DEPARTMENT OF PHYSICS

LABORATORY MANUAL

for

1st Year B.Tech. (Common)

PHYSICS PRACTICALS (PHI 102)

B.Tech. Common Lab (Room No. 528)

DEPARTMENT OF PHYSICS

(Academic Complex)

INDIAN INSTITUTE OF TECHNOLOGY

(INDIAN SCHOOL OF MINES)

DHANBAD 826004, JHARKHAND, INDIA

Effective from Session: 2020-2021

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Lab Safety: Do's and Don'ts for Students

General Work Procedure

1. Know emergency procedures.
2. Never work in the laboratory without the supervision of an instructor.
3. Always perform the experiments or work precisely as directed by your instructor.
4. Immediately report any spills, accidents, or injuries to your instructor.
5. Never leave experiments in-between while in progress.
6. Never attempt to catch a falling object.
7. Be careful when handling hot glassware and apparatus in the laboratory. Hot glassware/apparatus looks just like cold one.
8. Turn off all devices and apparatus, when not in use.
9. Do not remove any equipment or any other items from the laboratory.
10. Store your belongings, bags, and other personal items in designated areas.
11. Notify your instructor of any sensitivities that you may have.
12. Keep the floor clear of all objects.
13. Inspect all equipment for damage (cracks, defects, etc.) prior to use, do not use damaged equipment.

GENERAL INSTRUCTIONS

The minimum expectations from the students:

1. Student must report at <u>least 2 minutes before</u> the start of the scheduled class without any excuse.
2. Student is expected to come in class in a <u>well-groomed manner with proper dressing</u>.
3. Do not engage in practical jokes or boisterous conduct in the laboratory.
4. Never run in the laboratory.
5. The use of personal audio or video equipment is prohibited in the laboratory.
6. The performance of unauthorized experiments is strictly forbidden.
7. Sitting idle during laboratory hours is not allowed.
8. Use of mobile phones in the class or late arrival to the class may lead to suspension from the particular class and no attendance will be awarded for that class.

Allotment of Practicals/Experiments to be performed in the class:

1. Attendance is taken once in each class.
2. In this lab there are total **<u>08 (eight) experiments</u>** having 02 (two) setup for each experiments.
3. A particular section (having nearly 120 students) will be divided into two subgroups of nearly 60 students in each group.
4. These 60 students will be again sub-divided into smaller groups having 3-5 students in each sub-group and will be allotted these 08 experiments in rotation in cyclic manner.
   Week 1: Sub-group 1: Experiment 1, Sub-group 2: Experiment 2, Sub-group 3: Experiment 3, Sub-group 4: Experiment 4, Sub-group 5: Experiment 5, Sub-group 6: Experiment 6, Sub-group 7: Experiment 7, Sub-group 8: Experiment 8.
   Week 2: Sub-group 1: Experiment 2, Sub-group 2: Experiment 3, Sub-group 3: Experiment 4, Sub-group 4: Experiment 5, Sub-group 5: Experiment 6, Sub-group 6: Experiment 7, Sub-group 7: Experiment 8, Sub-group 8: Experiment 1.
   So on and so forth for further weeks.
5. For guiding the student in their regular practical classes, there will be certain number of Teaching Assistants (Research Scholars) in each class. Student has to perform the experiments under their assistantship.
6. There will be a Lab Assistant, a Senior Scientific Assistant, few Teaching Assistants (Research Scholars) and few Professors in the each lab class.

Performing Experiments allotted in a particular class:

1. One experiment will be performed per day.
2. Experiments will be performed by a group of 3-5 students together as mentioned in the above section.
3. However, the readings have to be taken independently by each student.
4. Before performing any experiments/handling any experimental set-ups, student is expected to go through the lab manual very carefully and note down the salient features of the experiments to be performed in the particular class, before coming to the laboratory.
5. Student needs to get the desired/required accessories/instruments-component allotted from the Lab Attendant.
6. **NOTE:** Any instrument must not be continuously SWITCHED-ON and OFF! Particularly, "Lasers". Any breakage / non functioning of instruments have to be brought to the notice of the teachers / lab attendant immediately.

7. Student can start the experiment after making the desired connections as mentioned in the Lab-manual or as instructed by the Teaching Assistant.
8. Student needs to carry a **small "Note Book"** (which is basically a rough note book) dedicated for this particular lab for this semester, a **record "Note book"** and obviously your geometry box, etc.
9. The **small note book** will be used for day-to-day recording of the experiments performed and writing the readings.
10. In the **Small Note Book**, student must also mention the Experiment No, Objectives/Aim of the experiment, Observations/Readings/Tables, calculations and result in short.
11. All the experimental readings must be recorded in the "Small Note Book".
12. **NOTE:** At-least one reading must be recorded in front of teaching assistant. The readings must be cross-verified (cross-signed) by the teaching assistants as proof.
13. Student must finish a particular experiment in all manner in a particular single lab class.
14. While leaving the lab, the apparatus has to be arranged in a manner as it was initially provided to the student. Switch off the power to your experiment, when you leave the lab.

NOTE: Though in the regular classes, student has to perform the experiment in group, but each individual student must pay proper attention to the experiments and must learn it properly as they need to perform these experiments individually in the examination without assistance of anyone else.

Submission of Lab Record:

1. Student must submit the Lab record (in record Note Book) in the very next class after performing/completing the experiments.
2. The lab record must have:
   On Right Side (Ruled side) of the copy:
   - Date of experiment performed,
   - Experiment number
   - Objective/Aim
   - Instruments required
   - Theory and Procedures including formulas, if any.
   - Observations/Tables
   - Calculations
   - Results upto significant figures with proper units
   - Relevant Error Calculations
   - Precautions

   On Left Side (Plain side) of the copy:
   - Figures/Diagrams, where ever applicable.
   - Graphs, if applicable,-sticked using glue/paper pin.
3. Student must use blue/black pen for writing in the right side (Ruled side) of the copy.
4. Similarly, for Left side (Plain side) of the copy, for drawing figures/diagrams, graphs etc. student must use only pencil.
5. All the figures/diagrams, graphs etc. should have proper labelling, ray directions as well as figure captions.
6. While drawing a particular graph student must use and mention proper clear scaling at top-right corner of the graph paper.
7. The data points on the drawn graphs must be encircled (⊙).
8. The general rules that should be followed in drawing graphs, straight lines or not, are the following:
   a. *Draw bold lines on the graph paper to serve as x and y axis.*

b. The independent variable should be plotted along the x-axis, and the dependent variable along the y-axis. Write the plotted quantity and its unit by the side of each axis. Note the range of values to be plotted along the two axis.

c. A small division along each axis is chosen to represent a convenient value of the quantity so that the available space on the graph paper is well utilized in accommodating these ranges.

d. At the large division marks along each axis, write the numerical values of the quantity to which they correspond. Plot each pair of the variables and mark the point by a small dot surrounded by a small circle. It is unnecessary to write the coordinates of the point by its side.

e. Draw the best continuous smooth curve through the average of the points. Use a fine pencil for this purpose. The curve should normally pass through most of the plotted points; other points should be evenly distributed on the two sides of the curve. Points lying far away from the curve should be rejected.

f. When the graph is a straight line, use a scale to draw it.

g. When the graph is not a straight line, take care not to introduce any sudden change of curvature. This may be checked by holding the graph horizontally at the eye level and looking tangentially.

h. It may be necessary to read a value from the graph. In that case, mark the corresponding point and draw its ordinate in broken lines.

9. The lab record contains certain marks, so student need to pay good attention to write and submit the lab record with proper care.

10. In each class, lab record will be evaluated out of 10 marks by the class teachers/professors.

11. No credit will be given for more than 2 weeks delay after the experiment is performed. No viva will be taken during weekly evaluation.

12. The evaluated marks will be entered in the departmental lab register for record by Senior Scientific Assistant.

About Practical Examination:

1. At the end of the semester student has to appear for the Practical Examination at specified date and time.
2. Out of the above 08 (eight) experiment, student will be allotted any one practical randomly (on the Lottery basis) during the practical examination.
3. Every student has to perform the allotted experiments individually without assistance of anyone else.
4. The total practical marks will have 50% contribution from the Practical performed in the regular classes throughout the semester and 50% from the Practical examination.
5. In the practical examinations, the total marks will have contribution for Practical performed during the examination, observations, results, and Viva-voce etc.
6. **Total Marks distribution for Physics Practicals:**

Lab Note Book Marks	:	**50**
Final Practical Examination		
a. **Experiment and Observation**	:	25
b. **Graphs/Figures/Working Formula/Circuit Diagrams**	:	10
c. **Results**	:	5
d. **Oral (Viva Voce)**	:	10
Grand Total for Physics Practicals	:	**100**

NOTE:

Please keep in mind that the manuals, which have been provided to you, are just a basic guideline to perform the experiments. You are always encouraged to improve on your experiments beyond whatever mentioned in the manuals. Do not hesitate to ask your doubts.

Experimental Error Estimation

'The aim of science is not to open a door of infinite wisdom, but to set a limit to infinite error'- by Galileo in 'The Life of Galileo' written by 'Bertolt Brecht

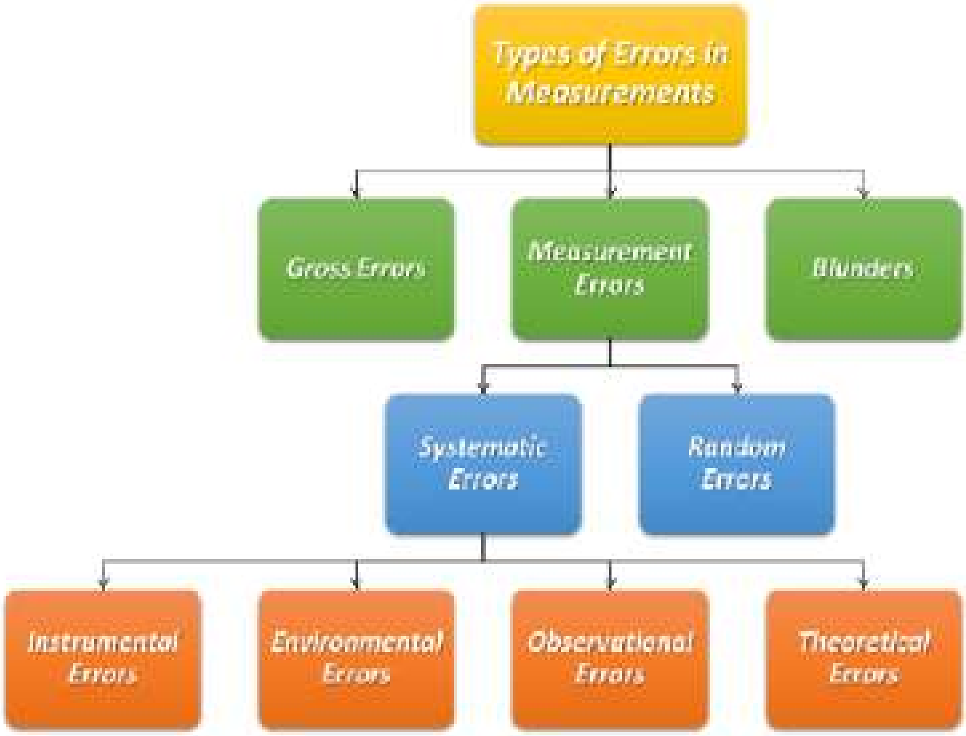
Brecht wrote these provocative words in his most famous piece "The Life of Galileo Galilei". We are aware that Science continuously provides evidence which enhances our knowledge and thereby can open the door to wisdom and set a limit to error.

Error Analysis/Estimation: Why it is so important?

An error is a variation of the 'true' value of a measured, or 'set', quantity (Instrumental Error) or of the value of a non-measured (assumed) quantity (Physical Model Error). The variation occurs because of the inability to know exactly, for different reasons, the conditions (the environment) in which the experiment takes place since these conditions affect our measured and unmeasured quantities. If we knew the exact values of all of the variables that make up the condition in which an experiment takes place, then we would have no error in our experiment-our data come out the same way every time we did the experiment.

This kind of reasoning applies to 'deterministic' physics. Sometimes we examine very complex phenomena where there are many, many conditions e\affecting our result and we perceive a random error. In order to reduce errors, physicists try to limit the number of conditions that affect experiments (known as trying to do an 'idealized' experiment or having a 'control' in your experiment. Here 'control' is used in the sense of controlling all of the conditions in the experiment except for the effect that you are trying to demonstrate).

Types of Errors in Measurements or Experiments



Experimental Errors

One can observe an error associated with your experiment, as given below:

An ***uncertainty*** is a range, estimated by the experimenter, that is likely to contain the true value of whatever is being measured. People often say "error" when they mean uncertainty.

A ***systematic error*** results reproducibly from faulty calibration of equipment or from bias on part of the observer. These errors must be estimated from an analysis of the experimental conditions and techniques.

Random error is the fluctuations in observations which yield results that differ from experiment to experiment and that requires repeated experimentation to yield precise results.

Probable error is the magnitude of error which is estimated to have been made in determination of results.

The ***accuracy*** of a measurement is a way of talking about the total error in your final result. An accurate measurement is very close to the true value. Just because a measurement is accurate doesn't mean it's precise; an accurate value with a wide possible range isn't very useful.

The ***precision*** of a measurement is the total amount of random error present. A very precise measurement has small random errors, but just because a measurement is precise doesn't mean that it's accurate (see above); undiscovered systematic errors might skew your results drastically.

The accuracy of an experiment is generally dependant on how well we can control or compensate for systematic errors. The precision of an experiment is dependent on how well we can overcome or analyze random errors.

Significant Figures and Importance of Round off

The precision of an experimental result is implied by the way in which the result is written, though it should generally be quoted specifically as well. To indicate the precision, we write a number with as many digits as are significant. The number of significant figures in a result is defined as follows:

1. The left most non-zero digit is the most significant digit.
2. If there is no decimal point, the rightmost non-zero digit is the least significant digit.
3. If there is a decimal point, the rightmost digit is the least significant digit, even if it is a 0.
4. All digits between the least and most significant digits are counted as significant digits.

For example, the following numbers each have four significant digits: 1,234; 123,400; 123.4; 1,001, 1,000., 10.10, 0.0001010, 100.0. If there is no decimal point, there are ambiguities when the right most digit is a 0. For example, the number 1,010 is considered to have only three significant digits even though the last digit might be physically significant. To avoid this ambiguity, it is better to supply decimal points or write such numbers in exponent form as an argument in decimal notation times the appropriate power of 10. Thus, our example of 1,010 would be written as 1,010. or 1.010×10^3 if all four digits are significant.

When quoting results of an experiment, the number of significant figures given should be approximately one more than that dictated by the experimental precision. The reason for including the extra digit is that in computation one significant figure is sometimes lost. Errors introduced by insufficient precision in calculations are classified as '*illegitimate error*'. If an extra digit is specified for all numbers used on the computation, the original precision will be retained to a greater extent. For example, in the experiment if the absolute precision of the result is 10 mm, the third figure is known with an uncertainty of ±1 and the fourth figure is not really known at all. We would be barely justified in specifying four figures for computation. If the precision is 2mm, the third digit is known quite well and the fourth figure is known approximately. We are justified in quoting four figures, but probably not justified in quoting five figures since we cannot even have much confidence in the value of the fourth figure.

When insignificant digits are dropped from a number, the last digit retained should be rounded off for the best accuracy. To round off a number to a smaller number of significant digits than are specified originally, truncate the number to the desired number of significant digits and treat the excess digits as a decimal fraction. Then

1. If the fraction is greater than 1/2, increment the least significant digit.
2. If the fraction is less than 1/2, do not increment.
3. If the fraction equals 1/2, increment the least significant digit only if it is odd.

In this manner, the value of the final result is always within half the least significant digit of the original number. The reason for rule (3) is that in many cases the fraction equals either 0 or 1/2 and consistently incrementing the least significant digit for a fraction of 1/2 would lead to a systematic error. For example, 1.235 and 1.245 both become 1.24 when rounded off to three significant figures, but 1.2451 becomes 1.25.

Statistical Error Analysis

A. Gaussian Distribution

Every measurement is subject to a certain amount of random error. Random errors can arise from minute vibrations in the apparatus, quantum uncertainties in the system being studied, and many other small but uncontrolled effects. Fortunately, almost all the random errors you encounter can be characterized by a Gaussian distribution, also known as a bell curve [Fig. 1]. This simple mathematical form describes the probability of encountering any given error.

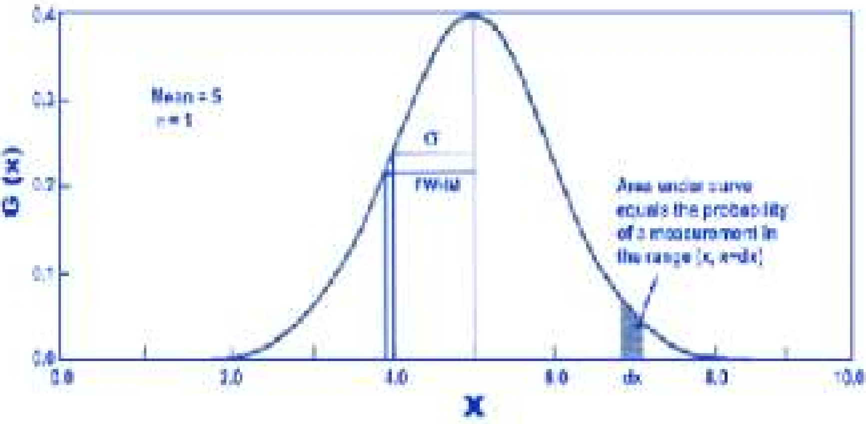


Figure 1: Gaussian Distribution

The Gaussian distribution has two free parameters: the mean and the standard deviation. The probability of finding a measurement in the range [x, x+dx] is equal to the area under the curve in that range. The curve is normalized to have a total area of 1, which is why its amplitude is not also a free parameter. Notice also that the distribution is symmetric; an error is equally likely to occur in either direction. The equation which describes this curve

$$G(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(x - x_m)^2}{2\sigma^2}\right]$$

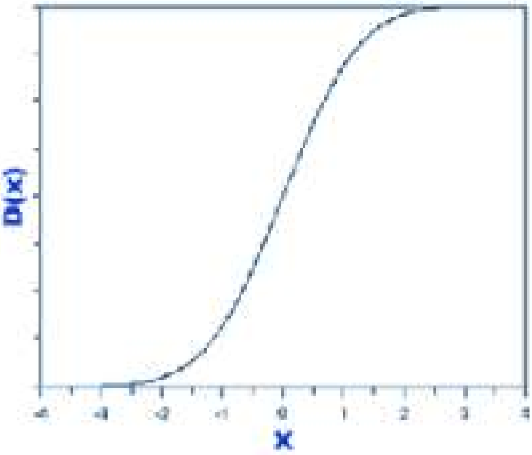
The standard deviation (σ) describes the width of the bell; a higher standard deviation means that you're more likely to find large errors. The mean (x_m) lies on the axis of symmetry of the bell. These two parameters completely determine the shape of the curve and are used to describe the results of your measurements. Another common way of describing the width of the bell is by using the "full width at half maximum", or FWHM, which is equal to 2.36σ and is easier to figure out from a plot. By integrating all or part of the Gaussian curve, we can make precise statements about how probable it is that our results are correct.

B. Cumulative Frequency Distribution

For statistical analysis, one more commonly use cumulative distribution function, which gives the probability that a variate assume a value <x, and is then the integral of the Gaussian function integrating from minus infinity to x. Cumulative distribution function is given by

$$\boxed{D(x) = \int_{-\infty}^{+\infty} P(x) = \frac{1}{2}\left[1+\mathrm{erf}\left(\frac{x-x_m}{\sigma\sqrt{2}}\right)\right]}$$

erf x is the error function.



The cumulative distribution is basically the answer to the question, "What is the probability that an instantaneous value of variate is less than x". Basically the point of inflection of the cumulative distribution corresponds to maximum probability.

C. Mean Value

Suppose an experiment were repeated many, say N, times to get, x_1, x_2, ... X_i, ..., X_n, N measurements of the same quantity, x. If the errors were random then the errors in these results would differ in sign and magnitude. So if the average or mean value of our measurements were calculated,

$$x_m = \frac{x_1 + x_2 + \dots + x_n}{N} = \frac{\left[\sum_{i=1}^{n} x_i\right]}{N}$$

Some of the random variations could be expected to cancel out with others in the sum. This is the best that can be done to deal with random errors: repeat the measurement many times, varying as many "irrelevant" parameters as possible and use the average as the best estimate of the true value of x. (It should be pointed out that this estimate for a given N will differ from the limit as N the true mean value; though, of course, for larger N it will be closer to the limit).

Doing this should give a result with less error than any of the individual measurements. But it is obviously expensive, time consuming and tedious. So, eventually one must compromise and decide that the job is done. Nevertheless, repeating the experiment is the only way to gain confidence in and knowledge of its accuracy. In the process an estimate of the deviation of the measurements from the mean value can be obtained.

D. Standard Deviation

In terms of the mean, the standard deviation of any distribution is,

$$\sigma = \sqrt{\frac{\sum_i (x_i - x_m)^2}{N}}$$

The quantity σ^2 is called the variance. The best estimate of the true standard deviation is,

$$\sigma_x = \sqrt{\frac{\sum_i (x_i - x_m)^2}{N-1}}$$

E. Error Propagation

Frequently, the result of an experiment will not be measured directly. Rather, it will be calculated from several measured physical quantities (each of which has a mean value of an error). What is the resulting error in the final result of such an experiment?

For instance, what is the error in Z = A + B where A and B are two measured quantities with errors ΔA and ΔB respectively? A first thought might be that the error in Z would be just the sum of the errors in A and B. After all,

$$(A + \Delta A) + (B + \Delta B) = (A + B) + (\Delta A + \Delta B)$$

And $$(A - \Delta A) + (B - \Delta B) = (A + B) - (\Delta A + \Delta B)$$

But this assumes that, when combined, the errors in A and B have the same sign and maximum magnitude; that is that they always combine in the worst possible way. This could only happen if the errors in the two variables were perfectly correlated, (i.e., if the two variables were not really independent).

If the variables are independent then sometimes the error in one variable will happen to cancel out some of the error in the other and so, on the average, the error in Z will be less than the sum of the errors in its parts. A reasonable way to try to take this into account is to treat the perturbations in Z produced by perturbations in its parts as if they were "perpendicular" and added according to the Pythagorean theorem,

$$\Delta Z = \{(\Delta A)^2 + (\Delta B)^2\}^{1/2}$$

i.e., if A = (100 + 3) and B = (6 + 4) then Z = (106 + 5) since $5 = (3^2 + 4^2)^{1/2}$.

This idea can be used to derive a general rule. Suppose there are two measurements, A and B, and the final result is Z = F(A, B) for some function F. If A is perturbed by ΔA then Z will be perturbed by

$$\left(\frac{\delta F}{\delta A}\right)\Delta A$$

Similarly the perturbation in Z due to a perturbation in B is,

$$\left(\frac{\delta F}{\delta B}\right)\Delta B$$

Combining these by the Pythagorean theorem yields

$$\Delta Z = \sqrt{\left(\frac{\delta F}{\delta A}\right)^2(\Delta A)^2 + \left(\frac{\delta F}{\delta B}\right)^2(\Delta B)^2}$$

In the example of Z = A + B considered above,

$$\frac{\delta F}{\delta A} = 1 \quad \text{and} \quad \frac{\delta F}{\delta B} = 1$$

so this gives the same result as before. Similarly if Z = A-B then,

$$\frac{\delta F}{\delta A} = 1 \quad \text{and} \quad \frac{\delta F}{\delta B} = -1$$

which also gives the same result. Errors combine in the same way for both addition and subtraction. However, if Z = AB then,

$$\frac{\delta F}{\delta A} = B \quad \text{and} \quad \frac{\delta F}{\delta B} = A$$

So,

$$\Delta Z = \sqrt{B^2(\Delta A)^2 + A^2(\Delta B)^2}$$

Thus,

$$\frac{\Delta Z}{Z} = \frac{\Delta Z}{AB} = \sqrt{\left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta B}{B}\right)^2}$$

or the fractional error in Z is the square root of the sum of the squares of the fractional errors in its parts. (You should be able to verify that the result is the same for division as it is for multiplication.) For example,

$$(100 \pm 0.3)(6 \pm 0.4) = 600 \pm 600\sqrt{\left(\frac{0.3}{100}\right)^2 + \left(\frac{0.4}{6}\right)^2} = 600 \pm 40$$

It should be noted that since the above applies only when the two measured quantities are independent of each other. It does not apply when, for example, one physical quantity is measured and what is required is its square.

If $Z = A^2$ then the perturbation in Z due to a perturbation in A is

$$Z = \frac{\delta F}{\delta A} \Delta A = 2A \Delta A$$

So, in this case,

$$(\mathbf{A} + \Delta\mathbf{A})^2 = \mathbf{A}^2 \pm 2\mathbf{A}\Delta\mathbf{A} = \mathbf{A}^2 (1 \pm 2\Delta\mathbf{A}/\mathbf{A})$$

and not $A^2 (1 \pm \Delta A)/A)$ as would be obtained by misapplying the rule for independent variables.

For example,

$(10 \pm 1)^2 = 100 \pm 20$ and not 100 ± 14

If a variable z depends on (one or) two variables (A and B) which have independent errors (ΔA and ΔB) then the rule for calculating the error in Z is tabulated in following table for a variety of simple relationships.

S.No.	Relation between Z and (A, B)	Relation between errors ΔZ and (ΔA, ΔB)
1.	$Z = A + B$	$(\Delta Z)^2 = (\Delta A)^2 + (\Delta B)^2$
2.	$Z = A - B$	$(\Delta Z)^2 = (\Delta A)^2 + (\Delta B)^2$
3.	$Z = AB$	$(\Delta Z/Z)^2 = (\Delta A/A)^2 + (\Delta B/B)^2$
4.	$Z = A/B$	$(\Delta Z/Z)^2 = (\Delta A/A)^2 + (\Delta B/B)^2$
5.	$Z = A^n$	$\Delta Z/Z = n(\Delta A/A)$
6.	$Z = ln\ A$	$\Delta Z = \Delta A/A$
7.	$Z = e^A$	$\Delta Z/Z = \Delta A/A$

F. Removing Systematic Errors

To hunt for systematic errors one should go through this mental process, while designing an experiment:

1. What physical quantities (including environmental factors) is the measurement most sensitive to?
2. Are there any other sources of error in the quantity that is being measured?
3. If so how we isolate the experiment from these effects?
4. If we can not get rid of the systematic error, can we measure it and account for it later?

Of course, there always remains the possibility that a systematic error is present which we might not think of. To account for this one needs to calibrate the instruments used and if possible, the experiment itself. Calibrating means that we use our instrument to measure some known quantities and check whether the measured answer tallies with known results. One should be cautious when using this method to correct results outside the domain which we have calibrated. There is no way to know whether other effects would become important in the new region.

If we do not have any good way of producing known values, and think of a systematic error which we are not able to remove from the experiment, then the only way to correct it is by using Physics. We make and educated guess as to the exact nature of the error, and then use an established theory to figure out what impact it will have on the experiment.

References

1. Physics Laboratory Workbook, UG First Year, IIT Kharagpur.

2. An Introduction to Error Analysis by J.R. Taylor, University Science Book, 1962
3. Statistical Treatment of Experimental Data by H.D. Young, McGraw Hill 1962.
4. Data Reduction and Error Analysis for the Physical Sciences by P. R. Bevington, McGraw-Hill 1969 519.8 BEV/D

EXPERIMENT NUMBER 1

AIM:

To calculate the band gap of semiconductor by measuring the resistivity at different temperatures.

APPARATUS:

Four probe set-up with probe arrangement, Sample (Ge or Si crystal in form of chip), Oven, thermometer.

BRIEF DESCRIPTION OF THE APPARATUS

- **Probes Arrangement:** It has four individually spring-loaded probes, coated with Zn at the tips. The probes are co-linear and equally spaced. The Zn coating & individual spring ensure good electrical contacts with the sample. The probes are mounted in a teflon bush which ensure a good electrical insulation between the probes. A teflon spacer near the tip is also provided to keep the probes at equal distance. The whole arrangement is mounted on a suitable stand and leads are provided for current and voltage measurements.
- **Sample:** Ge or Si crystal in the form of a chip/slice.
- **Oven :** It is a small oven for the variation of temperature of the crystal from room temperature to about 150 °C.
- **Four Probes Set-up:** (Measuring Unit) - It has three subunits all enclosed in one cabinet.

(i) **Multirange Digital Voltmeter:** It has high accuracy, auto zero to less than 10 µV, zero drift-less than 1 µV/°C, input bias current of 10 pA and roll over error of less than one count.

Range: X-1 (0 - 200.0 mV) & X-10 (0 - 2.000 V)

Resolution: 100 µV at X 1 range

Overload Indicator: Sign of 1 on the left and blanking of other digits.

(ii) **Constant Current Generator**: It is an IC regulated current generator to provide a constant current to the outer probes irrespective of the changing resistance of the sample due to change in temperatures. Variations in the current are achieved by a potentiometer included for that purpose. The supply is a highly regulated and practically ripple free d.c. source. The current is measured by the digital panel meter.

(iii) **Oven Power Supply**: Suitable voltage for the oven is obtained through a step-down transformer with a provision for low and high rates of heating. A glowing LED indicates, when the oven power supply is 'ON'.

Figure 1: Four probe experimental set-up

THEORY:

In figure-2 four probes 1, 2, 3 and 4 are spaced apart. Current I is passed through the outer probes (1 & 4) and the floating potential V is measured approx the inner pairs of probes 2 & 3.

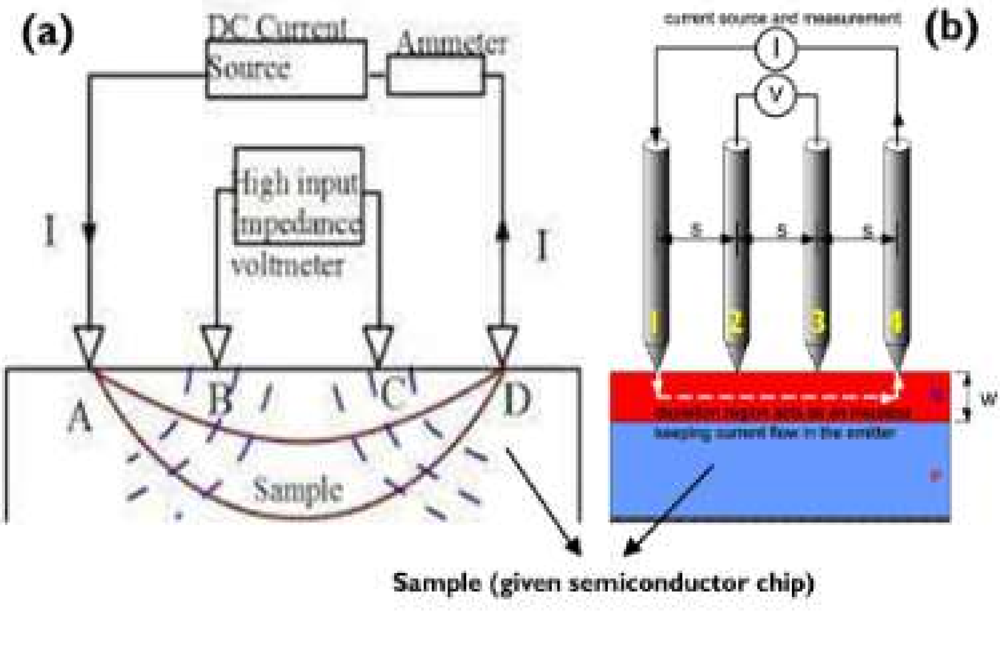


Figure 2: Circuit diagram for resistivity measurements.

The potential difference V between probes 2 & 3 can be written as

$$V = \frac{I\rho_0}{2\pi s} \quad \text{(i)}$$

Where, ρ is the resistivity of the material, I is the amount of current passing through the material. S – Spacing between the probes in meter. Therefore,

$$\rho_0 = 2\pi s \frac{V}{I} \quad \text{(ii)}$$

Since the effective thickness of the crystal (w) is very small compared to the probe distance a correction factor for it has to be applied

$$\rho = \frac{\rho_0}{f\left(\frac{w}{s}\right)}$$

Now substituting the values,

$$\rho_0 = 2 \times 3.14 \times 0.2 \times \frac{V}{I} = 1.256\,\frac{V}{I}$$

and the correction factor i.e. f (w/s) is 5.89

$$\rho = \frac{\rho_0}{5.89} = \frac{1.256}{5.89}\frac{V}{I}$$

$$\rho = 0.213\,\frac{V}{I} \quad \text{(iii)}$$

Thus ρ may be calculated for various temperatures.

Now, if we plot $\log_{10}\rho$ vs. $\frac{1}{T}$, we get a curve which is linear at higher temperatures.

We know resistivity, $\rho = C\exp\left(\frac{E_g}{2KT}\right)$, where C is a constant. From this expression we can have: $\ln\rho = \left(\frac{E_g}{2K}\right)\frac{1}{T} + \ln C$

Therefore, width of the energy gap may be determined from the slope of the linear portion of the experimental curve: $\frac{\Delta\log_{10}\rho}{\Delta\frac{1}{T}} = \frac{\Delta\ln\rho}{2.303\times\Delta\frac{1}{T}} = \frac{1}{2.303}\times\frac{E_g}{2K}$

Thus we have

$$\boxed{E_g = 2.303\times 2K\,\frac{\Delta\log_{10}\rho}{\Delta\frac{1}{T}} \qquad \cdots(iv)}$$

Where K is Boltzman's Constant [$K = 8.6\times 10^{-5}$ eV/Kelvin]

PROCEDURE:

1. Switch on the circuit (make sure that the oven is switched off).
2. Align the voltmeter/ammeter display changer switch at ammeter position and fix the value of the probe current to any fixed value (approx. 4 – 8 mA).
3. Align the display changer switch to voltmeter position and note the temperature and record the corresponding voltage value.
4. Switch on the oven at low heating mode.
5. As the temperature starts to increase, record all the corresponding values of the voltage at the interval of 10 °C up to 60 °C and from thereon till 140 °C at the interval of 5 °C.
6. Switch off the oven and then switch off the circuit.
7. Plot $\log_{10}\rho$ vs T^{-1} and find out the slope from the linear portion of the graph.
8. Complete the calculation to find out the value of the Band gap for the given semiconductor.

OBSERVATION TABLE:

Current (I) = xx mA.

S. No.	Temperature (°C)	Voltage (V)	T (K)	Resistivity (ohm-cm)	T^{-1} (K^{-1})	$\log_{10}\rho$

CALCULATION:

According the equation number (iii), we can calculate the band gap of semiconductor as given below:

$$E_g = 2.303 \times 2K \frac{\Delta \log_{10} \rho}{\Delta \frac{1}{T}}$$

Hence, substituting the obtained slope in the above equation,

E_g = 2.303 × 2 × 8.6 × 10^{-5} × (slope from the graph) = ……

Average value = ……..

ERROR ESTIMATION:

If $E_g = \frac{M}{N}$, then $\frac{\delta E_g}{E_g} = \sqrt{\left|\left(\frac{\delta M}{M}\right)^2 + \left(\frac{\delta N}{N}\right)^2\right|}$

Here, $M = \Delta \log_{10} \rho$ and $N = \Delta\left(\frac{1}{T}\right)$

Hence, $\delta M = \delta(\Delta \log_{10} \rho)$= smallest division on the y-axis of the graph=

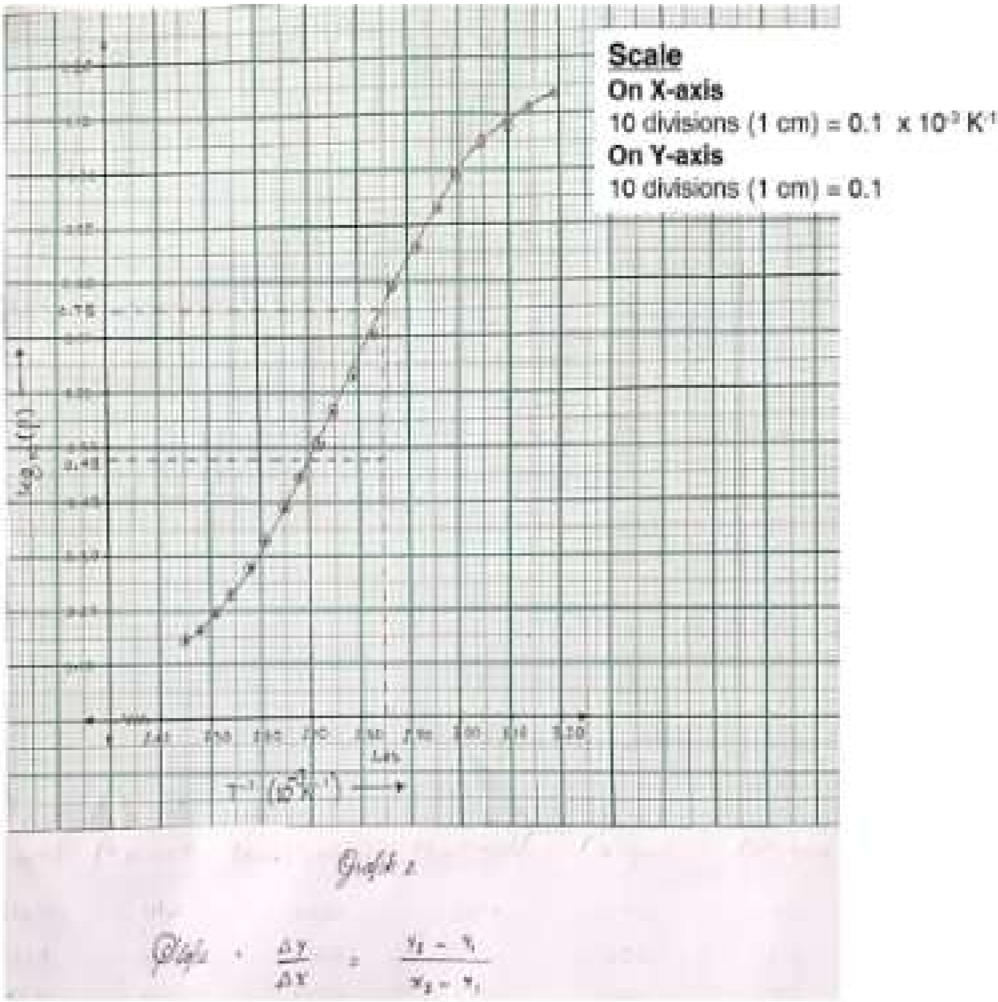
and $\delta N = \delta\left\{\Delta\left(\frac{1}{T}\right)\right\}$= smallest division on the x-axis of the graph=

Putting values of E_g, M, N, ΔM and ΔN, we get δE_g=

The percentage error is $\left(\frac{\delta E_g}{E_g}\right) \times 100\%$

GRAPH:

Draw a smooth curve passing through maximum number of data points and <u>take slope on the linear portion of the graph</u>.



Graph 1: (example of) $\log_{10}\rho \ vs \frac{1}{T}\ plot$

FINAL RESULT:

The band gap of the given semiconductor is $(E_g \pm \delta E_g)$ eV.

PRECAUTIONS: (Student must write it in their own language).

(i) The connection should be tight.

(ii) Take the room temperature reading before switching on the oven.

(iii) Oven should not be switched off while noting the reading for increasing temp.

(iv) Apparatus should be handled carefully.

(v) Insert the thermometer inside the instrument carefully.

FEW FREQUENTLY ASKED QUESTIONS:

a. What is Conductor, Semiconductor and Insulator?
b. What is intrinsic and extrinsic semiconductor?
c. What are 'p-type' and 'n-type' semiconductor?
d. What do you mean by band gap? Explain band gap of materials.
e. What is typical band gap for conductor, insulator and semiconductors?
f. What is 4 probe method? Why it is better than 2 probe?
g. How the resistivity in conductor, insulator and semiconductors vary with temperature?
h. Explain the difference between an ammeter and a voltmeter.

EXPERIMENT NUMBER 2

AIM:

To study the Hall Effect of a semiconductor.

APPARATUS:

Hall effect setup having Hall probe, Electromagnet, Constant current power supply, digital Gauss meter.

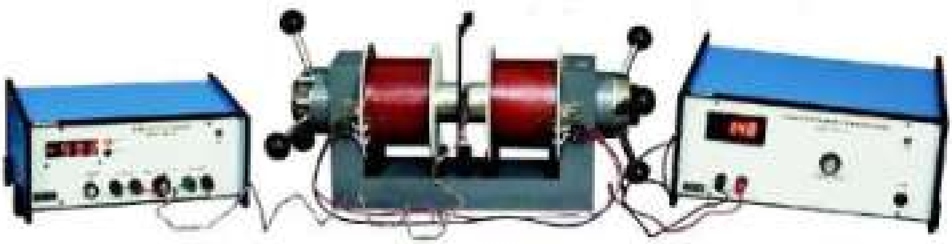


Figure 1: Hall effect experimental setup.

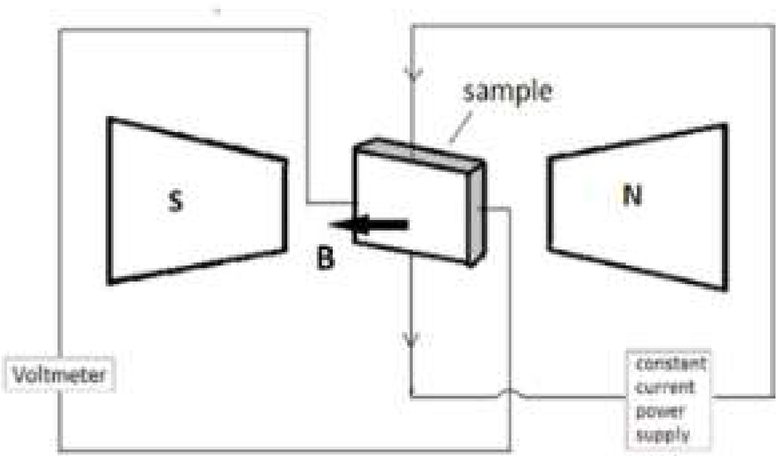


Figure 2: Hall effect circuit diagram.

THEORY:

The phenomenon of production of transverse e.m.f. in a current-carrying conductor, when a magnetic field is applied perpendicular to the direction of current, is known as Hall effect. This effect helps us to know not only the nature of charge carrier in a conductor but also the number density of such carriers. To understand this effect, consider a rectangular conducting strip with three edges parallel to three co-ordinate axes. Suppose a current I be made to flow through the stripe along Y axis and magnetic field is applied along Z axis, a voltage (Hall voltage) is developed along X-axis, which is given by

$$V_H = Bv_d\, b$$

Where v_d is drift velocity of charge carrier given by $v_d = I/neA$ and b is the breadth of the strip. Here, n is carrier density, e is charge and A is cross sectional area which is defined as $A = b.d$. Hence, $V_H = BIb/neA = BIb/nebd = BI/ned$ (as $A = b.d$), where d is the thickness of the strip. The quantity $1/ne$ is called Hall coefficient and is given by $V_H d/B\, I$ and the term V_H/I is known as Hall resistance, R_H which is written as $R_H = B/n\, e\, d$

PROCEDURE:

Connect the width wise contacts of the Hall probe to the terminals marked voltage and lengthwise contacts to the terminals marked current. Switch ON the Hall Effect setup. Now place the probe in the magnetic field, switch ON the electromagnet power supply and adjust the current such that magnetic field becomes 900 Gauss. Rotate the Hall probe till it becomes perpendicular to the magnetic field. Adjust current to desired value in Hall prove and measure corresponding Hall voltage V_H by moving knob of digital meter to the other side. Note down at least 8 readings for a particular magnetic field. Again, set another value of magnetic field (1000 Gauss) and take another set of voltage versus current readings. Given the thickness of sample (d) = 0.5 mm.

OBSERVATION TABLE:

Set-1:

Magnetic field: 900 Gauss = 0.09 Tesla

Sl. No.	I (mA)	V_H (mV)

Set-2:

Magnetic field: 1000 Gauss = 0.10 Tesla

Sl. No.	I (mA)	V_H (mV)

Set-3:

Magnetic field: 1200 Gauss = 0.12 Tesla

Sl. No.	I (mA)	V_H (mV)

CALCULATIONS:

For the 1st magnetic field: 900 Gauss

Hall coefficient (η_H) = $V_H\, d/BI$ = ...

Carrier density (n) = $BI/V_H\, e\, d$ = ...

Hall resistance (R_H) = $B/\, n\, e\, d$ = ...

Similarly, do the calculations for 2[nd] and 3[rd] magnetic field:

ERROR ESTIMATION:

Consider, $Hall\ coefficient\ (\eta_H) = \frac{M\, d}{N\, B}$, $M = \Delta V_H\ and\ N = \Delta I$,

Then, $\frac{\delta\eta_H}{\eta_H} = \sqrt{\left[\left(\frac{\delta M}{M}\right)^2 + \left(\frac{\delta N}{N}\right)^2 + \left(\frac{\delta B}{B}\right)^2\right]}$

Neglecting error in d, since this is supplied

$\delta M = \delta(\Delta V_H)$ = smallest division on the y-axis of the graph=

$\delta N = \delta(\Delta I)$= smallest division on the x-axis of the graph=

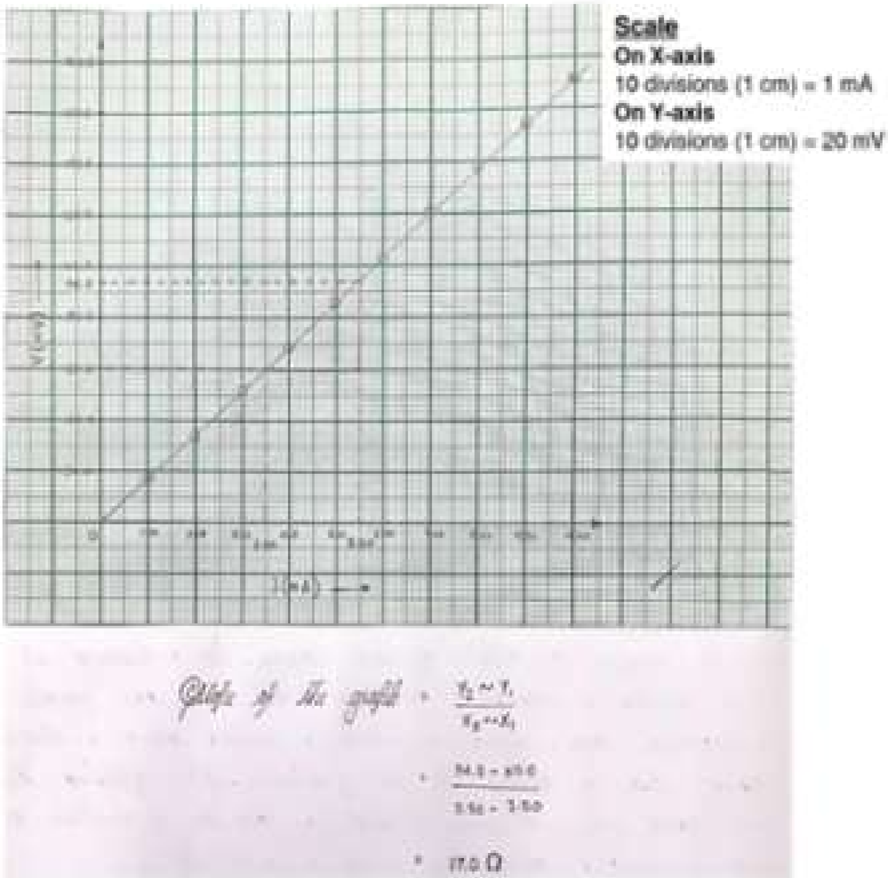
δB = 0.5*least count of Gaussmeter

Putting values of η_H, B, M, N, δB, δM and δN, estimate $\delta\eta_H$=

Similarly calculate error in carrier density and Hall resistance

GRAPH:

Plot V_H vs I and determine the slope.



Graph 1: (example of) V_H vs I plot for magnetic field 900Gauss

NOTE: Similarly, V_H vs I graphs for other magnetic fields must be also plotted.

RESULT:

The Hall Effect is verified at various magnetic fields. The obtained values of are given below:

For the magnetic field: 900 Gauss

a) Hall coefficient $(\eta_H) = (\eta_H \pm \delta\eta_H)\ m^3C^{-1}$
b) Carrier density (n) = $(n + \delta n)\ m^{-3}$
c) Hall resistance $(R_H) = (R_H + \delta R_H)\ \Omega$

NOTE: Also write results for the other set of data.

PRECAUTIONS: (Student must write it in their own language).

1. Hall probe should be kept perpendicular to the magnetic field while measuring
2. Note zero error of Gaussmeter and voltmeter and adjust readings accordingly
3. Prolonged experiment might cause heating of the sample

FEW FREQUENTLY ASKED QUESTIONS:

a. What is a Conductor, Semiconductor and Insulator?
b. What is intrinsic and extrinsic semiconductor?
c. What are 'p-type' and 'n-type' semiconductor?
d. Define Hall effect, Hall coefficient, carrier density, and Hall resistance?
e. What does positive and negative Hall coefficient signify?
f. How does Hall coefficient vary with temperature?
g. How to make an electromagnet stronger?
h. Which is more suitable as the core of electromagnets? Steel and Soft iron?
i. How does a gauss meter work?

EXPERIMENT NUMBER 3

AIM:

To determine the thermal conductivity of bad conductor by Lee's method.

APPARATUS:

Lee's apparatus, Thermometer, Vernier callipers, Screw gauge, Electric heater, Specimen.

THEORY:

The apparatus consists of a hollow cylindrical chamber and a solid disc of equal diameters. The materials whose thermal conductivity is to be determined is taken in the form of a disc of radius equal to either of the above disc and heat is passed through the chamber. At steady state heat conducted through the experimental disc per second is given by:

$$\frac{dQ}{dt} = \frac{KA(\theta_1 - \theta_2)}{d} \tag{1}$$

where K, A and d are thermal conductivity, area and thickness of the specimen respectively and θ_1 and θ_2 are the steady temperatures of upper and lower surface of the bad conductor (in the set up it is the temperature of the steam chamber and lower disc) respectively. Now the heat coming to the lower disc is lost to the air from the exposed surface of the same in the steady state. Hence, heat lost per second will be

$$M.S\left(\frac{d\theta}{dt}\right)_{\theta_2} \tag{2}$$

where M, S and $\left(\frac{d\theta}{dt}\right)_{\theta_2}$ are the mass of the lower disc, specific heat of the material of the lower disc and the rate of cooling per second at θ_2. At steady state heat conducted (equation 1) and heat lost to air (equation 2) will be equal.

That is,

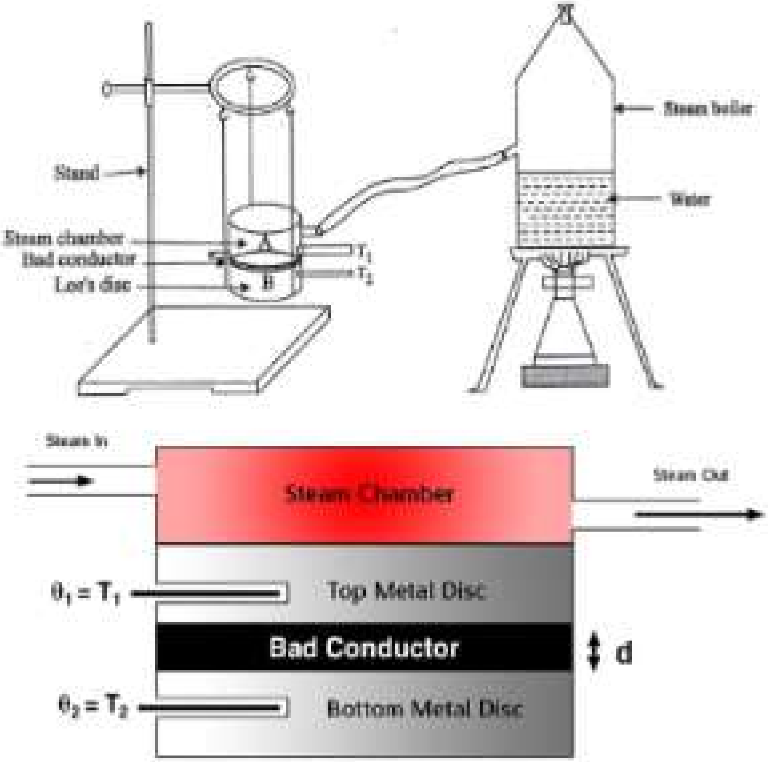
$$\frac{KA(\theta_1 - \theta_2)}{d} = M.S\left(\frac{d\theta}{dt}\right)_{\theta_2}$$

$$K = \frac{M.S.d.\left(\frac{d\theta}{dt}\right)_{\theta_2}}{A(\theta_1 - \theta_2)} \tag{3}$$

PROCEDURE:

Place the specimen between the chamber and the solid disc (Fig 1). Pass steam through the chamber and thermometer in the holes of the chamber and the lower disc. Wait until the thermometers show steady temperatures θ_1 and θ_2. To find out the rate of cooling, remove the chamber and the heat the lower disc directly with a heater so that temperature rises by 10°C above θ_2. Then place the specimen as before and note the fall of temperature at an interval of half minute until the temperature fall by 10°C below θ_2. Plot the time-temperature curve (Graph: 1) and draw tangent on the cure at the temperature θ_2 which is $\left(\frac{d\theta}{dt}\right)_{\theta_2}$.

Measure the radius and thickness of the sample (bad conductor) with slide calliper and screw gauge, respectively.



T_1: Temperature of the upper surface of bad conductor/Sample.

T_2: Temperature of the lower surface of bad conductor/Sample.

Figure 1: Experimental setup.

OBSERVATIONS:

Steady state temperature of hollow chamber (θ_1) = yy °C

Steady state temperature of lower disc (θ_2) = xx °C

Mass of the lower disc = 790 g

Specific heat of brass = 0.095 cal/g °C

TABLE 1: Temperature vs time data

S. No	Temperature of lower disc (°C)	Time (every 0.5 minute)
1		
2		
3		
4		
5		
6		
7		

TABLE: 2: (Calculation for radius of specimen by slide callipers)

Least count = 1 MSD – 1 VSD =

Zero error =

S. No	MSR	VS Div	VSR (VSD*LC)	Total	Mean (Diameter)	Mean (Radius)
1						
2						
3						

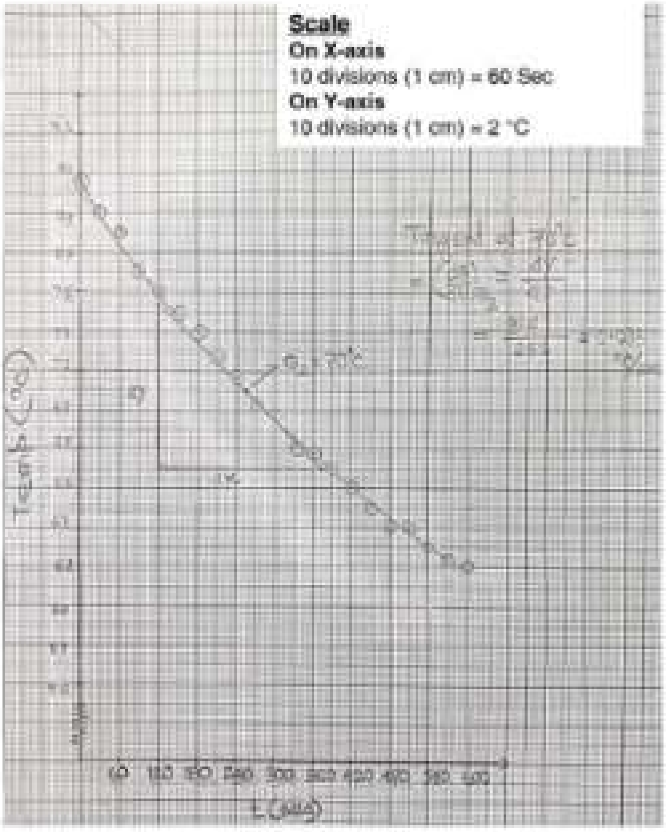
TABLE 3: (Calculation for thickness of the specimen by screw gauge)

Least count =

S. No	MSR	CS Div	CSR	Total	Mean
1					
2					
3					

GRAPH:

Draw a smooth curve passing through maximum number of data points. <u>Draw a tangent to the curve at temperature θ_2 and take the slope of the this tangent.</u>



Graph 1: Time dependence of the temperature

CALCULATION:

Thermal conductivity $K = \dfrac{M.S.d.\left(\dfrac{d\theta}{dt}\right)_{\theta_2}}{A(\theta_1 - \theta_2)}$ = 790 × 0.095 × .... = ...

ERROR ESTIMATION:

$$\frac{\delta K}{K} = \sqrt{\left(\frac{\delta d}{d}\right)^2 + \left(2\frac{\delta r}{r}\right)^2 + \left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta(\theta 1 - \theta 2)}{(\theta 1 - \theta 2)}\right)^2}$$

Here, $A = \pi r^2$, $\frac{\delta A}{A} = 2\frac{\delta r}{r}$,

$m = \left(\frac{d\theta}{dt}\right)_{\theta 2}$, the slope obtained from the graph. Hence, $\frac{\delta m}{m} = \sqrt{\left(\frac{\delta(\Delta\theta)}{\Delta\theta}\right)^2 + \left(\frac{\delta(\Delta t)}{\Delta t}\right)^2}$

Alternatively, one can make two attempts to estimate the tangent and take the difference of the two as δm.

δd = 0.5*least count of the screw gauge=

δr = 0.5*least count of the Vernier callipers =

$\delta(\theta 1 - \theta 2) = \sqrt{(\delta(\theta 1))^2 + (\delta(\theta 2))^2}$ where $\delta(\theta 1) = \delta(\theta 2)$ = 0.5*minimum division of the thermometer

$\delta(\Delta\theta)$ = one minimum division of the graph paper in temperature axis (y-axis)

$\delta(\Delta t)$ = one minimum division of the graph paper in time axis (x-axis)

Putting the values one can estimate δK.

The percentage error is $\left(\frac{\delta K}{K}\right)$*100%.

FINAL RESULT:

The calculated thermal conductivity of the test specimen by Lee's method is $(K \pm \delta K)$ $(cal/sec)/(cm\ ^{\circ}C)$ or $Wm^{-1}K^{-1}$.

PRECAUTION: (Student must write it in their own language).

(i) Operate the thermometer carefully.
(ii) Avoid touching heated object and hot steam.
(iii) View thermometer perpendicularly (Avoid paradox).
(iv) Zero error of apparatus must be taken carefully.

FEW FREQUENTLY ASKED QUESTIONS:

a. What is thermal conductivity? Write its units and dimension.
b. How does thermal conductivity depend on the size of the specimen?
c. Explain the working principles of Lee's disk method.
d. Can Lee's disc method be used for good conductors?
e. Why a disc is taken in this experiment?
f. Give some daily life examples to explain the importance of thermal conductivity. (i.e. use of some good and bad thermal conductor)?
g. What is entropy?
h. Give different law's of thermodynamics.

EXPERIMENT NUMBER 4

AIM:

Determination of wavelength of light by plane diffraction grating.

APPARATUS:

Spectrometer, sodium vapor lamp, Plane diffraction grating, grating stand, magnifying glass, torch and spirit level.

THEORY:

An arrangement consisting of a large number of equidistant parallel narrow slits of equal width separated by equal opaque portions is known as a diffraction grating. The plane transmission grating is a plane sheet of transparent material on which opaque rulings are made with a fine diamond pointer. The modern commercial form of grating contains about 15000 lines per inch. The rulings act as obstacles having a definite width '*b*' and the transparent space between the rulings act as slit of width '*a*'. The combined width of a ruling and a slit is called grating element (*e*). Points on successive slits separated by a distance equal to the grating element are called corresponding points.

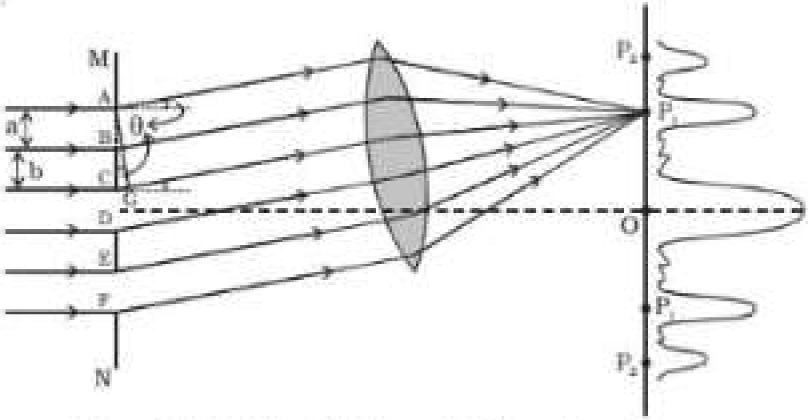


Figure 1. Diffraction of light passing through grating.

MN represents the section of a plane transmission grating. AB, CD, EF ... are the successive slits of equal width '*a*' and BC, DE ... be the rulings of equal width '*b*' (Fig. 1). The grating element $e = a + b$.

Let a plane wave front of monochromatic light with wave length λ be incident normally on the grating. According to Huygen's principle, the points in the slit AB, CD ... etc act as a source of secondary wavelets which spread in all directions on the other side of the grating. Let us consider the secondary diffracted wavelets, which makes an angle θ with the normal to the grating. The path difference between the wavelets from one pair of corresponding points A and C is $CG = (a + b) \sin\theta$. It will be seen that the path difference between waves from any pair of corresponding points is also $(a + b) \sin\theta$. The point P_1 will be bright, when $(a + b) \sin \theta = m\lambda$ where $m = 0, 1, 2, 3, \ldots$ etc. In the undiffracted position $\theta = 0$ and hence $\sin \theta = 0$.

$(a + b) \sin \theta = 0$, satisfies the condition for brightness for $m = 0$. Hence the wavelets proceeding in the direction of the incident rays will produce maximum intensity at the center O of the screen. This is called zero order maximum or central maximum. If $(a + b) \sin \theta_1 = \lambda$, the diffracted wavelets inclined at an angle θ_1 to the incident direction, reinforce and the first order maximum is obtained. Similarly, for second order maximum, $(a + b) \sin \theta_2 = 2\lambda$. On either side of central maxima different orders of secondary maxima are formed at the point P_1, P_2. In general, $(a + b) \sin \theta = m\lambda$ is the condition for maximum intensity, where m is an integer, the order of the maximum intensity.

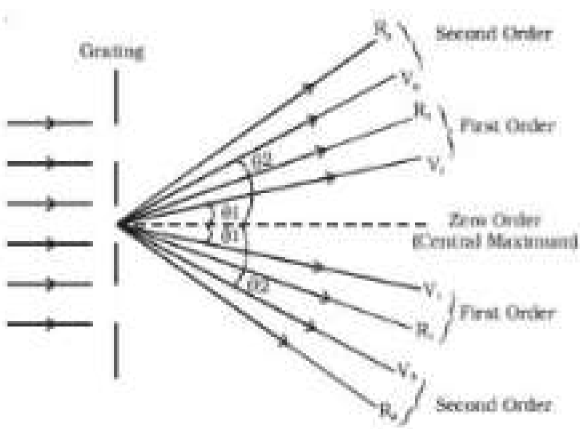


Figure 2: Diffraction of white light.

$$\sin \theta = m\lambda/(a + b)$$

or $\sin \theta = m\lambda L$

where, $L = 1/(a+b)$, gives the number of grating element or number of lines per unit width of the grating.

When white light is used, the diffraction pattern (Fig. 2) consists of a white central maximum and on both sides continuous colored images are formed. In the undiffracted position, $\theta = 0$ and hence $\sin \theta = 0$. Therefore, $\sin \theta = Lm\lambda$ is satisfied for $m = 0$ for all values of λ. Hence, at O all the wavelengths reinforce each other producing maximum intensity for all wave lengths. Hence an undispersed white image is obtained. As θ increases, $(a + b) \sin \theta$ first passes through $\lambda/2$ values for all colors from violet to red and hence darkness results. As θ further increases, $(a + b) \sin \theta$ passes through λ values of all colors resulting in the formation of bright images producing a spectrum from violet to red. These spectra are formed on either side of white, the central maximum.

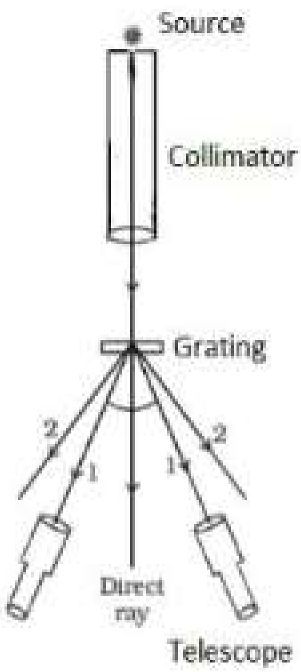


Fig 3: Experimental setup.

The wavelength of a spectral line can be very accurately determined with the help of a diffraction grating and spectrometer. Initially all the preliminary adjustments of the spectrometer are made. The slit of collimator is illuminated by a monochromatic light; whose wavelength is to be determined. The telescope is brought in line with collimator to view the direct image. The given plane transmission grating is then mounted on the prism table with its plane is perpendicular to the incident beam of light coming from the collimator. The telescope is slowly turned to one side until the first order diffraction image coincides with the vertical cross wire of the eye piece. The reading of the position of the telescope is noted (Fig. 3).

Similarly, the first order diffraction image on the other side, is made to coincide with the vertical cross wire and corresponding reading is noted. The difference between two positions gives 2θ. Half of its value gives θ, the diffraction angle for first order maximum. The wavelength of light is calculated from the equation $\lambda = \sin\theta / Lm$. Here L is the number of rulings per meter in the grating.

(In this experimental setup impure sodium vapour lamp is used as source. Since it is an impure sodium vapour lamp, it has four spectral lines Green, Yellow-1, Yellow-2 and Red).

PROCEDURE:
Adjust the spectrometer step by step. At first level the spectrometer using spirit level. Mount the grating in the grating holder and clamp holder on the prism table by fixing screw. Adjust the slit of the collimator through the telescope such that the image of the slit is to be bright and narrow. Turn the telescope by 90^0 to the collimator and clamp there. Turn the grating by moving the base of the prism table so that the reflected light from the collimator reaches telescope. At that moment the grating plane and the incident light ray at an angle 45^0. Turn the grating another 45^0 so that the plane of the grating is accurately perpendicular to the incident light beam from collimator. Fix the prism table at this position so that once the telescope is rotated the grating table does not rotate.

By moving the telescope, observe the 1st order and 2nd order spectra on the both sides of the central maxima. Take readings (both Main Scale Reading and Verneir Scale Reading) of all visible lines starting from one side to another side excluding central maxima.

FIGURE:

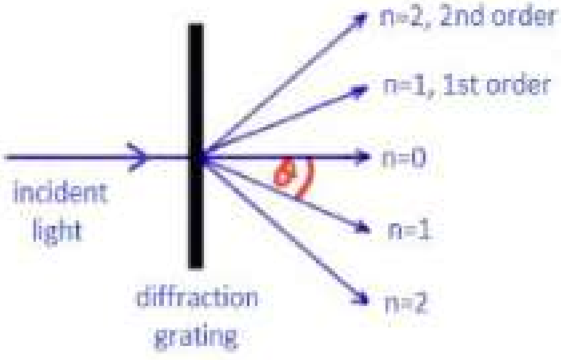


Fig 4: Ray diagram for diffraction grating experiment.

OBSERVATION:

Vernier Constant of the spectrometer:

Smallest main scale division = m'

N^{th} smallest Vernier scale division = $(N-1)^{th}$ smallest main scale division

So, 1 smallest Vernier scale division = $(N-1)/N$ smallest main scale division

Vernier Constant = $(1/N)$ * (smallest main scale division) = $[(1/N)*m]'$

Calculation of Least Count of Spectrometer:

Least Count (L.C.) = 1 main scale division (msd) − 1 vernier scale division (vsd)

As, 60 vsd = 59 msd ➔ 1 vsd = 59/60 msd

Least Count (L.C.) = 1 msd − 59/60 msd = 1/60 msd (1)

Also, x msd = 10' ➔ 1 msd = $(10/x)'$ (2)

Therefore, from equation (1) and (2), **Least Count (L.C.) = (1/60) × $(10/x)'$**

TABLE:

S. No	Order of diffraction (n)	Color	One side from the central maxima						Other side from the central maxima						$2\theta = (V_1 \sim V_1)$	$2\theta = (V_2 \sim V_2)$	Average 2θ	λ
			V_1			V_2			V_1			V_2						
			MSR	VSR	Total	MSR	VSR	Total	MSR	VSR	Total	MSR	VSR	Total				
1	1	Green																
2	1	Yellow																
4	1	Red																
5	2	Yellow																

CALCULATION:

The wavelength of different spectral lines of the given sodium light is estimated by the formula, $\lambda = \sin\theta / Nm$

ERROR ESTIMATION:

$$\delta\lambda = \lambda\left|\frac{\delta(\sin\theta)}{\sin\theta}\right| = \frac{1}{Nm}\left|\frac{d(\sin\theta)}{d\theta}\delta\theta\right| = \frac{1}{Nm}\left|(\cos\theta)\delta\theta\right|$$

In our case $\delta\theta = \frac{\sqrt{(\delta V_1)^2 + (\delta V_2)^2}}{2} = \frac{\delta V_1}{\sqrt{2}}$

$\delta V_1 = \delta V_2$ =0.5* Vernier constant (must be taken in radian).

Putting value of $\delta\theta$, one can estimate $\delta\lambda$

Percentage error = $\left(\frac{\delta\lambda}{\lambda}\right) \times 100\%$

RESULTS:

1st order wavelength of green light = $(\lambda \pm \delta\lambda)$ nm

1st order wavelength of yellow light = $(\lambda + \delta\lambda)$ nm

1st order wavelength of red light = $(\lambda \pm \delta\lambda)$ nm

2nd order wavelength of yellow light = $(\lambda + \delta\lambda)$ nm

PRECAUTIONS: (Student must write it in their own language).

(i) Level the spectrometer properly so that diffraction spectra are uniformly visible through the telescope from both side of the central maxima.
(ii) Grating should be mounted optically perpendicular to the incident light on the prism table.
(iii) To avoid parallax error, take the reading vertically.
(iv) Never touch the surface of the grating.

FEW FREQUENTLY ASKED QUESTIONS:

a. What is Diffraction?
b. Mention the two types of diffraction?
c. Give some examples and application of diffraction in real life?
d. What is difference between interference and diffraction?
e. What is a diffraction grating? What happens if the number of lines per cm is changed?
f. What do you expect if the width of the slits is gradually inceased?
g. What is the effect of increasing the width of the opaque space, keeping the slit width constant?

EXPERIMENT NUMBER 5

AIM:
To measure the Brewster's angle of a glass plate and hence to find the refractive index of glass using He-Ne laser.

APPARATUS:
He.-Ne Laser, polarizer, circular table, glass plate, screen.

THEORY:
Brewster made a remarkable discovery in 1811 that at polarizing angle the reflected and refracted rays on plate are just 90° apart as shown in the figure. The angle of refraction θ_p, is therefore equal to $(90^\circ - \phi_p)$ and we have for the refractive index of glass, $\mu = sin\phi_p/sin\theta_p = sin\phi_p/cos\phi_p = tan\phi_p$, where angle ϕ_p is called Brewster's angle. By measuring it one can calculate refractive index of glass.

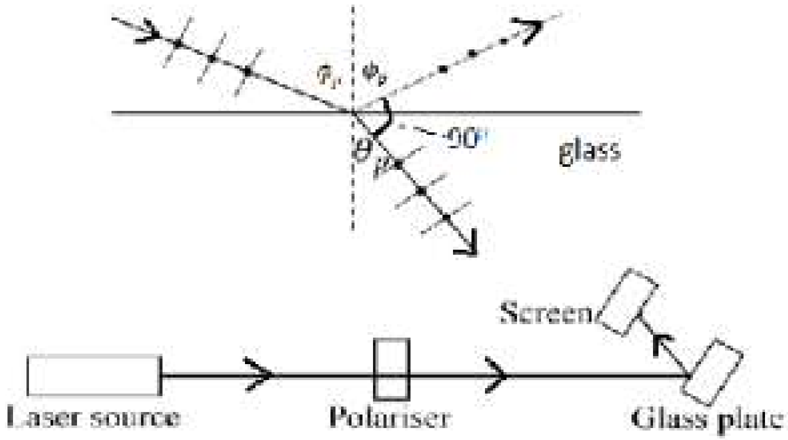


Figure: Ray diagram for polarization of light at the Brewster's angle and the experimental setup.

PROCEDURE:
The glass plate is mounted on the circular table. The polarizer is put in the path of the laser beam. Initially, the glass plate is kept normal to the laser beam and then rotated so that the intensity of reflected beam becomes minimum. To obtain minimum intensity we have to rotate the polarizer also. The reflected spot will have the minimum intensity at the Brewster angle. Measure the angle ϕ_p and use the formula $\mu = tan\phi_p$ for finding the refractive index of glass.
Repeat the above experiment for different values of initial angle.

Calculation of least count:

10 vsd = 9 msd and 1 msd =1^0

LC = 1 msd-1 vsd = 0.1 msd = 0.1^0

Sl. No.	Initial Reading			Final Reading			Difference	Mean
	MSR	VSD	TSR	MSR	VSD	TSR	$\phi_{p,n}$	ϕ_p
1.								
2.								
3.								

ERROR ESTIMATION:

$$\delta\mu = \left|\frac{d(\tan\phi_p)}{d\phi_p}\delta\phi_p\right| = \left|(\sec^2\phi_p)\delta\phi_p\right|$$

If ϕ_p is taken as average of N measurements then, $\delta\phi_p = \frac{(\delta\phi_{p,n})}{\sqrt{N}}$

Here $\delta\phi_{p,n}$ is half of the least count and it must be taken in radian.

Putting value of $\delta\phi_{p,n}$, one can estimate $\delta\mu$

The percentage error is $\left(\frac{\delta\mu}{\mu}\right)$*100%.

FINAL RESULT:

The Brewster's angle is $(\phi_p \pm \delta\phi_p)^{\circ}$

The refractive index of the given glass plate is $(\mu \pm \delta\mu)$

PRECAUTION: (Student must write it in their own language).

(i) Laser beam should be placed accurately

(ii) Optical levelling of different components should be maintained

(iii) Take care of error during taking reading

FEW FREQUENTLY ASKED QUESTIONS:

a. What is full form of a Laser?
b. What are some important properties of a Laser?
c. Define Brewster's law and Brewster's angle.
d. What is polarization of light?
e. What is the difference between linear and circular polarization?
f. How does a polarized sunglass work?

EXPERIMENT NUMBER 6

AIM:

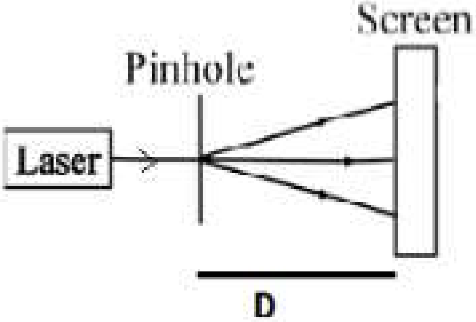
To measure the diameter of a circular aperture using Fresnel's diffraction.

APPARATUS USED:

He-Ne Laser, Circular aperture, Screen, Measuring scale/tape.

THEORY:

When the laser beam is passed through a small aperture, it gets diffracted. The diffraction pattern is projected on screen placed at some distance. The distribution of light shows a bright central maximum surrounded by a no. of secondary minima and maxima of decreasing intensity.



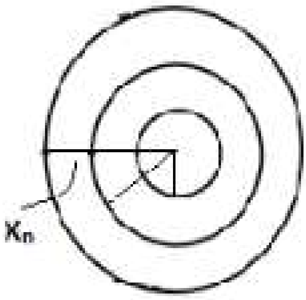


Figure: (left) Ray diagram for diffraction for a circular aperture (right) Diffraction pattern for the circular aperture as seen on the screen

Suppose the diameter of a circular aperture is d and the screen is placed at a distance D from the aperture, then the radius of the n^{th} dark ring is given by

$$X_n = nD\lambda/d \tag{1}$$

where λ is the wavelength of laser used ($\lambda = 6328\ \text{Å}$)

PROCEDURE:

Mount a pinhole on the stand adjusting the laser beam to fall on the hole. Allow the outgoing beam to fall on the screen. The screen should be about 2 meters away from the aperture and the aperture should be about 20 cm away from the laser to have the clarity of diffraction pattern. Mark the dark rings with a pencil. Now measure the diameter ($2X_n$) of n^{th} dark ring and obtain the radius X_n. Then measure the distance D of the screen from aperture and calculate diameter 'd' of the aperture by using the formula,

$$d = nD\lambda/X_n \tag{2}$$

Repeat the above experiment for different values of D's.

Observation table:

Sl. No.	$D\ (cm)$	n	$2X_n\ (cm)$	$X_n\ (cm)$	$d_i(\lambda)$
1	130	1			
2		2			
3		3			
4	150	1			
5		2			
6		3			
7	170	1			
8		2			
9		3			

Finally obtain the average diameter $d = \frac{\sum_1^N d_i}{N}$ (mm or μm)

Where N is no. of observation (repetition in observation).

ERROR ESTIMATION:

Error in individual measurement, $\frac{\delta d_i}{d_i} = \sqrt{\left(\frac{\delta D}{D}\right)^2 + \left(\frac{\delta X_n}{X_n}\right)^2}$

δD = 0.5*least count of the scale =

δX_n = 0.5*least count of the scale =

Error in the average $\delta d = \frac{\sqrt{(\delta d_1)^2 + (\delta d_2)^2 + \cdots}}{N} = \frac{(\delta d_i)\sqrt{N}}{N} = \frac{(\delta d_i)}{\sqrt{N}}$

Putting the values one can estimate δd.

The percentage error is $\left(\frac{\delta d}{d}\right)$*100%.

FINAL RESULT:

The diameter of the circular aperture is $(d \pm \delta d)\ \mu m$

PRECAUTION: (Student must write it in their own language).

(i) The distance between source and aperture should be varied slowly
(ii) Trace the dark rings carefully
(iii) Do not look directly into the laser beam
(iv) Laser beam should be placed accurately

FEW FREQUENTLY ASKED QUESTIONS:

a. What is Huygens-Fresnel principle?
b. What is meant by Fresnel diffraction?
c. What is difference between Fraunhofer and Fresnel diffraction?
d. What will happen if you vary the distance between source and the pinhole?
e. What is a laser and its important properties?

EXPERIMENT NUMBER 7

AIM:

To estimate the Stefan's constant by the black copper radiation plates thermocouple method.

APPARATUS:

Stefan's constant kit, thermocouple, power supply, ac voltmeter, dc voltmeter, black copper radiation plates with heater element in-between.

Figure 1: Experimental setup for measuring Stefan's constant

THEORY:

The electricity fed to the heater element is radiated by radiating disc whose steady state temperature gives the total power radiated. As the efficiency of the heating element is nearly equal to one, almost entire electrical energy supplied to the heater will be converted into heat energy. If E is the total amount of heat radiated per unit area of the body per unit time and T is the absolute temperature of the body, then according to Stefan's law:

$$E = \sigma T^4$$

where, σ is the Stefan's constant. The body will also receive heat from the surrounding with temperature T_0. The amount of heat energy received from surrounding is given by σT_0^4. The net amount of heat radiated by the body per unit area per unit time is therefore.

$$E_1 = \sigma(T^4 - T_0^4)$$

If A is the total area of the body, then the net heat radiated per unit time is given by

$$E_2 = \sigma A(T^4 - T_0^4)$$

In the present case, there is practically no loss of heat energy from heating element by conduction, convection or radiation. Therefore, entire heat energy of the heating element is transferred to the discs. If we neglect the heat transfer on account of conduction and convention of the air in contact, heat energy radiated by copper discs per unit time is equal to the power supplied to heater element. Therefore, if V is the potential difference across the heater and I is the current passing through it, then,

$$E_2 = VI = \sigma A(T^4 - T_0^4)$$

or

$$\sigma = VI/A(T^4 - T_0^4) \text{ watt m}^{-2}\text{ K}^{-4}$$

From this relation the Stefan's constant is determined. *V*, *I* & *T* are measured from Voltmeter, Ammeter and temperature indicator.

PROCEEDURE:

a) Connect the (sandwiched) heating element between black radiation discs to the kit terminals marked 'Black plate' and thermocouple to the terminals marked 'Sensor'.
b) Switch ON the instrument.
c) Note down the surrounding room temperature (T + 273 K) as displayed on the instrument.
d) Adjust with the help of potentiometer P, the potential difference (V) and current (I) for heating element for desired value.
e) Tabulate the temperature reading as a function of time at an interval of 2 min each and plot the graph.
f) Observe the temperature till the temperature increase rate is attains nearly steady state condition (equilibrium, for example, let us say nearly 0.5°C/min).
g) Several sets of observations (as much as possible within the given lab time) must be taken by varying the potential difference (V) & current (I) with the help of potentiometer.
h) Calculate Stefan's constant for each value using relation $\sigma = VI/A(T^4 - T_0^4)$ as indicated in sample calculation.
i) The area of the plate can be calculated by measuring the radius of the disc.

OBSERVATION TABLE:

(i) V=50V, I= 0.60A

S. No.	Time (t in min.)	Temp. (°C)	Temp. (°K)
1	0		
2	2		
3	4		

Repeat this for other sets of V and I

Radius of the copper plates:

Area of the copper plates = 2 x area of one flat face of the plate.

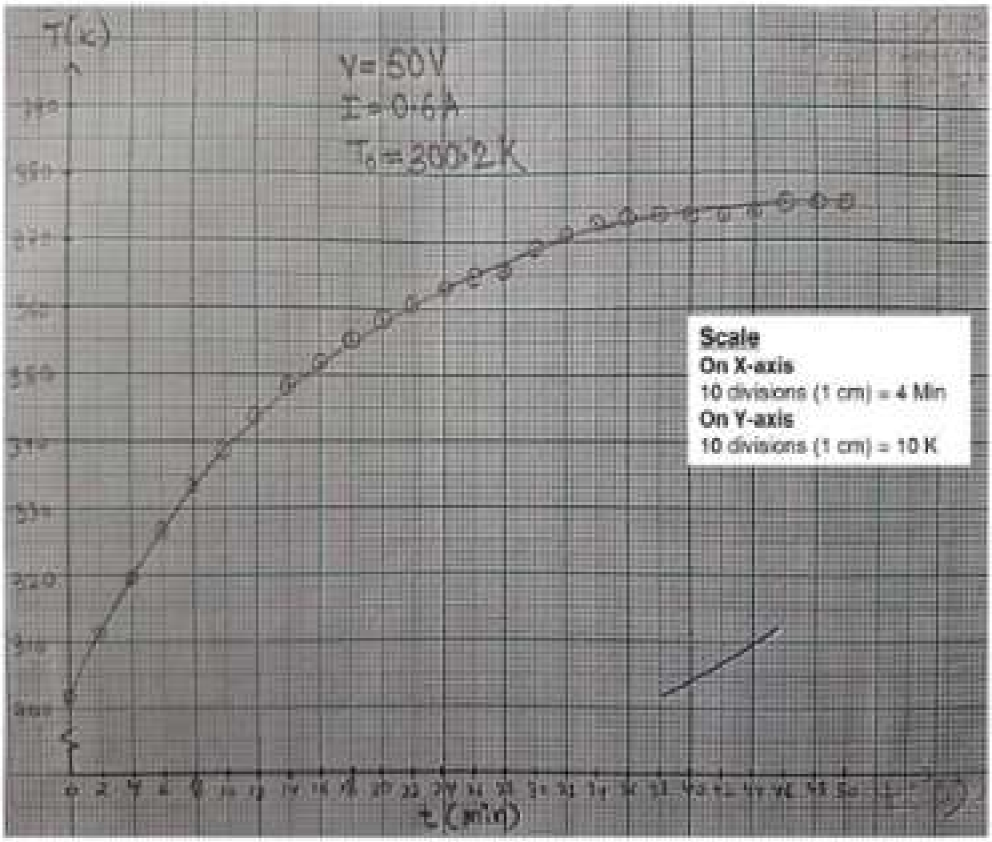
CALCULATION:

We can estimate the Stefan's constant using the expression given below:

$$\sigma = VI/A(T^4 - T_0^4) \text{ watt m}^{-2}\text{ K}^{-4}$$

Hence, substituting the value of V, I and T, the value of σ is obtained.

GRAPH:



Graph 1: Temperature vs time plot

ERROR ESTIMATION:

Here, $\frac{\delta\sigma}{\sigma} = \sqrt{\left(\frac{\delta V}{V}\right)^2 + \left(\frac{\delta I}{I}\right)^2 + \left(\frac{\delta A}{A}\right)^2 + \left(\frac{\delta(T^4 - T_0^4)}{T^4 - T_0^4}\right)^2}$

δV = 0.5*smallest count of the voltmeter

δI = 0.5*smallest count of the Ammeter

Since, $A = 2\pi r^2$, $\frac{\delta A}{A} = 2\frac{\delta r}{r}$ and δr = 0.5*least count of scale (take $\delta r = 0$ if r is supplied)

Now, $\delta(T^4 - T_0^4) = \sqrt{(\delta T^4)^2 + (\delta T_0^4)^2} = \sqrt{(4T^3\delta T)^2 + (4T_0^3\delta T_0)^2}$

$\delta T = \delta T_0$ = 0.5*minimum division of the thermometer

Putting the values one can estimate $\delta\sigma$.

The percentage error is $(\delta\sigma/\sigma) * 100\%$.

FINAL RESULT:

The Stefan's law of radiation is verified by thermocouple method. The measured Stefan's constant is $(\sigma \pm \delta\sigma)$ watt m^{-2} K^{-4}

PRECAUTION: (Student must write it in their own language).

(i) Thermocouple and sensor should be connected as per the colour coding.
(ii) Black body should be connected to the main body only in switched off condition.
(iii) Don't touch the hot plates.
(iv) Before switching on the heater note down the room temperature.

FEW FREQUENTLY ASKED QUESTIONS:

a. What is a blackbody?
b. State Stefan's law. What is its significance?
c. What are emissive and absorptive power?
d. Define heat and temperature.
e. What is a thermocouple?

EXPERIMENT NUMBER 8

AIM:

Study of the hysteresis curves of various magnetic materials of different shapes and determination of their energy losses.

APPARATUS:

Universal B-H curve tracer kit, CRO having X-Y gain, trace paper/graph paper, Magnetizing coil, Magnetic field sensing probe, Holder for magnetizing and sensing probe, Different magnetic materials.

Figure 1: Universal B-H curve tracer kit.

THEORY:

Ferromagnetic materials contain large number of small regions, called domains. In each domain all the atomic magnets are locked in rigid parallelism. Thus each domain has a net magnetization in a particular direction. When the specimen is exposed to an external magnetic field H, the domains with magnetization component along the direction of the field grow at the expense of those, which are not favourably oriented. Thus, the magnetization increases with field as shown in figure 2. When all the domains are aligned in the field direction, the specimen gets magnetically saturated. When the external field is removed, the domain boundaries do not move completely back to their original positions and as such lead to remnant magnetization. This in turn leads to a phase lag between the field and the magnetization, when the specimen is exposed to an alternating magnetic field. This phase difference between B and H causes the hysteresis loop. A material's ability to retain residual magnetic flux density after removing the magnetizing field is called its retentivity. Coercivity defines the amount of reverse magnetizing field intensity needed to make the magnetic flux density of a material return to zero after reaching magnetic saturation. The tendency of the domains to turn around give rise to mechanical stresses in the specimen, which in turn produce heating. The energy wasted as heat due to cyclic magnetization is given by the area enclosed by the hysteresis loop. This area depends on how far the material is taken into saturation in each cycle and on the properties of the magnetic material. Thus a study of the hysteresis loop of different magnetic materials helps us to understand their magnetic properties. For example, in Figure 2, the material on left hand side is suitable for permanent magnet and the one on right hand side is good for application in transformer and motor cores.

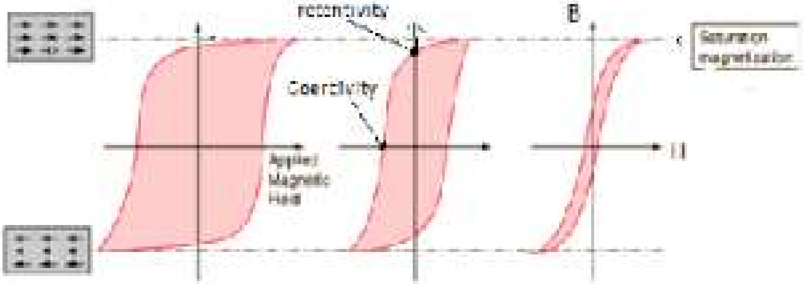


Figure 2: Hysteresis loop for different magnetic materials.

EXPERIMENTAL SETUP:

For this experiment we use the universal B-H curve tracer kit (Fig 1) and a cathode ray oscilloscope (CRO) having X-Y gain. The specimen is put inside the solenoid and is subject to a varying magnetic field H. A specially designed integrated circuit probe is used to measure the flux density B. Any magnetic specimen can be inserted in the magnetizing coil without disturbing the arrangement. Different specimen results in different shape of the hysteresis curve.

PROCEDURE:

a. Connect one terminal of the magnetizing coil to point C of main unit. The other terminal should be connected to V_1 (6 Volts ac).
b. Connect H to the horizontal input of the CRO and V to vertical input of the CRO. Operate the CRO in X-Y mode.
c. Connect the IC probe to the "IC" marked on main unit.
d. Switch ON the kit. To get proper loop vary the resistance to the maximum value with the help of knob P on the panel.
e. With no specimen inserted in the coil, adjust the horizontal gain of the CRO until a convenient X-deflection is obtained. Note down this reading as S_H.
f. Insert a magnetic specimen through magnetizing coil such that it couches the probe at the centre. Make sure that sample touching IC only and conducting tracks should not be shorted in any case.
g. Adjust the oscilloscope vertical gain (Y-gain) until a trace showing the B-H loop conveniently fills the screen. Note down this reading as S_V.
h. One might need to reverse the connection of the magnetizing coil to have the loop on CRO screen in proper orientation.

i. Trace the area of the loop on butter paper from the screen of CRO (Fig. 3) and retrace it on a graph paper.

j. Measure the area of the loop with the help of graph paper. Remember, the area of the loop has unit of $S_V S_H$). One can take the area as unit less quantity and multiply with S_V and S_H.

k. Energy loss E = $\frac{0.5\times R}{N\times L} \times (S_H \times S_V \times \text{area of the loop})$ Joule/m^3-cycle.

l. Repeat the experiment for V_2 (9 Volts ac) and V_3 (12 Volts ac).

m. Repeat the experiment for other specimens provided (as much as possible within the allotted lab time-may be atleast 02 specimens).

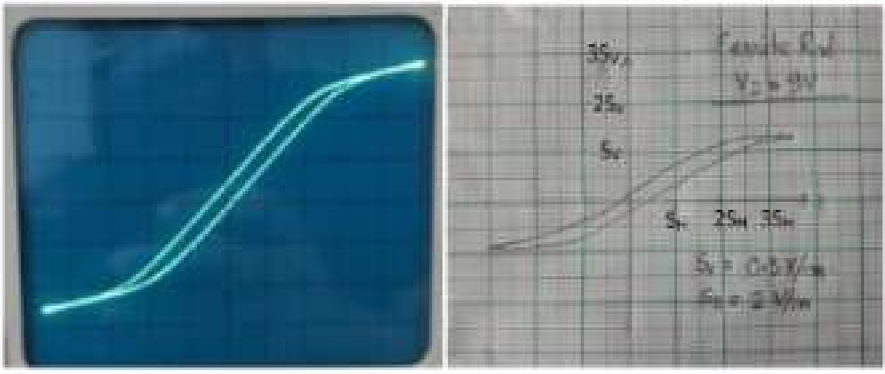


Figure 3: (a) B-H loop for transformer core sample on the CRO screen (b) one such loop traced in a graph paper.

OBSERVATION TABLE:

N=300 turns, R=1 Ω, L= 3.3 cm

1. Material: ....

Sl no.	Applied voltage (V)	S_V (V/cm)	S_H (V/cm)	Area (in unit of $S_V S_H$)	Energy loss Joule/ m^3-cycle
1.					
2.					
3.					

Repeat the experiment for other given materials

ERROR ESTIMATION:

$\frac{\delta E}{E} = \frac{\delta A}{A}$, where A= area of the loop

δA=0.5*(no of smallest squares intersected by the curve) *area of one smallest square

Area of one smallest square on the graph = $S_V S_H$/100

Percentage error is $\left(\frac{\delta E}{E}\right) \times 100\%$

RESULT:

The energy loss of the given magnetic material is $(E \pm \delta E)$ Joule/ m^3-cycle.

PRECAUTIONS: (Student must write it in their own language).

(i) The specimen should touch the probe.
(ii) All wires should be connected properly at appropriate position.
(iii) Do not disturb the CRO while tracing the loop.

FREQUENTLY ASKED QUESTIONS:

a. What is retentivity and coercivity?
b. What is the significance of B-H curve?
c. Explain hard and soft magnetic materials.
d. Explain domain theory of ferromagnetism.
e. What is saturation magnetization?
f. Briefly explain the working principle of a CRO.

Online Video Links for Reference

S.No.	The Experiments / Practicals	Link
1.	**Experiment 1: Band Gap of a Semiconductor** To calculate the band gap of semiconductor by measuring the resistivity at different temperatures.	**Virtual Lab Link:** 1. http://mpv-au.vlabs.ac.in/modern-physics/Resistivity_by_Four_Probe_Method/experiment.html **You Tube Link:** 1. https://www.youtube.com/watch?v=L0NGS978DWA 2. https://www.youtube.com/watch?v=I9RmGM1kbs8
2.	**Experiment 2: Hall Effect of a Semiconductor** To study the Hall Effect of a semiconductor.	**Virtual Lab Link:** 1. http://mpv-au.vlabs.ac.in/modern-physics/Hall_Effect_Experiment/experiment.html **You Tube Link:** 1. https://www.youtube.com/watch?v=_AwjbHzwWLo&t=277s 2. https://www.youtube.com/watch?v=IHtDYkIiRZI 3. https://www.youtube.com/watch?v=uy0NU_UEc8Y
3.	**Experiment 3: Thermal Conductivity by Lee's Method** To determine thermal conductivity of bad conductor by Lee's method.	**Virtual Lab Link:** 1. https://vlab.amrita.edu/?sub=1&brch=194&sim=353&cnt=1 **You Tube Link:** 1. https://www.youtube.com/watch?v=kEUJz5gJ9F4 2. https://www.youtube.com/watch?v=NMVVbd6rAoc&t=75s
4.	**Experiment 4: Wavelength of Light by Diffraction Grating** Determination of wavelength of sodium light by plane diffraction grating.	**Virtual Lab Link:** 1. https://vlab.amrita.edu/?sub=1&brch=281&sim=334&cnt=1 **You Tube Link:** 1. https://www.youtube.com/watch?v=N0lxwqANsd4&t=747s 2. https://www.youtube.com/watch?v=n-qVhLo93g0

5.	**Experiment 5:** **Refractive Index of Glass using He-Ne Laser** To measure the Brewster's angle of a glass plate and hence to find the refractive index of glass using He-Ne laser.	**Virtual Lab Link:** 1. https://vlab.amrita.edu/?sub=1&brch=189&sim=333&cnt=1 2. http://lo-au.vlabs.ac.in/laser-optics/Brewsters_Angle_Determination/# **You Tube Link:** 1. https://www.youtube.com/watch?v=ZlvAfXaG97E
6.	**Experiment 6: Fresnel's Diffraction using Laser** To measure the diameter of a circular aperture using Fresnel's diffraction	**You Tube Link:** https://www.youtube.com/watch?v=aEd4FFeBV6U **(NOTE:** Not exact, our actual experimental setup is a little bit different).
7.	**Experiment 7: Verification of Stefan's Law** To estimate the Stefan's constant by the black copper radiation plates thermocouple method.	**Virtual Lab Link:** 1. https://vlab.amrita.edu/?sub=1&brch=194&sim=548&cnt=1 2. http://vlabs.iitb.ac.in/vlabs-dev/vlab_bootcamp/bootcamp/vlabs_recbanda/labs/exp1/simulation.html **You Tube Link:** 1. https://www.youtube.com/watch?v=ew3SJkv8PDM
8.	**Experiment 8: Energy Loss from Hysteresis Curves** Study of the hysteresis curves of various magnetic materials of different shapes and determination of their energy losses.	**Virtual Lab Link:** 1. https://vlab.amrita.edu/?sub=1&brch=282&sim=1507&cnt=1 **You Tube Link:** 1. https://www.youtube.com/watch?v=Iq3Xv2GdgQk&t=244s

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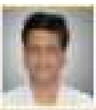
1.	**Prof. JAIRAM MANAM** Professor **Qualification** : M.Sc, Ph.D.(I.I.T.Kh.)	
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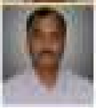
3.	**Dr. VINEET KUMAR RAI** Professor **Qualification** : M. Sc. (Physics), M.Sc. (Mathematics), Ph. D. (Physics) BHU	
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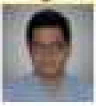
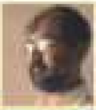
5	**Dr. SHAILENDRA KUMAR SHARMA** Associate Professor **Qualification** : M.Sc. , M.Phil. & Ph.D. (I.S.M.)	
6.	**Dr. ASIT KUMAR KAR** Associate Professor **Qualification** : Ph.D.	
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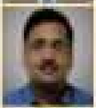
8.	**Dr. PANKAJ MISHRA** AssociateProfessor **Qualification** : M. Sc., Ph. D. (BHU),	
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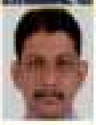
11.	**Dr. P. M. SARUN** Associate Professor **Qualification** : M.Sc. (Kannur University, INDIA), Ph.D. (NIIST, CSIR/CUSAT, INDIA)	
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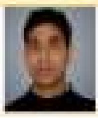
13.	**Dr. SRIDHAR SAHU** Associate Professor **Qualification** : M.Sc (Ravenshaw University), Ph.D (IIT Bombay).	
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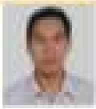
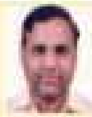
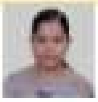
15.	**Dr. MOIRANGTHEM RAKESH SINGH** Associate Professor **Qualification** : M.Sc., Ph.D. (Taiwan), Post-doc (Max Planck, Germany)	
16.	**Dr. UMAKANTA TRIPATHY** Associate Professor **Qualification** : M.Sc. (Berhampur University Orisa & PhD (IIT Madras), Post Doc (University of Saskatchewan, McGill University, Canada).	
17.	**Dr. BINATA PANDA** Assistant Professor **Qualification** : M.Sc. (Utkal University, INDIA), Ph.D. (IOP, INDIA), Post-doc (HRI, INDIA)	
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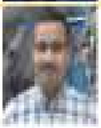
21.	**Dr. Soumya Bagchi** Assistant Professor **Qualification** : PhD, University of Groningen, the Netherlands. Postdoc: GSI Helmholtzzentrum, Darmstadt, Germany	
22.	**Dr. Sudeshna Sen** Assistant Professor **Qualification** : PhD Postdoc: School of Physics, Science Centre North, Belfield, Dublin-4, Ireland	
23.	**Dr. Ritwik Mondal** Assistant Professor **Qualification** : PhD Postdoc: Uni Konstanz, Germany (2018 - 2020), FZU, Prague (2021 - 2022).	

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