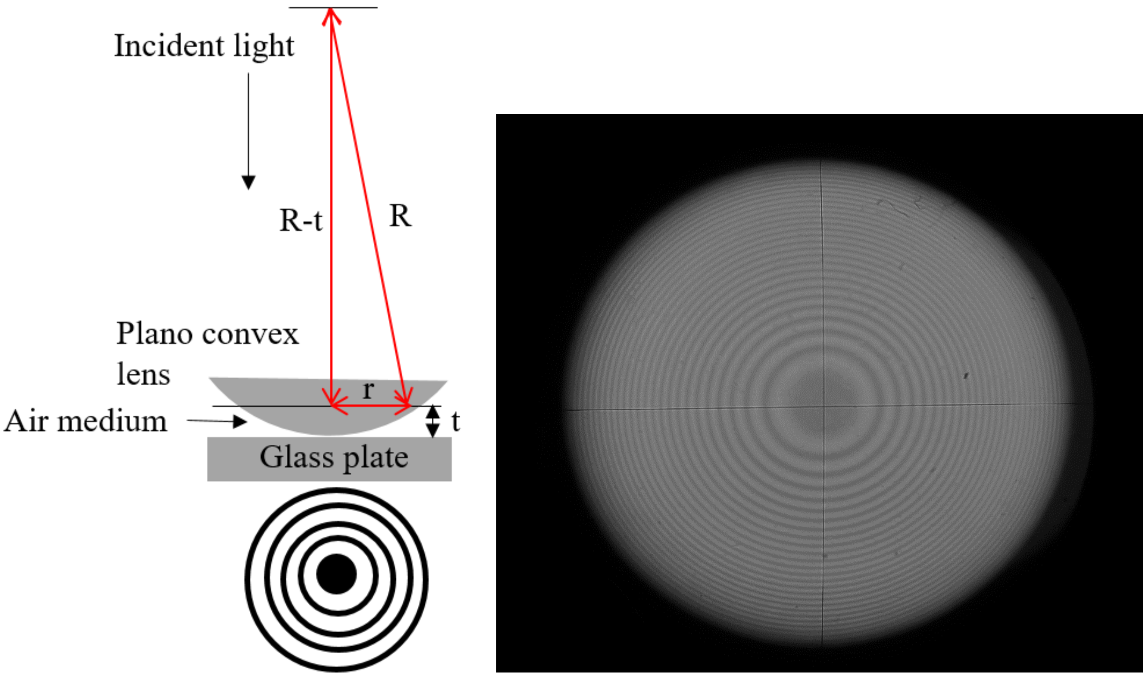


Figure 2: (Left) Geometry of Newton’s rings arrangement and (right) digital photograph of Newton’s rings recorded@IITBhilai.

If R is the radius of curvature of the lens and ’r’ is the distance of the point under consideration to the point of contact of the lens and glass plat, then

$$R^2 = \left(R - t^2\right) + r^2 \quad \text{(Pythagoras theorem)}$$
$$R^2 = R^2 - 2tr + t^2 + r^2$$

Since $t^2 << r^2$ and $D_n^2 = 2r$ diameter of the rings

$$2t = \frac{r^2}{R} \quad \text{and} \quad 2t = \frac{D_n^2}{4R}$$

Combining this with the condition for say the n[th] dark ring (2t = nλ), one gets for the diameter of that ring.

$$n\lambda = \frac{D_n^2}{4R}$$

If D_{m+n} and D_n are the diameter of the higher and lower successive dark ring then the wavelength of given source can be obtained by

$$\lambda = \frac{D_{n+m}^{2} - D_{n}^{2}}{4Rm}$$

Summary

The wavelength of the light is given by

$$\lambda = \frac{D_{n+m}^{2} - D_{n}^{2}}{4Rm}$$

where, λ – wavelength of the light

D_{m+n} – diameter of (n+m)th of higher dark ring ,where m is an integer

D_{n} – diameter of nth of lower dark ring

m – integer that is the difference in the order of two rings considered

R – radius of curvature of the spherical surface of the plano-convex lens (R = 471.5 mm)

Procedure

1. Fix the objective, eyepiece and glass plate carefully.
2. Place the stand below the travelling microscope and keep the circular glass plate at its center. Make sure that glass plate is free from dust.
3. Place the sodium lamp near the Newton's ring apparatus, connect it to the power supply and turn it on.

Figure 3: Digital photograph of the experimental setup

4. Identify the curved surface of the plano-convex lens and mount it on lens holder in such a way that the curved surface faces the circular glass plate.
5. Fix the square glass plate on the mount at 45° inclination using the tilt adjustment provided.
6. Adjust the screw of the microscope to view the rings. Make fine adjustments by screw once the rings are visible and make sure that there are about 20 clear rings on either side of the central ring.

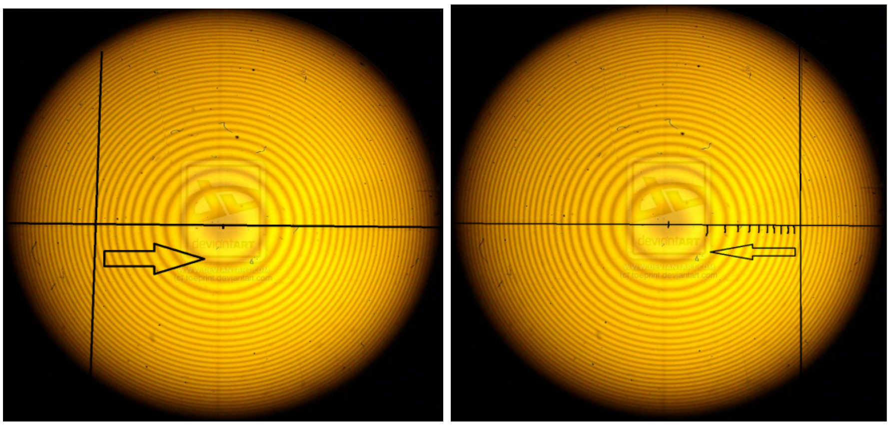


Figure 4: Microscope moved from left to right. Digital photographs recorded@IITBhilai.

7. Starting from the central spot, move the cross wire outward to one side by counting the number of dark rings. Place the crosswire tangential to the 15^{th} *dark* ring (say). Take the reading on the horizontal scale (see Figure 4).
8. Move the cross-wire towards the center and take readings at the position of every dark ring. Continue the readings on the other side up to the 15^{th} ring for the same orders. Then difference between the two sides of the readings of a particular order of the ring gives the diameter of that particular ring.
9. Now calculate the difference between the micrometer readings on the left and right side of each ring gives the diameter (D) of the respective ring.
10. Tabulate your readings as shown in table
11. Determine the radius of the curvature (R) of the surface of the lens by distant object method. Knowing R we can calculate the wavelength of the incident light.
12. Draw a graph with order n rings on X-axis and $(diameter)^2$ along Y-axis

Observations

(A) Determination of least count of the microscope
One value of smallest division of the main (pitch) scale…………mm
Number of division on the Vernier (head) scale………………….mm
Least count of Microscope……………..mm

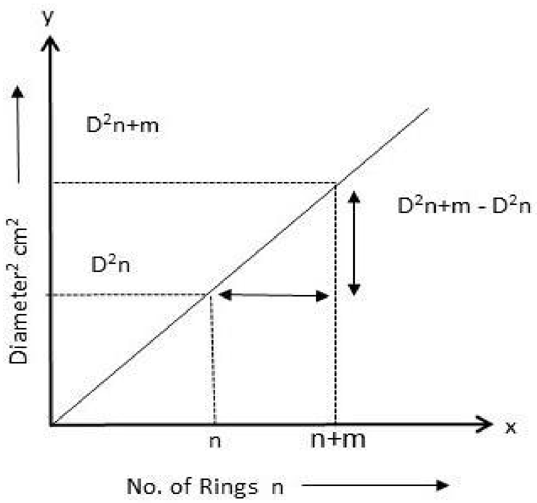
(B) Radius of Curvature of Plano convex R = 471.5 mm (for 1000mm focal length)

Order of Ring	Micrometer Reading (mm)		Diameter D (mm) (a-b)	$(\text{Diameter})^2$ D^2 (mm)
	X_{Right} (a)	X_{Left} (b)		
15				
.				
.				
1				

Graph

Draw a graph with order of ring on x- axis and diameter square on the y – axis. It is a straight line passing through the origin.

The slop of the graph gives the value of $\frac{D_{n+m}^{\ 2}-D_{n}^{\ 2}}{m}$



Calculation

Substitute the values in the following formula for n and m values that differ by about 9 rings.

$$\lambda = \frac{D_{n+m}^{\ 2}-D_{n}^{\ 2}}{4Rm}$$

Assuming the wavelength of sodium light = 589.3 nm, calculate the radius of curvature of the lens. Also estimate the error in finding R.

Results

Using the graphical calculations, the wavelength of sodium light....................... Å.
Do graphical error analysis

Questions

1. What happens to the diameter of the rings if we have higher refractive material instead of air?
2. How does the pattern looks if we use white light source instead of sodium lamp?
3. What do you mean by interference of light?
4. Explain the conditions for sustained interference of light?
5. What do you mean by coherent sources?
6. How Newton's rings are formed in your experiment?
7. Why the central ring is dark?
8. How can you get central bright spot in Newton's rings?
9. On what factors does the diameter of a ring depend?
10. What are the applications of Newton's rings?
11. How does the interference phenomenon in Newton's ring experiment and Young's double slit experiment differ?
12. What information do you get from Young's double slit experiment?

Precautions

1. Do not touch the active region of optical component with bare hands
2. Make environment of experimental room dust free and low light.
3. The lens used should be of large radius of curvature.
4. The sources of light used should be an extended one.
5. Before measuring the diameter of rings, adjust the range of the microscope.
6. Cross wire should be focused tangentially.

References

1. Fundamental of Optics by F. Jenkins and H. White
2. Optics by A. Ghatak
3. Optics by E. Hecht and Zajac

3. Band gap of a semiconductor

Aim: To find the energy band gap of the given sample.

Apparatus: Energy band gap kit, silicon oil, thermometer, silicon and germanium diodes, 180 mL beaker.

Introduction and theory: Pure semiconductors are referred to as intrinsic semiconductors. Doping of pure semiconductor material with an impurity atoms result in extrinsic semiconductors. However, the presence of impurity atom slightly modifies the energy gap of the pristine counterpart. Hence, to reduce the contribution of impurity atoms the impurity atoms as subdued by passing very low forward current. When the forward current is low, most of the impurity atoms are quiet and do not participate in conduction. Hence, conduction is purely due to parent element; hence, one can make use extrinsic semiconductor in energy gap determination. Varieties of extrinsic semiconductors are available in *pn* junction form that can be used for the measurement of energy gap. Some of the commonly used semiconductors are listed Table 1.

Materials	Device	E_g (eV)
Si	Diode 4007	1.15
Ge	Diode DR25	0.67
GaP	LED Green	2.22
GaPN	LED yellowish green	2.17
GaAsP	Led Yellow	2.10
Ga AsP N	LED Orange red	1.99
GaAsAl	LED standard red	1.92
GaAsSi	LED infrared	1.30
SiC	LED Blue	3.50
GaAsP	LED white	4.20

At absolute zero-degree temperature, semiconductors are pure insulators. As the temperature is increased thermal energy create vibration in crystal lattice and few electrons, which acquire sufficient vibrational energy break their covalent bond, become free, and move to conduction band. The energy required to rapture the covalent bond is called the energy gap E_g and termed as energy gap or band gap energy.

A *pn* crystal is called junction diode. Diode can be forward or reverse biased using a voltage source. The forward current is given by,

$$I_F = I_R\left(e^{\frac{qV}{\eta kT}} - 1\right)\text{.................(1)}$$

where,
I_F = forward current.
I_R = reverse current or reverse saturation current.
q = electronic charge e= 1.6 x 10^{-19} C.
η = called ideality factor varies between 1 and 1.5.
k = Boltzman constant= 1.38 x 10^{-23} J/K.
T = temperature in degree Kelvin.

Figure 1: Experimental setup

when the diode is reverse biased negligible reverse current flows through the diode. The reverse current is given by

$$I_R = BT^3\left(e^{\frac{-E_g}{\eta KT}} - 1\right) \text{.............................} \textbf{(2)}$$

The reverse current in case of silicon diode is zero that makes it a perfect diode. Germanium diodes show reverse current and gets the name leaky diode. LEDs also have very small reverse current. The reverse current is temperature dependent. The constant B appearing in equation 2 is a constant depends on the structure or the area of the depletion region.
Substituting equation 2 in equation 1

$$I_F = BT^3\left(e^{\frac{-E_g}{\eta KT}} - 1\right)\left(e^{\frac{qV}{\eta KT}} - 1\right) \text{....................(3)}$$

Taking natural logarithm on both sides

$$\frac{E_g}{\eta kT} = ln\left(\frac{BT^3}{I_F} + \frac{qV}{\eta kT}\right) \text{.........................(4)}$$

$$V = \frac{E_g}{q} = \left[ln\left(\frac{BT^3}{I_F}\right)\right]\frac{qV}{\eta KT} \text{.......................(5)}$$

Equation 5 is an equation of straight-line graph with slope

$$slope = -\ ln\left[\frac{BT^3}{x_F}\right]\frac{\eta k}{q}$$

and

$$Y_{imtercept} = \frac{E_g}{q}$$

$$E_g = Y_{imtercept} \times q$$

Knowing the Y intercept the energy gap can be calculated.

To determine the energy gap E_g a small constant current is passed through the diode at various temperatures. The voltages developed at the junction are noted. The junction voltage versus temperature graph is drawn. From the straight-line graph, Y intercept gives the E_g directly in electron volt. From the slope, constant B can be calculated by manipulating the slope term. For small forward current of the order of hundreds of microampere e^{slope} is unity. It indicates that the graphs for different diodes are all parallel and the constant B is independent of diode material, it depends only on the forward current, hence it is connected with majority carriers.

Procedure

The diodes are provided with long (10 inch) wires that can be directly connected to the constant current source, in series with a digital DC micro ammeter and circuits is completed as shown in Figure 1.

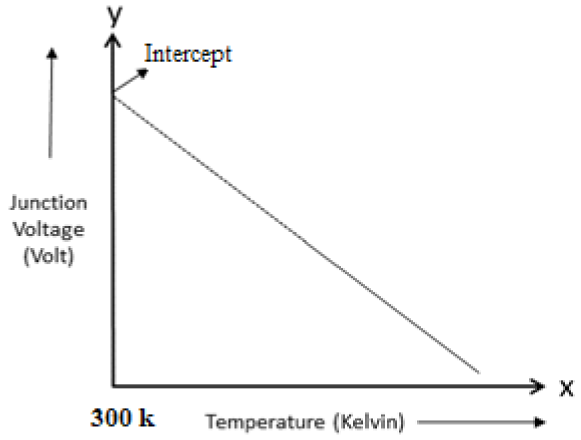
1. Switch ON the energy band gap kit.
2. Connect a diode with an energy band gap kit.
3. Keep the diode and a thermometer inside of the glass beaker.
4. The diode along with the thermometer is placed in the 180 mL beaker.
5. Switch ON the oven and heat the oil up to 50 °C then switch off the oven. (even though the temperature of oil raises up to 100 °C.
6. As silicon oil cools, the temperature decrease. junction voltage is noted for different temperature at 5 (°C) interval. The reading obtained are tabulated.
7. A graph is drawn taking temperature in (Kelvin) along X-axis and junction voltage along Y-axis. The straight-line curve is extended to cut the Y-axis and the Y intercept is noted

Observations

S.No.	Temperature (°C)	Junction voltage(V)
1		
.		
15		

Graph

1. Draw a graph between the junction voltage and absolute temperature as shown below



Extrapolate the curve to 0 K. the value expressed in electron volts gives the energy band gap of the material of the diode.

Results

When extrapolate the line up to 0 K the line intersects the Y axes at……. Volts. So the Forbidden Energy band gap of the experiment diode is

1. Energy(E_g) of given diode is =________eV.

Questions

1. What is a semiconductor? What is the difference between intrinsic and extrinsic semiconductors?
2. What are valence band and conduction bands?
3. For conduction to take place is it always necessary that the electrons are available in conduction band.
4. For solid sodium, there is a considerable gap between the conduction band and valence band; yet it is a good conductor. How it is so?
5. What is energy gap? Is there energy gap for gases also?
6. Are there any materials for which energy gap is zero? Are there any materials for which energy gap is infinity?
7. In a doped semiconductor. How the conduction occurs at room temperature/ Explain why there is no conductivity at temperature close to ok.
8. The electrical conductivity increases with rise of temperature in semiconductors, where as it decreases in the case of conductors. Explain.
9. How do you differentiate between a conductor, an insular and a semiconductor in relation to energy gap?
10. What do you mean by a hole? Explain the hole conduction through a *p* – type germanium.

Precaution

1. Ensure proper and tight connection of apparatus.
2. Do not heat to higher temperature (>100 centigrade).
3. Graduation on energy regulator knob does not indicate the temperature. They simply indicate the

ON/OFF time of the heater.

References

1. Engineering Physics Practical: Dr. Rubey Das, C.S. Robinson, Rajesh Kumar, Prasant Kumar Sahu.
2. Physics of Semiconductor Devices, S. M. Sze.

4. Characteristics of a n-p-n Transistor

Aim: To study the input, output and transfer characteristics of a n-p-n transistor.

Apparatus: Bipolar Junction Transistor kit with inbuilt transistor (N-P-N, P-N-P), DC variable power supply, digital voltmeter, ammeter, resistance and connecting wires.

Introduction: A transistor is a three terminal semiconductor device. The three terminals are the emitter, the base and the collector. A transistor transfers a signal from low resistance to high resistance; hence it is named as transistor.

In a transistor, the N and P type semiconductor sections are alternated. The transistor in which one p-type material is placed between two n-type materials is known as NPN transistor. Similarly, where n-type material is between two p- type materials is known as PNP transistor. The middle appears to be sandwiched between the other two, namely the emitter and the collector. In comparison to the doping level of the collector, the emitter is always heavily doped in order to provide a large supply of charge carriers, and the base is lightly doped to minimize the recombination that occurs in it between the electrons and the holes. The collector will be having a large area in order to efficiently gather the charge carriers. In order to identify the terminals, you should carefully observe the transistor. You can locate a small projecting flap at its bottom edge. The nearest lead to this tab is always the emitter lead, and the farthest one is the collector lead. The lead between the emitter and the collector is the base lead. The NPN transistor amplifies the weak signal enter into the base and produces strong amplify signals at the collector end. In NPN transistor, the direction of movement of an electron is from the emitter to collector region due to which the current constitutes in the transistor. Such type of transistor is mostly used in the circuit because their majority charge carriers are electrons which have high mobility as compared to holes.

One of the major difference between the NPN and PNP transistor is that in the NPN transistor the current flow between collector to emitter when the positive supply is given to the base, whereas in PNP transistor the charge carrier flows from the emitter to collector when negative supply is given to the base.

Working of NPN transistor: The forward bias causes the electrons in the N type emitter to flow towards the P type base. This constitutes the emitter current Ie. As these electrons flow through the P type base, then tend to combine with holes. As the base is lightly doped and very thin, therefore, only a few electrons combine with holes to constitute base current Ib. The remainder cross over into the collector region to constitute collector current Ic. In this way, almost the entire emitter current flows in the collector circuit. It is clear that emitter current is the sum of collector and base currents.

i.e., $Ie = Ib + Ic$

If we now join together two individual signal diodes back-to-back, this will give us two PN-junctions connected together in series that share a common P or N terminal. The fusion of these two diodes produces a three layer, two junction, three terminal device forming the basis of a Bipolar Junction Transistor, or BJT for short. BJT has three terminals connected to three doped semiconductor regions. In an NPN transistor, a thin and lightly doped P-type *base* is sandwiched between a heavily doped N-type *emitter* and another N-type *collector*; while in a PNP transistor, a thin and lightly doped N-type *base* is sandwiched between a heavily doped P-type *emitter* and another P-type *collector*. BJT may be used in amplifying or switching applications. Bipolar transistors are so named because their operation involves both electrons and holes, as opposed to unipolar transistors, such as field effect transistors, in which only one carrier type is involved in charge flow. Although a small part of the transistor current is due to the flow of majority carriers, most of the transistor current is due to the flow of minority carriers and so BJTs are classified as minority carrier devices.

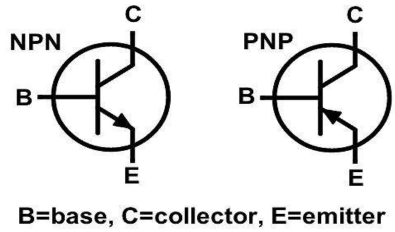
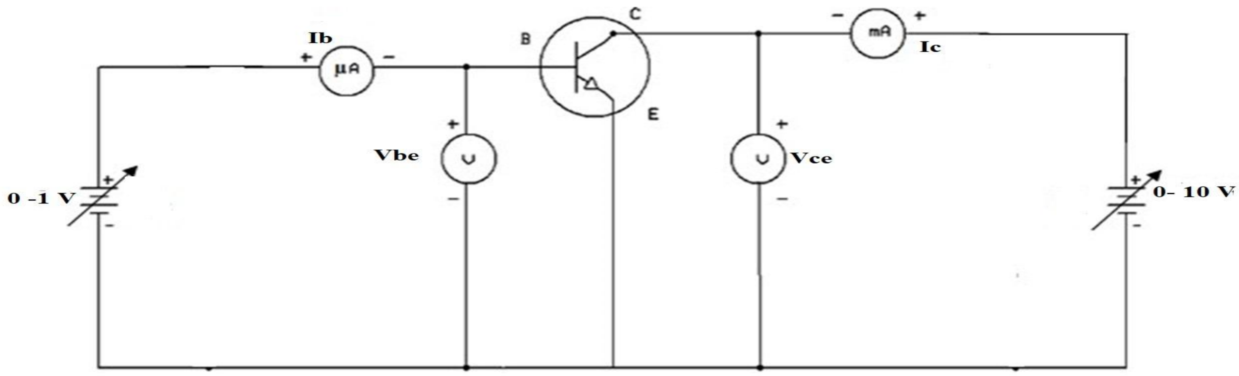


Figure 1. Identification of a transistor

The following conventional nomenclature will be used

V_{BE} - Base to emitter voltage

V_{CE} - Collector to emitter voltage



I_B - Base current

I_C - Collector current

Figure 2: NPN Transistor common emitter configuration circuit diagram

Input characteristics: The input voltage V_{BE} is varied and the corresponding input current I_B is noted, keeping V_{CE} constant. The input characteristics are similar to the forward biased characteristics of p-n junction diode. Curves of input characteristics can be drawn for different values of V_{CE}. When V_{CE} is increased, it produces greater depletion region in the collector-base junction. This reduces the distance between CB and EB depletion regions. Consequently, more of the charge carriers from the emitter flow across the CB junction, and fewer flow out via the base terminal and base current decreases.

From this graph we can determine input impedance R_{IN} by the formula,

$$R_{IN} = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right) V_{CE}(constant)$$

Output Characteristics: In plotting output characteristics, I_B is maintained constant at several convenient levels. V_{CE} is adjusted in steps, and the I_C is measured. For each value of I_B, I_C *is* plotted versus V_{CE} to give a family of characteristics. I_C increases slightly to some extent with increasing V_{CE} although I_B is held constant. I_C reduces to zero when V_{CE} becomes zero.

In this graph we can determine output impedance R_{OUT} by the formula,

$$R_{OUT} = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right) I_B$$

Transfer characteristics: Current transfer characteristic graph is plotted between collector current I_C and base current I_B. by keeping V_{CE} constant, I_C is determined for each value of I_B. It is also a straight line.

In this graph we can determine current gain β by the formula,

$$\beta = \left(\frac{\Delta I_C}{\Delta I_B}\right) V_{CE}$$

Remember β is always greater than unity, because I_C is always greater than I_B

Procedure

Connect the transistor in common emitter (CE) configuration circuit as shown in Figure 2.

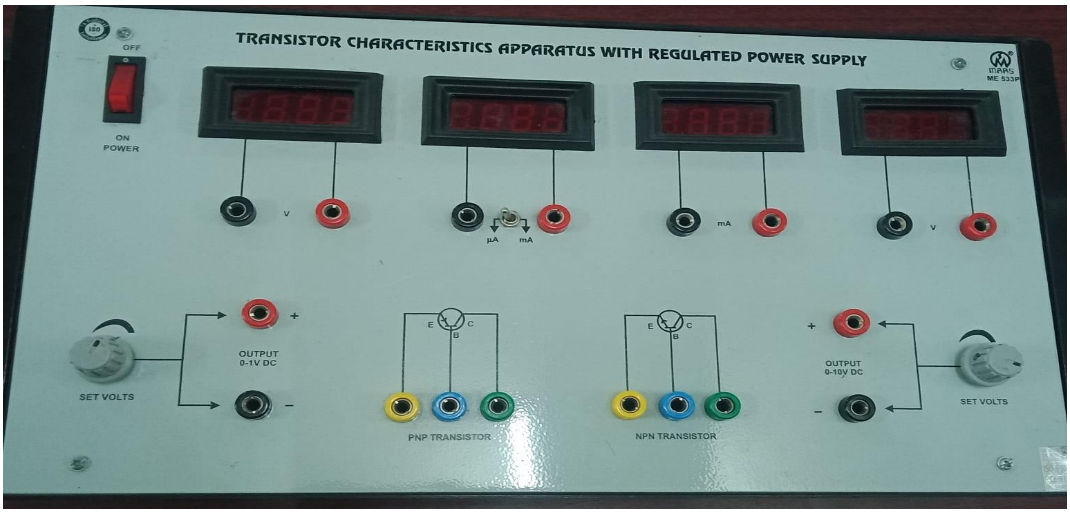


Figure 3: Experiment setup

Input characteristics

In this the collector emitter (V_{CE}) voltage is fixed and base current (I_B) is measured as the base to emitter voltage (V_{BE}) is varied in steps.

1. Keep the voltage V_{CE} = 1 volt.
2. Increased V_{BE} in steps an optimal value such that you will be able to get nearly 10 data points minimum and note down base current (I_B) correspondingly.
3. Take care that the V_{CE} remains constant.
4. Take different sets of readings for different values of V_{CE} (i.e. V_{CE} = 1V and V_{CE} = 5V).
5. Plot graph of I_B (along Y- Axis) against V_{BE} (along X - Axis).

Observations

S.No.	V_{CE} = 1 V		V_{CE} = 5 V	
	V_{BE} (V)	I_B (μA)	V_{BE} (V)	I_B (μA)
1				
2				
…				
10				

Output characteristics

In this the base current (I_B) is fixed and collector current (I_C) is measured as the collector to emitter voltage (V_{CE}) is varied in steps.

1. Set the base current (I_B) to 200 micro-amps by adjusting V_{BE}.
2. Vary collector to emitter voltage (V_{CE}) and note down the value of I_C for different values of V_{CE}.
3. Increase the I_B value into 400 μA and repeat step 2.
4. Plot graph (e.g. as shown in figure 10.4) of I_C (along Y-axis) against V_{CE} (along X - axis) for different values of I_B.

Observations

S.NO.	I_B = 200 μA		I_B = 400 μA	
	V_{CE} (V)	I_C (mA)	V_{CE} (V)	I_C (mA)
1				
2				
.				
10				

Transfer characteristics

In this case, we study the variation of I_C versus I_B, e.g., input Vs output.

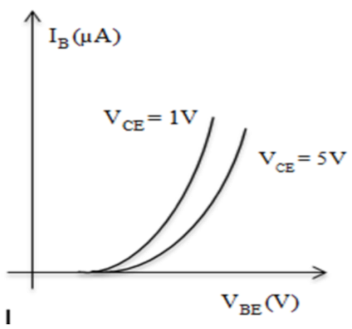
1. Adjust V_{CE} to 5 volts.
2. Vary I_B from 0 up to 150 micro amps in steps of 10 micro amps and note down respective values of I_C.
3. Repeat step 2 for different values of V_{CE}.

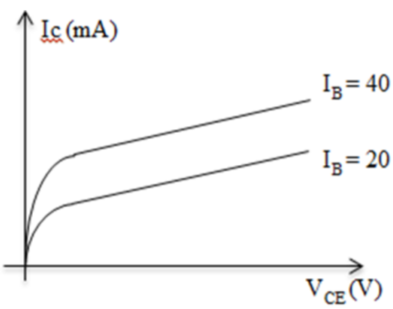
Plot graph of I_C (along Y-Axis) against I_B (along X-Axis) for different values of V_{CE}.

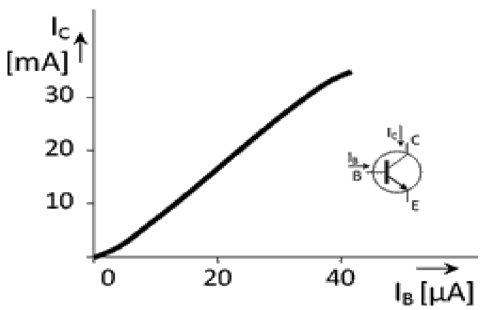
Observations

S.NO.	V_{CE} = 5V		V_{CE} = 10 V	
	I_B (μA)	I_C (mA)	I_B (μA)	I_C (mA)
1				
2				
.				
10				

Representative graphs







Results

Input impedance: This is the ratio of V_{BE} to I_B Keeping V_{CE} constant. This is obtained by drawing a tangent to the input characteristic.

Input impedance $R_{IN} = \frac{V_{BE}}{I_B} = \frac{1}{Slope} of\ tangent\ at\ the\ onset\ of\ the\ raise$**..................ohm**

Output impedance: This is the ratio of V_{CE} to I_C keeping V_{BE} constant. This is obtained by drawing a tangent to the output characteristic,

Output impedance $R_{OUT} = \frac{V_{CE}}{I_C} = 1/Slope\ of\ tangent$**................ohm**

Current amplification factor: This is the ratio of I_C against I_B with V_{CE} constant. This is obtained by finding slope of tangent to transfer characteristic.

$$\text{Current amplification factor} \quad \beta = \frac{I_C}{I_B} = slope\ of\ tangent$$

Questions

1. What is a transistor?
2. What are the three regions in a transistor? Which region of the transistor is very highly doped?
3. Define the role of emitter, base and collector of a transistor.
4. What is the significance of arrow mark in the symbol of a transistor?
5. What is the direction of conventional current through the body of a NPN transistor?
6. Why NPN transistors are preferred over to PNP transistors?
7. In how many ways can a transistor be used? Which of these circuits is better?
8. Why the input resistance of a transistor is low and output resistance is high?
9. Define α and β of a transistor for DC current. What is the relation between the two?
10. What is a BJT?

Precautions

1. Always connect voltmeter in parallel and ammeter in series.
2. Connection should be proper and tight.
3. Switch on the supply after completing the circuit.
4. DC supply should be increased slowly in step
5. Reading of voltmeter and ammeter should be accurate.
6. Before switching off the supply, DC supply should be brought to minimum value

References

1. Physics of Semiconductor Devices, S. M. Sze.

Hall Effect

Aim: To find the Hall coefficient, carrier density and carrier mobility of the given specimen.

Apparatus: The apparatus consists of an electromagnet, Gauss meter, Gauss probe, power supply (0-5 A) and the probes to measure the Hall voltage, multipurpose stand and electric wires.

Background: Understanding the behavior of charged particles in electric and/or magnetic field is rather essential in fundamental and application point of view. For example, in solar cells, the inbuilt electric field across the p-n junction drives the photogenerated charge carriers to their respective electrodes. On the other hand, in particle accelerators, combinations of electric and/or magnetic field are employed to guide and accelerate the charged particles. In the present experiment, we test the concept of 'Hall Effect' experimentally and find the aforementioned properties.

Theory: Let us assume that a current carrying conductor (or a semiconductor) is placed in an external magnetic field where the direction of the field is perpendicular to the direction of the flow of electrons. The magnetic field pushes the moving charges to either side depending on their sign of charge. These pushed charge carriers induce some finite voltage across the sample in the direction perpendicular to both the current and the magnetic field. The schematic of the sample in a finite magnetic field is shown in Figure 1. The induced voltage can be translated into electric field if the sample dimensions are known. These voltage and electric field are known as Hall voltage and Hall electric field, respectively.

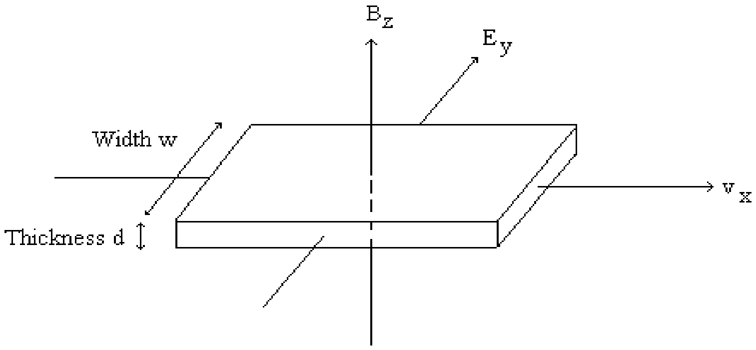


Figure 1. Schematic of a sample in an external magnetic field.

In this scenario, the moving charge experiences two stimuli, *viz.* external magnetic field ($\vec{B}$) and internally induced electric field ($\vec{E}$) for a finite charge carrier velocity ($\vec{v}$). Note that, if carrier velocity is zero, then the magnetic field has no effect on the charge carrier. Indeed, the force can be explained by the well-known Lorentz force ($\vec{F}$) as described by the following equation.

$$\vec{F} = e(\vec{E} + \vec{v} \times \vec{B}) \qquad (1)$$

where, e-charge of the electron and all quantities are in SI units.

The force due to the induced electric field compensates (equal and opposite) that of from the magnetic field. Such a balance is known as 'steady state condition'. Based on the equation (1), for the given sample configuration in Figure 1, the force exerted on the charge carrier along the Y-direction can be written as

$$\vec{F}_y = e\left(\vec{E}_y - \vec{v}_x \times \vec{B}_z\right) = 0 \qquad (2)$$

Hence the steady state Hall electric field along the Y- direction can be written as

Yielding $$\vec{E}_y = \left(\vec{v}_x \times \vec{B}_z\right)$$ $$v_x = E_y/B_z \qquad (3)$$

As mentioned in the beginning, the aim of this experiment is to find the electrical characteristics of sample, such as carrier density and carrier mobility. For this, we need to convert the measurables (induced voltage, external magnetic field, sample dimensions) into the unknown quantities. If one recalls the linear relation between the conductivity (σ) and mobility (μ) for a given carrier concentration (n),

$$\sigma = ne\mu \qquad (4)$$

By definition, μ is velocity of the charge carrier (v_x) per unit field, i.e. $\mu = v_x/E_x$, where E_x is associated with the bias (external electric field and measurable quantity) that drives the electrons in the conductor (or semiconductor).

Thus from equation (4) $\sigma = (v_x/E_x)ne$

$\Rightarrow \sigma E_x = v_x ne = J_x$, where J_x is the current density along the X-axis

$$\Rightarrow v_x = J_x/ne \qquad (5)$$

Now by considering the equations (3) and (5) it is clear that

$$v_x = J_x/ne = E_y/B_z$$
$$\Rightarrow 1/ne = E_y/(J_x B_z) \qquad (6)$$

Equation (6) yields the Hall coefficient,

$$R_H = \frac{1}{ne} = E_y/(J_x B_z) \qquad (7)$$

From Figure 1, the current density can be easily calculated from $J_x = I_x/(dw)$, where d and w are thickness and width of the sample and I_x is the current flowing through the sample. Equation (7) can be written as

$$R_H = \frac{1}{ne} = (dw)E_y/(I_x B_z) \qquad (8)$$

Note that the quantity wE_y corresponds to the voltage across the Y-axis, which is nothing but the Hall voltage (V_H).

$$V_H = R_H I_x B_z/d \qquad (9)$$

From equation (9) if the other quantities are known, then the Hall voltage is an accurate measure of the magnetic field. Also, we can see that the Hall voltage is proportional to

- applied magnetic field
- current through the sample
- 1/thickness of the sample

Summary

$$R_H = dV_H/(I_x B_z)$$

$$\mu = R_H \sigma$$

$$n = \frac{1}{R_H e}$$

Where, d= 5 x 10^{-2} cm

and σ = 0.1 cm^{-1} $Volt^{-1}$ Sec^{-1} Coulomb

Method

1. Refer to and strictly observe the warning signs annotated on the instruments. Also note that the σ and d were given in the manual

2. Connect the electromagnet (EMU-50) coils in series to the DC power supply (DPS-50V). A digital photograph is given in Figure 2.

3. Place the Hall probe between pole pieces and adjust the distance between them to a minimum. Note that magnetic poles should not touch the probe. Once optimized, do not alter the distance between the poles during the rest of the experiment. Now remove the Hall probe from the air gap between the pole pieces.

Figure 2. Digital photograph of the experimental setup.

4. Connect the Gauss meter with mains and switch it 'ON'. Put the range switch at X1 position (2 k Gauss) and set zero with the 'ZERO ADJ' knob keeping the Gauss probe away from the electromagnet.

5. Place the Gauss probe in the gap such that the probe face is perpendicular and centre of the magnetic field. Orientation of the probe should depict +ve reading on the Gauss meter (DGM-102). North pole is annotated on the on the Gauss probe which corresponds to that of North pole of the electromagnet.

6. Switch 'ON' the power supply for the electromagnets to energies the coil and measure the flux density over a suitable range of coils current (A) I say 0.2 A, 0.4 A, 0.6 A up to a **maximum of 3.5 A**. Take a note of the corresponding magnetic field from the Gauss meter which produces a calibration curve of the electromagnet.

Table 1: Calibration of the electromagnet.

S.No.	Current (I) A	Magnetic field, B_z (Gauss or Tesla)

1.	0.2	
	.	
	3.5	

7. Turn off the power supply and take out the Gauss probe and secure it by pulling the streel tube over.
8. Connect the Red-Black wires of sample to current terminal and Green-Yellow wire of sample to voltage to the source measure unit (DHE-21A).
9. Switch ON the Hall Effect set-up (DHE-21A) and adjustment current in mA.
10. Switch over the display to voltage side. There may some voltage even outside the magnetic field. This is due to imperfect alignment of the four contacts of the Hall probe. In case its value is comparable to the Hall voltage it should be adjusted to a minimum possible for Ge Hall probe only. In all cases, this error should be subtracted from the Hall voltage.
11. Now place the Hall probe in the magnetic field and Rotate the Hall probe till it become perpendicular to magnetic field and the crystal side of the hall probe should face the North pole of electromagnetic (Hall voltage will be maximum in this adjustment). The setup is ready for the experiments. For n-type probe Hall voltage will show –ve sign and for p, +ve sign.
12. Measure the Hall voltage as a function of current keeping the magnetic field constant.
13. Switch on the electromagnet power supply and adjust current to produce a desired magnetic field. Now measure the Hall voltage (V_H) with respect to Hall probe current I_x (mA) say 0.5 mA, 1 mA……to **a maximum of 8 mA**. Tabulate the Hall voltage corresponding to current, I_x.

Table 2: Measuring the Hall voltage for a fixed magnetic field.

Magnet current =____ A; Magnetic field, B_z = ____Gauss		
S.No.	Current (I_x) mA	Hall voltage, V_H (mV)
1	0.5	
2	.	
..		
	8	

Plot a graph between I_x and V_H where a straight line is expected. The slope of this curve corresponds to V_H/I_x (V/A). Now use the equations in the **Summary** and the data on the Gauss meter to calculate R_H, μ and n for the given Hall probe.

Results

1. The calculated value of Hall coefficient = ………………cm^3/Coulomb

2. The sign of the Hall coefficient is ……………….
3. Therefor the given semiconductor is of ………… type.
4. The carrier density =…………… cm^{-3}
5. The mobility of the charge carriers =……………… cm^2/Vs

Questions

1. Give some examples of other semiconductors that you can think off?
2. Why it is advantageous to have a thin sample in Hall effect measurements?
3. What information do you get about a solid from Hall effect measurements?
4. What are the applications of Hall effect in instrumentation?
5. What happens to the Hall voltage if you just turn on only one magnetic coil in the same sample configuration?
6. What is the velocity of the electrons when the electric field is 10 V/m and the magnetic field is 15A/m?
7. At equilibrium compare Lorentz and Hall forces on the charge. greater/equal/less.
8. What is the dependency of mobility on the electrical conductivity?
9. If the carrier density is decreased what happens to the magnitude of the hall coefficient?
10. Calculate the Hall voltage induced on a human heart when subjected to MRI scanning. Assume that the conducting path of heart to be 10 cm with a velocity of 10 cm/s in a magnetic field of 1.5 T.

Precautions

1. All connection should be appropriately performed.
2. Mount the *probe* properly for getting maximum voltage.
3. Vary the current through the magnetic coils slowly to avoid damage of coils/power supply.
4. Handle the probes carefully and do not touch probe during experiment.
5. The current through the sample should not be large enough to cause heating (8 mA maximum).
6. Do not use the instrument in wet/ humid environment.

References

1. Engineering Physics Practical: Dr. Rubey Das, C.S. Robinson, Rajesh Kumar, Prasant Kumar Sahu, Laxmi Publications Pvt Ltd, Delhi.
2. Introduction of Solid State Physics, by Charles Kittel, Wiley publishing, New Delhi.
3. W. Angrist, Scientific American, 205, 124 (1961).
4. E. M. Putley, “The Hall Effect and Related Phenomena”, Butter

Diffraction

Aim: To study the phenomenon of diffraction, measuring the diameter of single wire, cross wire, single slit, double slit and spacing between the lines in a grating.

Apparatus: Diode laser and power supply, cell-mount with diffraction cell, optical rail, screen.

Introduction: All carriers of energy and momentum, such as light and electrons, propagate like wave and exchange energy like a particle.

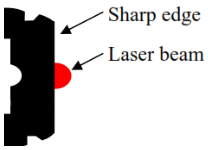
The convincing evidence showing light behaves like waves, is through experiments on interference and diffraction convincing demonstrate that light behaves like waves.

What is diffraction of light? How does a diffraction pattern look like?

Diffraction is the bending of waves around obstacles or spreading of waves on passing them through an aperture/ opening. When light diffracts off of the edge of an object, it creates a pattern of light referred to as a *diffraction pattern*. Following are some examples of *diffraction patterns* that are shown by certain objects, if a monochromatic light source, such as a laser, is used to observe diffraction.

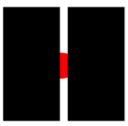
Diffracting element

Diffraction patterns recorded @ IITBhilai except (a)

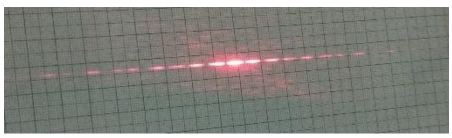


Razor edge

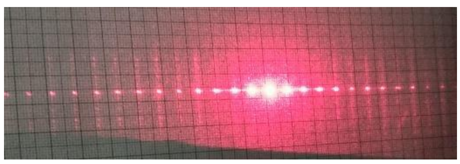
(a)

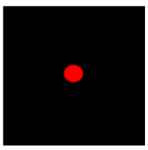


Single slit



Wire





Pinhole

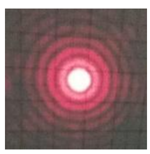


Figure 1: Schematic of various diffracting elements and the corresponding digital images of diffraction patterns.

Following assumptions are made to describe diffraction pattern.

- The slit size is small, relative to the wavelength of light; Aperture size $\leq \lambda$, wavelength.
- The screen is far away.

- Cylindrical waves are represented in 2D diagrams as circular waves.
- The intensity at any point on the screen is independent of the angle made between the ray to the screen and the normal line between the slit and the screen. This is possible because the slit is narrow.

Theory

For single slit, double slit, single wire and cross wire: -

The intensity distribution for a diffraction pattern from a single slit is described mathematically as a *sinc* function where:

$$\text{Intensity} = \{(\sin(y)/y)\}^2$$

If we plot intensity with reference to position (y), the pattern would look like as shown below, where minimum or zero intensity is, y_n

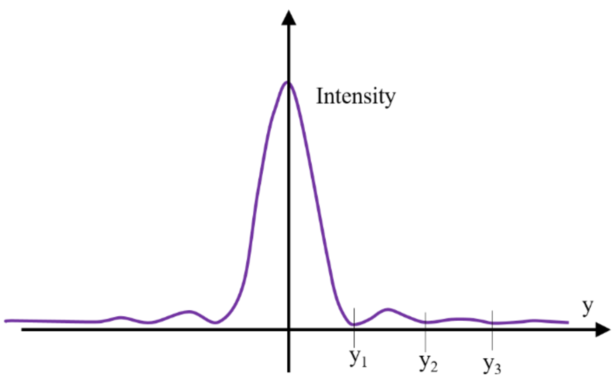
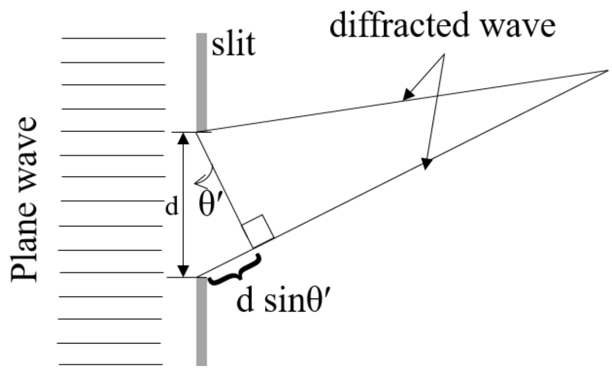


Figure 2: Intensity distribution of a diffraction pattern.

Minimums are caused by the destructive interference of plane waves diffracting off the edges of the slit. Destructive interference occurs when two plane waves are out of phase with respect to each other. The minimum occurs when the phase difference, β of two plane waves are equal to multiples of π. In figure shown below, $\beta = \frac{\pi d}{l} \text{Sin } \Theta'$; and zeros occur when $\beta = n\pi$ when $n = \pm1, \pm2, \pm3, \ldots$

$$\mathbf{n\,\lambda = d\,\text{Sin}\,\theta'}$$



We can derive the relationship between the diameter of the slit, d, and the distance to a minimum or zero in the sinc function, y_n. Refer to the following figure

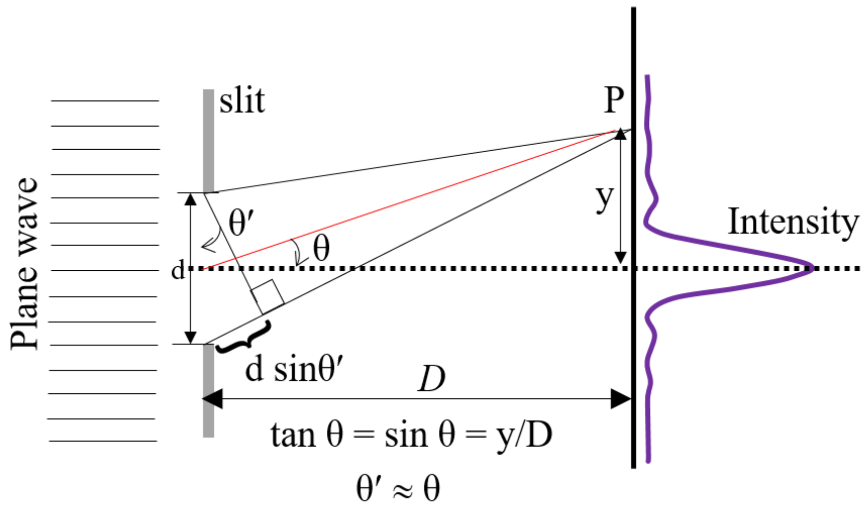


Figure: Intensity distribution of a diffraction pattern shown with conditions of phase matching.

where,
d = slit diameter, n = a minimum or zero (±1, ±2, ±3,)

$\theta^{'}$ = diffracted wave angle; λ = laser wavelength

θ = sinc(y) function angle for zero

D = distance from slit to screen

$y_n =$ distance from center of diffraction pattern to a minimum or zero.

Assumptions

D >> d, therefore, θ′ = θ,

$$\tan tan\, \theta_n = \frac{y_n}{D}; \quad \tan tan\, \theta_n \sim sin\theta_n \sim \theta_n \sim\theta = \frac{y_n}{D}$$

The condition for minimum; $d\, Sin\, \theta_n = n\lambda$

$$\text{Thus, } d = \frac{nD}{y_n}\lambda$$

The same formula is used for measuring the thickness of a wire or human hair. Refer to the figures shown in the beginning and compare the diffraction pattern of wire and single slit. The distance from the minimums to the center of the diffraction pattern is still the same for the two cases by a wire of the same thickness as a slit. The only difference is that the center of the diffraction pattern looks brighter because the percentage of the laser beam that is not diffracted by the wire add to the intensity of the center of the pattern.

F

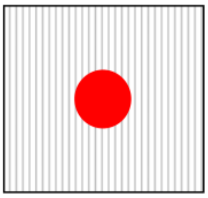
One can also calculate the wavelength, of the laser used by measuring y from a diffraction pattern of a slit or wire of known d.

How does diffraction pattern look like for an object with a periodic structure, example grating?

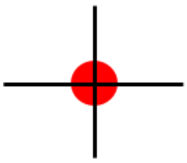
If a *laser* is used to observe diffraction, below are some examples of *diffraction patterns* that are created by certain objects with repeated patterns:

Diffracting element

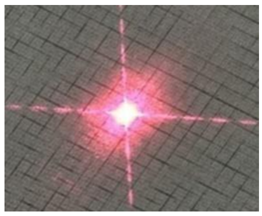
Diffraction patterns obtained @IIT Bhilai

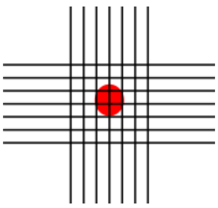


Grating

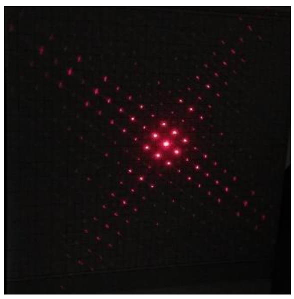


Crossed wire



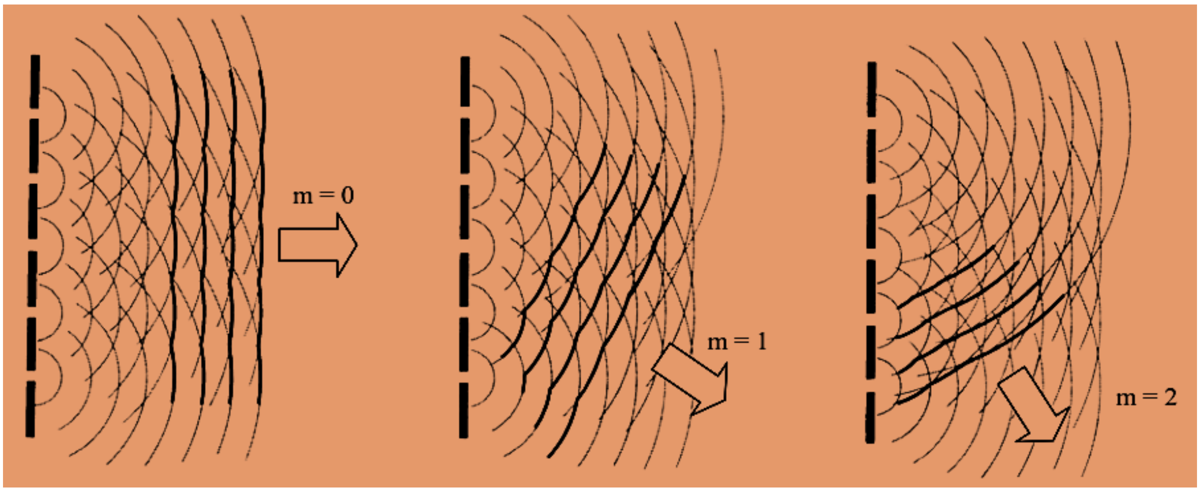


Mesh



The diffraction pattern from a grating differs from the pattern from and individual object. A diffraction grating is a collection of reflecting or transmitting elements separated by a distance comparable to the wavelength of light under study. It may be thought of as a collection of diffracting elements, such as a pattern of transparent slits in an opaque screen

To understand wave behavior from a number of slits combined, we look at the combined wavelets shown by the figure below, one can see different *orders*, m, of wavelets moving away from the slits.



We have seen the shape of a diffraction pattern intensity from a single slit. When plane waves are diffracted from multiple slits (# = N), of equal distance apart, are combined, the diffraction pattern gets more mathematically complicated. The equation for the diffraction pattern intensity becomes:

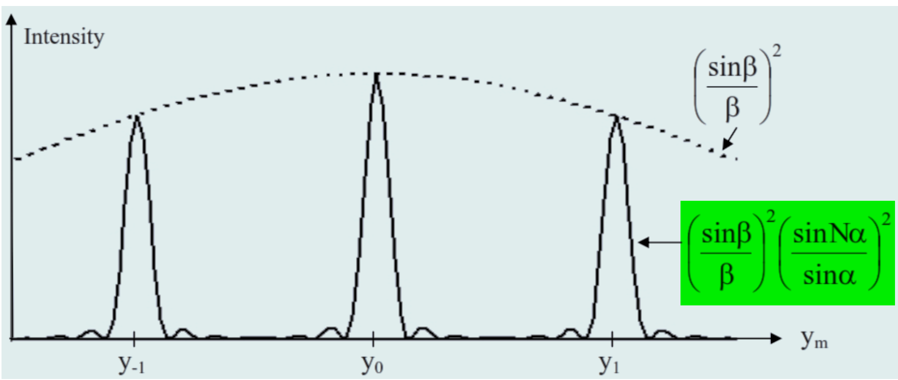
$$\text{Intensity} \rightarrow (\sin \beta / \beta)^2 (\sin N\alpha / \sin \alpha)^2$$

where,

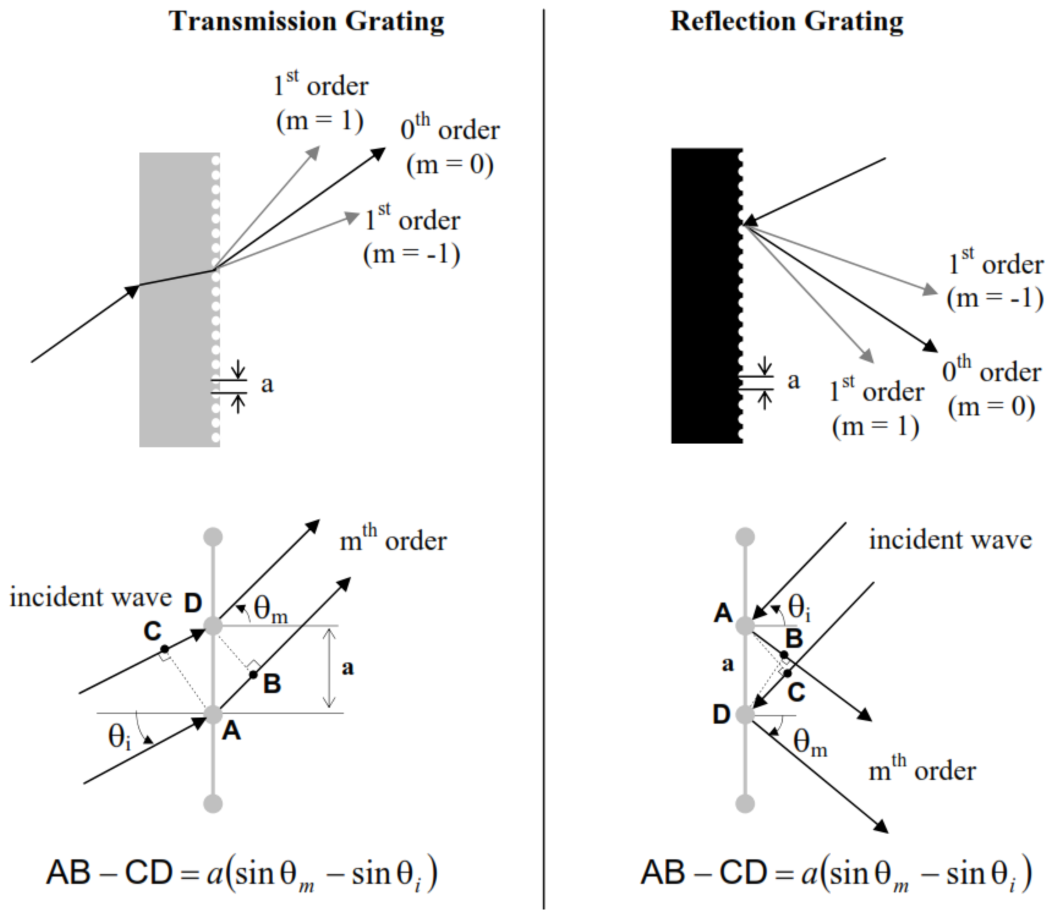
β= phase difference between diffracted waves from individual slit

α = phase difference between waves diffracted off of N slits

A generalized plot is shown below



In the present experiment we have two types of gratings; one that transmits, and one that reflects



When taking measurements on the diffraction pattern from a grating, one would measure the distances between the central order (or 0th order) and higher order maxima. Therefore, the measured areas of the pattern are where there is constructive interference. Maxima created by constructive interference occur when the difference in phase, α, is a multiple of π. At normal incidence, when

$\theta_i = 0$, we arrive at

$$\alpha = \frac{\pi a}{l} \sin\theta_m$$

The position of maxima are where $\alpha = m\pi$ when m = 0, ±1, ±2, ±3,…..
Therefore,

$m\lambda = \alpha \sin \Theta_{m,}$ this is called the Grating Equation.

An electromagnetic wave incident on a grating will upon diffraction, have its electric field amplitude, or phase, or both, modified in a predictable manner.
In the Figure1, the path different between AP & CP is CB which is denoted by δ.
From ΔCAB,

$$Sin\theta = \frac{CB}{AC} = \frac{\delta}{d} \quad ……...................(1)$$

$$\delta = dSin\theta$$

But according to interference law path between them is

$$\delta = m\lambda \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(2)}$$

By equation (1) and (2),

$$m\lambda = dSin\theta$$

Then

$$d = \frac{m\lambda}{Sin\theta}$$

The diffraction equation is, (condition for minima)

$$Sin\theta_m = \frac{m\lambda}{d}$$

We can also write for angle (single slit, double slit, single wire, cross wire) which minimum intensity occur and this can find out the width ‘d’ as,

$$d = \frac{m\lambda}{Sin\theta}_{min}$$

And the diffraction equation (for grating) is,

$$m\lambda = d(Sin\theta_i + Sin\theta_m)$$

Since angle θ_i is not considered, (ie. the angle of incidence is 0).

$$m\lambda = Sin\theta_m$$

Then width ‘d’ as,

$$d = \frac{m\lambda}{Sin\theta_m}$$

Summary

The diameter and angle of equation

$$d = \frac{m\lambda}{Sin\theta_m}$$

$$\theta_m = tan^{-1}\frac{y_m}{D}$$

Number of lines per meter, $\frac{1}{d}$

where,

d -width of the slits (for grating, combined width of the opaque region and transparent region of the grating)

m- is the order of diffraction.

θ_m is the angle subtended with the central maximum and mth order minimum.

λ is the wavelength of a laser.

Error Analysis: -

Use the method of differentiation.

Procedure

1. Fix kinematic laser mount on the optical rail, as shown in the figure below.
2. Mount the diode laser.
3. Place the cell mount and the single slit on to the mount carefully.
4. Place the screen in front of the single slit at a particular distance.
5. Switch ’ON’ the laser and align the laser beam in such a way that the beam falls exactly on the slit and through it on the screen.
6. To determine width of the slit, the distance ’D’ (distance between the screen and the slit) measured directly.
7. The distance, ’Y_m’, between the central maximum and mth minimum in the intensity distribution of the diffraction pattern are measured directly.
8. Repeat the above procedure for double slit, single wire, cross wire and grating.

Figure: Experimental setup

Observation

Single wire

Wavelength laser light λ= 650 nm

Order (m)	Distance between the screen and slit (D) cm	Distance between central maxima and mth order minima (Y_m) cm	$\theta_m = tan^{-1}\frac{y_m}{D}$	$sin\theta_m$	$d = \frac{m\lambda}{sin\theta_m}$ µ m
1					
2					
3					

Mean diameter of the wire d =……………………… µ m

Cross wire

Wavelength laser light λ= 650 nm

Order (m)	Distance between the screen and slit (D) cm	Distance between central maxima and mth order maxima (Y_m) cm	$\theta_m = tan^{-1}\frac{y_m}{D}$	$sin\theta_m$	$d = \frac{m\lambda}{sin\theta_m}$ µ m
1					
2					
3					

Mean Diameter of the wire d =………………… µ m

Single slit

Wavelength laser light λ= 650 nm

Order (m)	Distance between the	Distance between central maxima	$\theta_m = tan^{-1}\frac{y_m}{D}$	$sin\theta_m$	$d = \frac{m\lambda}{sin\theta_m}$

	screen and slit (D) cm	and mth order minima (Y_m) (cm)			µ m
1					
2					
3					

Mean slit width d =……………………… µ m

Double slit

Wavelength laser light λ = 650 nm

Order (m)	Distance between the screen and slit (D) cm	Distance between central maxima and mth order maxima (Y_m) (cm)	$\theta_m = tan^{-1}\frac{y_m}{D}$	$sin\theta_m$	$d = \frac{m\lambda}{sin\theta}_m$ µ m
1					
2					
3					

Mean slit width d =……………………… µ m

Grating

Wavelength of the laser light λ = 650 nm

Order (m)	Distance between the screen and slit (D) cm	Distance between central maxima and mth order maxima (Y_m) (cm)	$\theta_m = tan^{-1}\frac{y_m}{D}$	$sin\theta_m$	$d = \frac{m\lambda}{sin\theta}_m$ µ m
1					
2					
3					

Mean d =……………………… µ m

Therefore, the number of lines per millimeter, $1/d$ =………..lines/mm.

Results

1. Diameter of single wire is .... μ m.
2. Diameter of cross wire is .... μ m.
3. The groove spacing of given grating is .... μ m.
4. The number of line per meter in transmitting grating is.........lines/mm.
5. Perform the error analysis via the method of differentiation method.

Questions

1. Is there any advantage of reflective grating when compared to that of transmission grating?
2. Can we observe diffraction pattern from a wire of 5 mm diameter?
3. What is meant by diffraction & classify?
4. What is the condition for diffraction?
5. What is a grating?
6. What is dispersion? Distinguish between diffraction and dispersion.
7. What is the effect of no. of ruling on the diffraction pattern?
8. Distinguish between diffraction and interference.
9. Distinguish between Fresnel and Fraunhofer diffraction?
10. What do you mean by polychromatic & monochromatic source?
11. Define principle maxima and secondary maxima observed in your experiment.
12. What is the light source you are using? What are its properties? How does it differ from conventional source like sodium vapor lamp?

Precautions

1. The distance between laser mount and screen should be large to observe the good and clear diffraction pattern.
2. Make environment dust free and dark.
3. After setting or mounting the laser stand do not touch them. Disturbing the stand may lead to an error in the observation.
4. Do not touch the diffraction objects with bare hands. Touching them with bare hands in the middle will destroy them permanently.

References

1. Fundamental of Optics by F. Jenkins and H. White
2. Optics by A. Ghatak
3. Optics by E. Hecht and Zajac

7. Stefan's law and Zener diode

Aim: (a) To verify the Stefan's law and (b) to study the characteristics of a Zener diode

Apparatus: Stefan's law kit, with Built-in Regulated power supply (0-12 V DC) with potentiometer, DPM for voltage and current, connecting leads and 12 W electric bulb (with tungsten filament).

Theory: As we are aware, a body kept at a non-zero temperature (absolute temperature) gains heat from the surroundings that are at higher temperature and lose heat to the surroundings at lower temperatures, through radiation. The rate of heat loss to the surroundings depends on the temperature of the body as well as the area of the body. Stefan's law states that the energy radiated per unit area form a black body is directly proportional to fourth power of surface temperature

$$\mathbf{P = Ae\sigma T^4}$$

where,

e is the emissivity of the surface of the radiating body,

σ is Stefan's constant ($\sigma = 5.66 \times 10^{-8}$ W/m^2-K^4 = Stephan-Boltzmann constant)

A is the area of the radiating surface,

In the present experiment, an incandescent bulb is treated as the body kept at high temperatures so that, significant amount of heat is lost by radiation.

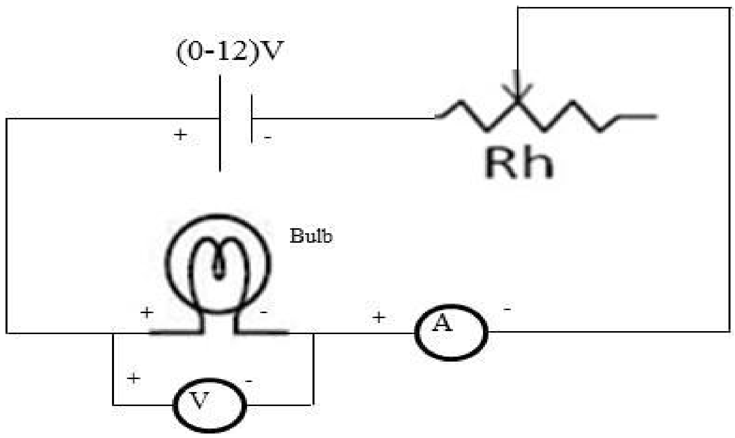


Figure 1: Circuit diagram for verification of Stefan's law.

We know that the resistance of a metal (filament in the present case) at a given temperature T is given as,

$$\mathbf{R_T = R_0 (1 + \alpha T)}$$

where, R_0 is the resistance of the filament at 0 °C (273 K) and is the temperature coefficient of the tungsten filament and its value (α) is 0.0089/C The temperature of the filament is calculated from the above relation.

For bodies other than black body, we have

$$P = C\left(T^m - T_0^m\right)$$

where P is the power emitted by a body at a temperature 'T' surrounded by another body at temperature T0. C is constant depending upon the material and area of the body; m is very near to the value 4.

The equation can be written as;

$$P = C\,T^{m}\left[1 - \frac{T_0^{m}}{T^{m}}\right]$$

$$\textbf{If } T > T_0 \textbf{ then } \quad P = C\,T^{m}$$

Or

$$\mathbf{Log_{10}\,P = log_{10}\,(const.) + m\,log_{10}T.}$$

It is in the form of a equation of a straight line, y = m x + C.

Plotting Log_{10} (P) Vs Log_{10} (T) we get a straight line with slope m.

Procedure

1. Make the connections of the circuit diagram as shown in Figure 1.
2. Switch on DC power supply and adjust the knob until the voltmeter (V) reads 0.5 V. Read out the corresponding current (I) through the bulb and record the voltage and current in the observation table.
3. Calculate the resistance of the filament V/I and use it as R_0 in your formula, to be used later.
4. Increase voltage in steps of 1 V **up to a maximum of 10 V** and find the corresponding current. Calculate the resistance of the filament (R_T = V/I) for the various readings.
5. Calculate the corresponding power.

Figure 1: Experimental setup

Observations

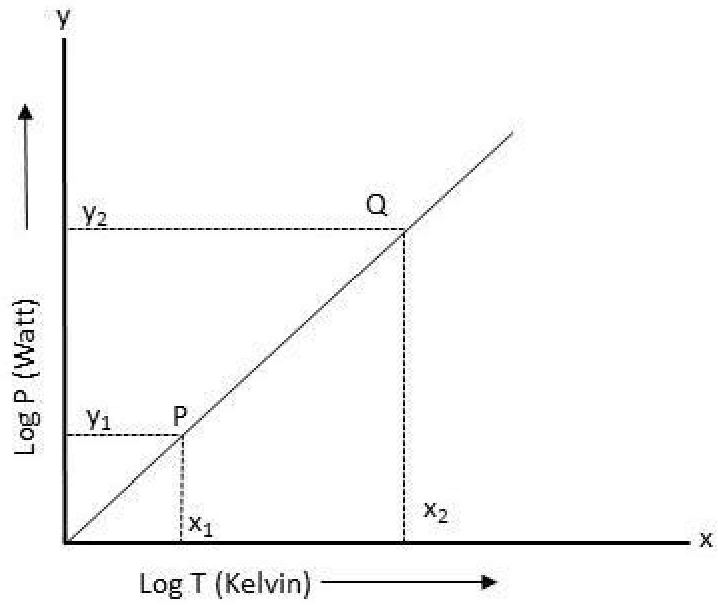
S.No.	Voltage (V)	Current (I)	Resistance R = V/I	Power P=VI(Watt)	Temperature of the filament (K)	log P	log T
1	0.5						
2	1						
.	.						

.	10						

Calculation and graph

Draw a graph of log P versus log T. The slope of the graph gives n value,

$$n = Slope = log\ P/logT =$$



And put n value, **P=AeσT^n**

Questions

1. How much is the total radiative energy output of the Sun? Radius of the sun is ~696000 km, surface temperature of the sun, ~ 6000 K
2. State Stefan's law
3. How does Stefan's law differ from Newton's law of cooling?
4. How can Stefan's constant be deduced from Newton's law of cooling?
5. What is a perfect black body? What is a black body radiation?
6. What is Emissivity?
7. What is emissive power and absorptive power?
8. What is thermal radiation? What speed does it travel?
9. What is Kirchoff's law of black body radiation?
10. State Wein's law.
11. Define solar constant

Precautions

1. DO NOT increase the voltage beyond 10 V.
2. Reduce the voltage to zero after the readings are taken and switch off the kit.
3. Do not touch the Bulb.

References

1. A heat transfer text book, Joh H. Lienhard V and John H. Lienhard IV, 4th edition, Dover publications.

(b) Characteristics of a Zener diode

Aim: To study the voltage-current characteristics of a Zener diode.

Apparatus: Zener diode kit and connecting wires.

Theory: Biasing a diode means applying appropriate DC voltage to a diode. A forward biased diode conducts easily whereas reverse biased diode practically conducts no current. It means that forward resistance of a diode is quite small as compared with its reverse resistance. Forward current is the current flowing through a forward biased diode. Every diode has a maximum value of forward current, which it can safely carry. If this value is exceeded, the diode may be destroyed due to excessive heat. Reverse current or leakage current is the current that flows through the reverse biased diode. This current is due to the minority carriers. Under normal operating voltages the reverse current is quite small. Its value is extremely small for silicon diodes but it is appreciable for germanium diodes. Peak inverse voltage is the maximum reverse voltage that a diode can withstand without destroying the junction. If the reverse voltage across a diode exceeds this value, the reverse current increases sharply and breaks down the junction due to excess heat. Peak inverse voltage is important when diode is used as a rectifier. Zener diode is a heavily doped pn junction diode, meant to operate in reverse bias condition. The breakdown or Zener voltage depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin and consequently the breakdown of the junction will occur at a lower reverse voltage. On the other hand, a lightly doped diode has a higher breakdown voltage. When Zener diode is forward biased, its characteristics are just same as ordinary diode. A Zener diode is a special kind of diode which permits current to flow in the forward direction as normal, but will also allow a large current to flow in the reverse direction when the voltage is above a certain value the breakdown voltage known as the Zener voltage.

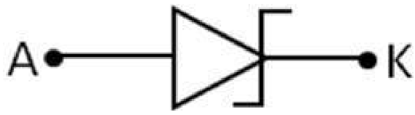


Figure 1: Zener diode circuit symbol

Zener diodes are widely used to regulate voltages in circuits. When connected in parallel with a variable voltage source so that it is reverse biased, the Zener diode conducts when the voltage reaches the diode's reverse breakdown voltage thereby controlling the voltage.

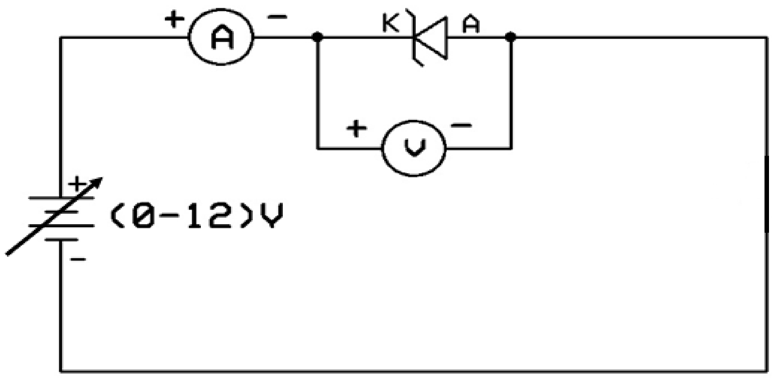


Figure 2: Schematic of reverse bias condition for a Zener diode

Procedure

1. Connect the Zener diode in reverse bias as shown in Figure 2.
2. Turn on the power supply and adjust it such that V is 0.5V, note I_z from the ammeter.
3. Increase V in steps of 0.5V up to 9.0V, by adjusting V and note the corresponding I_z values. Observe the Readings.
4. Draw the graph by plotting the V values in negative X-axis and I_z values in negative Y-axis.
5. Determine the Zener breakdown voltage (V_z) from the graph.

Figure 3: Experimental setup.

Observations

S. No.	Reverse Bias		
	$V_{applied}$ (V)	Vz (V)	I (mA)
1			
2			
.			

Connect the Zener diode in forward bias and repeat the above experiment.

S. No.	Forward bias		
	$V_{applied}$ (V)	Vz (V)	I (mA)
1			
2			
.			

$V_{applied}$ (V)- Applied voltage across the diode to be measured with multimeter.

Calculation

Plot a graph voltage (volt) versus current(mA).

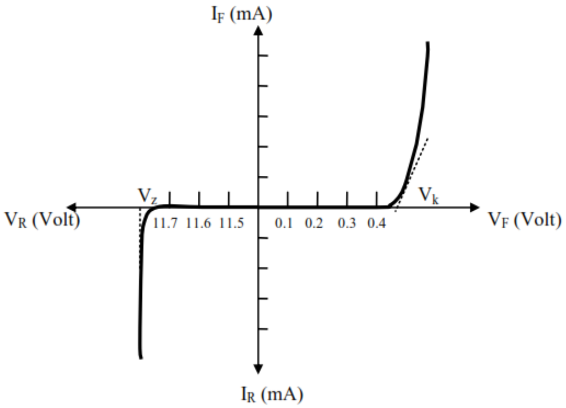


Figure 4: Find the Zener voltage or breakdown voltage from the graph.

Results

The Zener breakdown voltage (V_z) of given diode is: V.

Questions

1. What is diode? What is a Zener diode? What is the difference between the two?
2. On what factor does the breakdown voltage of a Zener diode depends?
3. Why is Zener diode always reverse biased?
4. Distinguish the flow of current in Zener diode under reverse and forward biasing condition.
5. What is Zener breakdown?
6. What do you mean by avalanche breakdown?
7. List the differences between avalanche breakdown and Zener breakdown.
8. How the width of the depletion region in the reverse biased diode varies with the impurity concentration?
9. How the value of the potential barrier depends on the amount of doping of the semiconductor?
10. Under what condition a Zener diode behaves like an ordinary p-n junction diode?
11. Can we use Zener diode as a voltage regulator?

Precautions

1. Excessive flow of current may damage the diode.
2. Current for sufficiently long time may change the characteristics.
3. All connections should be neat, clean and tight.

References

1. Physics of Semiconductor Devices, S. M. Sze.

Cathode Ray Oscilloscope

Aim: (a) To study different waveforms, measure peak and rms voltages and the frequency of AC (b) To study Lissajous patterns and superposition principle.

Apparatus: Digital storage oscilloscope, function generator. BNC connectors, digital multimeter.

Theory: Cathode ray oscilloscope (CRO) is one of the most useful electronic equipment, which gives a visual representation of electrical quantities, such as voltage and current waveforms in an electrical circuit. It utilizes the properties of cathode rays of being deflected by an electric and magnetic fields and of producing waveforms on a fluorescent screen. Since the inertia of cathode rays is very small, they are able to follow the alterations of very high frequency fields and thus electron beam serves as a practically inertia less pointer. When a varying potential difference is established across two plates between which the beam is passing, it is deflected and moves in accordance with the variation of potential difference. When this electron beam impinges upon a fluorescent screen, a bright luminous spot is produced there which shows and follows faithfully the variation of potential difference.

When an AC voltage is applied to Y-plates, the spot of light moves on the screen vertically up and down in straight line. This line does not reveal the nature of applied voltage waveform.

Thus to obtain the actual waveform, a time-base circuit is necessary. A time-base circuit is a circuit which generates a saw-tooth waveform. It causes the spot to move in the horizontal and vertical direction linearly with time. When the vertical motion of the spot produced by the Y-plates due to alternating voltage, is superimposed over the horizontal sweep produced by X-plates, the actual waveform is traced on the screen.

Procedure

Measurement of AC Voltage

The magnitude of the line is proportional to the peak-to-peak voltage of the applied wave (V_{PP}).

Calculate the peak voltage of the sinusoidal using formula V_P= Number of division's x Voltage sensitivity /2 in Volts.

Figure 1: Experimental setup

1. Calculate $V_{RMS} = \frac{V_P}{\sqrt{2}}$

2. In the digital multi meter (DMM) set the function dial to A.C. voltage and the range to 20V (say). Read the output voltage from the FNG directly with DMM.
3. Repeat such measurements for two more values.
4. Set the function knob of FNG to first square and then to triangle and observe the shapes on the C.R.O. or DSO as before for different voltages applied from the FNG in these square/triangle modes calculate the voltages using both the CRO or DSO and the DMM and tabulate the results.

Observations

Wave (~10s of kHz)	(V) Input Voltage Signal from function generator	Voltage Sensitivity (V)	V_P (V)	V_{RMS} (from CRO)	V_{RMS} (in Multimeter)
1. Sine wave	V1 =				
	V2 =				
2. Square wave	V1=				
	V2 =				
3.Triangle wave	V1=				
	V2=				

Note

For Sine wave $V_{RMS} = \frac{V_P}{\sqrt{2}}$

For Square wave $V_{RMS} = V_P$

For Triangular wave $V_{RMS} = \frac{V_P}{\sqrt{3}}$

Measurement of frequency

1. Apply about 1 V, 20 kHz sine wave from the signal generator to the Y-input of C.R.O. Adjust the time base and Y gain so that a wave of 2 or 3 cycles is displayed. Measure the width of one cycle and note as T
2. Repeat the procedure for square and triangular wave.

Observations

S.No	Shape of wave	Time sensitivity (s)	Time duration (s)	Frequency (Hz)
1	Sine			
2	Square			
3	Tringle			

Lissajous patterns and superposition principle

1. Set the CRO in XY mode. and Keep the sensitivity of both CH.1(X) and CH.2(Y) same (Say, 0.2 V/division).
2. Switch on both the function generators. Set them both at 1 kHz (say). Also, set the output amplitudes of both about the same using the coarse and fine control knobs.
3. Apply the two outputs from the two FNGs to the plates CH.1(X) and CH.2(Y) using BNC cables.
4. Adjust the continuous frequency control dial of one of the FNGs and obtain a CIRCLE on the screen. The CIRCLE will keep changing to ellipse and momentarily into a straight line etc. continuously (Why?). This is called the Lissajous pattern. The figure CIRCLE shows that the two frequencies applied to X Y plates are in the ratio 1:1. Sketch the Lissajous figures obtained for the ratios (1: 2, 2:1, 2:3 etc.) by keeping the frequency of one FNG fixed and changing the other continuously. Repeat the experiment for different frequencies and tabulate the results.

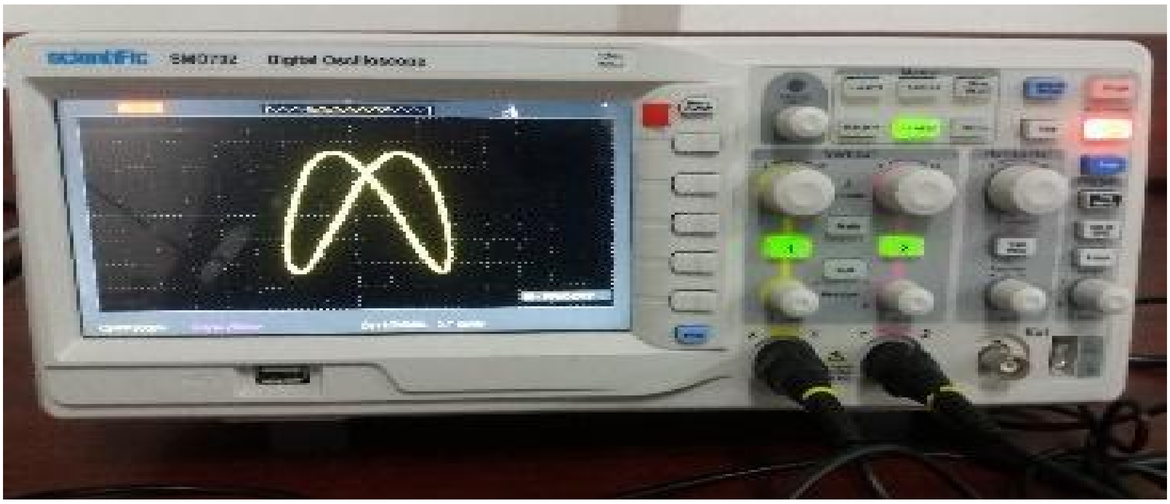


Figure 2: Digital photograph of an example Lissajous figure

Observations

S.No.	Signal Generator 1 (Hz)	Signal Generator 2 (Hz)	Figure	Ratio
1	1000	1000		1:1
2	.	.		.
3	.	.		.
4				

Results

1. Different waveforms studied ………………..
2. Ratio of Lissajous Patterns………………….

Questions

1. Why are vertical and horizontal plate provide in a CRO?
2. What does a triggering circuit do in a CRO?
3. What are the essential components of a CRT?
4. What is an electron gun? What is the purpose of electron gun assembly in CRT?
5. What is the purpose of grid with a hole in a CRO?
6. What is meant by the deflection sensitivity of a CRO?
7. What is meant by the deflection factor of a CRO?
8. What is Astigmatism control?
9. What is graticule?
10. What is meant by retrace time?
11. What is sweep time?
12. What is a Lissajous pattern?
13. How do you reduce the error in measurement?
14. What does CRO measure; voltage?
15. What is the relation for period of a waveform?
16. If two sinusoidal waves of same frequency produce Lissajous figure, what is the phase difference condition for a straight line?
17. If two sinusoidal waves of same frequency produce Lissajous figure, what is the phase difference condition for a circle?

Precaution

1. BNC cable should be connected properly.
2. Connect BNC cables from the CRO terminal first.

References

1. Cundy, H. and Rollett, A. "Lissajous's Figures." §5.5.3 in Mathematical Models, 3rd ed. Stradbroke, England: Tarquin Pub., pp. 242-244, 1989.

2. Gray, A. Modern Differential Geometry of Curves and Surfaces with Mathematica, 2nd ed. Boca Raton, FL: CRC Press, pp. 70-71, 1997.

3. Lawrence, J. D. A Catalog of Special Plane Curves. New York: Dover, pp. 178-179 and 181-183, 1972.

4. MacTutor History of Mathematics Archive. "Lissajous Curves." http://www-groups.dcs.st-and.ac.uk/~history/Curves/Lissajous.html.

5. Wells, D. The Penguin Dictionary of Curious and Interesting Geometry. London: Penguin, p. 142, 1991.

Appendix

The cathode ray oscilloscope is an instrument commonly used in a laboratory to display measure and analyze various waveforms in electronic circuits. The cathode - ray oscilloscope (C.R.O.) consists of the following components:

1. The electron gun.
2. The deflecting plates.

3. A fluorescent / a phosphorous screen.

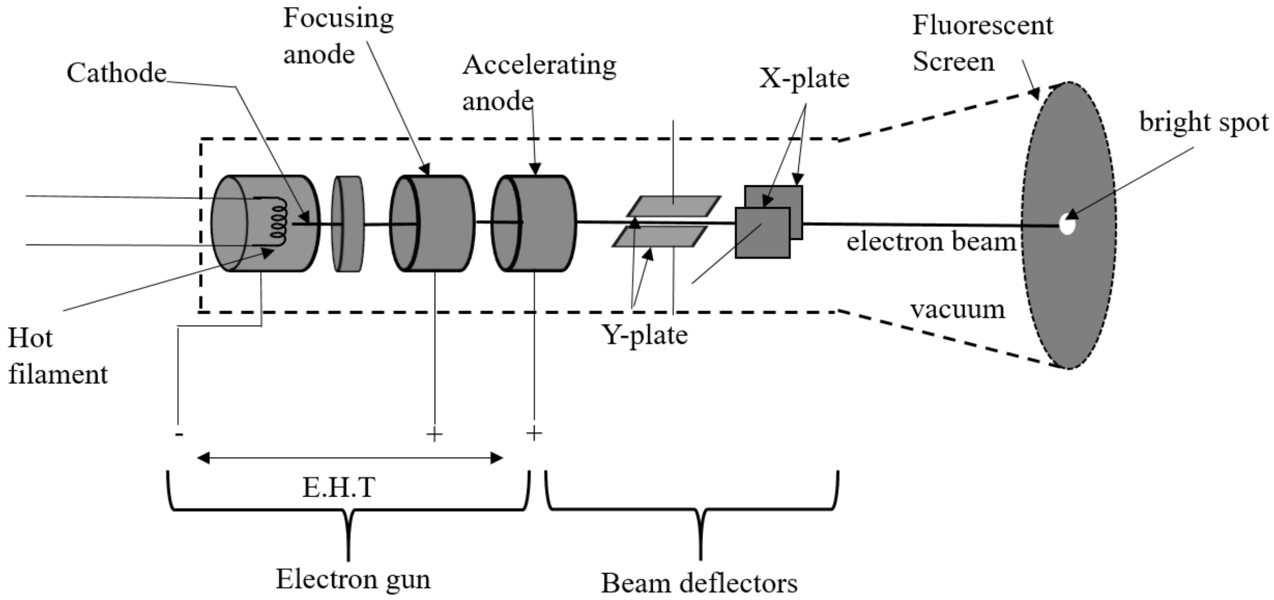


Figure: Schematic of a conventional cathode ray oscilloscope.

Function of Various parts of CRO

Filament: a tiny tungsten coil heated by current, gives off electrons due to heat generated by an electric current.

Cathode: source of electrons, releases electrons when heated by filament

Grid: is connected to a negative potential. The more negative this potential, the more electrons will be repelled from the grid and fewer electrons will reach the anode and the screen. The number of electrons reaching the screen determines the brightness of the light. *Hence, the negative potential of the grid can be used as a brightness control.*

Focusing anode and accelerating anode: The anode at positive potential accelerates the electrons, and the electrons are focused into a fine beam as they pass through the anode.

Electron gun: The electron gun makes a narrow beam of electrons. Its cathode gives off electrons and anode accelerate them.

y-plate: When a voltage is applied across the Y-plates, the electrons beam is deflected in the vertical direction.

x-plate: When a voltage is applied across the X-plates, the electron beam is deflected in the horizontal direction.

Y-offset moves the whole trace vertically up and down on the screen, while X-offset moves the whole trace from side to side on the screen.

Common oscilloscope controls:

Most of the oscilloscopes consist of two input channels (Channel 1 and 2 or Channel A and B), the so called dual channel CROs. Therefore, two waveforms can display simultaneously on the screen. In this section, we will introduce the most common controls in an oscilloscope.

1. POWER: To switch on and off of the oscilloscope
2. FOCUS: To control the focus of the spot on the screen
3. INTENSITY: To control the brightness of the spot on the screen
4. VOLTS/DIV selector switch: (separate controls available for Channel 1 and 2)

* "Volts/Div." wheels amplify an input signal so that for a division a given voltage level is in valid. A "division" is a segment, a square on the screen of the oscilloscope.

* A setting of ".5" means that the height of a single square equals a voltage of 0.5 V. An amplitude of 1 V would have a size of two divisions vertical to the abscissa.

5. VERTICAL POSITION control: (separate controls available for Channel 1 and 2).
6. INPUT SELECTOR switch: (AC, DC, GND) (separate controls available for Channel 1 and - 2). DC/AC. switch DC, – DC and AC. voltage displayed. AC– only AC voltage displayed.

Set at DC where all AC and DC components both will be displayed on the screen.

Set at AC where a coupling capacitor passes the AC quantity and blocks the DC component.

Set at GND to disconnect the input signal and grounds the input terminal.

7. TIME BASE control: Whenever we switch on the time-base, we are actually applying a saw-tooth voltage to the X-plates.

* This make the electron beam sweep across the screen at a constant speed.

* By knowing the period of each cycle, T, we can then know how fast the beam is sweeping across the screen. The time-base is thus a measure of time for the oscilloscope.

8. HORIZONTAL TIME/DIV selector switch: (apply to both Channel 1 and 2)
9. HORIZONTAL POSITION control: (apply to both Channel 1 and 2)
   Set the sensitivity of the display to input voltages, adjusting this control makes the displayed waveform to compress and expand in the vertical axis. Used to move each waveform vertically up or down the screen to set it in the best position for viewing.

Set at DC where all AC and DC components both will be displayed on the screen.
Set at AC where a coupling capacitor passes the AC quantity and blocks the DC component.
Set at GND to disconnect the input signal and grounds the input terminal.
Adjust the rate at which a waveform is draw across the screen
Use to move all waveforms horizontal left or right to set them in the best position for viewing

10. TRIGGER LEVEL control: Adjust the triggering point of the input wave.
11. TRIGGER SOURCE selector switch: Use to select the source of the triggering,
    normally select INT (internal trigger source), which means the time base is triggered from one of the input waveforms.
12. X-Y MODE selector switch, Used to change between V-T and X-Y mode
13. X-input and Y - input

Electric input connect to the X-plate and Y-plate.

NOTE:

If the two deflection voltages are held constant, the electron beam would strike a fixed point on the phosphorescent film and a stationary point would be visible on the screen.
However, most voltages of interested are time-varying and so the voltage applied to the Horizontal deflection plates is varied with time in such a way that the spot moves from left to right on the screen as time passes. Since the phosphorescent material has the property of emitting light for several milliseconds after the electrons have passed, the total effect is for the electrons to leave behind a visible trail –a time-varying signal.

The horizontal deflection voltage (of "sweep voltage") is also varied in such a way that when the beam reaches the right-hand edge of the screen, it starts over at the left-right side.
If the signal to be displayed varies periodically in time, it is possible to synchronize the sweep voltage with the signal so that the curve appears motionless on the screen. This is done with the **Trigger Level** control which sets the oscilloscope to begin a trace when the voltage it measures reaches a certain value. If a trace that is running across the screen can usually be stabilized by adjusting the trigger level (as long as the waveform is periodic!).

LISSAJOUS PATTERNS

We have seen how to use an oscilloscope to observe and measure ac waveforms. Can we observe a voltage-versus-voltage pattern also? The pattern of voltage versus voltage is referred to as a *Lissajous pattern.* It is observed by eliminating the time parameter by applying two ac waveforms to both the horizontal and vertical amplifiers.
Knowing one of the two input waveforms, we can measure the frequency, phase, and magnitude relationships between the two waveforms from the Lissajous pattern
The simplest case is when both input waveforms are sinusoidal, the resulting Lissajous pattern may take many forms depending upon the frequency ratio and phase difference between the waveforms. Figure below shows **Lissajous patterns for sinusoids of the same frequency, but varying phase relationship**

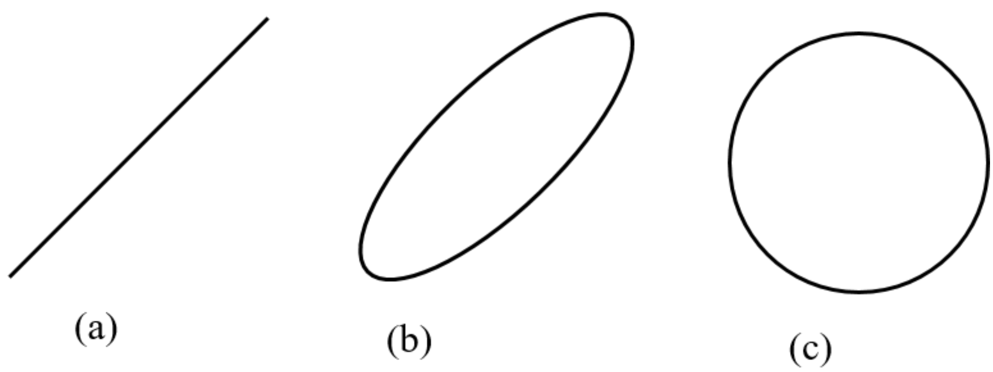
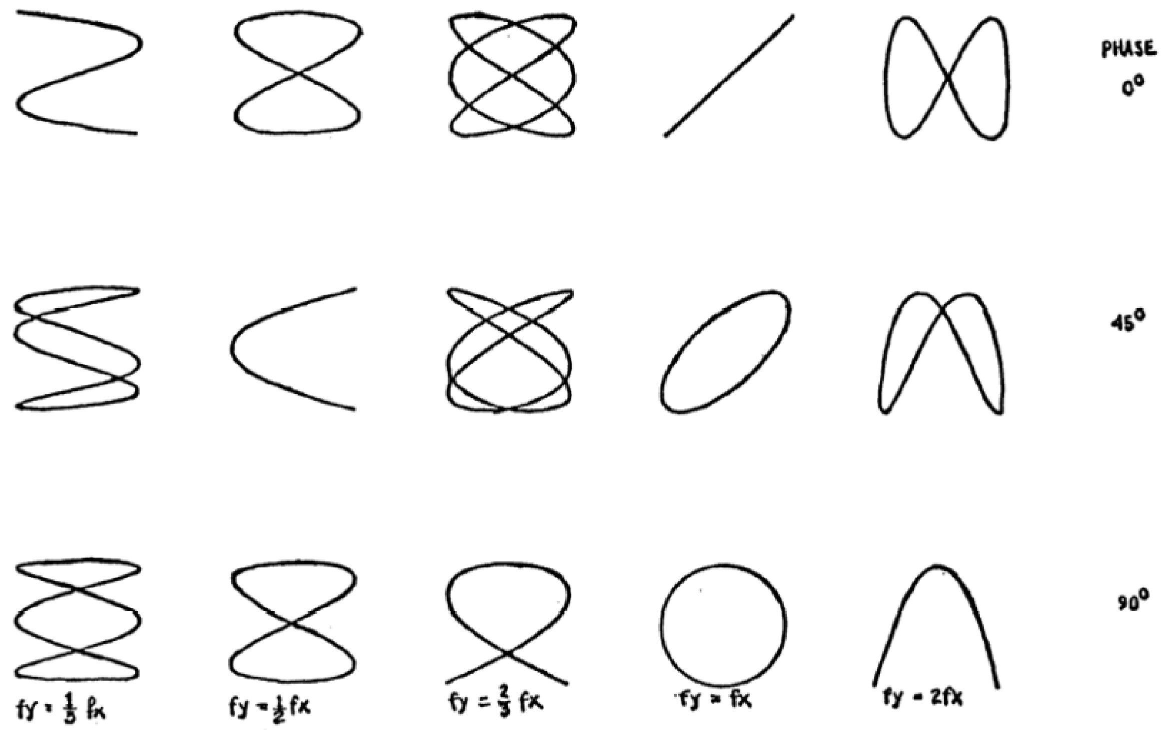


Figure: Lissajous patterns for a phase difference of 0° (left), 45°(middle) and 90°(right) originating from the same frequency. Images recorded@IITBhilai

The Lissajous patterns shown below are from sinusoids of varying frequency and phase relationships. These are sine-vs-sine plots (Lissajous figures) for several frequency ratios

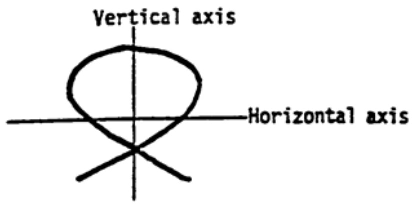


To determine the frequency ratio, draw horizontal and vertical lines through the center of the pattern.

The *frequency ratio* is defined as the ratio of the number of horizontal axis crossings to the number of vertical axis crossings.

$$\frac{f_y}{f_x} = \frac{number\ of\ horizontal\ crossings}{number\ of\ vertical\ crossings}$$

where f_x and f_y are the frequencies of the two waveforms. Now let us take an example, selecting a pattern, say



To determine the frequency ratio, draw horizontal and vertical lines through the center of pattern;

$$\frac{f_y}{f_x} = \frac{number\ of\ horizontal\ crossings}{number\ of\ vertical\ crossings} = \frac{2}{3}$$

Therefore, $f_y = \frac{2}{3} f_x$

9. Gouy's method: Measurement of magnetic susceptibility

Aim: To determine the magnetic susceptibility of para-magnetic solid (Aluminum) by Gouy's method.

Apparatus: Digital Gouy's balance, electromagnet (Model EM-20), power supply (Model CP-11)), digital Gauss meter (Model DGM-20) and samples.

Introduction: Materials may be split into one of three magnetic classes: diamagnetic materials, paramagnetic materials, and ferromagnetic materials. In diamagnetic materials, like water, the magnetic effects of spin and orbital motion cancel each other out. Small dipole moments can be induced by an external field. Thus, a regular magnet weakly repels diamagnetic materials. Paramagnetic materials, like aluminum, have permanent magnetic dipole moments in each particle. They are weakly attracted to an ordinary magnet. Ferromagnetic materials greatly strengthen the magnetic field and are strongly attracted to an ordinary magnet.

The magnetic susceptibility is a phenomenon that arises when a magnetic moment is induced in an object, by the presence of an external magnetic field. Magnetic susceptibility (denoted χ) is one measure of the magnetic properties of a material. The susceptibility indicates whether a material is attracted into or repelled out of a magnetic field, which in turn has implications for practical applications. quantitative measures of the magnetic susceptibility also provide insights into the structure of materials, providing insight into bonding and energy levels.

The magnetic susceptibility 'χ' is quality unique to each material (like conductivity and Resistivity) and is defined as the ratio of magnetization of the material to applied magnetic field.

$$M = \chi H$$

where,

M is the magnetization

H is the magnetic field.

Thus, the ferromagnetic materials produce a much bigger force and change in the magnetic field than those of the other two categories. In this experiment, we will use diamagnetic and / paramagnetic substances.

Gouy's method is one simple way to determine the magnetic susceptibility of a specific material. The method determines the force exerted on the sample through a change in mass, and use that value to find susceptibility.

Theory: For diamagnetic materials, let us imagine that an atom that is a nucleus in a stationary cloud of electrons is placed in a magnetic field, as in Fig. 1a. When the field increases, a torque is exerted on the charges. As a result, the charges circulate in the direction as shown in Fig. 1b. A circulating current is therefore set up in a direction opposite to the electron flow (Fig. 1c). This current produces a magnetic field in a direction opposite to the applied field, and so the substance is repelled by the magnetic field.

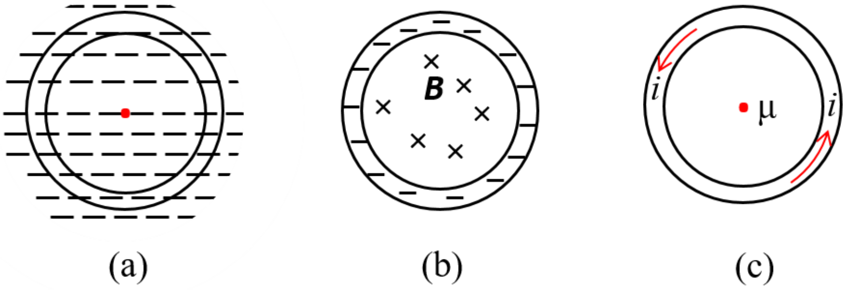


Figure 1: The origin of diamagnetism. (a) electron cloud, (b) current induced by a varying magnetic field into the plane of the paper, (c) magnetic field induced by this current is out of the plane of the paper (opposite to the inducing field)

If we lower a sample of a substance into a region of magnetic field between two poles, a force will be produced. The Gouy balance measures this force as an apparent change of mass of a sample. Using a simple mass balance, two measurements are taken, m_0 (the initial mass reading) and m_f (the final mass reading after lowering the sample into the field).
The force is given by

$$\mathbf{F = \Delta m_g = (m_f - m_0)\, g} \text{.......(1)}$$

where g is the acceleration due to gravity (9.8 m/sec^2)
And the force applied by the magnet on the sample having magnetic permeability (μ)is given by

$$\mu = \mu_0 (1+\chi) \text{..................(2)}$$

where,
μ_0 is the permeability of free space or the magnetic constant (4π x 10^{-7} N/A)
χ is the magnetic susceptibility.

By solving equation (1 and 2), and substituting necessary Parameter we will get,

$$\chi = \frac{2\mu_0 \Delta mg}{AH^2}$$

where,
μ is the permeability of free space or the magnetic permittivity (4π x 10^{-7} N/A^2)
χ is the magnetic susceptibility.
where g is the acceleration due to gravity (9.8 m/sec^2) A is cross-sectional area of the material normal to the magnetic flux.
H is the magnetic field.

(Detailed derivation is given in Appendix)

Procedure

1. Set the apparatus as shown in below figure and adjust the spacing between the pole pieces such that samples can be easily inserted between the pole pieces.

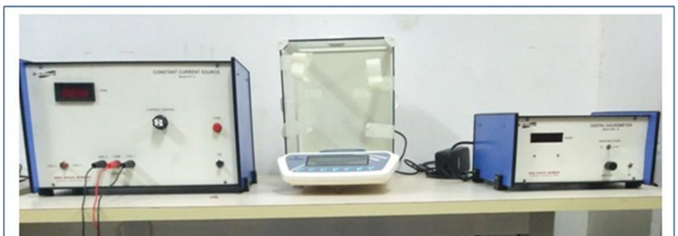


Figure2: Experimental setup

2. Connect the electromagnet coils in series to the power supply.
3. Connect the Gauss meter with mains and switched it 'ON'. Put the range switch at X1 position and set zero with the 'ZERO ADJ'. knob keeping the Hall probe away from the electromagnet.
4. Switch 'ON' the electromagnet power supply to energies the coil and measure the flux density over a suitable range of coils current say 0.2 A, 0.4 A, 0.6 A.......3.0 A. Note the corresponding field in the Gauss meter. Tabulate these readings.
5. Turn off the power supply and take out the Hall probe and Put it in the rear side of Gauss meter carefully.
6. Switch ON the digital balance and attach the Aluminum (Al) sample with the hook provided and measure initial weight (m_0).
7. Switch 'ON' the constant current power supply and very the current from 0 to 3.0 A. in step of 0.2 A. Note the corresponding weight of the Al sample for each value of current. Record all these readings in table as shown below.
8. Plot a graph between Δm and H^2 and calculate the susceptibility of given sample using equation.

Observations

Area of cross section of the given sample = ...mm^2
Weight of the sample at zero magnetic field (m_0) = ... gm

s.no	Current (I) (A)	Magnetic field (Gauss)	Sample Weight m(gram)	Change Weight $m-m_0$ (gram)
1	0.2			
2	.			
.	.			
	3.0			

Calculation

1. Find the value of $\frac{\Delta m}{H^2}$ using plot graph.
2. Then find the Susceptibility of sample using formula,

$$\chi = \frac{2\mu_0 \Delta m g}{AH^2}$$

Results

The susceptibility of given Aluminum sample is χ= ....

Questions

1. What will be the change in the weight ($m-m_0$) if we use iron (Fe) instead of aluminium?
2. What is magnetic susceptibility?
3. Define diamagnetism, paramagnetism and ferromagnetism.
4. How does an electromagnet works? What is the governing law behind it?
5. What is the principle of operation of Gauss meter?

Precautions

1. Do not touch the Gauss meter and electromagnetic coil during entire experiment.
2. Do not change the distance between the poles during entire experiment.
3. Before the power supply is turned off the dial should be at the minimum position.
4. Turned off the entire instrument after noting down the observations

References

1. Purcell, Edward M. Electricity and Magnetism. Vol. 2, McGraw-Hill, 1985. Print. Ch 11, 397-450.
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3. Ford, Kenneth W. Classical and Modern Physics. Vol. 4, Xerox Corporation, 1972. Print. Sec. 16.10 "Magnetism in matter," 797-800.
4. Feynman, Richard. The Feynman Lectures. Vol. 2. www.feynmanlectures.caltech.edu Chapter 34 "The Magnetism of Matter."
5. Teachspin, Inc. The Relaxation Times. Vol. IV, No. 9. February 2015. "Foundational Magnetic Susceptibility."

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APPENDIX

We may find the difference in magnetic potential energy per unit volume between a substance of magnetic permeability μ and the displaced medium (in our case, air, which has the permeability of free space):

$$\Delta\left(\frac{U}{V}\right) = \left(\frac{H^2}{2\mu_0}\right)_{\text{air}} - \left(\frac{H^2}{2\mu}\right)_{\text{sample}} = \frac{H^2}{2\mu_0} - \frac{H^2}{2\mu_0(1+\chi)}$$

$$\Delta\left(\frac{U}{V}\right) = \frac{\chi H^2}{2\mu_0(1+\chi)} \tag{3}$$

Eq. 3 may be further simplified knowing the fact that (that is, the magnetic susceptibility is significantly smaller than 1). When this is the case, a value like χ becomes negligible. So we can make the approximation $1 + \chi \sim 1$ to get:

$$\Delta\left(\frac{U}{V}\right) = \frac{\chi H^2}{2\mu_0} \tag{4}$$

Let us now consider a gradient in the field along the *z*-direction (upwards direction), as there is in the case of this experiment. If we assume that the magnetic susceptibility is constant throughout the sample, the force per unit volume *f* experienced by the sample is given by:

$$f = -\frac{\partial U}{\partial z} = -\frac{\chi}{2\mu_0}\frac{\partial}{\partial z}(H^2) \quad (5)$$

Using Eq. 5, we can then integrate over the length (with a constant cross-sectional area *A*) to find the total force on the sample by the magnetic field. Here, we will simply denote the top and the bottom *z*-values of the sample as "top" and "bottom".

$$F = \int_{\text{bottom}}^{\text{top}} fA dz = \frac{\chi A}{2\mu_0}\left({H_{\text{bottom}}}^2 - {H_{\text{top}}}^2\right) \quad (6)$$

where *A* is the cross-sectional area of the sample and *H* is a measure of magnetic field at the top and bottom of the sample, respectively.

H_{top} and H_{bottom} are the measured magnetic fields at the top and bottom of the sample. If the length of the sample is sufficiently long, H_{top} may be treated as zero and H_{bottom} may be generalized to simply *H*. Thus, Eq. 5 can be simplified.

$$F \approx \frac{\chi A}{2\mu_0} H^2 \quad (7)$$

Now, if we equate Eq. 1 and Eq. 7, we can solve for the magnetic susceptibility:

$$\chi = \frac{2\mu_0 \Delta m g}{AH^2} \quad (8)$$

Table: Magnetic Susceptibilities and densities of some materials.

S.No.	Material	Magnetic Susceptibility	Density (10^3 kg/m^3)
1	Aluminum	1.65×10^{-5}	2.70
2	Copper	-5.46×10^{-6}	8.96
3	Lead	-2.30×10^{-5}	11.36
4	Tin	-3.74×10^{-5}	7.28
5	Titanium	1.51×10^{-4}	4.50
6	Zinc	-9.15×10^{-6}	7.12
7	Water	-9.04×10^{-5}	1.00

Uncertainty in the slope of the graph

You have to find the maximum and minimum slope of the centroid as described in the following, see the figure below.
'Best' line: by visually judging the data and measure the slope (S_{Best}).
'Minimum' line: again by visually judging a reasonably smaller slope. This should still represent the functional behavior of the data. Determine the slope of this line (S_{Min}).
'Maximum' line: similar to that of 'minimum' line, now draw a line with maximum slope measure the slope of this line (S_{Max}).
Note: Slope for the 'minimum and maximum lines' should be calculated using a very large triangle as shown for the 'Best fit' in the figure below.

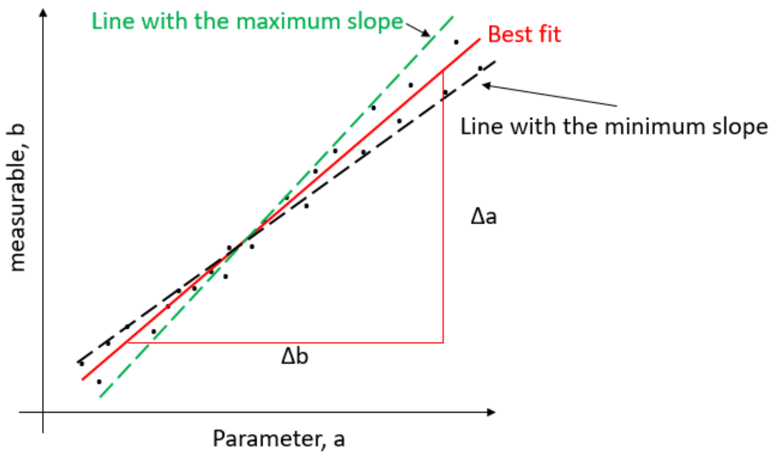
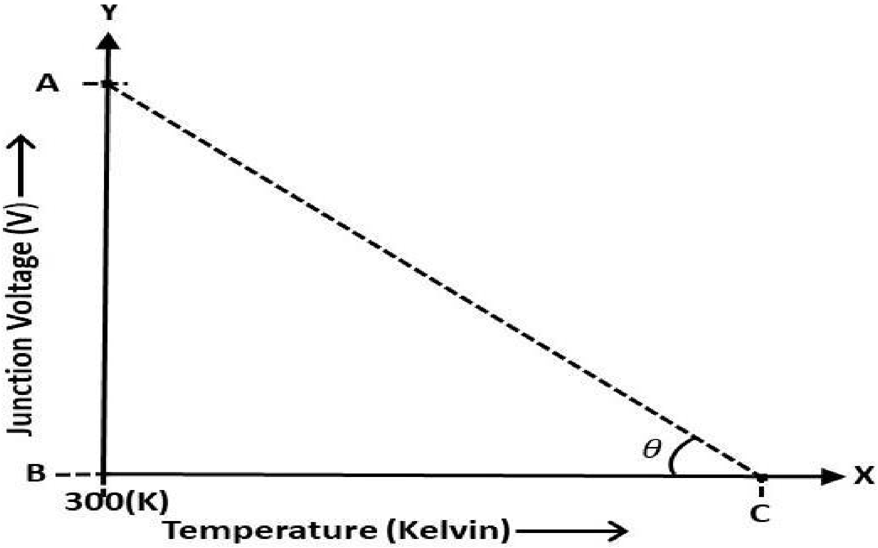


Figure: Schematic showing the lines of maximum and minimum possible slopes along with the best fit. Slope for the best fit = Δa/Δb.

Uncertainty in determining the slope (S_{Error}) for the best fit, $S_{Error} = (S_{Max} - S_{Min})/2$

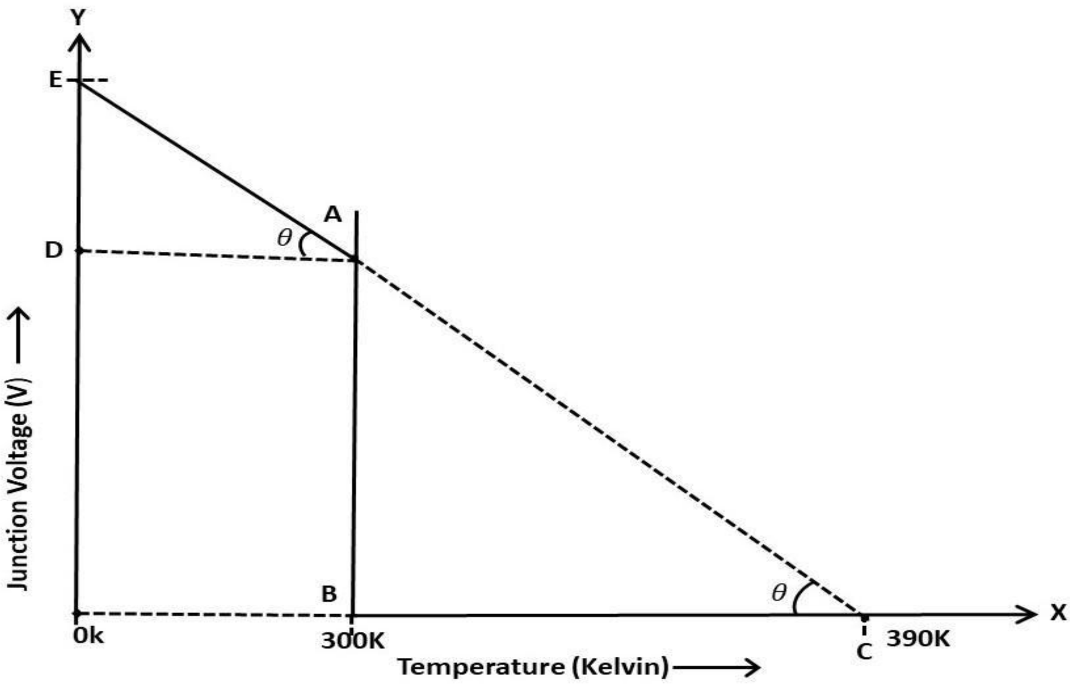
To report: $S_{Best} \pm S_{Error}$

- **Plot from Experiment:**



- **Analysis to find the E_g : Extrapolation Temperature evaluate the band gap:**

$$\Delta\, ABC, \qquad tan\theta = \frac{AB}{BC}$$



Don not plot this on the graph sheet

$$\Delta\, ADE,\ tan\theta = \frac{DE}{AD},\ \ DE = DAtan\theta = (300K)tan\theta$$

Band gap $= (AB + DE)e$ eV

AB is Know,

$E_g = \{AB + (300K).\, tan\theta\}e$ eV