APPLIED PHYSICS LAB MANUAL

DEPARTMENT OF PHYSICS

UNIVERSITY OF ENGINEERING AND TECHNOLOGY, LAHORE, PAKISTAN

<u>Don't forget to bring following accessories while attending the lab sessions.</u>

i. Lab manual

ii. Student Faculty Card

iii. Scientific Calculator

iv. Fully equipped compass box including 2-B Pencil, scale, sharpener and eraser

v. Practical Note Book

vi. Minimum three graph papers

Instructions

1. Attend the Lab sessions in time
2. Switch-off your cell phones when you are in the lab.
3. Bags should be kept aside while performing the experiment. On lab tables keep only whatever is required for the experiment.
4. Handle the instruments with due care. Note that you are fully responsible for your apparatus in your lab session.
5. In case of electronic experiments, don't switch on the circuits unless checked by teacher or lab assistant. Operate multimeters with proper AC/DC settings & proper ranges.
6. On the day of performance, Students are advised to check the circuit diagram or figures and formulae, ensure the connections, the experimental set-up and start taking the observations.
7. Record all your lab work in the lab manual and get it approved & signed by teacher.
8. All graphs are to be plotted in the lab itself. These can be directly attached in the practical note book.
9. Complete your practicals in regular sessions only and complete your note books in time. Avoid repeat sessions.

Take care of your belongings.

Scheme of Experiments

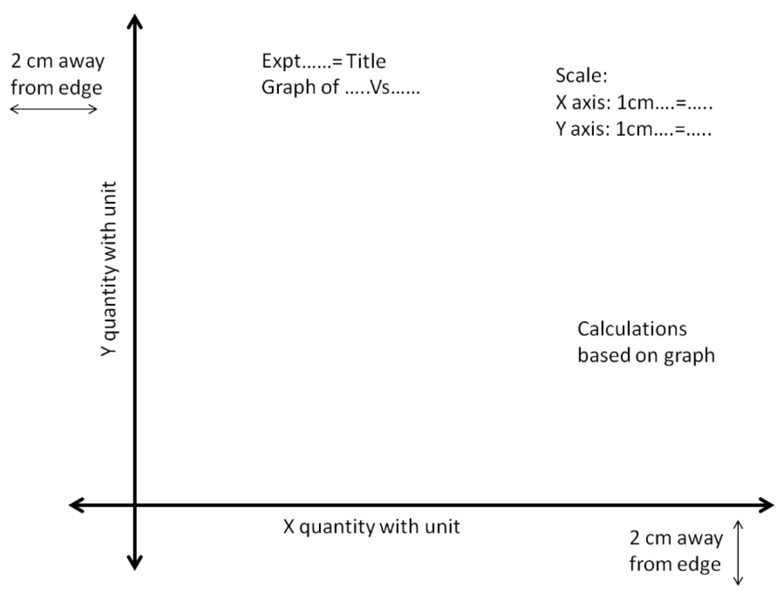
Students are required to perform 4-5 experiments in the Lab I and 4-5 experiments in Lab II. Each regular experimental turn of 2-3 hours consists of Performance and oral assessment. In the first week of the semester, the students will be introduced to the laboratory practices with on-board explanation followed by a detailed demonstration of each experiment. Manuals will be distributed to the students via e-form, e.g., website, email as well as 1 printed copy. Students are required to either download the manuals from the website and print on their own or get it copied. Each student is required to have his own copy of the manual and preserve it for the entire semester.

Students need to come prepared for the experimental turn, both with the understanding of the basic theory and the experiment.

How to write practical note book

Following are the guidelines for the students to prepare their practical note books.

1. **Right side of the note book** should be written by pen containing title of experiment, Aim, Apparatus, Procedure, Theory and Applications. Note that you are not permitted to reduce the contents of the write up.
2. **Left Side of the Note book** should contain name of experiment, aim, Figures, Formulae, Observation Tables, Calculations, Results written with 2B pencil.
3. The viva voce questions at the end of each experiment are only for enhancing the understanding of the experiments. Viva voce questions are not to be written in the note book.
4. Each student is required to write down the observations and calculations of the corresponding experiment individually.
5. Graph should be as per following format



<u>The Scheme for Lab Assessment</u>

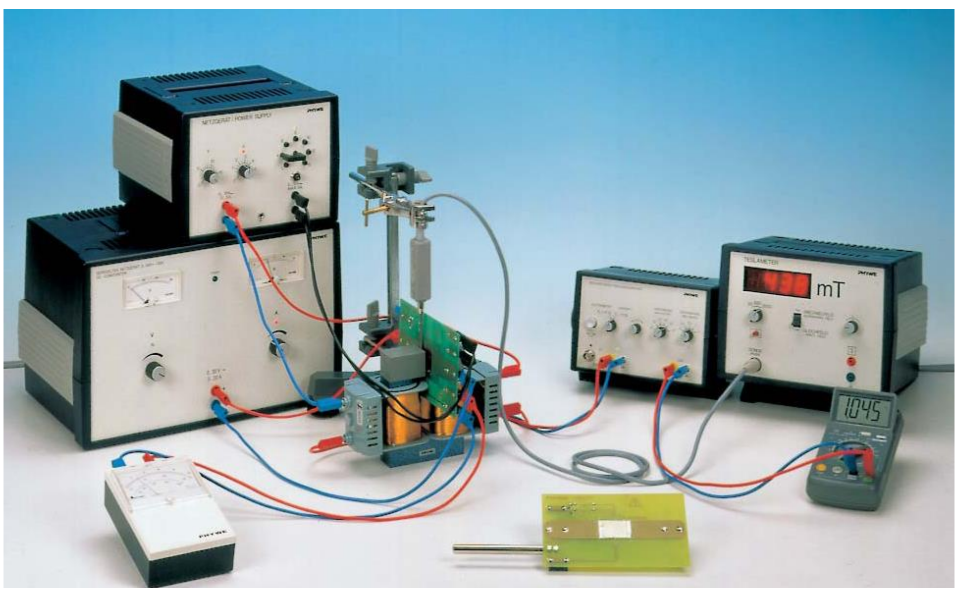
1. The lab work for Physics Lab is for 100 marks.
2. Students performing a lab of 3 contact hours are required to perform the experiment and have oral assessment at of the previous experiment at the end of the performance.
3. Students performing a lab of 2 contact hours will be assessed after two performances.
4. While assessing the lab work, 80% weightage is for performing the experiments, writing neat practical note books and viva voce (oral assessment) of each experiment performed, 10% weightage is for comprehensive exam of all experiments and 10 % weightage is for lab attendance.

   Following methodology will be used for assessing the lab work

a. Each experiment contains 10 marks which include performance of the experiment, neatly written experiment in note book and oral assessment. Student attending the practical in repeat session will get less marks.
b. The marks of total number of experiments will be converted to 80 marks.
c. 10 marks will be given for comprehensive oral assessment of lab experiments and marks for lab attendance.

Experiment 1

To Study the Hall Effect in Metals



EXPERIMENT 1

To Study the Hall Effect in Metals

Objectives

1. To Measure the Hall voltage in thin copper foil.
2. To determine the Hall coefficient from measured current and magnetic induction.

Related Concepts

Electric field, magnetic field, charge carriers, Hall effect, Hall coefficient, mobility.

Apparatus

- Copper carrier board for Hall Effect
- Coils (300 turns)
- U-shaped Iron core with pole pieces
- Power supply, stabilized, 0...30 V- / 20 A
- Power supply, universal
- Universal measuring amplifier
- Digital Teslameter
- Tangential Hall probe with protective cap
- Digital multimeter
- Clamps and Tripod base
- Connecting cables

Experimental Arrangement

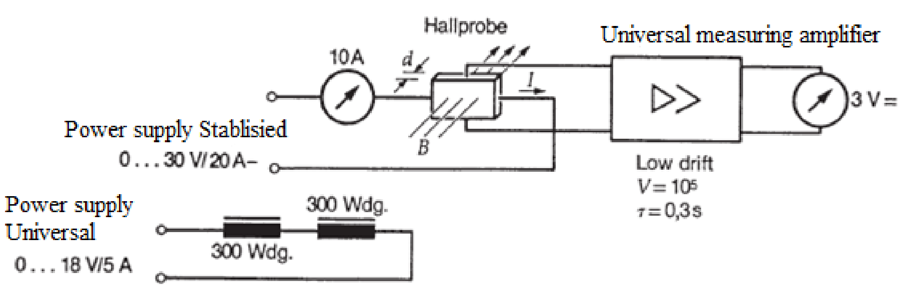


Figure 1: Circuit diagram to measure Hall voltage in a copper strip.

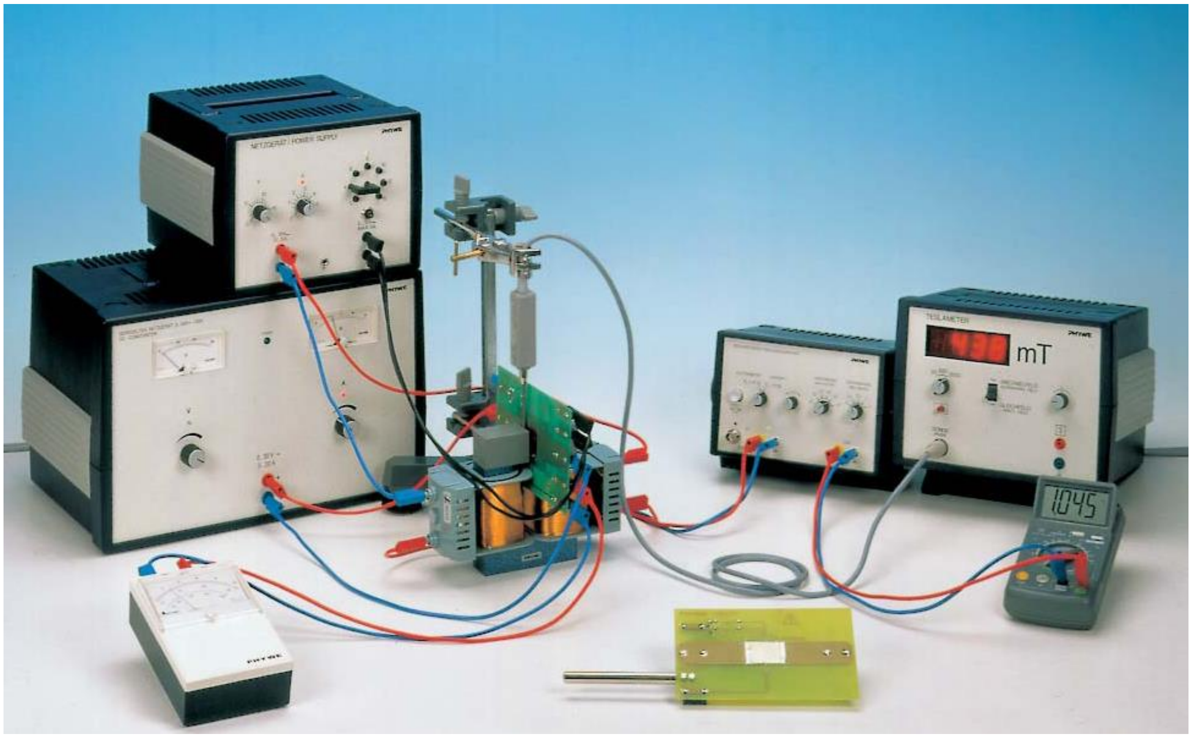


Figure 2: Photographic view of Experimental arrangement

Procedure

1. Arrange the field of measurement on the plate midway between the pole pieces.
2. Carefully place Hall probe in the center of the magnetic field.
3. The measuring amplifier takes about 15 min. to settle down free from drift and should therefore be switched on correspondingly earlier.
4. To keep interfering fields at a minimal level, make the connecting cords to the amplifier input as short as possible.
5. Take the transverse current I for copper strip from the power supply unit. It can be up to 15 A for short periods.

Note: The Hall probe will show a voltage at the Hall contacts even in the absence of a magnetic field, because these contacts are never exactly one above the other but only within manufacturing tolerances. Before measurements are made, this voltage must be compensated with the aid of the potentiometer as follows;

i. Connect the transverse current.
ii. Twist the connecting cords between hall voltage sockets and amplifier input in order to avoid as much as possible stray voltages.
iii. The determination of the Hall voltage is not quite simple since voltages in the microvolt range are concerned where the Hall voltages are superposed by thermal voltages, induction voltages due to stray fields, etc. The following procedure is recommended:
iv. Set the transverse current to the desired value.
v. Set the field strength B to the desired value (on the power supply, universal)

Precautions

1. The end of hall probe should be placed away from other magnets, iron & objects such as loud speaker and telephone, which contains magnets.
2. Check the mains supply voltage and current corresponds to that given on the Cu plate fixed on the instrument.

Observations and Calculations

Part A: Constant current and variable magnetic field

I = 12 A

Sr. No.	Magnetic Field **B** (mT)	Hall Voltage U_H (μV)	Hall Coefficient R_H m^3/As	Reverse Magnetic Field **B** (mT)	Hall Voltage U_H (μV)	Hall Coefficient R_H m^3/As
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Part B: Constant magnetic field and variable current

B= 250 mT

Sr. No.	Current **I** (A)	Hall Voltage **U_H** (μV)	Hall Coefficient **R_H** m^3/As	Reverse Current **I** (A)	Hall Voltage **U_H** (μV)	Hall Coefficient **R_H** m^3/As
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

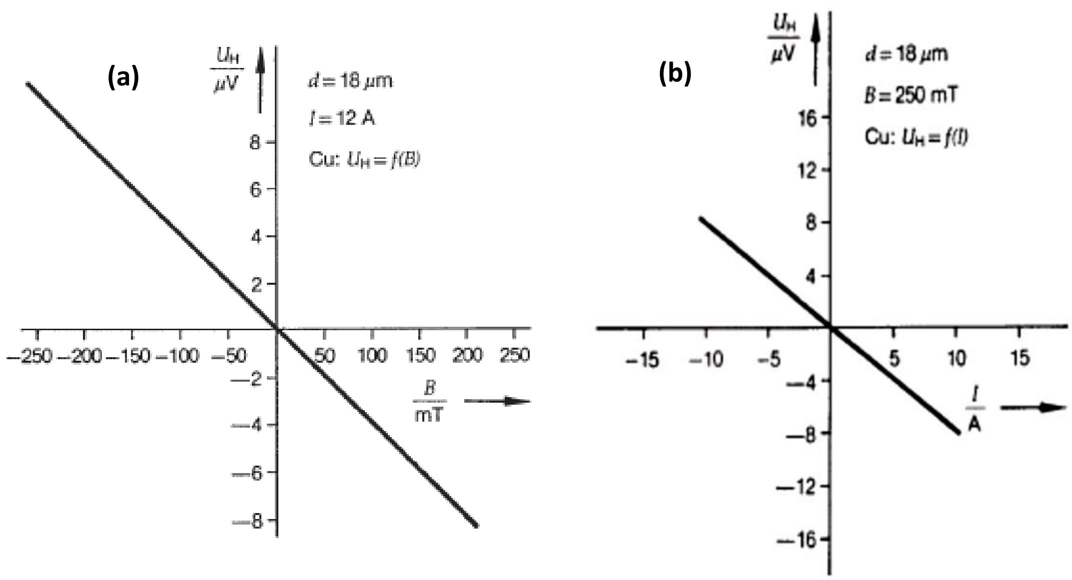


Figure 3: Hall voltage as a function of (a) magnetic field and (b) transverse current.

Theory

The Hall Effect was discovered by EDVIN HALL in 1879. He found that when a magnetic field is applied to a current carrying wire, it produces an electric field normal to the current and magnetic field. This electric field is called HALL FIELD.

Let us consider a conductor in the form of a flat strip. The charges with in the strip are driven to the opposite sides of the strip by the magnetic force (F=qvB) on them; here v is the drift velocity of the moving charges in the material.

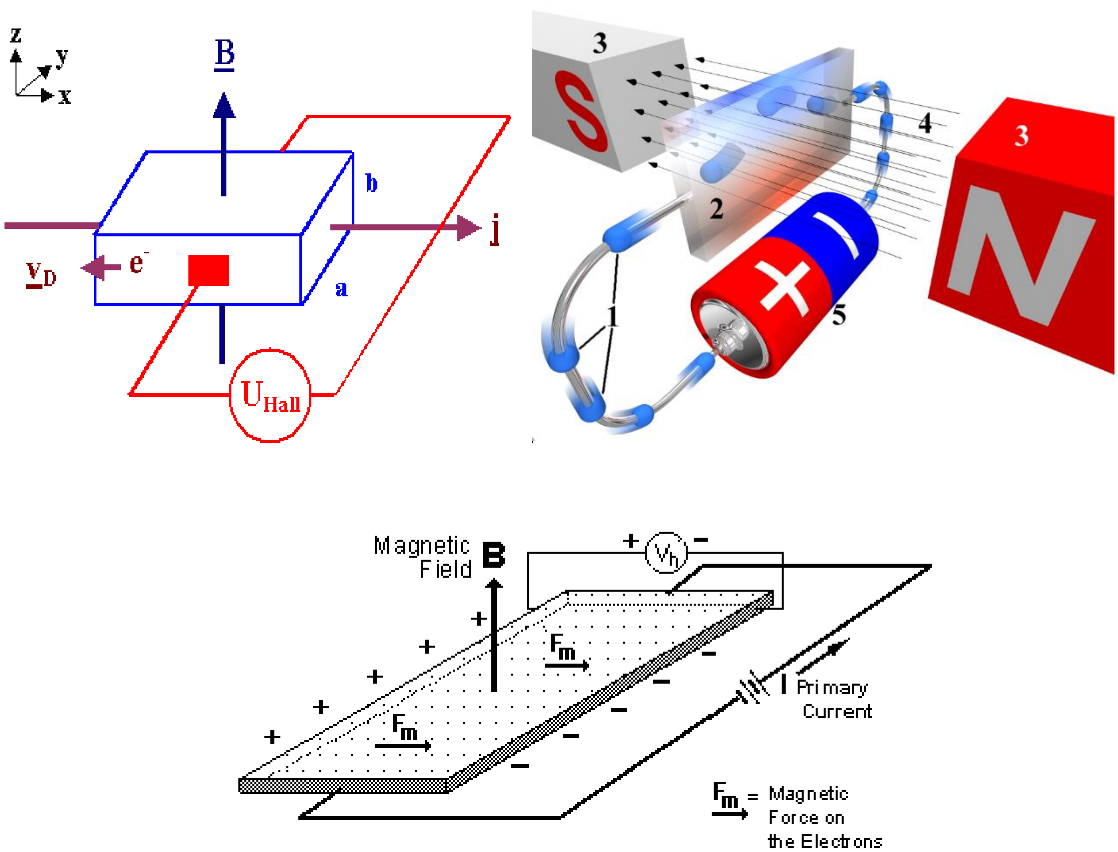


Figure 4: Forces on charge carriers in a conductor in a magnetic field

If the charge carriers are the electrons then an excess negative charge accumulates at one side leaving an excess positive charge on the other side. This accumulation continues to a point where the resulting transverse electrostatic field E causes a force of magnitude qE, that is equal and opposite to the magnetic field force of magnitude qvB then there is no longer any net force to deflect the moving charges side-ways. A potential difference between the opposite edges of the strip can be measured with a potentiometer, is called the hall voltage.

$$U_H = \frac{R_H B I}{d}$$

R_H is the Hall coefficient and d is the thickness of the strip.

The type of charge carriers can be deduced from the sign of the Hall coefficient: a negative sign implies carriers with a negative charge ("normal Hall effect"), and a positive sign, carriers with a positive charge ("anomalous Hall effect"). In metals, both negative carriers, in the form of electrons, and positive carriers, in the form of defect electrons, can exist. The deciding factor for the occurrence of a Hall voltage is the difference in mobility of the charge carriers: a Hall voltage can arise only if the positive and negative charge carriers have different mobilities.

Applications

- One of the applications of Hall probes is its use as magnetometer. It is used to measure magnetic fields, or inspect materials (such as tubing or pipelines) using the principles of magnetic flux leakage.
- Hall Effect sensors are suitable for a large number of applications that contains both the sensor plus a high gain integrated circuit (IC) amplifier in a single package. Recent advances have further added into one package an analog-to-digital converter and I^2C (Inter-integrated circuit communication protocol) IC for direct connection to a microcontroller's I/O port.
- Hall Effect devices are applied for position sensing. These are better than alternative means such as optical and electromechanical sensing.
- Hall Effect sensor is also applied as current sensor with internal integrated circuit amplifier.

- When electrons/current flows through a conductor, a magnetic field is produced. Thus, it is possible to create a non-contacting current sensor. It is a three-terminal device. A sensor voltage is applied across two terminals and the third provides a voltage proportional to the current being sensed.
- Hall Effect sensors may be used as rotating speed sensors (bicycle wheels, gear-teeth, automotive speedometers, electronic ignition systems etc.).
- Hall Effect sensors are used such as fluid flow sensor in EFI vehicles, pressure sensors, electric airsoft guns, triggers of electro-pneumatic paintball guns.
- Hall Effect sensors may be used as go-cart speed controls, smart phones, Global Positioning Systems**,** Ferrite toroid Hall effect current transducer, electronic compasses, position and motion sensors in brushless DC motors, Automotive ignition and fuel injection (direct replacement for the mechanical breaker points in fuel injection systems), Wheel rotation sensing in anti-lock braking systems, Electric motor control,
- Applications for Hall Effect have also expanded to industrial applications e.g.
- Hall Effect joysticks are used to control hydraulic valves, replacing the traditional mechanical levers with contactless sensing. Such applications include; Mining Trucks, Backhoe Loaders, Cranes, Diggers, Scissor Lifts etc.
- A Hall Effect Thruster (HET) is a low power device used to propel a spacecraft when these get into orbit or far away in space. In HET, atoms are ionized and accelerated by an electric field. A radial magnetic field established by magnets on the thruster to trap electrons orbiting and creating an electric field due to the Hall Effect. A large potential is established between the end of the thruster where neutral propellant is fed and the part where electrons are produced, so electrons trapped in the magnetic field cannot drop to the lower potential. These energetic electrons can ionize neutral atoms. Neutral propellant is pumped into the chamber and is ionized by the trapped electrons. Positive ions and electrons are then ejected from the thruster as plasma, eating thrust. Corbino disc – dashed curves represent logarithmic spiral paths of deflected electrons. A radial current through a circular disc, subjected to a magnetic field perpendicular to the plane of the disc, produces a "circular" current through the disc. The absence of the free

transverse boundaries renders the interpretation of the Corbino effect simpler than that of the Hall Effect. This is explained in the following figure.

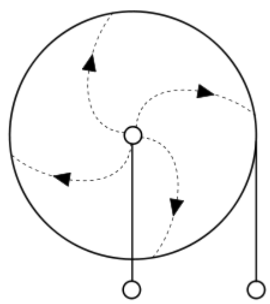


Figure 1: Hall Effect Thruster

- Hall Effect current sensors measure AC and DC currents and provide electrical isolation between the circuit being measured and the output of the sensor. Open loop current sensors consist of a Hall sensor mounted in the air gap of a magnetic core as shown in figure below. A conductor produces a magnetic field comparable to the current. The magnetic field is concentrated by the core and measured by the Hall sensor. The signal from the Hall generator is low, so it is amplified which becomes the sensor's output.

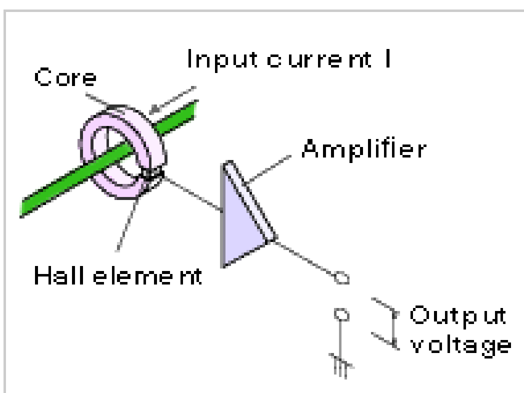


Figure: Principle of open loop hall current sensors.

- Two digital output Hall Effect devices can be used to determine the direction of rotation of a ring magnet. The two hall sensors are located close together along the circumference of the ring magnet. If the magnet is rotating in the direction for example counter-clockwise, the time for the south pole of the magnet to pass from sensor 2 to sensor 1 will be shorter than the time to complete one revolution. If the ring magnet's direction is reversed, the time it takes the South Pole to pass from sensor 2 to sensor 1 will be almost as long as the time for an entire revolution. By comparing the time between actuations of sensors 2 and 1 with the time for an entire revolution (successive actuations of sensor 2), the direction can be determined.

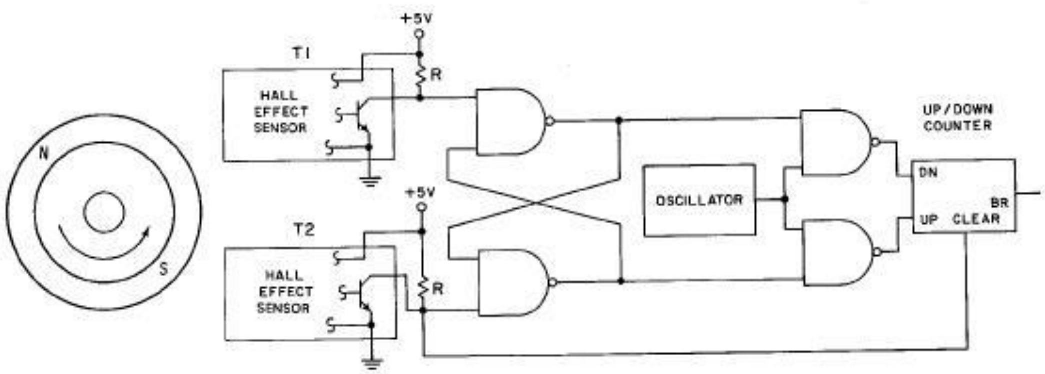


Figure: Digital output direction sensor.

- The Hall Effect vane sensor is used in industrial machinery, electronic injection, automation etc. It consists of a Hall IC and a permanent magnet (SmCo, NdFeB disc or block), which are hermetically sealed (air tight) in plastic. The sensor is actuated by a soft iron vane that passes through the air gap between the magnet and Hall IC. In the automotive industry it may be used as a trigger in electronic systems, in control engineering it may be used in those areas where switches/sensors must operate maintenance free under harsh environmental conditions, e.g. RPM sensors, limit switches, position sensors, speed measurements, shaft encoders, scanning of coding disks etc.
- A gear tooth sensor is a magnetically biased Hall Effect integrated circuit to accurately sense movement of ferrous metal targets. An example of an assembled gear tooth sensor is shown in Figure 3. The IC, with discrete capacitors and bias magnet, is sealed in a probe type, non-magnetic package for physical protection and cost-effective installation. As a gear tooth passes by the sensor face, it concentrates the magnetic flux

from the bias magnet. The sensor detects the change in flux level and translates it into a change in the sensor output. When the magnetic field sensed by the Hall element changes by a pre-defined amount, the signal from the Hall element to the trigger circuit exceeds the trigger point and the output transistor switches ON (low). The trigger circuit switches the transistor output OFF (high) when the Hall signal is reduced to less than 75% of the operating value.

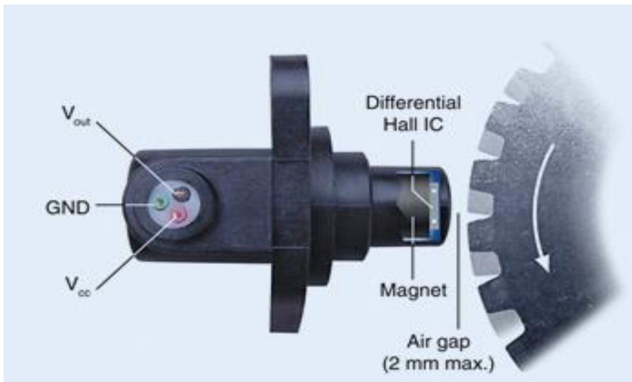


Figure: Schematic of IC gear tooth sensor.

- Hall probes are often used as magnetometers, i.e. to measure magnetic fields, or inspect materials (such as tubing or pipelines) using the principles of magnetic flux leakage.
- Hall effect sensors are readily available from a number of different manufacturers, and may be used in various sensors such as rotating speed sensors (bicycle wheels, gear-teeth, automotive speedometers, electronic ignition systems), fluid flow sensors, current sensors, and pressure sensors.
- Common applications are often found where a robust and contactless switch or potentiometer is required. These include: electric airsoft guns, triggers of electro-pneumatic paintball guns, go-cart speed controls, smart phones, and some global positioning systems.
- Hall sensors are used to monitor the electromagnetic pollution (power lines, radar installations, radio, TV, cell phones and many other electric appliances, even in household where there are unshielded power circuits) that can cause harmful effects to the natural environment. The monitoring of the EM radiations is a significant part of

this process. For this monitoring, the sensitivity of hall sensors ranges from a few pico Tesla (pT) to milli Tesla (mT). Hall sensors have been extensively used for low frequency signals but high frequency Hall sensors are based on Giant Magneto Impedance effect (GMI) in which large variation of the impedance of a metallic magnetic conductor is observed when submitted to the action of a dc magnetic field which is under consideration.

- A distinct environmental application of Hall Effect sensors is the space field monitoring. Each satellite is equipped with field sensors, in order to perform meteorological measurements apart from craft navigation.
- Hall sensors in environmental application involve the counting process in domestic areas. Counting of vehicles in traffic with corresponding corrective actions in traffic signaling is an important issue in all big cities.
- Engineers have been using Hall effect measurements to characterize materials. Hall effect measurements are used in many phases of the electronics industry, from basic materials research and device development to device manufacturing.
- Crystal manufacturers also use this measurement technique. For example, nanotechnology researchers studying graphene, a single-atom-thick, crystalline form of carbon, determined recently that the material demonstrated the quantum Hall effect; therefore, the electrons flowed through the crystal with relativistic effects.
- A Hall effect measurement system can actually be used to determine quite a few material parameters, but the primary one is the Hall voltage (VH). Other important parameters such as carrier mobility, carrier concentration (n), Hall coefficient (RH), resistivity, magnetoresistance (R), and the conductivity type (N or P) are all derived from the Hall voltage measurement.
- **Hall Effect Sensor for Measuring Metal Particles in Lubricant:**

  Lubricant degradation is a major cause of damage in machinery such as engine, pump, compressor and transmission system etc. The use of degenerated lubricant has been one of cause making the machine damage. The metal particles which is mainly contamination of scrap metal parts due to wear and tear of machinery. The time of oil change for the machines based on the quality and lifespan. There are many papers studying about the relation between the quality of lubricant after using and the failure of machines.

Contamination of the oil may cause by inside and outside of the machine such as wear and tear of the machinery or the contamination from in-let air in opened system, so the wear particles are both non-ferrous and ferrous metal or either, all of them affect to the performance of the machine and including system shut down and damage.

Figure 1 below shows the overall structure of the measurement system based on the principle of a magnetic field. The permanent magnet generates a magnetic field (*B*), which can be effect to metal contaminants in the lubricant that is cause of the magnetic field changed according to the weight of the contaminants. The Hall sensor can detect changing of magnetic field and generate the voltage output to the 12 bit- Analog to Digital convertor for sending data to the data acquisition based on microcontroller then it passes data to store on the computer and data analysis.

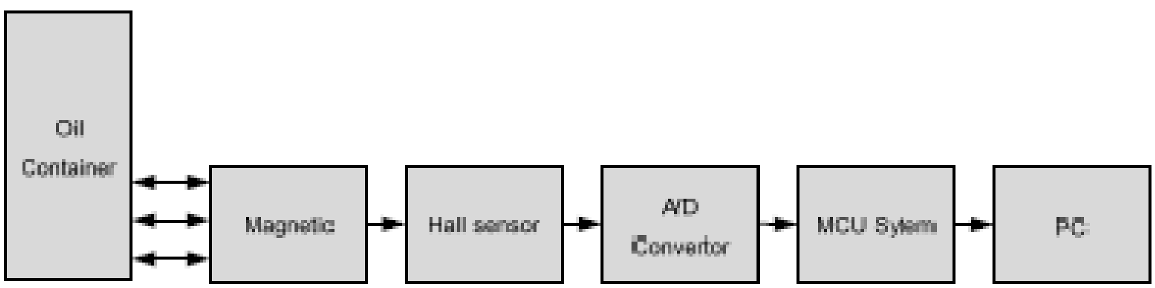


Figure 1: Schematic diagram of Hall Effect sensor system

The structure of the measurement system has shown in Figure 2. Measurement system consists of a permanent magnet for generating a magnetic field (magnetic field, *B*) to the sample in the oil container and Hall sensor for detecting the magnetic field. The permanent magnet size is 2 mm. of thickness, 12 mm. of width and 15 mm. of length. The hall sensor is mounted into the center of permanent magnet on another side of the acrylic plate. The gap between hall sensor and permanent magnet is 3 mm. in order to protect the saturated output voltage of hall sensor in case of the magnetic field over the range.

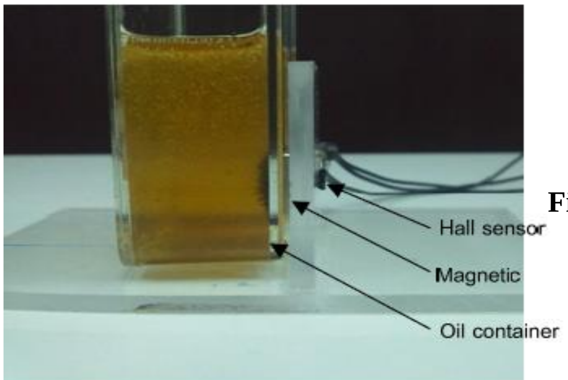


Figure 2: Hall Effect sensor Installation

- Magnetometer sensors work on the principle of Hall Effect i.e. they produce a voltage proportional to the applied magnetic field and also sense the polarity. They are used in applications where the magnetic field strength is relatively large. Magnetometers assist exploration of different magnetic minerals and magnetic anomalies which represent ore, this includes iron ore, magnetite ore, hematite ore.
- Solid-State Hall Effect sensors are one of the types of Hall Effect Magnetometer. These sensors work on the principle of Hall Effect i.e. they produce a voltage proportional to the applied magnetic field and also sense polarity. They are used in applications where the magnetic field strength is relatively large. On this account, this instrument is used to explore different minerals such as magnetite hematite and granite.
- The design of small motors to large water wheel and turbine generators can be improved with the help of information obtained from Hall probe, with the advantage of magnetic flux pattern studies in machines as a core loss tester.

Hall Probe is a Hall Effect sensor mounted in a convenient package for the user to operate. Transverse Hall probe, semi-flexible and only 1mm thick by 4mm wide is the result of the experience of industrial designers. This designed standard product enables operators to take measurements in tight spaces and narrow air gaps.

VIVA VOCE

Q. 1. What is electric field?

Ans. The region around the electric charges in which other charges experience forces or effect of charge is called electric field.

Q.2. What is magnetic field?

Ans. A magnet produces the magnetic field, at all points in the space around it.

It can be defined by measuring the force which the field exerts on a moving charged particle, such as an electron.

The force F = q(**v** x **B)**, where q is the charge, v is speed of the particle and B is magnitude of the field.

Q.3. What is Hall Effect?

Ans. Hall Effect is a phenomenon where a transverse potential difference is set up in a conductor carrying a current in a magnetic field and this magnetic field is called hall field.

Q.4. Define Hall Voltage?

Ans. Due to Hall Effect there occurs an excess of positive charge on one side of the strip and a deficiency of charges on the other side. This results in a potential difference across the strip, which is called the Hall voltage.

Hall voltage has a different polarity for positive and negative charge carriers, and it has been used to study the details of conduction in semiconductors and other materials which show a combination of negative and positive charge carriers.

Q.5. What is Lorentz force?

Ans. The Lorentz force is a combination of electric field force and magnetic field force. The **Lorentz force** is the force on a point charge due to electromagnetic fields. It is given by the following equation in terms of the electric and magnetic fields:

$$\mathbf{F} = \mathbf{E}q + \mathbf{v}q \times \mathbf{B},$$

Q.6. What is the relation between hall field, current and magnetic field?

Ans. Hall field is proportional to current and magnetic field.

Q.7. What in the direction of external magnetic field?

Ans. In a metallic platelet, the external magnetic field is perpendicular to the direction of current.

Q.8. What is the drift velocity?

Ans. The average net speed of charge carriers that are moving in a current due to the force exerted on them by electric field, driving the current.

The drift velocity of electrons in a copper wire can be calculated from

$$v_d = \frac{I}{neA}$$

n=free electron density

Q.9. What is the hall coefficient?

Ans. The Hall coefficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, as its value depends on the type, number, and properties of the charge carriers that constitute the current

$$R_{Hall} = \frac{E_y}{B_x . j_x}$$

Q.10. What is current density?

Ans. Current density is the number of electrons crossing a unit area per unit time multiplied by the charge on the electron.

Q.11. What type of specimen used in wafer?

Ans. Copper metal

Q.12. What is the mechanism of Hall Effect in Copper?

Ans. The Hall Effect on the Cupper metal with which the polarity of the Hall voltage generated corresponds to a conducting mechanism based on the mobile negative charge carriers.

Q.13. How the potential difference is produced in the presence of magnetic field in semiconductor materials?

Ans. The magnetic field causes charge carriers (holes and electrons) to move towards the top or bottom of the strip creating a potential difference between the bottom & top of a strip thus producing electric fields.

Q.14. How the potential difference is produced in the presence of magnetic field in conductors (metals)?

Ans. The magnetic field causes charge carriers (electrons and defected electrons) to move towards the top of the strip creating a potential difference between the bottom & top of a strip thus producing electric fields.

In metals both negative carriers in form of electrons and positive carriers in form of defect electrons, can exist. The deciding factor for the occurrence of a hall voltage is the difference in mobility of charge carriers.

Q.15. For how long does the potential difference exist?

Ans. This potential difference grows until the force on the charge carriers by magnetic and electric field balance each other and there in no remaining vertical force on the carriers.

Q.16. If the value of Hall coefficient is small then what does that mean?

Ans. It means that the number of charge carriers per unit volume is large, i.e. conductor has a low resistance.

Q.17. What is Hall Probe?

Ans. A hall probe contains an indium compound crystal such as indium antimonide, mounted on an aluminum backing plate, and encapsulated in the probe head. The plane of the crystal is perpendicular to the probe handle. Connecting leads from the crystal are brought down through the handle to the circuit box.

Q.18. What is the function of Hall Probe?

Ans. When the Hall Probe is held so that the magnetic field lines are passing at right angles through the sensor of the probe, the meter gives a reading of the value of magnetic flux density (B). A current is passed through the crystal which, when placed in a magnetic field has a "Hall Effect" voltage developed across it.

Q.19. What in the basic principle of Hall probe?

Ans. The basic principle of Hall probe is based on Hall Effect.

Q.20. What are different type Hall probes?

Ans. Tangential hall probe and Axial hall probe.

Q.21. What type of hall probe is used in this experiment?

Ans. Tangential hall probe

Q.22. What is the main precaution while using hall probe?

Ans. The end of probe should be placed away from other magnets, iron & objects such as loud speaker and telephone, which contains magnets.

Q.23. What is an electromagnet?

Ans. An electromagnet is a magnet that runs on electricity. Unlike a permanent magnet, the strength of an electromagnet can easily be changed by changing the amount of electric current that flows through it. The poles of an electromagnet can even be reversed by reversing the flow of electricity.

An electromagnet works because an electric current produces a magnetic field, according to amperes law.

Q.24. What is the basic use of Hall Effect?

Ans. In the manufacturing techniques of electronic devices we need to know the number of carriers at some specific place i.e. density of carriers so we apply Hall Effect.

Q.25. What are Hall Effect sensors?

Ans. Hall Effect sensors are solids state devices which form part of electric circuit and when pass through a magnetic field, there will be the change in voltage.

Q.26. What are Hall Effect switches?

Ans. Hall switches work under the principle that by measuring hall voltage across the element one can determine the strength of magnetic field applied. So, hall switches turn on or off when the applied magnetic field reaches a certain level.

Q.27. Hall effect switches consist of what?

Ans. Generally Hall Effect switches consist of a Hall Effect sensor.

Q.28. What is the functional principle of a hall sensor?

Ans. The output voltage of the sensor and the switching state respectively depend on the magnetic flux density through the hall plate.

Q.29. Basic applications of Hall Effect?

Ans. Hall probes, Magnetic sensors and hall switches.

Q.30. What is the modern technique of measuring magnetic field?

Ans. Hall probes which work on the principle of Hall Effect.

Experiment 2

Band Gap of Germanium

EXPERIMENT 2

Band Gap of Germanium

Objectives

1. To measure the voltage across a germanium test-piece as a function of temperature.
2. To study effect of temperature on electrical conductivity of germanium for determination of its band gap energy.

Related Concepts

Band theory, valence band, conduction band, band gap, semiconductor, types of semiconductor, intrinsic conduction, extrinsic conduction.

Apparatus

- Hall effect module
- Intrinsic conductor, Ge, carrier board
- Power supply, 12 V/5 Amp AC
- Tripod base
- Support rod, square, L = 2.5 cm
- Right angle clamp
- Digital multimeter
- Connecting cables

Hall Effect module

Function elements at the front of the Hall module:

1. Rotary knob for the sample current I_p.

2. Digital display, displays either sample current I_p or sample temperature T_p as selected.

3. Threaded socket for screwing in the holding rod supplied.

4. Series of LEDs which indicate the operating mode of the sample heating and whether the digital display shows sample current I_p or sample temperature T_p.

5. Pair of 4 mm safety sockets for pick up of the Hall voltage U_H.

6. Positioning bore hole for a tangential magnetic field probe.

7. Press switch for selection of the display of sample current I_p or sample temperature.

8. Rotary knob for compensation of the Hall voltage U_H for fault voltage.

9. Shaft for acceptance of the sample board with contact strip as shown in **Fig. 3.**

10. 4 mm safety sockets for pick up of the sample voltage U_p.

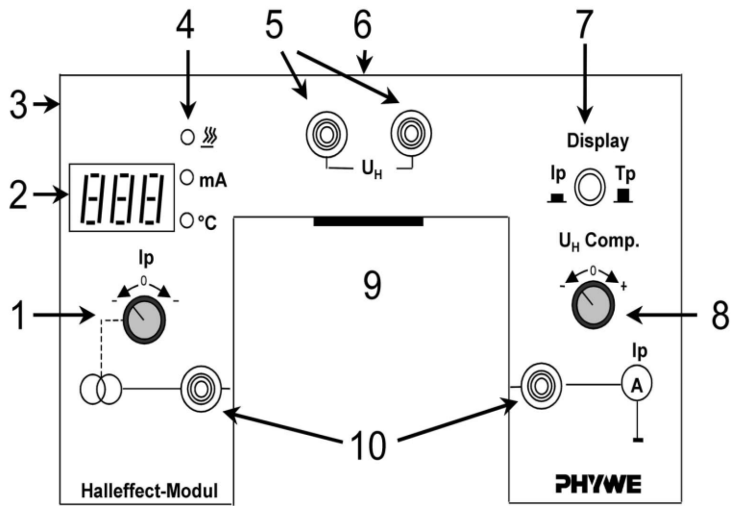


Figure 1: Front view of the Hall module with the various operating elements and displays.

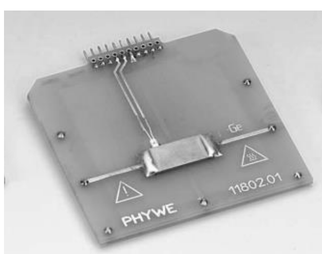


Figure 2: Carrier board with germanium sample.

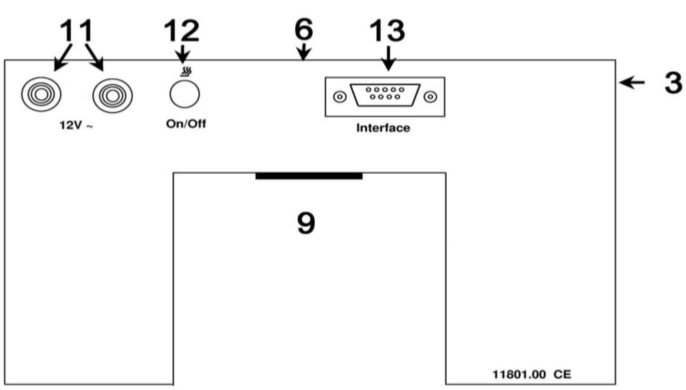


Figure 3: Rear view of the Hall module.

Function elements at the back of the Hall module:

11. Pair of 4 mm safety sockets for connection of the supply voltage.

12. Press switch for heating to be "On" or "Off".

Technical Specifications

Hall Effect module

Power supply	12 V AC, max. 35 VA
Max. Specimen current	±60 mA
Max. Specimen temperature	170°C
Outer dimensions	$(160 \times 25 \times 105)\ mm^3$
Fork width	70 mm
Mass with holding rod	0.4 kg

Carrier board

Sample dimensions	$(10 \times 20 \times 1)\ mm^3$
Spec. resistance of intrinsic Ge	approx. 50 Ω
Temperature probe	Pt 100
Heating meander	approx. 3 Ω
Dimensions	$(73 \times 70 \times 2.5)\ mm^3$
Weight	0.028 kg

Experimental Arrangement

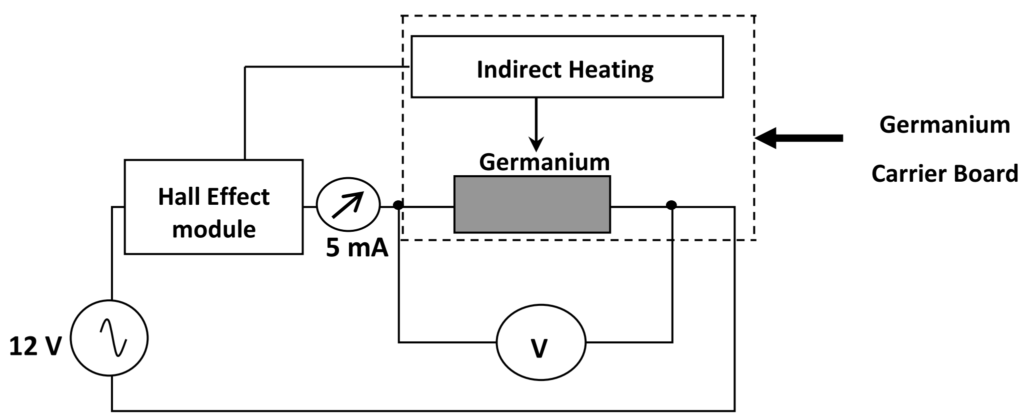


Figure 4: Circuit diagram for determination of voltage as a function of temperature.

Figure 5: Experimental setup for determination of voltage as a function of temperature.

Procedure

1. The circuit diagram and experimental set-up are shown in Fig. 4 and Fig. 5 respectively.
2. The germanium carrier board has to be put into the hall-effect module via the guided-groove.
3. The Hall effect module must be supplied with a 12 V alternating voltage. The module creates from this an adjustable and controlled sample direct current of each sign, a fault voltage compensator and the heating power for the meandering heating path on a carrier board.
4. The voltage across the sample is measured with a digital multimeter which is connected to the lower two sockets on the front-side of the module.
5. The current and temperature can be easily read on the integrated display of the module by the adjustment of "Display" knob.
6. At the beginning, set the current to a value of 5 mA. The current remains nearly constant during the measurement, but the voltage changes according to a change in temperature.

7. Set the display in the temperature mode and keep it in this mode during measurement. Activate the heating coil with the "on/off" knob on the backside of the module.
8. When the maximum temperature of T = 170° C is reached, the heating is automatically switched off. It is recommended that a control measurement be carried out during the cooling phase.
9. Record the voltage as a function of temperature for a temperature range of room temperature to a maximum of 170° C, in Table 1.
10. Calculate the conductivity of Ge specimen at each value of temperature using data recorded in Table 1 and Equation 1.

$$\sigma = \frac{1}{\rho} = \frac{l \cdot I}{A \cdot U_P}[\frac{1}{\Omega mm}] \qquad \textbf{(1)}$$

11. Plot natural log of conductivity (ln σ) versus reciprocal of absolute temperature. Find the slope m of this linear curve.
12. Band gap energy of germanium can be calculated using relation given in Equation 2.

$$E_g = -m \times 2k \qquad \textbf{(2)}$$

Precautions

1. Ensure that the edge-board connection fits securely in the contact strip.
2. The Hall Effect module must be supplied with a 12 V **alternating voltage**.
3. The display should be in temperature mode during experiment.
4. The carrier board can get very hot during operation. There is a danger of burns to hands. Do not handle the board until the module has been switched off and an appropriate cooling-down time has elapsed.

Observations and Calculations

Length of Ge specimen $\boldsymbol{l}$ = 20 mm

Area of cross-section of Ge specimen $\boldsymbol{A}$ = 10 × 1 mm^2

Current $\boldsymbol{I}$ = 5mA

Table: Probe voltage measured as a function of temperature.

Sr. No.	Temperature **T** (˚C)	Absolute Temperature **T´ = T+273** (K)	Reciprocal of Absolute Temperature **1/T´** (1/K)	Probe Voltage **U_p** (V)	Conductivity $\sigma = \frac{l.I}{A.U_P}$ (Ω^{-1} mm^{-1})	**lnσ**
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
15.						

Graphs

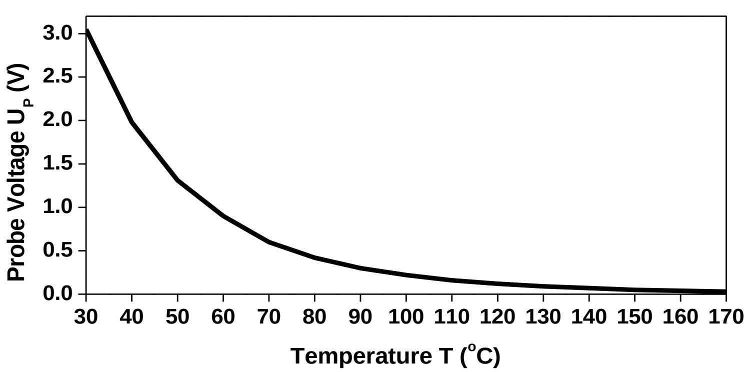


Figure 6: Typical measurement of the probe-voltage as a function of the temperature.

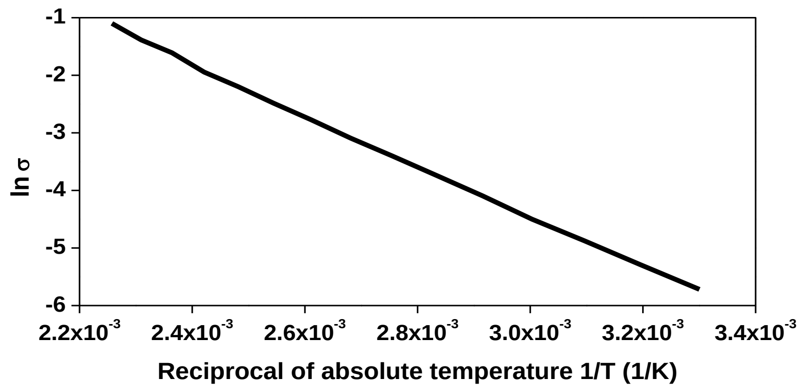


Figure 7: Conductivity versus the reciprocal of the absolute temperature.

From the graph like in Fig. 7, calculate the slope of the line by taking any two points (x_1, y_1) and (x_2, y_2) on the straight line and using the formula given below:

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

Experimental value of band gap energy $E_g = - m \times 2k$

Here $k = 8.625 \times 10^{-5}$ eV

Theoretical value of band gap energy = 0.67 eV

$$\%ageError = \frac{Theoretical - Experimental}{Theoretical} \times 100$$

Theory

Energy Bands

Energy bands consisting of a large number of closely spaced energy levels exist in crystalline materials. The bands can be thought of as the collection of the individual energy levels of electrons surrounding each atom. The wave functions of the individual electrons, however, overlap with those of electrons confined to neighboring atoms. The Pauli Exclusion Principle does not allow the electron energy levels to be the same so that one obtains a set of closely spaced energy levels, forming an energy band.

Among the many energy bands in an atom, energy bands to be discussed here are valence band, conduction band and forbidden band. Valence band contains electrons which are present in the outermost shell of atom. The conduction band contains free electrons. These electrons are called free because they are under the influence of many nuclei so they are most loosely bound electrons. The forbidden band carries the disallowed energy states so it is always empty. Actually, this defines the energy difference between highest energy level of valence band and lowest energy level of conduction band. It is also called the **band gap.**

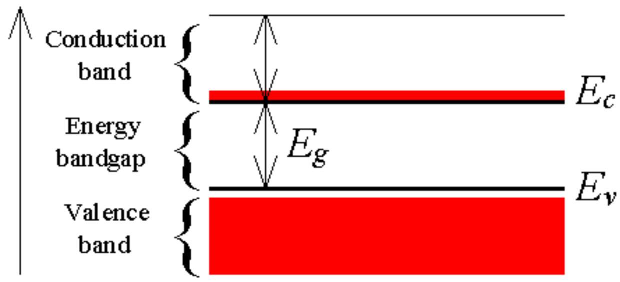


Figure 8: Energy band diagram of a material.

The Fig.8 shows the concept of different energy bands in a material. Here the shaded area shows filled energy levels. E_c and E_v are conduction band minimum and valence band maximum respectively. Energy gap or band gap is defined by E_g.

Metals, Insulators and Semiconductors

On the basis of energy band diagram, materials can be classified as metals, insulators and semiconductors**.** For this, it should be known that which energy levels are occupied and whether specific bands are empty, partially filled or filled. Empty bands do not contain electrons. Therefore, they are not expected to contribute to the electrical conductivity of the material. Partially filled bands do contain electrons as well as available energy levels at slightly higher energies. These unoccupied energy levels enable carriers to gain energy when moving in an applied electric field. Electrons in a partially filled band therefore do contribute to the electrical conductivity of the material. Completely filled bands contain plenty of electrons but do not contribute to the conductivity of the material. This is because the electrons cannot gain energy since all energy levels are already filled.

In order to find the filled and empty bands we must find out how many electrons can be placed in each band and how many electrons are available. Each band is formed due to the splitting of one or more atomic energy levels. Therefore, the minimum number of states in a band equals twice the number of atoms in the material. The reason for the factor of two is that every energy level can contain two electrons with opposite spin. To further simplify the analysis, we assume that only the *valence* electrons (the electrons in the outer shell) are of interest. The core electrons are tightly bound to the atom and are not allowed to freely move in the material.

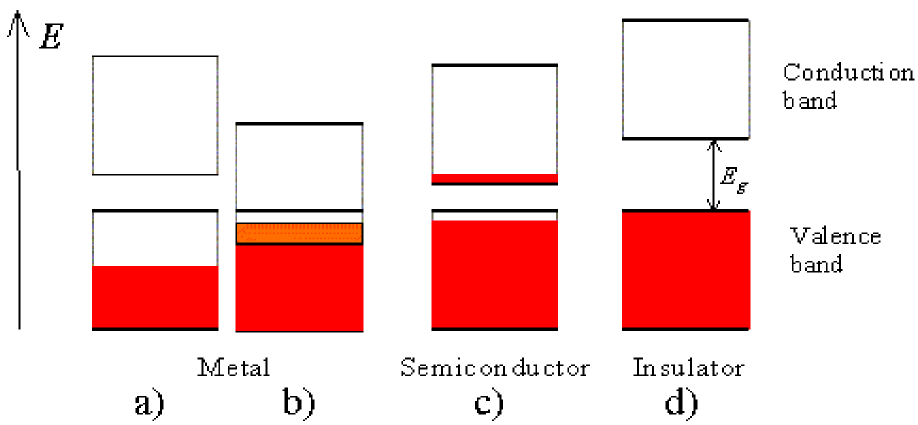


Figure 9: Possible energy band diagrams of a crystal. Shown are: **a)** a half-filled band, **b)** two overlapping bands, **c)** an almost full band separated by a small bandgap from an almost empty band and **d)** a full band and an empty band separated by a large bandgap.

Four different possible scenarios are shown in **Fig.9** A half-filled band is shown in **(a)**. This situation occurs in materials consisting of atoms, which contain only one valence electron per atom. Most highly conducting metals including copper, gold and silver satisfy this condition. Materials consisting of atoms that contain two valence electrons can still be highly conducting if the resulting filled band overlaps with an empty band. This scenario is shown in **(b)**. No conduction is expected for scenario **(d)** where a completely filled band is separated from the next higher empty band by a larger energy gap. Such materials behave as insulators. Finally, scenario **(c)** depicts the situation in a semiconductor. The completely filled band is now close enough to the next higher empty band that electrons can make it into the next higher band. This yields an almost full band below an almost empty band. We will call the almost full band the *valence band* since it is occupied by valence electrons.

The almost empty band will be called the *conduction band*, as electrons are free to move in this band and contribute to the conduction of the material.

Direct and indirect band gap semiconductors

Direct band gap-semiconductors are those in which the bottom of the conduction band and the top of the valence band occur at the momentum k=0. In the case of direct band gap semiconductors, energy released during band-to-band electron recombination with a hole is converted primarily into radiation (radiant recombination). Wavelength of emitted radiation is determined by the energy gap of semiconductor.

On the other hand, indirect bandgap semiconductors are those in which bottom of the conduction band does not occur at effective momentum k=0, i.e. is shifted with respect to the top of the valence band, which occurs at k=0; energy released during electron recombination with a hole is converted primarily into phonon.

Direct band gap semiconductors find many applications in optoelectronic devices.

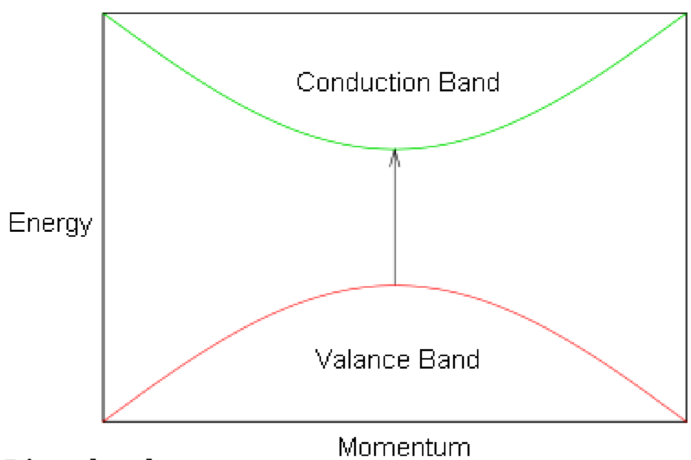


Figure 10: Direct band gap.

Energy vs. crystal momentum for a semiconductor with a direct band gap, showing that an electron can shift from the lowest-energy state in the conduction band to the highest-energy state in the valence band without a change in crystal momentum. Depicted is a transition in which a photon excites an electron from the valence band to the conduction band.

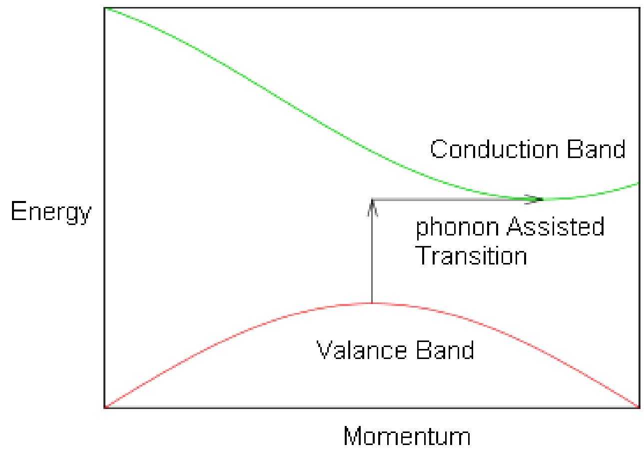


Figure 11: Indirect band gap. Energy vs. crystal momentum for a semiconductor with an indirect band gap, showing that an electron cannot shift from the lowest-energy state in the conduction band to the highest-energy state in the valence band without a change in momentum. Here, almost all of the energy comes from a photon (vertical arrow), while almost all of the momentum comes from a phonon (horizontal arrow).

Phonon, in solid-state physics is a quantum of lattice vibrational energy. In analogy to a photon (a quantum of light), a phonon is viewed as a wave packet with particle like properties. The way phonons behave determines or affects various properties of solids. Thermal conductivity, for instance, is explained by phonon interactions.

Conductivity of Semiconductors

Electrical conductivity or specific conductance is a measure of a material's ability to conduct an electric current. Conductivity is the reciprocal (inverse) of electrical resistivity, ρ, and has the SI units of siemens per meter ($S \cdot m^{-1}$) and CGSE units of inverse second (s^{-1}). Electrical conductivity is commonly represented by the Greek letter σ.

$$\sigma = \frac{1}{\rho}$$

Conductivity of semiconductor strongly depends upon temperature. When a semiconductor is extremely cold, almost all electrons are held tightly by individual atoms. It is hard to make them move through the material. When a semiconductor is heated, the heat energy knocks loose some of the electrons. These loose electrons can move through the material easily. The conductivity is higher. As more heat energy is added, more electrons break away from individual atoms, becoming free to move through the semiconductor. Higher temperature means greater conductivity. This is NOT true for conductors. Conductors already have plenty of loose electrons. Higher temperature tends to go into these loose electrons. Adding energy makes the loose electrons move in less organized patterns. It becomes more difficult to control the direction of the electrons. This makes the conductor have less conductivity when temperature is higher.

Conductivity in terms of current and voltage can be defined as

$$\sigma = \frac{1}{\rho} = \frac{l \,.\, I}{A.\ U}\left[\frac{1}{\Omega m}\right]$$

with ρ = specific resistivity, l = length of test specimen,

A = cross section, I = current, U = voltage.

Effect of temperature on energy band gap

The energy band gap of semiconductors tends to decrease as the temperature is increased. This behavior can be understood if one considers that the inter-atomic spacing increases when the amplitude of the atomic vibrations increases due to the increased thermal energy. This effect is quantified by the linear expansion coefficient of a material. An increased inter-atomic spacing, decreases the average potential seen by the electrons in the material, which in turn reduces the size of the energy bandgap.

The conductivity of semiconductors is characteristically a function of temperature. Temperature causes electrons to be promoted to the conduction band and from donor levels, or holes to acceptor levels. The dependence of conductivity on temperature is like other thermally activated processes:

$$\sigma = A \exp(-E_g / 2kT)$$

where ***A*** is a constant (the mobility varies much more slowly with temperature). **σ = Electrical conductivity E_g = Energy gap, k = Boltzman's constant, T= Absolute temperature.**

Now above equation can be written as

$$\sigma = \sigma_0 e^{-\frac{E_g}{2kT}}$$

The logarithm of this equation implies that

$$\ln\sigma = \ln[\sigma_0 \cdot e^{-\frac{E_g}{2kT}}]$$

$$\ln\sigma = \ln\sigma_0 - \frac{E_g}{2kT} \tag{3}$$

Now equation **(3)** can be compared with equation of straight line

$$y = mx + c$$

$$\Rightarrow y = \ln\sigma\,,\; x = \frac{1}{T}\,,\; m = -\frac{E_g}{2k}\,,\; c = \ln\sigma_o$$

Plotting ***ln σ*** vs. **1/*T*** produces a straight line of slope $E_g / 2k$ from which the band gap energy can be determined using the relation

$$E_g = m \times 2k$$

Here k = 8.625 x 10^{-5} eV

Applications

- Band Gap of a material is used to find the efficiency of photovoltaic cell or a solar cell (un-concentrated sunlight). If the bandgap is too high, most daylight photons cannot be absorbed; if it is too low, then most photons have much more energy than necessary to excite electrons across the bandgap and the rest of the energy is wasted.

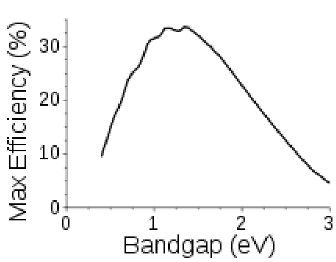


Figure 12: Band Gap Vs Max. Efficiency curve of a solar cell.

The semiconductors are commonly used in commercial solar cells that have bandgaps near the peak of this curve, for example silicon (1.1eV) or CdTe (1.5eV).

- The band gap of a material is used to determine a relation between the optical properties and the electrical properties of those materials. In almost all inorganic semiconductors, such as silicon, gallium arsenide, etc., there is very little interaction between electrons and holes (very small exciton binding energy), and therefore the optical and electronic bandgap are essentially identical, and the distinction between them is ignored. However, in some systems, including organic semiconductors, the distinction may be significant.
- Band gap of materials are used to determine photonic and phononic properties of materials. In photonics band gaps or stop bands, if tunneling effects are neglected, no photons can be transmitted through a material. A material exhibiting this behaviour is known as a photonic crystal. Similar physics applies to phonons in a phononic crystal.
- As germanium is transparent in the infrared (because of its band gap), it is a very important infrared optical material, that can be readily cut and polished into lenses and windows. It is especially used as the front optic in thermal imaging cameras working in the 8 to 14 micron wavelength range for passive thermal imaging and for hot-spot detection in military, night vision system in cars, and fire fighting applications. It is therefore used in infrared spectroscopes and other optical equipment which require extremely sensitive infrared detectors.
- Band gap engineering is an emerging technology to modify the material properties according to the requirement. In a similar context, germanium-tin alloys are attracting renewed interest for applications including the strain control of Complementary Metal Oxide Semiconductor (CMOS) active channels in integrated circuits, and mid-infrared optical devices for medical imaging, chemical spectroscopy, and military counter-measures. With sufficient Sn content above about 10 %, there is the particularly interesting possibility of an energy bandgap that is direct, which may lead to efficient light emitters and detectors. In a recent work reported by Department of Electrical and Computer Engineering, University of Delaware, USA, direct bandgap of 0.623 eV is

observed at 100 K for $Ge_{0.88}Sn_{0.12}$ alloy. This bandgap is about 100 meV lower than the bandgap of bulk Ge at this temperature.

- Heterojunction diodes of p-GeSn/n-Ge have also been fabricated which showed nearly ideal rectifying characteristics with a low turn-on voltage of about 0.4 volts. With increasing Sn concentration, and increasing temperature, the reverse dark current increased, which was attributed to a decreasing bandgap.
- Silicon-germanium alloys are rapidly becoming an important semiconductor material, for use in high-speed integrated circuits. Circuits utilizing the properties of Si-SiGe junctions can be much faster than those using silicon alone. SiGe alloys combine silicon, the most common microchip material, with germanium at nanoscale dimensions. The result is a robust material that offers important gains in toughness, speed and flexibility.
- The robustness is crucial to silicon-germanium's ability to function in space without bulky radiation shields or large, power-hungry temperature control devices. Compared to conventional approaches, SiGe electronics can provide major reductions in weight, size, complexity, power and cost, as well as increased reliability and adaptability. Silicon-germanium is beginning to replace gallium arsenide (GaAs) in wireless communications devices also.
- The most notable optical characteristics of germania (GeO_2) are its high index of refraction and its low optical dispersion. These make it especially useful for wide-angle camera lenses, microscopy, and for the core part of optical fibers. GeSbTe is a phase change material used for its optical properties, such as in rewritable DVDs.
- When a germanium-doped silica optical fiber is exposed to a high-intensity ultraviolet light, the refractive index of the fiber core is permanently changed. The amount of change in the refractive index can be controlled by Ge quantity and the growth methods because the defects caused by Ge in the lattice are served as absorption centers for UV (241 nm-245 nm). The phenomenon of the change in the refractive index of the fiber upon light irradiation is usually referred as photosensitivity.

- Highly pure crystals of germanium are used as a detector in Dark Matter Spectroscopy. In this spectroscopy, weakly interacting massive particles (WIMPs) collide with the Ge detector and transfer energy to the lattice. Resultant ionization and phonons process gives information about the nature of particles.
- A team of researchers from Xiamen University in China and the University of North Carolina at Charlotte describe successfully creating zinc oxide (ZnO) nanowires with a zinc selenide (ZnSe) coating to form a material structure known as a type-II heterojunction that has a significantly lower bandgap than either of the original materials. The team reported that arrays of the structured nanowires were subsequently able to absorb light from the visible and near-infrared wavelengths, and show the potential use of wide bandgap materials for a new kind of affordable and durable solar cell.
- "High bandgap materials tend to be chemically more stable than the lower bandgap semiconductors that we currently have," noted team member Yong Zhang, a Bissell Distinguished Professor in the Department of Electrical and Computer Engineering and in the Energy Production and Infrastructure Center (EPIC) at the University of North Carolina at Charlotte.
- The size of atoms and electronegativities are two factors that determine the bandgap of a material. Materials with small atoms and strong electronegative atomic bonds are associated with wide bandgaps. Smaller lattice spacing results in a higher perturbing potential of neighbors. Elements high on the periodic table are more likely to be wide bandgap materials. so there is a relation between lattice constant and composition of a solid solution at constant temperature. Structural properties of material are determined by band gap.
- The high breakdown voltage of wide bandgap semiconductors is a useful property in high-power applications that require large electric fields. Devices for high power and high temperature applications have been developed. Both gallium nitride and silicon carbide are materials well suited for such applications. Cubic boron nitride is used as well.

- Germanium (Ge) in fiber optics has been an important use. The fibers used in long-distance cables are silica fibers 7-10 μm in diameter which are doped with GeO_2. Several transparent materials e.g. chalcogenide, fluoride, germanate, silica glasses, as well as plastics have been employed as optical fibers for the transmission of analog or digital information. High refractive index of Ge & its low chromatic dispersion reduce losses of light for total internal reflection in fibers.
- Ge has potential application in solar cells which uses environment friendly solar energy. Multilayer solar cell with triple-junction of gallium indium phosphide on GaAs on germanium solar cells have been constructed for solar panels in terrestrial& space use. These cells convert 32 % of the incident energy to electric power. The top layer converts the highest energy light, and the middle and bottom layers each convert part of the light spectrum that reaches them; thus, each layer contributes to the cell's conversion efficiency.
- Germanium is a metallic-looking, grayish-white element. Germanium is found in small quantities in the minerals germanite(copper iron germanium sulfide) and argyrodite(Ag_8GeS_6, Silver Germanium Sulfide). It is also present in zinc ores. It can also be recovered from the by-products of combustion of certain coals. Germanium is used in optical fiber sensors (thermal response test TRT) for measurement of ground thermal conductivity of geological samples (multi-layers of soils).
- Pure Germanium has the band gap of 0.67eV. Since Germanium is found in small quantities in the minerals GERMANITE. So, by determining the band gap of the sample of Ge extracted from Germanite can assure us the purity and quality of Germanium.
- Germanium semiconductor detectors are used to measure radioactive materials in foods, drinking water and other items that humans ingest.
- PCBs intended for extreme environments often have a conformal coating, which is applied by dipping or spraying after the components have been soldered. The coat prevents corrosion and leakage currents or shorting due to condensation. The earliest conformal coats were wax; modern conformal coats are usually dips of dilute solutions

of silicone rubber, polyurethane, acrylic, or epoxy or plastic sputtering onto the PCB in a vacuum chamber.

- In electronics, **potting** is a designing process of filling a complete electronic assembly with a solid or gelatinous compound for resistance to shock and vibration, and for exclusion of moisture and corrosive agents. Thermo-setting plastics or silicone rubber gels are often used.
- Many semiconductor devices are molded out of an epoxy plastic that provides adequate protection of the semiconductor device, and mechanical strength to support the leads and handling of the package.

VIVA VOCE

Q.1 What is meant by energy band?

Ans When atoms are placed in electric fields, the energy states split into many sub energy level which are collectively called as energy band.

Q.2 Name different energy bands present in a material.

Ans Conduction band, valence band and forbidden band.

Q.3 What are the types of materials on the basis of band theory?

Ans Conductors/ metals, insulators and semiconductors.

Q.4 What is band gap?

Ans It is the energy difference between highest energy level of valence band to lowest energy level of conduction band.

Q.5 What is the band gap of semiconductors?

Ans It roughly ranges from 1 eV to 3 eV.

Q.6 What is the band gap of Germanium?

Ans 0.67 eV at room temperature.

Q.7 What is conductivity of semiconductors?

Ans The electrical conductivity of semiconductors ranges from about 10^{3} to 10^{-9} ohm^{-1} cm^{-1}.

Q.8 What is an intrinsic semiconductor?

Ans A semiconductor in which the concentration of charge carriers is characteristic of the material itself and it is free from impurities and crystal defects is called an intrinsic semiconductor.

Q.9 How electrons and holes are generated in the intrinsic semiconductor?

Ans Electrons in the conduction band and holes in the valence band are created by thermal excitation of electrons from the valence to the conduction band.

Q.10 What is extrinsic semiconductor?

Ans A semiconductor that contains certain amount of impurity which has changed its physical properties.

Q.11 What is p-type material?

Ans Semiconductor material "doped" or "poisoned" by valence +3 acceptor impurities is termed *p*. Typical valence +3 impurities used are boron, aluminum, indium, and gallium.

Q.12 What is n-type material?

Ans A material doped by valence +5 donor material is termed *n*-type. Valence +5 impurities used are arsenic, antimony, and phosphorus.

Q.13 What is electrical conductivity?

Ans Electrical conductivity or specific conductance is a measure of a material's ability to conduct an electric current.

Q.14 What is unit of conductivity?

Ans In S.I. its unit is siemens per meter ($S \cdot m^{-1}$)

Q.15 How can you classify the materials from band gap?

Ans There is virtually no bandgap in most metals, but a very large one in an insulator (dielectric). In a semiconductor, the bandgap is small.

Q.16 What are direct band gap semiconductors?

Ans Direct band gap-semiconductor in which the bottom of the conduction band and the top of the valence band occur at the momentum k=0; in the case of direct band gap semiconductors, energy released during band-to-band electron recombination with a hole is converted primarily into radiation (radiant recombination); wavelength of emitted radiation is determined by the energy gap of semiconductor.

Q.17 What are indirect band gap semiconductors?

Ans Indirect bandgap semiconductor in which bottom of the conduction band does not occur at effective momentum k=0, i.e. is shifted with respect to the top of the valence band which occurs at k=0; energy released during electron recombination with a hole is converted primarily into phonon.

Q.18 Give some examples of direct band gap materials.

Ans GaAs, InP, ZnS, ZnO, CdS, CdSe etc.

Q.19 Give some examples of in-direct band gap materials.

Ans Si, Ge, GaP, GaAsP etc.

Experiment 3

Capacitance of Different Metal Spheres

EXPERIMENT 3

Capacitance of Different Metal Spheres

Objectives

1. To determine the capacitance of a metal sphere by conduction method.
2. To study the effect of radius of metal spheres on its capacitance.

Related concepts

Charge, electric field, electric potential, conduction, electrostatic induction, capacitance.

Apparatus

- Conductor balls, d = 2 cm, 4 cm and 12 cm
- Insulating stem with Barrel base
- High-value resistor, **10 MΩ**
- High voltage supply unit **V** = 0-10 kV
- Auxiliary Capacitor **C** = 10 nF
- Universal measuring amplifier
- Multi-range meter
- Screened cable, BNC, **L** = 75 cm
- Adapter, BNC socket
- Connector, T type, BNC

Experimental Arrangement

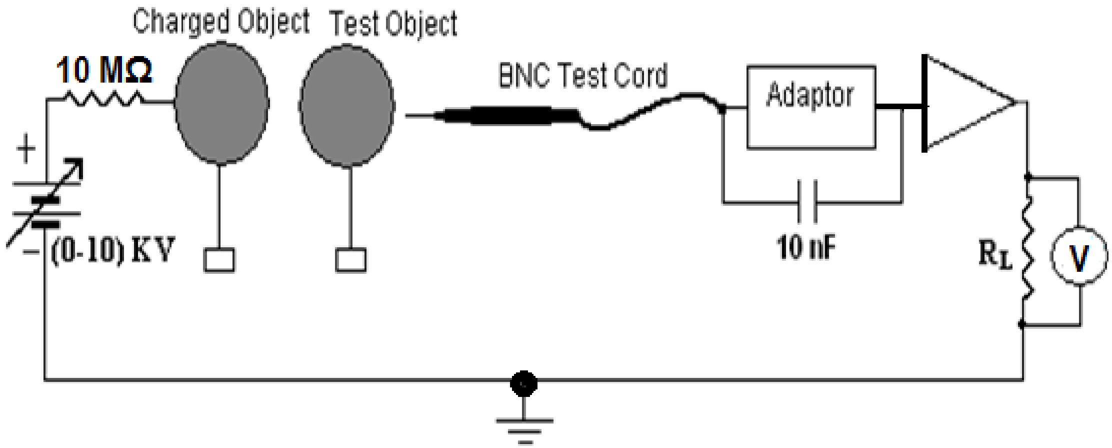


Figure 1: Circuit diagram for determination of the capacitance of conducting spheres.

Figure 2: Experimental setup to determine the capacitances of conducting spheres.

Procedure

1. The circuit diagram and experimental set-up require to determine the capacitance of spherical conductors is shown in Figure 1 and Figure 2 respectively.
2. The spherical conductor (charged sphere) is held on an insulated barrel base. It is connected to the positive terminal of the high voltage power supply by means of the

high voltage cord over the **10 MΩ** protective resistor. The negative terminal of power supply is earthed.

3. After charging this sphere for short time (~ ten seconds), power supply is disconnected. The charged sphere is shortly brought into contact (~ ten seconds) with the Test Sphere (whose capacitance is to be determined).
4. To measure the charges on the test sphere, it is connected with measuring amplifier via BNC test cord. This cord connects test sphere with a 10 nF auxiliary capacitor in parallel, to transfer the charge from test sphere to known value capacitor.
5. This charge is converted into voltage by electrometer of measuring amplifier using high-resistance input and is measured from voltmeter.
6. The capacitance of the test sphere is determined from the voltage and charge values using formula

$$C_s = \frac{C_a U_1}{U_2} \qquad \text{(Experimental Calculations)}$$

where $\mathbf{C_s}$ = Capacitance of conducting sphere, $\mathbf{C_a}$ **=** Capacitance of auxiliary capacitor (10 nF), $\mathbf{U_1}$ = Measured voltage and $\mathbf{U_2}$ = Applied voltage.

7. Number of observations are taken for each test sphere by varying the applied voltage.
8. Mean value of capacitance should be determined for each sphere and compared with theoretical value of capacitance, calculated from radii value using formula

$$C = 4\pi\varepsilon_{\circ} R_{1,2,3} \qquad \text{(Theoretical Calculations)}$$

9. Plot a graph between applied voltage and measured voltage of the conducting spheres to study the effect of voltage and radius on charge storing capacity of spheres.

Note: Please ensure that the ‘charged’ sphere and ‘test’ sphere are discharged before taking each observation. Use a free earth connecting cable for discharging the spheres.

Precautions

1. Check all the cable connections before switching on the electrical supplies. **High voltage is used in this experiment so extra care is required.**

2. High voltage power supply must be reset to zero every time after charging the sphere.
3. The ‘charged sphere’ and test sphere must be discharged before each reading.
4. The charging time of sphere and contact time of two spheres should be same.
5. The high resistance input of the electrometer should be used.
6. Make sure, all conductive and non-conductive objects are away from your circuit. Remove metal objects such as rings, jewelry, watch etc. before working with high voltage – they make excellent electrodes.
7. Keep electrical equipment away from water or any other liquid, conductive or not.

Observations and Calculations

Table 1. For Radius (R_1) = cm

Applied Voltage “U_2” (kV)	**Measured Voltage “U_1” (V)**	**Experimental Capacitance “C_s” (pF)**
0.5		
1		
1.5		
2		
2.5		
3		
3.5		
4		
4.5		
5		

Theoretical Capacitance ‘C’ = -------- pF

Mean Experimental Capacitance ‘Cs’ = -------- pF

$$\%Error = \frac{Theoratical - Experimental}{Theoratical} \times 100 =$$

Table 2. For Radius (R_2) = cm

Applied Voltage "U_2" (kV)	**Measured Voltage "U_1" (V)**	**Experimental Capacitance "C_s" (pF)**
0.5		
1		
1.5		
2		
2.5		
3		
3.5		
4		
4.5		
5		

Theoretical Capacitance 'C' = -------- pF

Mean Experimental Capacitance 'Cs' = -------- pF

% Error = --------

Table 3. For Radius (R_3) = cm

Applied Voltage "U_2" (kV)	**Measured Voltage "U_1" (V)**	**Experimental Capacitance "C_s" (pF)**
0.5		
1		
1.5		
2		
2.5		
3		
3.5		
4		
4.5		
5		

Theoretical Capacitance ‘C’ = -------- pF

Mean Experimental Capacitance ‘Cs’ = -------- pF

% Error = --------

Graphical Representation

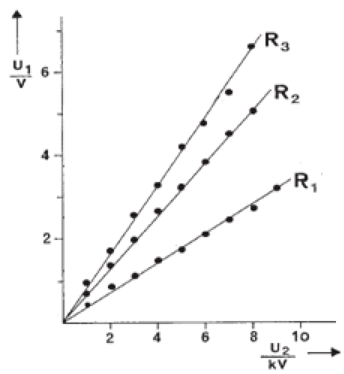


Figure 3: Graphical representation of measured voltage (**U_1**) as a function of charging voltage (**U_2**) for conducting spheres with three different diameters.

Theory

Electrostatic Charge

Atoms are composed of nucleus and its orbiting electrons. Nucleus carries the positive charge because of protons and electrons carry negative charge. As number of protons and electrons are equal, so the atom is electrically neutral. But this neutrality of atom is disturbed when electrons are added or removed from atoms by the process of charging or discharging.

Charging of a conductor

A conductor can be charged by means of three different methods:

(i) Friction

(ii) Conduction

(iii) Induction

(i) Friction

When two objects are rubbed together, the charge is transferred from one object to another. The object which loses electrons get positively charged and the object which gains electrons gets negatively charged. How easily a material gain or lose charge depends upon type of material.

(ii) Conduction

Charges can be transferred from one object to another object via conduction. For example, assume an arrangement of positively charged metal object and an uncharged metal sphere. The uncharged sphere is on an insulating stand so that it will not interact with anything else.

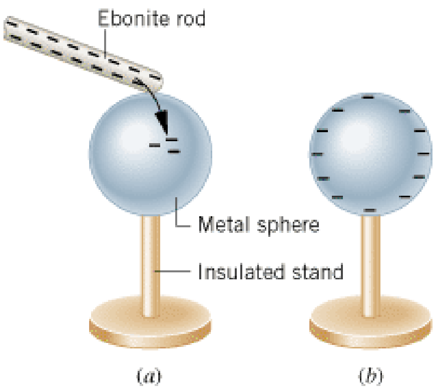


Figure 4: (a) Electrons are transferred by rubbing the negatively charged rod on the metal sphere. (b) When the rod is removed, the electrons distribute themselves over the surface of the sphere.

When the two objects are allowed to touch, some of the positive charges will transfer over to the uncharged metal object. This happens since the positive charges on the first object are repelling each other and by moving onto the second object they spread away from each other. When the charged object is removed, it will not be as positive as it was. Both of the objects have some of the positive charge but its magnitude depends on the size and the materials of the objects. If they are of the same size, made of the same materials, then the charge will be the same on both. Conduction by the flow of electrons depends upon the availability of free electrons. If large number of free electrons are available, then its conduction will be high and material is called a conductor/metal.

(iii) Induction

In the induction process, a charged object is brought near but not touched to a neutral conducting object. The presence of a charged object near a neutral conductor will force (or induce) electrons within the conductor to move. The movement of electrons leaves an imbalance of charge on opposite sides of the neutral conductor.

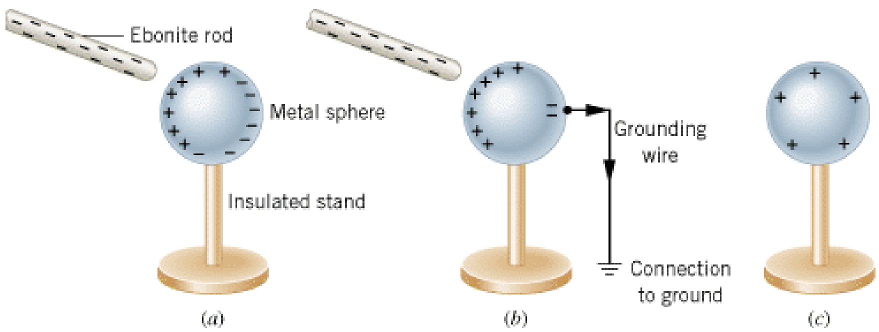


Figure 5: (a) When a charged rod is brought near the metal sphere some of the positive and negative charges in the sphere are separated. (b) Some of the electrons leave the sphere through the grounding wire, with the result (c) that the sphere acquires a positive net charge.

While the overall object is neutral (i.e., has the same number of electrons as protons), there is an excess of positive charge on one side of the object and an excess of negative charge on the opposite side of the object. Once the charge has been separated within the object, a *ground* is brought near and touched to one of the sides. The touching of the ground to the object permits a flow of electrons between the object and the ground. The flow of electrons results in a permanent charge being left upon the object. When an object is charged by induction, the charge received by the object is opposite the charge of the object which was used to charge it.

Capacitance

Capacitance is defined as the charge storage ability of an object. The SI units of capacitance are Farad. The charge stored (Q) on an object depends on the voltage (V) across object as in the following formula:

$$Q = CV \qquad (1)$$

where C is the capacitance.

Capacitance of an isolated charged sphere

Electric potential of an isolated charged sphere is determined using Gauss's Law and is given as:

$$V = \frac{Q}{4\pi\varepsilon_o R} \qquad (2)$$

Where ε_o is the permittivity of free space ($\varepsilon_o = 8.85 \times 10^{-12}$ $C^2 / N.m^2$)

The theoretical value of capacitance C of a sphere with radius R is calculated by using equation 1 and 2.

$$C = 4\pi\varepsilon_o R \qquad (3)$$

In order to calculate capacitance of conducting sphere experimentally, the value of charge stored on the sphere should be known.

$$Q = C_s U_2 \qquad (4)$$

Where U_2 is the applied voltage. To measure this charge Q, sphere is connected with auxiliary capacitor and measuring amplifier. The auxiliary capacitor and test sphere are in parallel connection so the total charge will be distributed as:

$$Q = Q_s + Q_a$$

$$Q = (C_s + C_a)\, U_1 \qquad (5)$$

where Q_s, Q_a are charges stored on test sphere and auxiliary capacitor respectively and U_1 is measured voltage. As $C_s << C_a$, So, equation 5 simplifies to

$$Q = C_a U_1 \qquad (6)$$

Comparing equation 4 and 6, we get

$$\boldsymbol{C_s = \frac{C_a U_1}{U_2}}$$

Applications

- Changing the effective area of the plates: Capacitive touch switches are now used on many electronic products.
- Metal spheres can be used for different electrical discharges depending upon size e.g. corona & induced current effects based on field intensification, associated with operation of high-voltage electric transmission lines. Corona is a phenomenon associated with all energized transmission lines and can transform discharge energy into very small amounts of sound, radio noise, heat, and chemical reactions of the air components depending on the conductor voltage, shape, diameter & surface irregularities (dust, water drops) which effects conductor's electrical surface gradient and its corona performance.

- Vaan De Graaff generator is a device that can be used to separate charges and create potential differences in the range of megavolts, whose construction is based on two metal spheres with different radii. Van de Graaff invented the generator to supply the high energy needed for early particle accelerators. Lightning, a natural phenomenon is an electrical discharge between clouds &the ground. Create it in miniature with a Van de Graaff generator for designing of variety of light emitting devices e.g. incandescent (filament) light bulbs, fluorescent tubes or lamps, gas filled tubes, old radio tubes, even tiny neon tubes.
- One example is a shielded cable, which has electromagnetic shielding in the form of a wire mesh surrounding an inner core conductor. These cables also contain dielectric material coatings inside. The shielding impedes the escape of any signal from the core conductor, and also prevents signals from being added to the core conductor. Some cables have two separate coaxial screens, one connected at both ends, the other at one end only, to maximize shielding of both electromagnetic and electrostatic fields.
- Mylar-film, oil-filled capacitor has very low inductance and low resistance, to provide the high-power and high speed discharge to operate a dye laser.
- A capacitor can store electric energy when disconnected from its charging circuit, so it can be used like a temporary **battery.** Capacitors are commonly used in electronic devices to maintain power supply while batteries are being changed (This prevents loss of information in volatile memory). In car audio systems, large capacitors store energy for the amplifier to use on demand. Flash tube requires a capacitor to hold the high voltage.
- Groups of large, specially constructed, low-inductance high-voltage capacitors (*capacitor banks*) are used to supply huge pulses of current for many pulsed power applications. These include electromagnetic forming, Marx generators, pulsed lasers (especially TEA lasers), pulse forming networks, radar, fusion research and particle accelerators.
- Large capacitor banks (reservoir) are used as energy sources for the exploding-bridgewire detonators or slapper detonators in nuclear weapons and other specialty

weapons. Experimental work is under way using banks of capacitors as power sources for electromagnetic armour and electromagnetic railguns and coilguns.

- Reservoir capacitors are used in power supplies where they smooth the output of a full or half wave rectifier. They can also be used in charge pump circuits as the energy storage element in the generation of higher voltages than the input voltage.

Figure: A 10 millifarad capacitor in an amplifier power supply

- Capacitors are connected in parallel with the power circuits of most electronic devices and larger systems (such as factories) to shunt away and conceal current fluctuations. A high-voltage capacitor bank used for power factor correction on a power distribution and transmission systems. Such capacitors often come as three capacitors connected as a three phase load. Usually, the values of these capacitors are given not in farads but rather as a reactive power in volt-amperes reactive (var). The purpose is to counteract inductive loading from devices like electric motors and transmission lines to make the load appear to be mostly resistive. Individual motor or lamp loads may have capacitors for power factor correction, or larger sets of capacitors (usually with automatic switching devices) may be installed at a load center within a building or in a large utility substation

Figure 1: Capacitor bank

- Polyester film capacitors are frequently used as coupling capacitors. Because capacitors pass AC but block DC signals (when charged up to the applied dc voltage), they are often used to separate the AC and DC components of a signal. This method is known as *AC coupling* or "capacitive coupling". Here, a large value of capacitance, whose value need not be accurately controlled, but whose reactance is small at the signal frequency, is employed.

Figure 2: capacitive coupling

- A decoupling capacitor is a capacitor used to protect one part of a circuit from the effect of another, for instance to suppress noise or transients. Noise caused by other circuit elements is shunted through the capacitor, reducing the effect they have on the rest of the circuit. It is most commonly used between the power supply and ground. An alternative name is *bypass capacitor* as it is used to bypass the power supply or other high impedance component of a circuit.
- Snubber capacitors are usually employed with a low-value resistor in series, to dissipate energy and minimize RFI.
- Capacitors are also used in parallel to interrupt units of a high-voltage circuit breaker in order to equally distribute the voltage between these units. In this case they are called grading capacitors.
- In single phase squirrel cage motors, the primary winding within the motor housing is not capable of starting a rotational motion on the rotor, but is capable of sustaining one. To start the motor, a secondary "start" winding has a series non-polarized *starting capacitor* to introduce a lead in the sinusoidal current. The start capacitor is typically mounted to the side of the motor housing. These are called capacitor-start motors that have relatively high starting torque.

- Capacitor-run induction motors have a permanently connected phase-shifting capacitor in series with a second winding. The motor is much like a two-phase induction motor. Motor-starting capacitors are typically non-polarized electrolytic types, while running capacitors are conventional paper or plastic film dielectric types.
- The energy stored in a capacitor can be used to represent information, either in binary form, as in DRAMs, or in analogue form, as in analog sampled filters and CCDs. Capacitors can be used in analog circuits as components of integrators or more complex filters and in negative feedback loop stabilization. Signal processing circuits also use capacitors to integrate a current signal.
- Capacitors and inductors are applied together in tuned circuits to select information in particular frequency bands. For example, radio receivers rely on variable capacitors to tune the station frequency. Speakers use passive analog crossovers, and analog equalizers use capacitors to select different audio bands. The resonant frequency*f* of a tuned circuit is a function of the inductance (*L*) and capacitance (*C*) in series, and is given by:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

  Where *L* is in henries and *C* is in farads.
- Capacitors with a flexible plate can be used to measure strain or pressure. Industrial pressure transmitters used for process control use pressure-sensing diaphragms, which form a capacitor plate of an oscillator circuit.
- Capacitors are used as the sensor in condenser microphones, where one plate is moved by air pressure, relative to the fixed position of the other plate.
- Some accelerometers use MEMS capacitors etched on a chip to measure the magnitude and direction of the acceleration vector. They are used to detect changes in acceleration, in tilt sensors, or to detect free fall, as sensors triggering airbag deployment, and in many other applications. Some fingerprint sensors use capacitors.
- A user can adjust the pitch of a therein musical instrument by moving his hand, since this changes the effective capacitance between the user's hand and the antenna.

- Electrical Capacitance Tomography is a widely popular and nonintrusive technique for sensing and measuring the spatial distribution, voidage, and velocities of flow of the materials in a pipe. It helps the chemical process engineer in indirectly visualizing the chemical process taking place inside the vessel which until now was not possible.
- Capacitive sensors are employed to sense the change in permittivity of the materials inside the vessel. The acquired data is used to construct permittivity distribution images, which aid in understanding the nature of activities taking place inside the vessel, by calculating various key parameters related to the chemical process. The images can also help in deciding the future course of control actions needed to be taken if required. The advantages of the technique are non-intrusive nature for measuring the capacitances, simple transduction principle, fast response, simple and efficient algorithm used to generate images of reasonably good resolution.
- Capacitance Level Probes are used for measuring level of

  1. Liquids
  2. Powered and granular solids
  3. Liquid metals at very high temperature
  4. Liquefied gases at very low temperature
  5. Corrosive materials like hydrofluoric acid
  6. Very high pressure industrial processes.
- Taking a significant step toward improving the power delivery of systems, niobium oxide was synthesized that shows high capability for both the rapid storage and release of energy.
- Niobium oxide would be used in a "super capacitor," a device that combines the high storage capacity of lithium ion batteries and the rapid energy-delivery ability of common capacitors. This development could lead to extremely rapid charging of devices, ranging in applications from mobile electronics to industrial equipment. For example, super capacitors are currently used in energy-capture systems that help power loading cranes at ports, reducing the use of hydrocarbon fuels such as diesel. Batteries

effectively store energy but do not deliver power efficiently because the charged carriers, or ions, move slowly through the solid battery material.

- Electrostatic shielding device, **Faraday cage** or **Faraday shield** is an enclosure formed by conducting material or by a mesh of such material. Such an enclosure blocks external static and non-static electric fields. An external static electrical field causes the electric charges within the cage's conducting material to be distributed such that they cancel the field's effect in the cage's interior. This phenomenon is used, for example, to protect electronic equipment from lightning strikes and electrostatic discharges. Typical materials used for electromagnetic shielding include sheet metal, metal screen and metal foam.

VIVA VOCE

Q.1 What is a capacitor?

Ans. An electrical device used to store charge.

Q.2 What are different types of capacitors?

Ans. Capacitors have different types e.g. Parallel plate capacitor, Spherical capacitors, Cylindrical capacitors, Variable capacitors etc.

Q.3 What do you mean by spherical capacitors?

Ans. A capacitor made of two concentric metal spheres with a dielectric filling the space between the spheres.

Q.4 What is electrostatic induction?

Ans. Modification in the distribution of electric charge on one material under the influence of an electric charge on a nearby object. It occurs whenever any object is placed in an electric field. When a negatively charged object is brought near a neutral object, it induces a positive charge on the near side of the object and a negative charge on the far side. If the negative side of the original object is momentarily grounded, the negative charge may escape, so that the object becomes positively charged by induction.

Q.5 What is the effect of increasing or decreasing radius on the capacitance of a conducting sphere?

Ans. Since the capacitance of a conducting sphere is given by:

$$C = 4\pi\varepsilon_0 R$$

So capacitance is directly proportional to radius (R) of sphere. By increasing radius capacitance will increase and vice versa.

Q.6 The two charged conductors are touched mutually and then separated. What will be the charge on them?

Ans. The charge on them will be divided in the ratio of their capacitances. We know that

$$Q = CV.$$

When the charged conductors touch, they acquire the same potential. Hence from the above equation it is concluded that **Q** is proportional to **C**.

Q.7 The plates of a charged capacitor are connected to a voltmeter. If the plates of the capacitor are separated further, what will be the effect on the reading of the voltmeter?

Ans. As the capacitor plates are separated, C decreases. Since charge on the plates remains the same, value of V increases. Hence, the reading of the voltmeter will increase.

Q.8 Any conducting object connected to earth is said to be grounded. Explain.

Ans. The earth is an electron source or sink and is arbitrarily said to be at zero potential. A conducting body connected to earth is also at zero potential or "ground potential". Alternatively, the capacitance of earth is so large that removal of electrons from it or supply of electrons to it makes no difference either on the charge or potential of earth.

Q.9 How does a spark discharge occur between two charged objects?

Ans. The air between the two charged objects is subjected to an electric field. If the potential gradient in the intervening air column becomes high enough, the air is ionized and conducting path is formed for free electrons which move across to discharge the surfaces. Stored electric potential energy is dissipated as heat, light and sound.

Q.10 Given a solid metal sphere and a hollow metal sphere which will hold more charge? Both spheres are of same radius.

Ans. Both the spheres will hold the same charge. It is because charge remains on the outer surface of a charged conductor (whether solid or hollow) and the spheres have equal surface areas.

Q.11 Two capacitors of capacitances 1 μF and 0.01 μF have same potential. Which will give more intense electric shock if touched?

Ans. Charge on a capacitor is given as:

$$Q = CV$$

Since V is constant so charge is directly proportional to capacitance. It means that capacitor having large capacitance will store more charge. Hence, when 1μF capacitor is touched, the discharging current will be high and you will get more intense electric shock than in case of 0.01 μF capacitor.

Q.12 Two spheres of different capacitances are charged to different potentials. They are then joined by a wire. Will total energy increase, decrease or remain the same?

Ans. The two spheres are at different potentials. Therefore, when they are connected by a wire, there will be redistribution of charge (i.e., flow of charge through wire) till the two spheres attain the same potential. Due to the flow of charge through the connecting wire, some energy will be lost as heat. Hence, the total energy after connecting the spheres will decrease.

Q.13 Can there be potential difference between two adjacent conductors which carry the same positive charge?

Ans. Yes. We know that V = Q/C. The capacitance depends upon the dimensions of the conductor. If the two conductors are of different shapes and sizes, they will be charged to different potentials when given the same charge.

Q.14 What is the difference between conductors and dielectrics?

Ans. (i) Conductors have a large number of free electrons while dielectrics have practically no free electrons.

(ii) When a conductor is placed in an external electric field, there is no electric field inside the conductor. However, when a dielectric is placed in an electric field, its molecules are polarized. The effect of this polarization is to weaken the applied electric field within the dielectric.

(iii) The dielectric constant of conductors is infinity while that of dielectrics is finite. **(iv)** The dielectric strength of conductors is zero while that of dielectrics is finite.

(v) There is no limit to the current that a conductor can carry, provided that it can be kept cool enough. However, there is a limit to the electric flux that a dielectric will carry without breaking down.

Q.15 What is capacitive reactance?

Ans. The opposition offered by a capacitor to the flow of A.C. current is called capacitive reactance and is measured in ohms (Ω).

Q.16 How does capacitor reactance depend on capacitance and frequency of applied voltage?

Ans. It is inversely proportional to capacitance and frequency of applied voltage.

Q.17 What is undesired or stray capacitance?

Ans. Any two conducting surfaces separated by some insulation possess capacitance. Thus every electrical and electronic circuit has some undesired capacitance also called stray capacitance. Stray capacitance exist between

(i) An insulated conductor and metal chassis

(ii) Two conductors in an electrical cable

(iii) The turns of an inductor

(iv) Primary and secondary coils of a transformer

(v) Between the input and output leads of a transistor

Q.18 What do you mean by time constant?

Ans. The time required to charge or discharges a capacitor to 63.2% of the available voltage.

Experiment 4

To Determine the Dielectric Constant of Different Materials

EXPERIMENT 4

To Determine the Dielectric Constant of Different Materials

Objectives

1. To determine the electric constant of air (ε_o) by measuring the charge on a parallel plate capacitor.
2. To determine the dielectric constant of plastic (ε) relative to air.

Related Concepts

Dielectric, polarization, free charge, bound charge, capacitance

Equipment Details

- Plate capacitor (plate diameter = 260 mm)
- Plastic plate (Thickness = 9.8 mm)
- High-value resistor (R = 10 MΩ)
- Universal measuring amplifier
- High voltage supply unit (0-10 kV)
- Auxiliary capacitor (220 nF)
- Multirange Voltmeter
- Connecting cords
- Screened cable (BNC test cord) with T type connector
- Adapter (BNC socket - 4 mm plug)

Experimental Arrangement

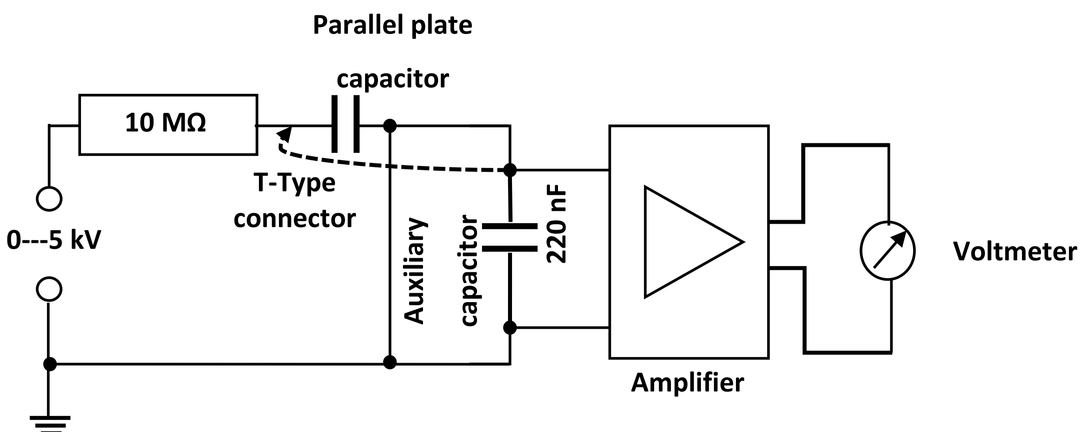


Figure 1: Circuit diagram for determination of the dielectric constant of different

Figure 2: Measurement set-up: Dielectric constant of different materials.

Procedure

1. Connections are to be made according to the circuit diagram in figure 1 and the corresponding set up shown in figure 2.
2. The highly insulated capacitor plate is connected to the upper positive terminal of the high voltage power supply with 10 MΩ protective resistor.

3. Both the middle connector of the high voltage power supply and the opposite capacitor plate should be grounded.
4. The measuring amplifier is set to high input resistance, to amplification factor 1 and to time constant 0.
5. Set the voltage across auxiliary capacitor to zero by using toggle switch of the measuring amplifier.
6. Charge the plates of the parallel plate capacitor by applying voltage using high voltage power supply. It will take only few seconds to charge the plates as the RC time constant is very small.
7. Remove the power supply connector from the plate and connect BNC test cord with plate to charge auxiliary capacitor of 220nF.
8. Voltage on the charged auxiliary capacitor should be measured through a voltmeter connected to amplifier.
9. Discharge the auxiliary capacitor and plate capacitor by using toggle switch.
10. Repeat steps 6 to 9 for various values of applied voltage.
11. As the charged plate capacitor acts like a battery and it is used for charging of auxiliary capacitor, so charge on auxiliary capacitor and plate capacitor at equilibrium can be measured by using equation.

    Q = CU

    Where U is the measured voltage on voltmeter, C = 220 nF
12. Electric constant of air can be measured by using the following equation.

$$\epsilon_o = \frac{Qd}{U_c A}$$

    where Q is charge on the plates, d is spacing between the plates, A is the area of the plates, U_c is applied voltage across the plates.
13. Repeat the same procedure for plastic and measure the dielectric constant of plastic relative to air using equation:

$$\epsilon = \frac{Q_{plasic}}{Q_{air}}$$

Where $Q_{plastic}$ is the charge on plates when dielectric is plastic and Q_{air} is the charge when dielectric is air.

Note: Please ensure that the 'parallel plate capacitor' and 'auxiliary capacitor' are discharged before taking each observation. Use a free earth connecting cable for discharging the capaciotrs.

Precautions

1. Check all the cable connections before switching on the electrical supplies. **High voltage is used in this experiment so extra care is required.**
2. High voltage power supply must be reset to zero every time after charging the sphere.
3. Keep your hands and body away from charged plates in order to avoid effects of stray capacitance on the capacitor.
4. Do not touch the connector of the second capacitor which is connected to the highly charged plate capacitor.
5. Do not remove the protective resistance from the upper connector of the high voltage power supply.
6. Do not remove or change the polarity of the capacitor of capacitance 220 nF.
7. Both the capacitors must be discharged after every reading.
8. Make sure, all conductive and non-conductive objects are away from your circuit. Remove metal objects such as rings, jewelry, watch etc. before working with high voltage – they make excellent electrodes.

Observations and Calculations

For Air

A (area of the plates) = 0.0531 m^2

d (distance between the plates) = 0.98 cm (equal to the thickness of plastic plate)

C = 220 nF

Table 1. Electric constant of air

Applied Voltage **"U_c"** (kV)	Measured Voltage **"U"** (V)	Stored charge on Plates **"Q_{air}"** (nC)	Electric constant $\epsilon_o = \frac{Qd}{U_c A}$ (pC/Vm)
0.5			
1			
1.5			
2			
2.5			
3			
3.5			
4			
4.5			
5			

Mean value of electric constant of air ε_o =

Actual value of electric constant of air ε_o =

For Plastic

Table 2. Dielectric constant of plastic

Applied Voltage **"U_c"** (kV)	Measured Voltage **"U"** (V)	Stored charge on Plates **"$Q_{plastic}$"** (nC)	Dielectric constant $\epsilon = \frac{Q_{plasic}}{Q_{air}}$
0.5			
1			
1.5			
2			
2.5			
3			
3.5			
4			
4.5			
5			

Mean value of dielectric constant of plastic ε =

Graphical Representation

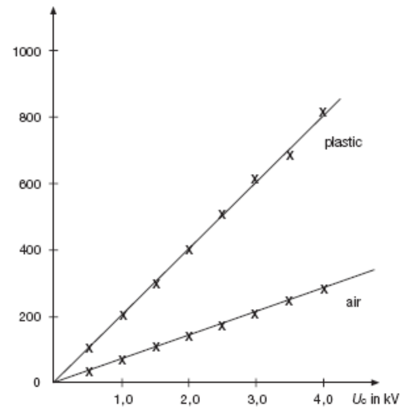


Figure 3: Electrostatic charge Q of a plate capacitor as a function of the applied voltage U_c, with air and plastic as dielectric between the plates (d = 0.98 cm).

Theory

A dielectric is an electrical insulator that may be polarized by an applied electric field. When a dielectric is placed in an electric field, electric charges do not flow through the material, as in a conductor, but only slightly shift from their average equilibrium positions causing **dielectric polarization**. Because of dielectric polarization, positive charges are displaced toward the field and negative charges shift in the opposite direction. This creates an internal electric field that partly compensates the external field inside the dielectric. If a dielectric is composed of weakly bonded molecules, those molecules not only become polarized, but also reorient so that their symmetry axis aligns to the field. The study of dielectric properties is concerned with the storage and dissipation of electric and magnetic energy in materials. It is important to explain various phenomena in electronics, optics, and solid-state physics.

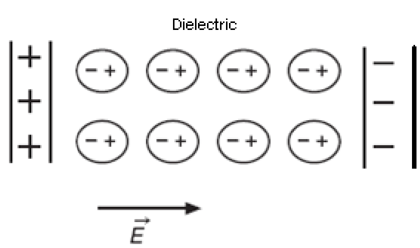


Figure 4: Generation of free charges in a dielectric through polarization of the molecules in the electric field of a **plate capacitor.**

Electrostatic processes in vacuum (and with a good degree of approximation in air) are described by the following integral form of Maxwell's equations:

$$\oint E.dA = \frac{Q}{\varepsilon} \qquad (1)$$

$$\oint E.dS = 0 \qquad (2)$$

Where *E* is the electric field intensity, *Q* the charge enclosed by the closed surface *A*, ε_0 the electric constant and *S* a closed path. If a voltage U_c is applied between two capacitor plates, an electric field *E* will prevail between the plates, defined by:

$$U_c = \int_1^2 E.dr \qquad (3)$$

Due to the electric field, electrostatic charges of the opposite sign are drawn towards the surfaces of the capacitor. As voltage sources do not generate charges, but only can separate them, so the absolute values of the opposite electrostatic induction charges must be equal. Assuming the field lines of the electric field always to be perpendicular to the capacitor surfaces of surface *A*, due to symmetry, which can be experimentally verified for small distances *d* between the capacitor plates, one obtains from equation (1):

$$\frac{Q}{\epsilon o} = \mathrm{E.A} = \frac{\mathrm{U_c}}{\mathrm{d}}.\mathrm{A} \qquad (4)$$

The volume indicated in figure 5, which only encloses one capacitor plate, was taken as volume of integration. Both the flow and the electric field *E* outside the capacitor are zero, because for arbitrary volumes which enclose both capacitor plates, the total enclosed charge is zero. The charge *Q* of the capacitor is thus proportional to voltage; the proportionality constant *C* is called the capacitance of the capacitor.

$$Q = CU_c = \epsilon_o \frac{A}{\mathrm{d}}.\mathrm{U_c} \qquad (5)$$

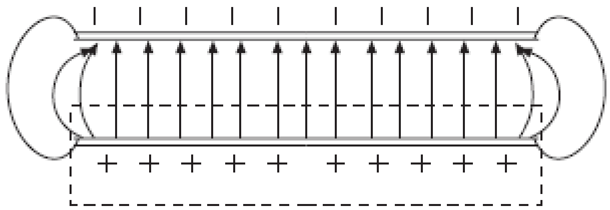


Figure 5: Electric field of a plate capacitor with small distance between the plates, as compared to the diameter of the plates. The dotted lines indicate the volume of integration.

Equation (5) shows that the capacitance C of the capacitor is directly proportional to area A of the plates and inversely proportional to the distance d between the plates:

$$C = \epsilon_o \frac{A}{\mathrm{d}} \qquad (6)$$

The electric constant of vacuum/air can be found by using equation 5 as:

$$\epsilon_o = \frac{d}{\mathrm{A}} \cdot \frac{Q}{\mathrm{Uc}} \qquad (7)$$

Equations (4), (5), (6) and (7) are valid only approximately, due to the assumption that field lines are parallel. With decreasing distances between the capacitor plates, capacitance increases, which in turn systematically yields a too large electric constant from equation (6). This is why the value of the electric constant should be determined for a small and constant distance between the plates.

Dielectric in Capacitors

Capacitance and charging of the plate changes once dielectrics are inserted between the plates. Dielectrics have no free moving charge carriers, as metals have, but they do have positive nuclei and negative electrons. The change in the capacitance is caused by a change in the electric field between the plates. The electric field between the capacitor plates will induce dipole moments in the material between the plates (polarization). These induced dipole moments will reduce the electric field in the region between the plates. A material in which the induced dipole moment is linearly proportional to the applied electric field is called a **linear dielectric**. In this type of materials, the total electric field between the capacitor plates E is related to the electric field E_{free} that would exist if no dielectric was present:

$$E = \frac{E_{free}}{\varepsilon} \quad (8)$$

where ε is called the dielectric constant of the dielectric material. Since the final electric field E can never exceed the free electric field E_{free}, the dielectric constant ε must be larger than 1.

The potential difference across a capacitor is proportional to the electric field between the plates. Since the presence of a dielectric reduces the strength of the electric field, it will also reduce the potential difference between the capacitor plates (if the total charge on the plates is kept constant)

$$\Delta V = \frac{1}{\varepsilon}\Delta V_{free} \quad (9)$$

as a result, one obtains from the definition of capacitance (5):

$$C = \epsilon . C_{free} \quad (10)$$

The general form of equation (5) is thus:

$$Q = \epsilon . \epsilon_o . \frac{A}{d} . U_c \quad (11)$$

In figure 3, charge Q on the capacitor is plotted against the applied plate voltage U_c for comparison to the situation with and without plastic plate between the capacitor plates, all other conditions remaining unchanged: thus, for the same voltage, the amount of charge of the capacitor is significantly increased by the dielectric, in this example by a factor of 2.9. If the charges obtained with and without plastic (equations [5] and [11]) are divided by each other:

$$\frac{Q(plastic)}{Q(air)} = \epsilon \quad (12)$$

The obtained numerical value is the dielectric constant of the plastic.

Commercially manufactured capacitors typically use a solid dielectric material with high permittivity as the intervening medium between the stored positive and negative charges. This material is often referred to in technical contexts as the "capacitor dielectric".

The most obvious ***advantage of using such a dielectric material*** is that

1. It prevents the conducting plates on which the charges are stored from coming into direct electrical contact thus allow smaller plate separations and therefore higher capacitances.
2. It reduces the possibility of shorting out by sparking (more formally known as dielectric breakdown) during operation at high voltage
3. A high permittivity allows a greater charge to be stored at a given voltage. This can be seen by treating the case of a linear dielectric with permittivity ε and thickness d between two conducting plates with uniform charge density σ_ε.

   In this case the charge density is given by

$$\sigma_\epsilon = \epsilon \frac{V}{d}$$

   And the capacitance per unit area by

$$c = \frac{\sigma_\epsilon}{V} = \frac{\epsilon}{d}$$

From this, it can easily be seen that a larger ε leads to greater charge stored and thus greater capacitance.

Choosing a Dielectric

Dielectric materials used for capacitors are also chosen such that they are resistant to ionization. This allows the capacitor to operate at higher voltages before the insulating dielectric ionizes and begins to allow undesirable current.

A **low-k dielectric** is a dielectric that has a low permittivity, or low ability to polarize and hold charge. Low-k dielectrics are very good insulators for isolating signal-carrying conductors from each other. Thus, low-k dielectrics are a necessity in very dense multi-layered IC's, wherein coupling between very close metal lines need to be suppressed to prevent degradation in device performance.

A **high-k dielectric**, on the other hand, has a high permittivity. Because high-k dielectrics are good at holding charge, they are the preferred dielectric for capacitors. High-k dielectrics are also used in memory cells that store digital data in the form of charge.

Applications

- Dielectric materials can be solids (glass, porcelain and most plastics), liquids (Mineral oil), or gases(Air, nitrogen and sulfur hexafluoride). In addition, a high vacuum can also be a useful, lossless dielectric even though its relative dielectric constant is only unity.
- Mineral oil is used extensively inside electrical transformers as a fluid dielectric and to assist in cooling. Dielectric fluids with higher dielectric constants, such as electrical grade castor oil, are often used in high voltage capacitors to prevent corona discharge and increase capacitance.
- Some ionic crystals and polymer dielectrics exhibit a spontaneous dipole moment which can be reversed by an externally applied electric field. This behavior is called the ferroelectric effect. These materials are analogous to the way ferromagnetic materials behave within an externally applied magnetic field. Ferroelectric materials often have very high dielectric constants, making them quite useful for capacitors.
- Specially processed dielectrics, called electrets (which should not be confused with ferroelectrics), may retain excess internal charge or "frozen in" polarization. Electrets have a semi-permanent external electric field, and are the electrostatic equivalent to magnets. Electrets have numerous practical applications in the home and industry.
- Since the dielectrics resist the flow of electricity, the surface of a dielectric may retain *stranded* excess electrical charges. This may occur accidentally when the dielectric is rubbed (the triboelectric effect). This can be useful, as in a Van de Graaff generator or electrophorus, or it can be potentially destructive as in the case of electrostatic discharge.
- Some dielectrics can generate a potential difference when subjected to mechanical stress, or change physical shape if an external voltage is applied across the material. This property is called piezoelectricity. Piezoelectric materials are another class of very useful dielectrics in various applications such as touch screens.
- A *dielectric resonator oscillator* (DRO) is an electronic component that exhibits resonance for a narrow range of frequencies, generally in the microwave band. Such

resonators are often used to provide a frequency reference in an oscillator circuit. An unshielded dielectric resonator can be used as a Dielectric Resonator Antenna (DRA). All antennas use dielectrics. The value of the dielectric constant is critical for correct design of an antenna. Dielectric Resonator Antenna (DRA) also has qualities useful in creating antenna arrays.

- Use of dielectrics in fabrication of capacitors, filtering out noise from signals as part of a resonant circuit and in a camera flash system.
- The phenomenon of dielectric breakdown is utilized in cigarette lighters where a spark must be produced in order to ignite the fuel.
- Another major application of Dielectric materials is in semiconductor chips to insulate transistors from each other. Dielectric materials are also used in various other electrical and electronic components.
- In the mid-1990s, the microelectronics industry has innovated high- and low-k dielectrics (k is the dielectric constant of a material) for continuing reduction of both horizontal and vertical dimensions of integrated circuits (ICs). Due to use of low k material the gate leakage current and heat dissipation can be brought down.
- A major use of dielectrics is in fabricating capacitors. These have many uses including storage of energy in the electric field between the plates, filtering out noise from signals as part of a resonant circuit, and supplying a burst of power to another component. The larger the dielectric constant, the more charge the capacitor can store in a given field, therefore ceramics with non-centrosymmetric structures, such as the titanates of group II metals, are commonly used. In practice, the material in a capacitor is in fact often a mixture of several such ceramics. This is due to the variation of the dielectric constant with temperature. It is generally desirable for the capacitance to be relatively independent of temperature; therefore, modern capacitors combine several materials with different temperature dependences, resulting in a capacitance that shows only small, approximately linear temperature-related variations.
- High electrical resistivity and low dielectric loss are the desirable properties for electrical insulation. Such dielectrics are used for insulation of wires, cables etc. Similar

property of dielectric makes them useful for sensor device e.g. a strain gauge sensor can be made by evaporating a small amount of metal onto the surface of a thin sheet of dielectric material as shown in figure below. Electrons may travel across the metal by normal conduction and through the intervening dielectric material by a phenomenon known as quantum tunneling. Tunneling in simple words is a process that allows particles to travel between two "permitted" regions that are separated by a "forbidden" region. The extent to which tunneling occurs decreases sharply as distance between the permitted regions increases (In this case the permitted regions are the solidified metal droplets, and the forbidden region is the high-resistance dielectric material). If the dielectric material is strained, it will bow causing the distances between the metal islands to change. This has a large impact on the extent to which electrons can tunnel between the islands, and thus a large change in current is observed. Therefore, the above device makes an effective strain gauge.

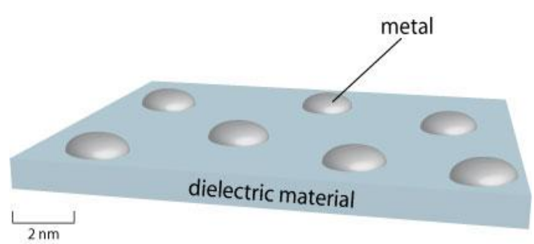


Figure: Strain Guage sensor using dielectric material.

- The dielectric constant of a material and its refractive index are closely linked by the equation $\kappa = n^2$. Materials with high dielectric constant will have high refractive index. Such materials are good option for the fabrication of waveguides supporting TE (transverse electric) and TM (transverse magnetic) modes like a more conventional hollow metallic waveguide. Like the metallic waveguide, if the dielectric waveguide is truncated, standing waves will exist and it will behave as a resonant cavity.

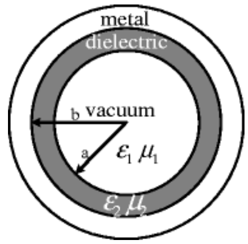


Figure: A schematic for use of dielectric layer in waveguide.

- All antennas use dielectrics. The value of the dielectric constant is critical for correct design of an antenna. If the dielectric constant is different, the antenna resonant frequency will change. For many antennas, it is critical to have known, consistent dielectric materials. A dielectric resonator when not enclosed by metal can be an efficient dielectric constant of the laminate material is key to determining the etch pattern. Higher dielectric constants will shrink the needed circuit size, enabling lower overall size and weight. antenna with wider bandwidth than comparably sized patch antennas. Dielectric Resonator Antenna (DRA) also has qualities useful in creating antenna arrays.
- Dielectrics are used as circuit board laminates. The laminate is plated with a conductive material on two sides. One side serves as the ground plane while circuit pathways are etched into the other side.
- **Dual-probe** capacitance level sensors can also be used to sense the interface between two immiscible liquids with substantially different dielectric constants. It is also used in the dielectric spectroscopy used for analyzing composition
- The capacitive level sensor used for wide variety of solids, aqueous and organic liquids, and slurries. The technique is frequently referred as **RF** as radio frequency signals applied to the capacitance circuit. The sensors can be designed to sense material with dielectric constants as low as 1.1 (coke and fly ash) and as high as 88 (water) or more. Sludges and slurries such as dehydrated cake and sewage slurry (dielectric constant approx. 50) and liquid chemicals such as quicklime (dielectric constant approx. 90) can also be sensed.

- Barium titanate shows dielectric properties and that's why it is very important in the field of metallurgy. It is a dielectric ceramic used for capacitors. It is a piezoelectric material for microphones and other transducers. As a piezoelectric material, it was largely replaced by lead zirconate titanate, also known as PZT. The dielectric properties of Barium titanate can be enhanced by sintering.
- Barium titanate is coated on different types of steels in order to increase micro hardness and corrosion resistance.
- Dielectric are used as coating media to prevent corrosion, e.g., parylene is used for coating purpose that provides a dielectric potential barrier between substrate and its environment hence prevent parts from corrosion.
- Niobium and niobium oxides are also emerging as dielectric materials used in the field of metallurgy and materials engineering to improved creep resistance and avoid failures due to creep.
- Determining oil quality usually requires complex laboratory equipment to measure the viscosity, refractive index, density, base number (BN), acid number (AN), water content, metals (additives and wear metals), color and flash point. However, the dielectric constant is another important indicator of oil quality that is easy to measure on-site. When the dielectric constant of lubricating oil is measured, changes in the dielectric constant of the used oil compared to new oil may indicate the presence of contaminants, such as water or particles, or changes in chemistry of the oil such as additive depletion or oxidation.

The dielectric constant of a material is a measure of its ability to transmit electrical potential energy. In electrical systems such as capacitors, the effectiveness of dielectrics is measured by their ability to store energy. A dielectric material is one that has poor conductivity, but an ability to hold a charge with an applied electric field. The dielectric constant is a simple number that is the relative ratio of the speed of an electric field in a material compared to the speed of the electric field in a vacuum. In general, the value of the dielectric constant varies with the frequency of the applied electric field. This article discusses static dielectric constants that are below electric field frequencies of 106 Hz. Dielectric constants at these frequencies are called static because the dielectric constant of materials shows virtually no frequency dependence in this frequency region.

Temperature also affects the value of the dielectric constant although the effects are relatively small for hydrocarbon lubrication oils. The typical decrease in dielectric constant for hydrocarbon oils is about 0.0013 or 0.05 percent per degree Celsius. The density of the oil also influences the dependence of the dielectric constant on temperature - the less dense an oil, the fewer number of oil molecules per unit volume. A smaller number of molecules per unit volume mean that there is less interaction with the electric fields and therefore a decrease in the dielectric constant. As the temperature increases, the density decreases and hence the dielectric constant of the oil also decreases.

- The dielectric behavior of earth materials can be observed through GPR. Ground penetrating radar (GPR) is a geophysical method that has been developed for sub surface investigations of the earth. GPR uses electromagnetic waves (generally 10 MHz to 1,000 MHz) to acquire subsurface information. Energy is propagated downward into the ground and is reflected back to the surface from boundaries. GPR has been used to aid in geologic investigations. GPR response is a function of the following electromagnetic properties:

- Dielectric permittivity
- Magnetic permeability
- Electrical conductivity

- Mica is a common earth material. It is a sheet silicate mineral commonly occurs as flakes. It is widely used as a dielectric having the dielectric constant 6.4. Mica is stable when exposed to electricity, light, moisture, and extreme temperatures. The principal use of mica is in gypsum wallboard joint compound, where it acts as a filler and prevents cracking.

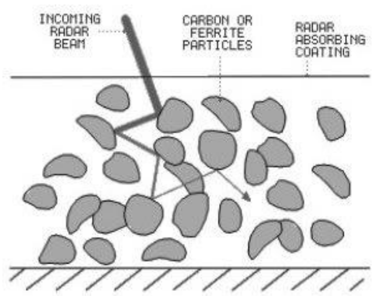
- In the paint industry mica prevents shrinkage of the paint film, provides increased resistance to water penetration and weathering, and brightens the tone of colored pigments.
- Sheet mica is used principally in the electronic and electrical industries. The major uses of sheet and block mica are as electrical insulators in electronic equipment, thermal insulation, kerosene heaters, dielectrics in capacitors, decorative panels in lamps and windows, insulation in electric motors.
- On the basis of different values of Dielectric Constants minerals can be separated from gangue.

  Method: Hatfield and Holman developed a method with which a gangue of 160 minerals has been separated successfully on the basis of different dielectric constant. The gangue of minerals was mixed in nitrobenzene and lamp-oil. Current from 110 volts, 60 cycles A.C. circuit was transformed to 220 volts by a small step-up transformer of low current capacity. All determinations were performed using the 60 cycles frequency. A 2000 ohms resistance was connected in series with the transformer and the current was carried to two needles mounted so that the points, bent facing each other, were 1 mm apart. The resistance serves the purpose of preventing burning the needles because a conducting mineral grain can be encountered. A snap switch was included in the line.

  The principle used in the dielectric separation of mineral powders depends upon the fact that the grains will be attracted to the needlepoints when immersed in a liquid of lower value of dielectric constant than the e of the mineral grain. Conversely, the grains will be repelled from the needles when the liquid is of higher value of dielectric constant. Since Dielectric Constant is the ratio of the permittivity of a substance to the permittivity of free space. It is an expression of the extent to which a material concentrates electric flux.
- Consumer electrical devices such as portable music players and notebook /desktop computers, processors, fans and tube lights require valid voltage to guarantee normal operations, usually provided by voltage-altering converters. System designers often see

challenges in designing capacitor arrays to be implemented on. System designers must take precautionary measures in taking sufficient capacitance, resulting in valid voltage, is causing stable operations of loads otherwise they are simply wasting component cost and PCB area by implementing surplus capacitance, therefore raising a unit cost of consumer device unnecessarily.

- The dielectric shielding is the reduction of an electric field in some region or in devices by interposing a dielectric substance (a thin layer of material with high relative permittivity compared to its surroundings, such as polystyrene, glass, or mica.
- Dielectric materials are used for radar camouflage now a day as radar absorber materials (RAM) which depends upon the magnetic permeability (μ) or dielectric permittivity (ε) of materials to provide EM impedance matching at the outer surface and dissipation of energy internally. Only magnetic ceramics are expected to be useful in suppression of near field radio & microwave interference. For designing of such environment friendly materials required combination is dielectric constant **ε=1-20** with permittivity **μ > 1**.



- High k dielectric materials can fulfill temperature requirements in air crafts, to avoid highly ionizing conditions at high altitude imposed during high speed flights also called corona resistant materials. Corona resistant materials depends upon intensity, duration, time, surface conduction and charge distribution on the insulation corona discharge, the environmental medium, its pressure & flow, chemical nature of insulating material itself.
- The minerals containing salt water, clay or metallic minerals conduct current. While the minerals containing fluids such as oil or gas does not allow current to pass through

them. Therefore, this conductivity differences can be used to distinguish between oil and water-saturated mines.

- Most capacitors are designed to maintain a fixed physical structure. The effects of varying the characteristics of the **dielectric** can be used for sensing purposes. Capacitors with an exposed and porous dielectric can be used to measure humidity in air. Capacitors are used to accurately measure the fuel level in airplanes; as the fuel covers more of a pair of plates, the circuit capacitance increases.

VIVA VOCE

Q.1 Define capacitance.

Ans. In electromagnetism and electronics, capacitance is the ability of a body to hold an electrical charge. Capacitance is also a measure of the amount of electric potential energy stored (or separated) for a given electric potential.

Q.2 What is equivalent capacitance in series combination?

Ans. It is defined as the capacitance of a single capacitor which stores the same charge as is stored by the combination of capacitors.

Q.3 A capacitor has a label on it saying, "100 WVDC". What does this label mean?

Ans. WVDC stands for "working voltage direct current" and 100WVDC means the capacitor's working voltage is 100 volts DC.

Q.4 What is the consequence of exceeding this rating (e.g.100WVDC)?

Ans. Failure of the dielectric material will result from exceeding this voltage rating. In electrolytic capacitors especially, the failure can be violent!

Q.5 A 10 μF capacitor is charged to a voltage of 20 volts. How many coulombs of electric charge are stored in this capacitor?

Ans. 200 μC of charge.

Q.6 Does a capacitor's opposition to alternating current increase or decrease as the frequency of that current increase? Also, explain why we refer to this opposition of AC current in a capacitor as reactance instead of resistance.

Ans. The opposition to AC current ("reactance") of a capacitor decreases as frequency increases. We refer to this opposition as "reactance" rather than "resistance" because it is non-dissipative in nature. In other words, reactance causes no power to leave the circuit.

Q.7 What are the differences between voltage and current controlled devices?

Ans. In any (electronic) device controlling parameter is current it is called current controlled device, e.g. bipolar transistor- output current is a function of base current. In any (electronic) device controlling parameter is voltage it is called voltage controlled device, e.g. Field effect transistor- output current is a function of gate voltage. It depends on the inherent physical mechanism which defines the primary (independent) controlling parameter.

Q.8 What is meant by dielectric strength?

Ans. The maximum electric field a material can withstand without the occurrence of breakdown is called its dielectric strength.

Q.9 What happened when dielectric break down occur?

Ans. An insulator starts conduction.

Q.10 What is triboelectric effect?

Ans. It is a type of contact electrification in which certain materials become electrically charged after they come into contact with another different material and are then separated (such as through rubbing).

Q.11 What is stray capacitance?

Ans. Any two adjacent conductors can be considered a capacitor, although the capacitance will be small unless the conductors are close together for long. This (often unwanted) effect is termed "stray capacitance".

Q.12 Why stray capacitance is not required in electrical circuits?

Ans. Stray capacitance can allow signals to leak between otherwise isolated circuits (an effect called crosstalk), and it can be a limiting factor for proper functioning of high frequency circuits.

Q.13 What are passive components in electronic circuits?

Ans. The components which do not have gain or directionality. In network analysis, they are called electrical elements. Resistors, capacitors, inductors, transformers, and even diodes are all considered passive devices.

Q.14 What are active components in electronics circuits?

Ans. Those components that have gain or directionality, in contrast to passive components, which have neither. They include semiconductor devices and vacuum tubes, transistors, silicon-controlled rectifiers.

Q.15 What is capacitive reactance?

Ans. Capacitive reactance (symbol X_c) is a measure of a capacitor's opposition to AC (alternating current). It is measured in ohms, Ω, its value depends on the frequency (f) of the electrical signal passing through the capacitor as well as on the capacitance, C. ($X_c = 1/2\pi fC$).

Q.16 What is meant by time constant of capacitor?

Ans. The time required to charge the capacitor, through the resistor, to 63.2 %(≈ 63 %) of full charge; or to discharge it to 36.8 (≈ 37) percent of its initial voltage. In an RC circuit, the value of the time constant (in seconds) is equal to the product of the circuit resistance (in ohms) and the circuit capacitance (in farads), i.e. $\tau = R \times C$.

Q.17 What is Dielectric constant?

Ans. The characteristic of a dielectric that describes its ability to store electric energy is called dielectric constant. Air is used as reference and is given a value of one. Mica can store six times as much energy for given dimensions as air; hence mica has dielectric constant of six.

Experiment 5

To Study the Temperature Dependence of the Resistance of Different Electrical Components

EXPERIMENT 5

To Study the Temperature Dependence of the Resistance of Different Electrical Components

Objectives

1. To find the resistance of electrical components at different temperature values.
2. Calculation of temperature coefficient for each electrical component.

Related concepts

Carbon film resistor, metallic film resistor, PTC, NTC, charge carrier generation, free path.

Apparatus

- Immersion probe
- Immersion thermostat TC10
- Accessory set for TC10
- Bath for thermostat, Makrolon
- Multirange Meter
- Connecting cables

Experimental Arrangement

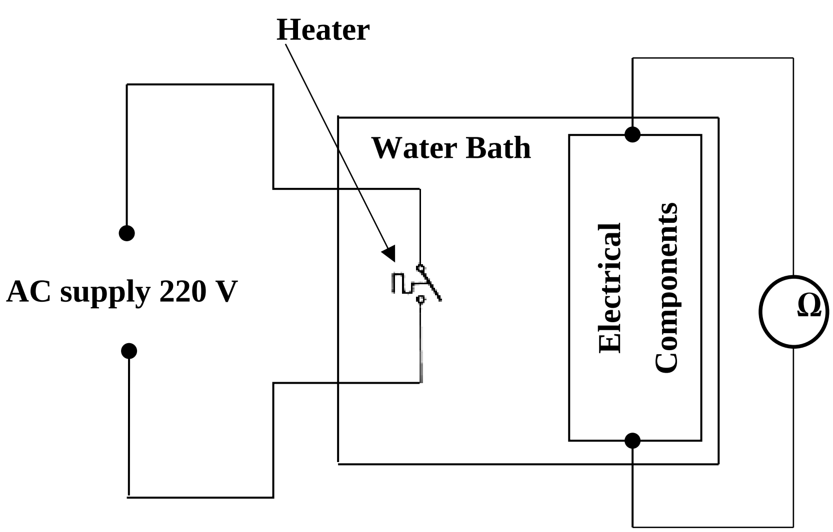


Figure 1: Circuit diagram of resistance measurement setup.

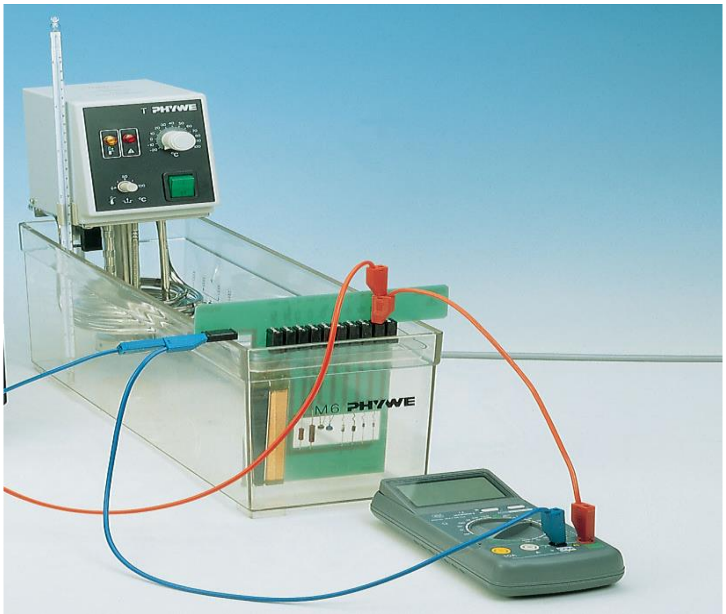


Figure 2: Photographic view of experimental setup

Procedure

1. Make the experimental arrangement as shown in figure 1 and figure 2.
2. Place the immersion probe set, enclosed in a watertight plastic bag, into the water bath.
3. Connect the digital multimeter parallel to the electrical component whose resistance is to be measured.
4. Measure the resistance values for the PTC, NTC, Cu, CuNi, Carbon film resistor (C) and metallic film resistor (Met) directly with the digital multimeter at regular temperature intervals.

For taking reading:

i. Set the temperature, from thermostat variable knob at which resistance of electrical component has to be measured.

ii. Note down the resistance value when thermometer will show exact set value of temperature.

iii. Repeat experimental steps (ii) and (iii) to take next readings of all electrical components.

iv. To take next reading, reset the thermostat at next higher value of temperature then again note down the resistance value when thermometer will show exact set value of temperature.

v. Repeat the procedure at different temperatures and complete Table 1.

5. Calculate temperature coefficient using the values of resistance in Table 1 and formula given below:

$$\mathrm{R}(T) = \mathrm{R}(T_0)(1 + \alpha \Delta T)$$

6. Plot resistance values as a function of temperature.

Precautions

1. Do not immerse the immersion probe set in water without its protective plastic bag.
2. The plastic bag should fit as tightly as possible around the immersion probe set.
3. Press out the air from the protective plastic bag before immersing the probe set.

Observations and Calculations

Operating temperature range: 25–70 ^{o}C

Table 1: Resistance of electrical components as a function of temperature.

Sr. No.	**Temperature T (^{o}C)**	**Resistance (Ω)**					
		CuNi	**Cu**	**C**	**Met**	**NTC**	**PTC**
1	25						
2	30						
3	35						
4	40						
5	45						
6	50						
7	55						
8	60						
9	65						
10	70						

Table 2: Temperature coefficient of electrical components.

Sr. No.	Electrical Component	Temperature coefficient (α)
1	PTC	
2	NTC	
3	Cu	
4	CuNi	
5	Met	
6	C	

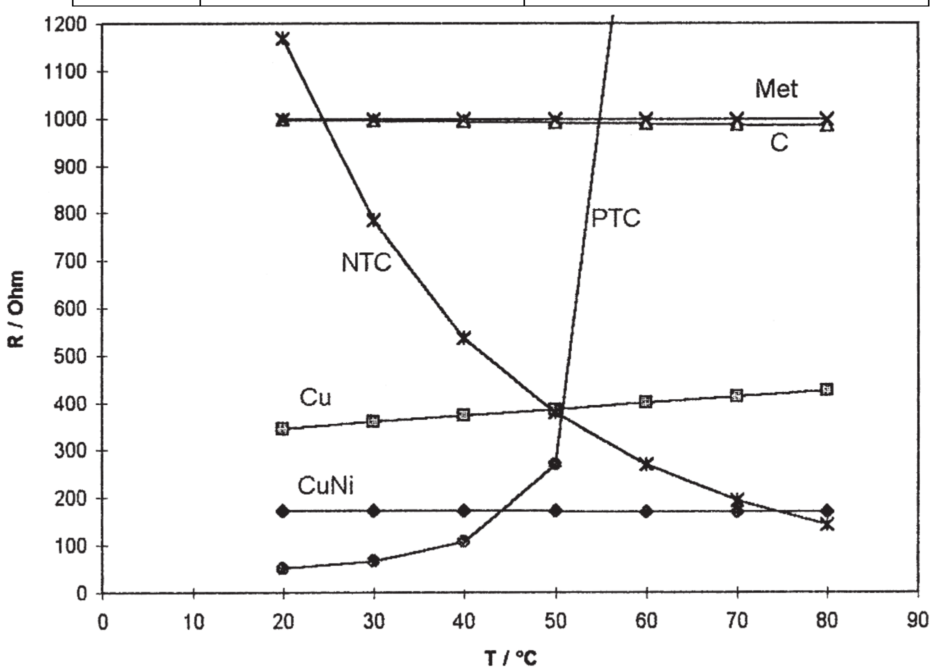


Figure 3: Resistance of some materials and components as a function of temperature.

Theory

In restricted temperature ranges the change in the resistance of the electrical components can be assumed to be linear. In these regions, the general formula for the dependence of the resistance on the temperature is valid

$$\mathrm{R}(T) = \mathrm{R}(T_0)(1 + \alpha\Delta T)$$

Where

R(T) = Resistance at temperature T

$R(T_0)$ = Resistance at temperature T_0

ΔT = Difference between T and T_0

α = Temperature coefficient

T = Temperature at time of measurement

By rearranging and substituting the measured values the temperature coefficient can be determined using the above formula.

The unit of temperature coefficient is K^{-1}.

Bimetallic Thermostat

Function

Thermostat is a device which is used to maintain a desired temperature in a system like refrigerator, air-conditioner, iron and in a number of devices.

Principle

Thermostat works on the principle of thermal expansion of solid materials.

Construction

A bimetallic thermostat device consists of a strip of two different metals having different coefficients of linear expansion. The bimetallic strip works as an electric contact breaker in an electric heating circuit. The circuit is broken when the desired temperature is reached, due to the difference in the coefficients of linear expansion of two metals. The bimetallic strip bends in the form of a downward curve and the circuit is broken. The metallic strip is in contact with a screw.

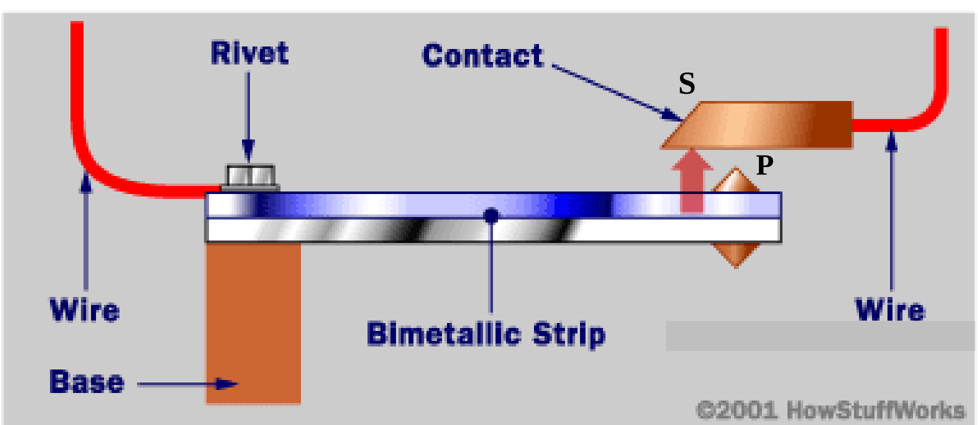


Figure 4. Bimetallic Thermostat.

When it becomes hot, bends downward and contact at '**P**' is broken. Thus, the current stops flowing through the heating coil. When the temperature falls, the strip contracts and the contact at '**P**' is restored.

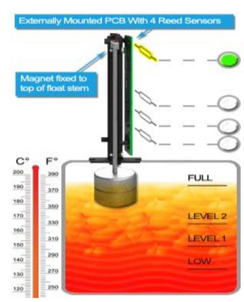
Applications

- In a temperature-controlled water bath, using the immersion probe system, different properties (resistance of conductors (metals), resistance of semi-conductors, diode threshold voltage (Si, Ge), diode blocking and conducting state voltage (Si, Ge), Z voltage for the zener effect, Z voltage by the avalanche effect) can be measured as a function of the temperature (up to approximately 100° C) of the immersion probe.
- Bimetallic thermostats are widely used in numerous appliances over a wide temperature range such as refrigerator, air conditioners, Iron, ice plants etc.
- Bimetallic strip functions as a circuit breaker relay that indirectly cuts the power of the equipment.
- Electric rice cooker, Electric pot, Hot plate, Inhaler, Humidifying device, General heater, Antifreeze, Fax machine, Copy machine, Portable compact iron, Aromatic instrument, Bath dryer, Clothes dryer, Futon dryer, Dish dryer, Hot-air heater, Auxiliary heater and many electrical appliances are the important applications.
- PTC thermistors are used in electronic lamp ballasts and switch-mode power supplies for delayed switching, and to degauss shadow masks in picture tubes.
- Special motor starter PTC thermistors are used in the compressors of refrigerators for instance.
- Thermal protection of motors and transformers (Eco friendly) is another example of the versatility of PTC thermistors. The applications extend to measurement and control engineering, to entertainment, household and automotive electronics, plus data systems and telecommunications.
- PTC thermistors are also suitable as self-regulating heating elements, in auxiliary heating, nozzle heating and carburetor preheating in automobiles, as well as in many

domestic appliances such as door locks for washing machines, or glue guns and hair curlers.

- PTC pills (pellets) are mounted in an aluminum radiator that is suitable for air heating. The power and the temperature can be easily adjusted by varying the speed of the fan that blows air over the radiator. Also, its power characteristics will change with changes in ambient temperature.
- NTC are suited to temperature sensing for various applications including thermoelectric coolers (tec). Some IC manufacturers include a p-n junction embedded in the IC package for use as a local sensor. Other manufacturers allow the use of a p-n junction in a discrete package for remote temperature sensing. The usual resolution that can be achieved using a p-n type semiconductor sensor is in the region of ± 1 to $\pm 2\,^{o}C$. However, the use of an NTC thermistor device as a temperature sensor allows resolutions of ± 0.1 to $\pm 0.2\,^{o}C$ to be easily achieved.
- The high sensitivity of NTC thermistor sensors combined with the availability of tight resistance tolerances makes them the ideal choice when designing temperature control systems.
- Materials with a negative temperature coefficient have been used in floor heating since 1971. The negative temperature coefficient avoids excessive local heating beneath carpets, bean bag chairs, mattresses etc., which can damage wooden floors, and may infrequently cause fires.
- Carbon film resistors are suitable to withstand high energy pulses, while having a relatively small size. For this reason, the carbon film resistors are used in various applications. Applications include protection of circuits, current limiting, television and other high-volume product, operational amplifiers, logic gates, analog to digital and digital to analog converters, telecommunications, household appliances, automotive, computer, high voltage power supplies and welding controls.
- The varying resistance helps in the identification of the materials like insulators, metals, semiconductors.

- This experiment helps in the choosing materials for the fabrication of different type temperature sensors. As during chemical reactions different temperature are required therefore a single material cannot be used to monitor all temperature at the same time since each resistance of each material varies in different proportion with rise of temperature.
- Polycrystalline barium titanate displays positive temperature coefficient, making it a useful material for thermistors and self-regulating electric heating systems.
- The positive temperature coefficient (PTC) over-current protector is connected in series with the load which is to be protected. When over current condition occurs, PTC switch into high resistance, limits the current flow to a point well below the normal. PTC for over-current protectors include protection of telephone line fault, transformer, transistor and speaker. PTC devices also specifically designed for self- regulating heater for constant temperature regardless of large fluctuations in ambient temperature or voltage applied such as temperature control of crystals, oscillators and liquid crystal displays (LCD’s).
- Copper-nickel **(Cu-Ni)** alloys are used in marines including seawater piping systems. Copper-nickel **(Cu-Ni)** alloys are the most economic to use due to their good resistance to corrosion and fouling (living & non-living organisms) over a range of flowing & static conditions and can tolerate heat at range of 800˚C to 900˚C.
- Negative Temperature Coefficient (NTC) thermistors are semiconductors, usually metal oxide ceramic such as manganese, nickel, cobalt, iron, copper and aluminum. In **Liquid level sensors,** the temperature thermistors depend on the medium surrounding the device. When the thermistor is immersed in a liquid the dissipation factor increases, the temperature decreases and the voltage lying across the NTC rises. Owing to this effect NTC thermistors are able to sense the presence or absence of a liquid. The NTC must be carefully selected w.r.t to resistivity against liquids to be detected.



- Carbon/carbon composites are considered high performance engineering materials with potential application in high temperature industries. In general engineering sectors, these are used in designing of engine components, refractory materials, heating elements (high temperature fasteners), liners & protection tubes, glass industries and in energy sectors as polar plates for fuel cells (storage batteries etc.).

- **Resistivity logging** is a method of well logging that works by characterizing the rock or sediment in a borehole by measuring its electrical resistivity. Resistivity is a fundamental material property which represents how strongly a material opposes the flow of electric current. In these logs, resistivity is measured using 4 electrical probes to eliminate the resistance of the contact leads. The log must run in holes containing electrically conductive mud or water.Resistivity logging is sometimes used in mineral exploration and water-well drilling, but most commonly for formation evaluation in oil- and gas-well drilling. Most rock materials are essentially insulators, while their enclosed fluids are conductors. Hydrocarbon fluids are an exception, because they are almost infinitely resistive. When a formation is porous and contains salty water, the overall resistivity will be low. When the formation contains hydrocarbon, or contains very low porosity, its resistivity will be high. High resistivity values may indicate a hydrocarbon bearing formation.

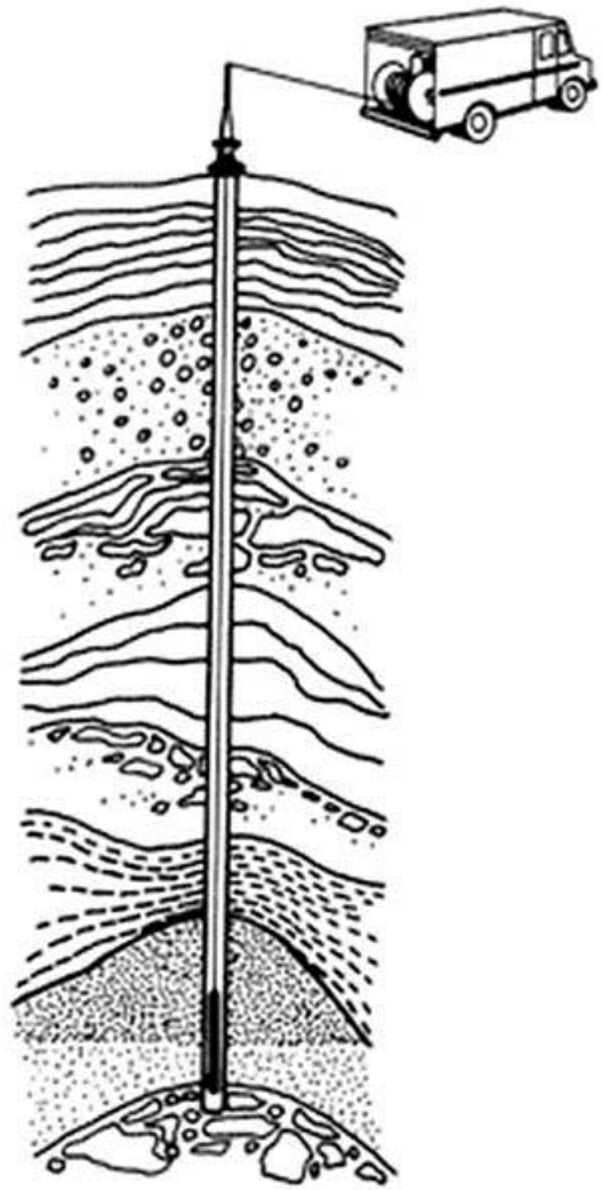


Figure 5: Schematic diagram of well logging using wire during hole drilling.

Usually while drilling, drilling fluids invade the formation, changes in the resistivity are measured by the tool in the invaded zone. For this reason, several resistivity tools with different investigation lengths are used to measure the formation resistivity. If water based mud is used and oil is displaced, "deeper" resistivity logs (or those of the "virgin zone") will show lower conductivity than the invaded zone. If oil based mud is used and water is displaced, deeper logs will show higher conductivity than the invaded zone. This provides not only an indication of the fluids present, but also, at least quantitatively, whether the formation is permeable or not.

- NTC and PTC materials are fabricated in Bole-hole sensors. During extraction of coal and hydrocarbons, as they are buried under high temperature and pressure so upon exposure by a drill, sudden change in temperature and pressure occurs, which may result the bore-blast of expensive oil rigs. Bore-hole sensors can control and monitor the temperature change, thus safely extracts them.
- Electrically heated thermostats are well shielded and designed user friendly in order to avoid any electrical shock.
- Many devices are molded out of an epoxy plastic that provides adequate protection of the semiconductor device, and mechanical strength to support the leads and handling of the package. Some devices, intended for high-reliability or aerospace or radiation environments, use ceramic packages, with metal lids that are brazed on after assembly, or a glass frit (a ceramic composition that has been fused in a special fusing oven, quenched to form a glass, and granulated). All-metal packages are often used with high power (several watts or more) devices, since they conduct heat well and allow for easy assembly to a heat sink. Often the package forms one contact for the semiconductor device. Lead materials must be chosen with a thermal coefficient of expansion to match the package material.

VIVA VOCE

Q.1 What are the carbon film resistors?

Ans. Carbon composition resistors consist of a solid cylindrical resistive element (Higher concentrations of carbon, a weak conductor, these resistors, however, if never subjected to overvoltage nor overheating were remarkably reliable considering the components size.) with embedded wire leads or metal end caps to which the lead wires are attached. The body of the resistor is protected with paint or plastic.

Q.2 What are the metal film resistors?

Ans. A common type of axial resistor is referred to as a metal-film resistor. Metal film resistors are usually coated with nickel chromium (NiCr). These resistors have a reasonable tolerance (0.5, 1, or 2%) and a temperature coefficient that is generally between 50 and 100 ppm/K. Metal film resistors possess good noise characteristics and low non-linearity due to a low voltage coefficient. Also beneficial are the components efficient tolerance, temperature coefficient and stability.

Q.3 Define Temperature Coefficient.

Ans. It is the relative change of a physical property e.g. resistance, when the temperature is changed by 1 K.

$$\mathrm{R}(T) = \mathrm{R}(T_0)(1 + \alpha\Delta T)$$

R is the physical property to be measured and T is the temperature at which the property is measured. T_0 is the reference temperature, and ΔT is the difference between T and T_0. **α** is the (linear) temperature coefficient. The unit of temperature coefficient is K^{-1}.

Q.4 Define Positive temperature coefficient.

Ans. A positive temperature coefficient (PTC) refers to materials that experience an increase in electrical resistance when their temperature is raised. Materials which have useful engineering applications usually show a relatively rapid increase in resistance with temperature, i.e. a higher coefficient. The higher the coefficient, the greater an increase in electrical resistance for a given temperature increase.

Q.5 Define Negative temperature coefficient.

Ans. A negative temperature coefficient (NTC) occurs when the thermal conductivity of a material rises with increasing temperature, typically in a defined temperature range. Most ceramics exhibit NTC behavior.

Q.6 What is Zener Diode?

Ans. A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as Zener voltage. Zener diodes are just heavily doped normal diodes that exploit the breakdown voltage of a diode to provide regulation of voltage levels.

Q.7 At what conditions Zener diode shows both NTC and PTC behavior?

Ans. In silicon diodes up to about 5.6 volts, the Zener effect is the predominant effect and shows a marked negative temperature coefficient. Above 5.6 volts, the avalanche effect becomes predominant and exhibits a positive temperature coefficient. In a 5.6 V diode, the two effects occur together and their temperature coefficients neatly cancel each other out, thus 5.6 V diode is the component of choice in temperature-critical applications.

Q.8 Explain microscopically, the dependence of resistivity upon temperature.

Ans. Electrical resistance of a conductor is dependent upon collisional processes within the wire, the resistance increase with temperature since there will be more collisions among electrons and atoms of the conductor. The temperature dependence of resistivity at temperatures around room temperature is characterized by a linear increase with temperature. Microscopic examination of the conductivity shows it to be proportional to the mean free path between collisions.

Q.9 Why the resistivity remains constant at low temperature?

Ans. At extremely low temperatures, the mean free path is dominated by impurities or defects in the material and becomes almost constant with temperature. With sufficient purity, some metals exhibit a transition to a superconducting state, e.g. resistivity of mercury suddenly dropped to zero at 4.2K, a phase transition to a zero-resistance state.

Q.10 What is Thermostat?

Ans. Thermostat is a device which is used to maintain a desired temperature in a system like refrigerator, air-conditioner, iron and in a number of devices. Thermostat works on the principle of thermal expansion of solid materials.

Q.11 What is the working of a thermostat?

Ans. The bimetallic strip works as an electric contact breaker in an electric heating circuit. The circuit is broken when the desired temperature is reached. The bimetallic strip bends in the form of a downward curve due to the difference in coefficients of linear expansion of two metals and the circuit is broken. When the temperature falls, the strip contracts and the contact is restored.

Q.12 What are bimetallic strips?

Ans. A bimetallic strip consists of two strips of different materials but of equal length. These two strips are riveted together at different points along their lengths such that they cannot slip sideways.

Q.13 How is a bimetallic strip made?

Ans. A bimetallic strip consists of a strip of two different metals having different coefficients of linear expansion. Normally, a bimetallic strip is made of brass on one side and steel on the other. Typically, a welding process is used for bonding, but rivets, bolts, adhesive and other fasteners can also be used.

Q.14 Why bimetallic strips bend?

Ans. **On heating** the strip, the metal having the higher coefficient of linear expansion expands more than the other metal and therefore the strip bends. The bending is such that the strip is concave on the side of the metal of low coefficient of expansion and convex on the side of the metal of large coefficient of expansion.

On cooling the strip, the reverse happens. Now, the metal having a higher coefficient of expansion contracts more and is therefore on the concave side while the metal of low coefficient of expansion contracts less and is on the convex side.

Q.15 Explain the working of thermostat (bimetallic) in electric irons.

Ans. Bimetallic in both refrigerator and electric iron is used as a thermostat, a device to sense the temperature of the surrounding and break the current circuit, if it goes beyond a set temperature point. Normally such bimetallic strips are in form of a coil to increase their sensitivity and a change in their length occurs in proportion to temperature, as they elongate they break the circuit. They are generally not put directly in the circuit but as a relay to control current.

Q.16 Which materials are used for bimetallic strips? Give some examples.

Ans. The materials are invar and brass or copper and steel for higher temperature range (thermostat, fire alarm) or for low temperature (20-120 K) use of bimetallic strip with vanadium or niobium (transition metal of group 5B) in combination with gallium, indium, silicon, germanium, tin, arsenic of group 3A, 4A or 5A. Basically any two metals or metalloid having substantially different coefficient of linear expansion joined (fused or amalgamated) together can be used as bimetallic strips.

Q.17 Define coefficient of linear expansion.

Ans. The coefficient of linear expansion is a proportionality constant that determines the rate of change in length in different materials when they are heated and cooled.

$$\frac{\Delta L}{L} = \alpha_L \Delta T$$

Where

α_L = coefficient of linear expansion

Q.18 Why water is used in Mekrolon, a heating bath for thermostat?

Ans. Water is the only available liquid with high thermal conductivity and high heat capacity (both for cooling and heating).

Q.19 What is mercury-in-glass thermometer?

Ans. A mercury-in-glass thermometer (a Practical example of thermal expansion), invented by German physicist Daniel Gabriel Fahrenheit, is a thermometer consisting of mercury in a glass tube.

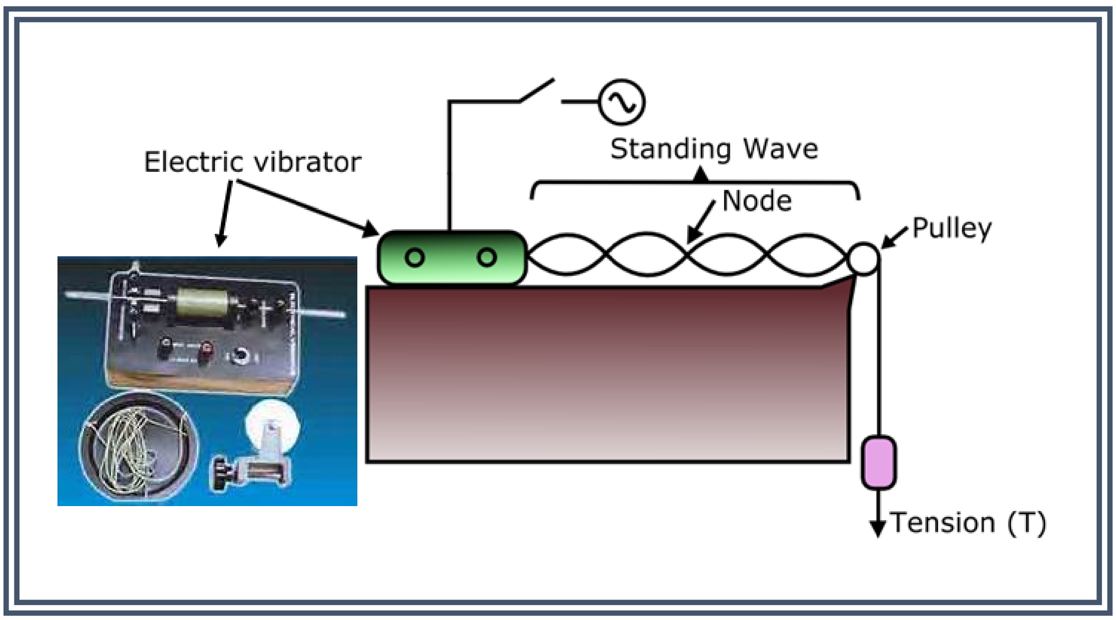
A mercury-in-glass thermometer is also temperature dependent because mercury used in it expands and contracts at temperature variations. Some manufacturers use galinstan, a liquid alloy of gallium, indium, and tin, as a replacement for mercury.

Q.20 How the air conditioner thermostats regulate the heating/cooling system?

Ans. An air conditioning thermostat generally has an external switch for heat/off/cool. Thermostat, when set to "cool", will only turn on when the ambient temperature of the surrounding room is above the set temperature. Thus, if the controlled space has a temperature normally above the desired setting when the heating/cooling system is off, it would be wise to keep the thermostat set to "cool", despite what the temperature is outside. On the other hand, if the temperature of the controlled area falls below the desired degree, then it is advisable to turn the thermostat to "heat".

Experiment 6

To Determine the Frequency of A.C. Mains



EXPERIMENT 6

To Determine the Frequency of A.C. Mains

Objective

1. Calculate the frequency of A.C. mains by Melde's experiment through transverse arrangement.

Related Concepts

mechanical waves, stationary waves, alternating current, magnetic field

Apparatus

- Alternating Main Supply (220 V)
- Electric vibrator (solenoid, electric bulb, soft iron rod, permanent magnet)
- Thread
- Frictionless Pulley
- Electronic balance
- Meter scale
- Weight box

Experimental Arrangement

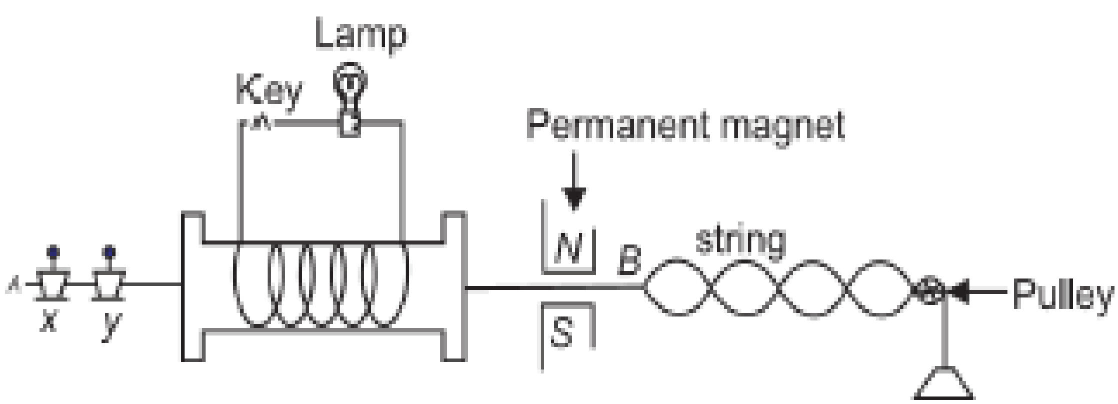


Figure 1: Experimental setup for generating standing wave pattern.

Procedure

1. Place an electric vibrator in the transverse position.

2. Take a uniform thread of one meter length and attach its one end to the point B of the rod and the other to a light pan.
3. Fix the rod at point A using screws x and y. Fix a pulley at one meter distance from the other end of the rod (that passes through poles of permanent magnet)
4. Note the mass of thread and pan by using electronic balance. Calculate mass per unit length of the thread. It is denoted by 'm'.
5. Make the thread straight by passing it over a frictionless pulley.
6. Connect the A.C. mains to the solenoid of an electric vibrator.
7. Fix the pulley and switch on the A.C current so that it passes through an electric vibrator. Thus, the changing magnetic field produces vibrations in the rod.
8. Add small weights in the pan such that the string vibrates in one loop with maximum amplitude under the forced vibrations of the rod.
9. Note the tension T (=weight of the pan + weights added to the pan) and measure the length *l* of the loop. By reducing the tension, the string is made to vibrate in two, three, four loops and so on.
10. Note the number of loops *p* formed in the length *L* of the thread. This gives the value of

$$l \text{ as } l = L/p.$$

11. Calculate the frequency of A.C. mains by using formula.

$$f = \frac{1}{2l}\sqrt{T/m}$$

Precautions

1. Pulley should be frictionless.
2. The loops formed in the thread should appear stationary.
3. Do not put too much load in the pan.
4. Pass the current for a short time.
5. Take accurate measurements of length and mass.

6. Do not apply DC power to this instrument. DC current will NOT cause the rod to vibrate and a larger than normal current may flow. This could cause excess heat and eventual damage to the instrument.

Observations and Calculations

Mass of the empty scale pan m_1 =……………………g.

Length of the thread =……………………………..cm

Mass of the thread =………………………………g

Mass per unit length of thread m =………………g/cm

No. of obs.	No. of loops **N**	Distance between two extreme nodes **L** (cm)	Length of each loop ***l* = L/N** (cm)	Mass added to the pan $\mathbf{m_2}$ (g)	Mass of pan m_1+Mass added m_2 $\mathbf{M=m_1+m_2}$ (g)	Tension in the thread **T=Mx981** (dynes)	Frequency of A.C. mains $f = \frac{1}{2l}\sqrt{T/m}$ (Hz)
1							
2							
3							

Mean frequency f =……………… (Hertz)

Standard result: Frequency of A.C. mains = ... cycles/sec.

Percentage error = ... %

Theory

An electric vibrator consists of a solenoid whose coil is connected to A.C. mains. The circuit includes a high resistance in the form of an electric bulb as shown in Fig1. A soft iron rod *AB* is placed along the axis of the solenoid, clamped near the end *A* with two screws *X* and *Y* while the end *B* is free to move. The rod is placed between the pole pieces of a permanent magnet *NS*. One end of the thread is attached to the end *B* and the other passes over a frictionless pulley and carries a weight. When an alternating current is passed in the coil of the solenoid, it produces an alternating magnetic field along the axis. The rod

AB gets magnetized with its polarity changing with the same frequency as that of the alternating current. The rod *AB* vibrates *n* times per second due to interaction of the magnetized rod with the permanent magnet. The tension in the string can be varied by placing different weights in the pan, stationary waves are produced due to the superposition of the direct waves sent by the strip and reflected waves from the pulley.

A wave is the propagation of a disturbance through a medium. The physical properties of that medium (*e.g.*, density and elasticity) will dictate how the wave travels within it. A wave may be described by its basic properties of amplitude, wavelength, frequency and period T. Figure 2 displays all of these properties. The amplitude, A, is the height of a crest or the depth of a trough of that wave. The wavelength λ is the distance between successive crests or successive troughs. The time required for a wave to travel one wavelength is called the period T. The frequency f is 1/T, and is defined as the number cycles (or crests) that pass a given point per unit time.

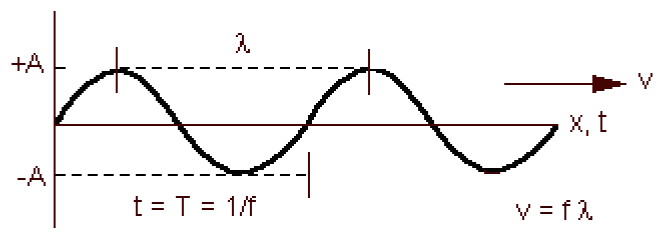


Figure 2: Properties of waves

Since the wave travels one wavelength in one period, the wave velocity is defined as.

The λ/T wave velocity can then be written as

$$v = \lambda f$$

when a vibrating body produces waves along a tightly stretched string, the waves are reflected at the end of the string which cause two oppositely traveling waves to exist on the string at the same time. These two waves interfere with each other, creating both constructive and destructive interference in the vibrating string. If the two waves have identical amplitudes, wavelengths and velocities, a standing wave, or stationary wave, is created. The constructive and destructive interference patterns caused by the superposition of the two waves create points of minimum displacement called nodes, or nodal points and points of maximum displacement called antinodes. If we define the distance between two nodes (or between two antinodes) to be L, then the wavelength of the standing wave is λ=2L. Figure 3 illustrates the case where the length of string vibrates with 5 nodes and 4 antinodes.

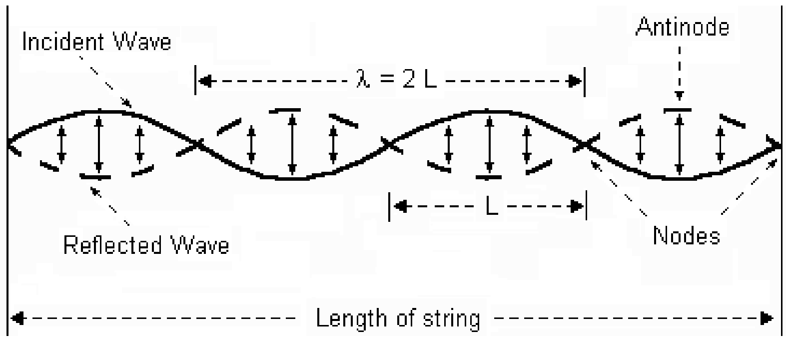


Figure 3. A standing wave is created when an incident and reflected wave have identical amplitudes, wavelengths and velocities.

It is possible to obtain many discrete vibrational modes in a stretched string. That is, for a string to vibrate with a specific wavelength, the tension applied to the string must have a certain value. It is possible for the string to vibrate with another specific wavelength, but the tension must be adjusted until that particular mode is reached. If the tension is such that it is between vibrational modes, the string will not exhibit the standing wave phenomenon and we won't see a standing wave. When the frequency of the vibrating body is the same as that of the particular vibrational mode of the string, resonance is established.

Any system in which standing waves can form has numerous natural frequencies. The set of all possible standing waves are known as the harmonics of a system. The simplest of the harmonics is called the fundamental or first harmonic. Subsequent standing waves are called the second harmonic, third harmonic, etc. The harmonics above the fundamental, especially in music theory, are sometimes also called overtones.

Filtering

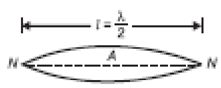
The best part of a standing wave is not that it appears to stand still, but that the amplitude of a standing wave is much larger that the amplitude of the disturbance driving it. It seems like getting something for nothing. Put a little bit of energy in at the right rate and watch it accumulate into something with a lot of energy. This ability to amplify a wave of one particular frequency over those of any other frequency has numerous applications.

Speed of transverse wave in stretched string

A string means a wire or a fiber which has a uniform diameter and is perfectly flexible *i.e.* which has no rigidity. In practice, a thin wire fulfills these requirements approximately. The speed of transverse wave in a flexible stretched string depends upon the tension in the string and the mass per unit length of the string. Mathematically, the speed v is given by

$$v = \sqrt{T/m}$$

Where T is the tension in the string and m is the mass per unit length of the string. When a wire clamped to rigid supports at its ends is plucked in the middle, transverse progressive waves travel towards each end of the wire. These waves are reflected at the ends of the wire. By the superposition of the incident and the reflected waves, transverse stationary waves are set up in the wire. Since the ends of the wire are clamped there is a node N at each end and anti-node A in the middle.



We know that the distance between two consecutive nodes is $\lambda/2$, where λ is wavelength. Hence if l be the length of the wire between the clamped ends, then $l = \lambda/2$ or $\lambda=2\ l$. If f be the frequency of vibration of the wire, then $f = v/\lambda = v/2\ l$ Substituting the value of v, we have $f = (1/2l)\sqrt{T/m}$

Applications

- Alternating current (AC) electricity is the type of electricity commonly used in homes and businesses throughout the world. AC electricity alternates its direction in a back-and-forth motion. The direction alternates between 50 and 60 times per second, depending on the electrical system of the country.
- The AC electricity can be readily transformed to higher or lower voltage levels. High voltages are more efficient for sending electricity at great distances, high voltages from the power station can be easily reduced to a safer voltage for use in the house. Changing

voltages is done by the use of a **transformer**. This device uses properties of AC electromagnets to change the voltages.

- Anything mechanical that can vibrate and has edges may have a standing wave on it. So, the shaft driving a ship's propellers, or turning a turbine, can go into a standing wave oscillation, flexing as it turns. The wings of an aircraft also flex like a springy ruler.
- Two-dimensional standing waves are likely wherever flat panels can vibrate, so they matter to the motor and to the building engineer. Three-dimensional standing waves are a problem for acoustic engineers. A good example is a loudspeaker cabinet enclosing a volume of vibrating air.
- Electromagnetic waves too can produce standing waves. Radio waves can form standing waves inside metal cavities. Radio waves have been used both to make very accurate measurements of the velocity of the waves, and in the design of powerful high frequency generators of microwaves.
- Basically, all non-digital musical instruments work directly on the principle of resonance. What gets put into a musical instrument is vibrations or waves covering a spread of frequencies (for brass, it's the buzzing of the lips; for reeds, it's the raucous squawk of the reed; for percussion, it's the relatively indiscriminate pounding; for strings, it's plucking or scraping; for flutes and organ pipes, it's blowing induced turbulence). What gets amplified is the fundamental frequency plus its multiples. These frequencies are louder than the rest and are heard. All the other frequencies keep their original amplitudes while some are even de-amplified. These other frequencies are quieter in comparison and are not heard.
- During speech, human vocal cords tend to vibrate within a much smaller range that they would while singing. How is it then possible to distinguish the sound of one vowel from another? English is not a tonal language (unlike Chinese and many African languages). There is very little difference in the fundamental frequency of the vocal cords for English speakers during a declarative sentence. (Interrogative sentences rise in pitch near the end. Don't they?) Vocal cords don't vibrate with just one frequency,

but with all the harmonic frequencies. Different arrangements of the parts of the mouth (teeth, lips, front and back of tongue, etc.) favor different harmonics in a complicated manner. This amplifies some of the frequencies and de-amplifies others. This makes "EE" sound like "EE" and "OO" sound like "OO".

VIVA VOCE

Q. 1 What do you mean by A.C. mains?

Ans. A current which changes its direction of flow *i.e.* continuously varying from zero to a maximum value and then again to zero and also reversing its direction at fixed interval of time. If a graph of the current against time has the form of a sine wave, the current is said to be sinusoidal

Q. 2 What is the frequency of your A.C. mains? What does it represent?

Ans. The number of times the current changes its direction in each second is called the frequency of A.C. mains. It's value is 50 cycles per second.

Q. 3 What do you understand by resonance?

Ans. In case of forced or maintained vibrations, when the frequencies of driver and driven are same then amplitude of vibration of driven becomes large. This phenomenon is called resonance.

Q. 4 Does direct current also have any frequency?

Ans. No, it does not change its direction.

Q. 5 How does the iron rod vibrate?

Ans. When alternating current is passed through the solenoid, the iron rod is magnetized such that one end is north pole while other end is south pole. When the direction of current is changed, the polarity of rod is also changed. Due to the interaction of this rod with magnetic field of permanent magnet, the rod is alternately pulled to right or left and thus begins to vibrate with frequency of A.C. mains.

Q. 6 What type of vibrations does the rod execute?

Ans. The vibrations are forced vibrations. The rod executes transverse stationary vibrations of the same frequency as that of A.C.

Q. 7 Can you use a brass rod instead of soft iron rod?

Ans. No, because it is non-magnetic.

Q. 8 How is it that by determining the frequency of the rod, you come to know the frequency of A.C. mains?

Ans. Here the rod vibrates with the frequency of A.C. mains.

Q. 9 What is the construction of an electric vibrator?

Ans. It consists of a solenoid in which alternating current is passed. To avoid the heating effect in the coil of solenoid, an electric bulb is connected in series. A rod passes through the solenoid whose one end is fixed while the other is placed in pole pieces of permanent horse shoe magnet.

Q. 10 What are resonant vibrations?

Ans. If the natural frequency of a body coincides with the frequency of the driving force, the former vibrates with a large amplitude. Now the vibrations are called as resonant vibrations.

Q. 11 When does resonance occur?

Ans. When the natural frequency of the rod becomes equal to the frequency of AC mains, resonance occurs.

Q. 12 Define Transverse waves?

Ans. The vibrations in which the particles of the medium vibrate in a direction perpendicular to the direction of wave motion are called as transverse vibrations or waves.

Q. 13 Define Stationary waves?

Ans. A stationary wave is formed when two identical waves travelling in the same medium but coming from opposite direction superimpose.

Q. 14 What types of waves are set up on the thread?

Ans. Transverse standing waves are set up on the thread.

Q. 15 What are node and anti-node points?

Ans. When a standing wave is set up in a medium, those points which are at rest and do not vibrate are called nodes. Those points which vibrate with maximum amplitude are called antinodes.

Q.16 What is the distance between two consecutive nodes or antinodes?

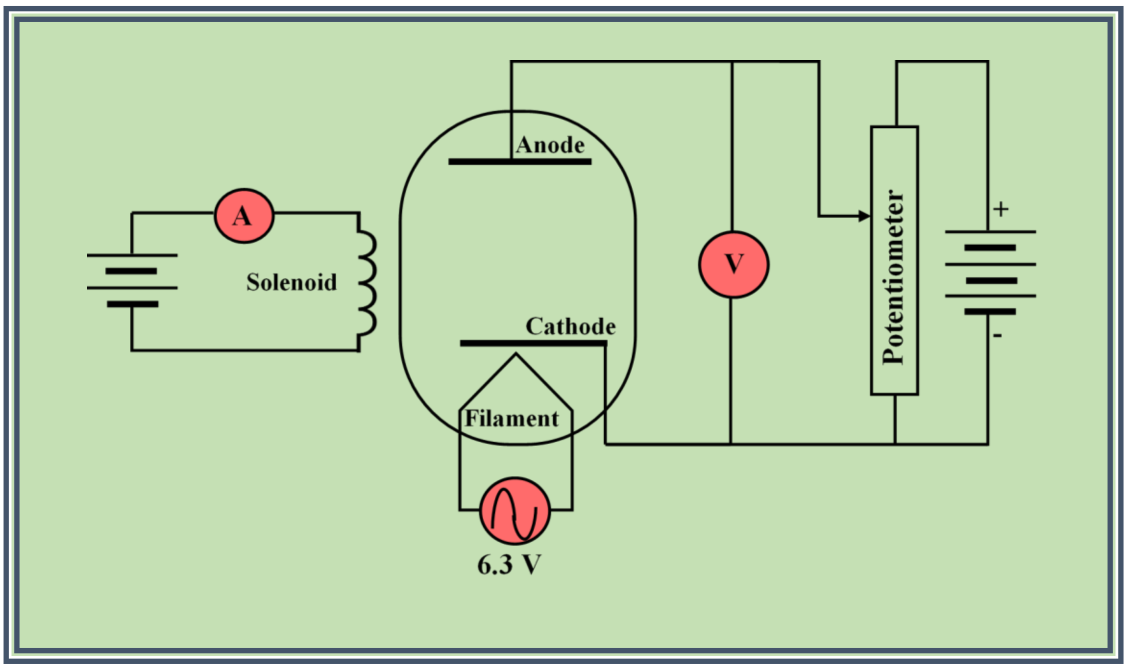
Ans. It is λ/2.

Q.17 What does Melde's experiment demonstrate?

Ans. It demonstrates the formation of stationary waves.

Experiment 7

To Determine the e/m Of an Electron by Deflection Method



EXPERIMENT 7

To Determine the e/m Of an Electron by Deflection Method

Objective

1. To determine the charge to mass ratio (e/m) of an electron by deflection method

Related Concepts

Thermionic emission, electron beam, electric field, magnetic field, luminescence

Apparatus

- Tuning indicator tube (Magic eye)
- Power supplies
- Solenoid
- Connecting cables
- Circular Disc / Coin

Experimental Arrangement

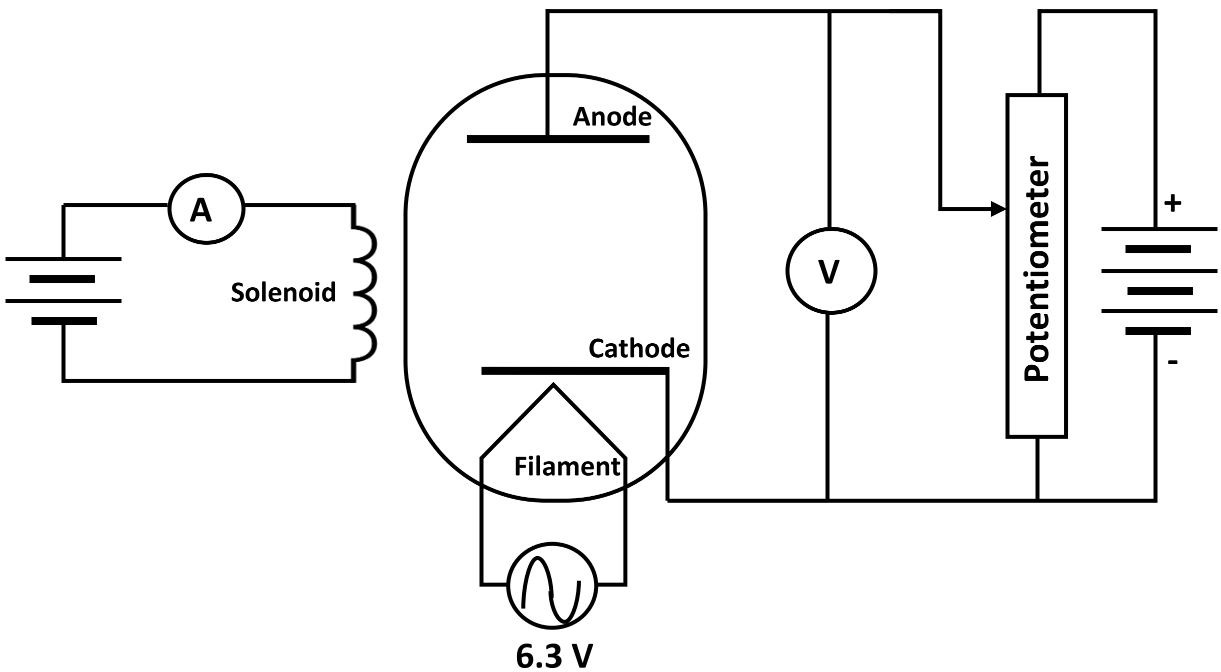


Figure1: Circuit diagram of experimental set-up used to measure e/m of electron by deflection method.

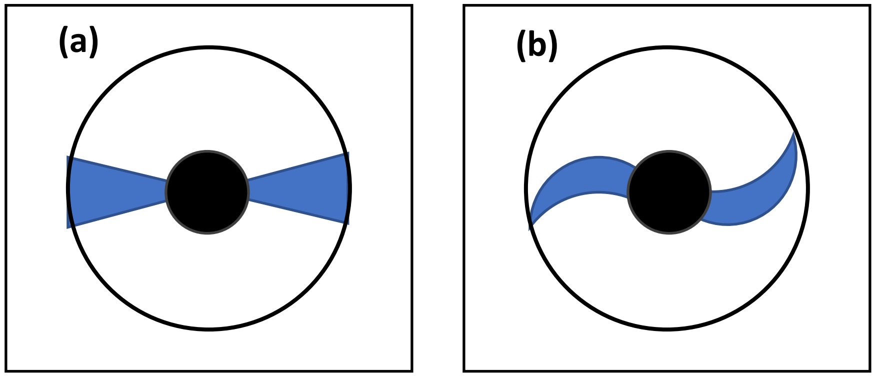


Figure 2: Top view of magic eye (a) in the absence of magnetic field and (b) in the presence of magnetic field.

Procedure

1. Arrange the apparatus as shown. Apply 6 VCD or AC to the filament of the tuning indicator tube (EM-34) and adjust the anode potential between 90 to 220 V. Slip the solenoid coil over the magic eye over the magic eye and connect up the solenoid in series with current supply and rheostat.
2. Without switching on the solenoid circuit, close the filament and anode circuits. Look straight down from above the magic eye. Something similar to Fig. (A) is seen. Now switch on the solenoid circuit and again look straight down into the tube. Now something similar to Fig. (B) is observed.
3. Place a glass sheet on the end of the solenoid and put a circular coin on the glass sheet. Vary the anode potential and solenoid current till the curvature of the edge of shadow is the same as that of the coin. Note the anode potential (voltmeter reading) and the solenoid current.
4. Repeat the experiment for three different values of the anode potential and solenoid current.
5. Measure the diameter of the coin by Vernier caliper and calculate its radius R. Note the number of turns of the solenoid.

Precautions

1. All the connections should be clean and tight

2. The curvature of the edge of the shadow should be compared carefully with the curvature of the coin by looking straight down.

Observations and Calculations

Diameter of coin d = ………………m

Radius of coin R = …………………m

Number of turns of the solenoid per meter = n = 4032

$\mu_o = 4\pi \times 10^{-7}$ Wb / A-m

No.	Anode Voltage V (volts)	Solenoid Current I (Amperes)	Magnetic Field $B = \mu_o nI$ (Tesla)	e/m $=2V/B^2R^2$ (C/Kg)
1				
2				
3				

Mean value of e/m of electron =

Actual value of e/m of electron =

Percentage error =

Theory

An electron is accelerated when it is subjected to an electric field. If it falls through potential difference V, the kinetic energy gained by it is given by:

$$\frac{1}{2}mv^2 = Ve \qquad (1)$$

Where v is the velocity acquired by electron, V is the applied potential difference, m is the mass of electron and e is the charge of an electron.

if the electron of velocity ‘v’ is projected perpendicular to a uniform magnetic field of strength ‘B’ it will be acted upon by a magnetic force ‘Bev’ normal to both its motion and the magnetic field. The electron will move in a circular path of radius ‘R’. Here necessary centripetal force is provided by the magnetic force

i.e.

$$Bev = \frac{mv^2}{R} \qquad (2)$$

Substituting the value of v^2 from equation 1

$$\frac{e}{m} = \frac{2V}{B^2R^2}$$

Thus e/m of the electron can be determined if we know V, B and R.

Fleming's Right hand rule

Fleming's Right hand rule states 'if we grasp the solenoid in our right hand such that the curled fingers indicate the direction of flow of current, then the extended thumb would indicate the direction of the magnetic field.

Fleming's Left hand rule

Fleming's Left hand rule states 'if the first finger of the left hand points the direction of magnetic field and the middle finger indicates the direction of current in a conductor, then the thumb indicates the direction of force applied on the conductor.

If the angle between B and V is not 90 then the electron would follow a helical path instead of circular.

e/m of electron

The anode mounted in the magic eye is of bowl shape and the cathode is at its center. The shadow formed on the anode is due to the very thin plates which are placed at the sides of the cathode.

Charge on an electron = - 1.6 x 10^{-19} C

Mass of on electron = 9.11 x 10^{-31} kg

e/m of electron = 1.759 x 10^{11} C/kg

Luminescence

Emission of light by an excited object when it returns back to the ground state is called luminescence. Phosphors are known for their light emitting properties and these materials are used in TV screens, cathode ray tubes etc. Some important phosphors include Zinc Sulfide, Yttrium Silicate, Zinc Orthosilicate and Zinc Cadmium Sulfide.

(i) **Fluorescence** When the emission of light by a substance does not persist after the removal of the exciting source is called fluorescence.

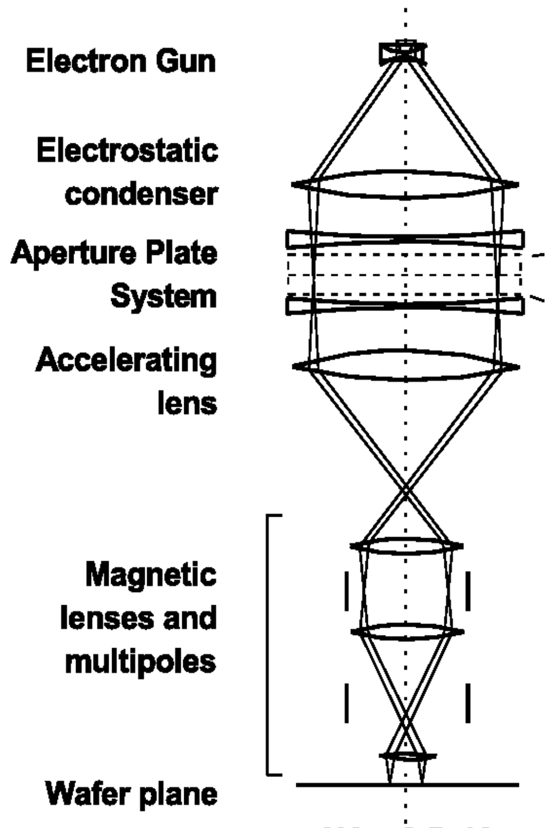
(ii) **Phosphorescence** When the emission of light by a substance persists significantly after the removal of the exciting source is called phosphorescence.

Thermionic Emission

Emission of electron that takes place by absorbing heat energy is called thermionic emission.

Applications

- The charge-to-mass ratio (e/m) is a physical quantity that is widely used in the electrodynamics of charged particles, e.g. in electron optics and ion optics. In classical electrodynamics, the importance of the mass-to-charge ratio is that two particles with the same mass-to-charge ratio move in the same path in a vacuum when subjected to the same electric and magnetic fields. This property is used in velocity selectors and mass spectrometers.
- Electron to mass ratio can be used detect isotopes of different elements.
- The control of electron beam by electric and magnetic fields appears in the scientific fields of lithography, electron microscopy, cathode ray tubes, accelerator physics, nuclear physics, Auger spectroscopy, cosmology and mass spectrometry.
- Electron Beam Lithography (EBL) refers to a lithographic process that uses a focused beam of electrons to form the circuit patterns needed for material deposition on (or removal from) the wafer. A typical EBL system consists of the following parts: 1) an electron gun or electron source that supplies the electrons; 2) an electron column that 'shapes' and focuses the electron beam; 3) a mechanical stage that positions the wafer under the electron beam; 4) a wafer handling system that automatically feeds wafers to the system and unloads them after processing; and 5) a computer system that controls the equipment. The resolution of optical lithography is limited by diffraction, but this is not a problem for electron lithography. The reason for this is the short wavelengths (0.2-0.5 angstroms) exhibited by the electrons in the energy range that they are being used by EBL systems. However, the resolution of an electron lithography system may be constrained by other factors, such as electron scattering in the resist and by various aberrations in its electron optics. Cathode Ray Tubes (CRTs) are the sophisticated

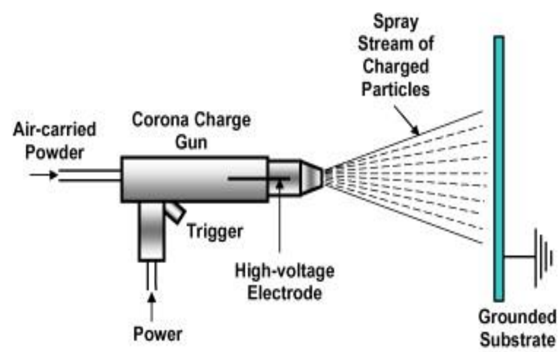


versions of vacuum tubes which are widely used for video display in television sets, computer monitors, oscilloscopes, and some other devices. CRTs shoot electrons at a screen coated with phosphors, which glow when struck by the electron beam.

- The electron microscope uses a beam of electrons to study very small objects, typically it consists of an evacuated column of magnetic lenses with an electron gun at the top and a fluorescent screen or photographic plate at the bottom. The various magnetic lenses (basically electromagnets) allow the operator to see details at the atomic level (0.2 nm resolution) at upto a million times magnification and to obtain diffraction patterns from very small areas. In transmission electron microscope (TEM), electrons are transmitted through the sample and form an image on the fluorescent screen or photographic plate. In the scanning electron microscope (SEM), the beam is focused to a point and scanned over the surface of the sample. Detectors collect the backscattered and secondary electrons coming from the surface and convert them into a signal that in turn issued to produce an image of the sample.
- The mass-to-charge ratio ratio (m/Q) is a physical quantity that is widely used in the electrodynamics of charged particles, e.g. in electron optics and ion optics. It appears in the scientific fields of lithography, electron microscopy, cathode ray tubes, accelerator physics, nuclear physics, Auger spectroscopy, cosmology and spectrometry.

Mass spectrometry works by ionizing chemical compounds to generate charged molecules or molecule fragments and measuring their mass-to-charge ratios. Mass spectrometry (MS) is an analytical technique in which atom is first ionized then accelerated so that all ions have same kinetic energy. The ions are then deflected by a magnetic field according to their masses. The lighter they are, the more they are deflected. The amount of deflection also depends on the number of positive charges on the ion - in other words, on how many electrons were knocked off in the first stage.

- Charge to mass (e/m) ratio of electron is used to remove volatile organic compound (VOC) in paint industry that causes the formation of lower atmospheric ozone layer (Troposphere). Painting systems use organic based solvents as carriers for the solid paint particles. As the paint cures, the solvent evaporates creating VOC emissions which contribute to the formation of ozone. Powder paints & waterborne coatings can replace the existing solvent systems. In corona powder paint, powders are sprayed out of a spray gun and charged by the ions produced. The negatively charged particles are attracted to & deposited onto a grounded substrate. The particles with high e/m ratio adhere more easily than with low e/m ratio. e/m ratio is inversely proportional to the particle radius. As the particle becomes larger e/m ratio becomes smaller. This would indicate that smaller particles should adhere selectively over large particles.



- High e/m ratio of electron is used by the Space Plasma Alleviation of Regolith Concentration in Lunar Environments by Discharge (SPARCLED), a tool designed to remove contaminating lunar regolith (the layer of loose material covering the bedrock of earth & moon, etc. comprising soil, sand, rock fragments, volcanic ash & glacial drift) from surfaces. SPARCLED uses an electron gun to rapidly charge dust contaminating a surface to a high e/m ratio to cause rapid removal of the dust grains. It utilizes only electrons and hence no consumables such as gases are needed for operation. This developing technology can help for humanity return to the Moon to extend human presence, scientific activities, use of Moon to prepare for future human missions to Mars, and expand Earth's economic sphere because the Apollo missions and other lunar explorations have identified significant lunar dust-related problems that will threaten future mission success.

- The first major application of industrial mass spectrometery was in the analysis of mixture of light hydrocarbons. There has been a continuing effort by numerous workers in the field to extend the molecular weight range, until at the present time hydrocarbons type analysis of materials in the gasoline, kerosene, and light gas oil boiling ranges have become standard.
- A few minerals have an interesting physical property known as "fluorescence". These minerals have the ability to temporarily absorb a small amount of light and an instant later release a small amount of light of a different wavelength. This change in wavelength causes a temporary color change of the mineral in the eye of a human observer. Minerals with fluorescence stop glowing when the light source is turned off.
- The mineral scheelite (calcium tungstate) an ore of tungsten, typically has a bright blue fluorescence. Geologists prospecting for scheelite sometimes go out at night with fluorescent lamps to look for deposits. They also use fluorescent lamps to examine core specimens and well cuttings.
- Fluorescent lamps can be used in underground mines to identify and trace ore-bearing rocks. (An ore is a type of rock that contains minerals with important elements including metals) and separate them from waste.
- Many gemstones are sometimes fluorescent including ruby, kunzite and opal. This property can sometimes be used to spot small stones in sediment or crushed ore. Specimens of calcite that do fluoresce glow in a variety of colors including: red, blue, white, pink, green and orange.
- In phosphorescence, the electrons remain in the excited state orbital for a greater amount of time before falling. Minerals with phosphorescence can glow for a brief time after the light source is turned off. Minerals that are sometimes phosphorescent include: celestine, colemanite, sphalerite, and willemite.

- There are around 3500 different types of minerals of which 500 with different combinations are Fluorescent or Phosphorescent. On this account Fluorescent and Phosphorescent minerals, their ores and their purification can be detected. Most fluorescent minerals have activators in them to initiate fluorescence. The activators are like impurities of the minerals. Manganese is one of the most common types of activators. Different activators cause different type of fluorescence or phosphorescence. On this ground, impurities present in the minerals can be identified. Some minerals are fluorescent/phosphorescent by themselves but contain such impurities which do not absorb any light e.g. calcite, willemite and fluorite. When these were illuminated with short wave UV lamp they show phosphorescence but there were also some dark spots in them showing the presence of Franklinite (zinc iron ore). Franklinite is not fluorescence but is often found with Calcite and Willemite.

  Calcite: On exposing to white light show milky white appearance and on exposing to UV radiation it emits a red/orange color.

  Willemite: On exposing to white light it is identified by its tan color. On exposing to UV light this mineral emits a vibrant green color.
- Cathode-ray tubes used in analogue oscilloscopes, which have mu-metal shields to prevent stray magnetic fields from deflecting the electron beam.

VIVA VOCE

Q. 1 What do you mean by specific charge?

Ans. The charge per unit mass of a charged body is called specific charge.

Q. 2 What are different methods of measuring e/m of electrons?

Ans. (i) J.J. Thomson’s method (ii) Bucher’s method (iii) Magnetron Method (iv) Millikan’s method

Q. 3 In the e/m experiment cathode is directly heated or indirectly heated?

Ans. Indirectly heated cathode is used

Q. 4 How magnetic field is generated in this experiment?

Ans. By using the solenoidal coil.

Q. 5 How magnetic field can be varied?

Ans. By changing the current in the solenoid.

Q. 6 At what point of the solenoid, magnetic field is maximum?

Ans. At the middle point of the solenoid.

Q. 7 What is the value of the magnetic field at either end of the solenoid?

Ans. One half of its value at the middle point.

Q. 8 What is the formula to calculate e/m?

Ans. $e/m = 2V/ B^2R^2$

Where V is the applied potential difference, B is the magnetic field and R is the radius of circular path traced out by electrons.

Q. 9 Which particle will deflect more by a given magnetic field a heavier particle or lighter one?

Ans. The radius of the circular orbit is R = mv/Be, which shows that the radius is proportional to the momentum of the particle, mv. Hence, heavier particles will deflect more as compared to lighter ones.

Q. 10 How much work is done on a charged particle by a magnetic force?

Ans. No work is done by a magnetic force on a charged particle because the force is always at right angle to the motion of particles.

Q. 11 How much magnetic force is experienced by a charged particle at rest?

Ans. Zero

Q. 12 What path is traced out by a charged particle when it is projected in a uniform magnetic field with an initial velocity perpendicular to the magnetic field?

Ans. It moves in a circular path

Q. 13 What path is traced out by a charged particle when it is projected in a uniform magnetic field with an initial velocity not perpendicular to the magnetic field?

Ans. It moves in a helix.

Q. 14 What is the effect of the voltage on the radius of the circle of electrons?

Ans. When voltage increases radius also increases.

Q. 15 What is the effect of the current on the radius of the circle of electrons?

Ans. When current increase, radius decreases.

Q.16 If the polarity of a magnetic field is changed how the circle is changed?

Ans. By reversing the polarity of the magnetic field, we get the circle in opposite direction.

Q.17 Proves that unit of e/m is Coulomb/kg in the relation $e/m=2V/B^2R^2$?

Ans. $e/m=2V/ B^2R^2$

$= 2 \text{ x volt x meter}^4/\text{weber}^2 \text{ x meter}^2$

$= 2 \text{ x volt x meter}^2/ (\text{volt x sec})^2$

$= 2 \text{ x meter}^2 \text{ x coulomb/joule x sec}^2$

$= 2 \text{ x meter}^2 \text{ x coulomb x sec}^2/ \text{kg. x meter}^2 \text{ x sec}^2$

$= 2 \text{ x coulomb/kg}$

Q.18 what are phosphors?

Ans. These are light emitting materials used in TV screens, cathode ray tubes etc

Q.19 What is luminescence?

Ans. Emission of light by an excited object when it returns back to the ground state is called luminescence.

Q.20 What is fluorescence?

Ans. When the emission of light by a substance does not persist after the removal of the exciting source is called fluorescence.

Q.21 What is phosphorescence?

Ans When the emission of light by a substance persists significantly after the removal of the exciting source is called phosphorescence.

Q. 22 Name some phosphor materials.

Ans. Zinc Sulfide, Yttrium Silicate, Zinc Orthosilicate and Zinc Cadmium Sulfide are same phosphors.

Q. 23 What is the source of electrons in this experiment?

Ans. The electrons are emitted by the cathode, placed inside the vacuum tube and are accelerated towards anode when a potential difference is applied between the cathode and anode.

Q. 24 What is the cause of green color in this experiment?

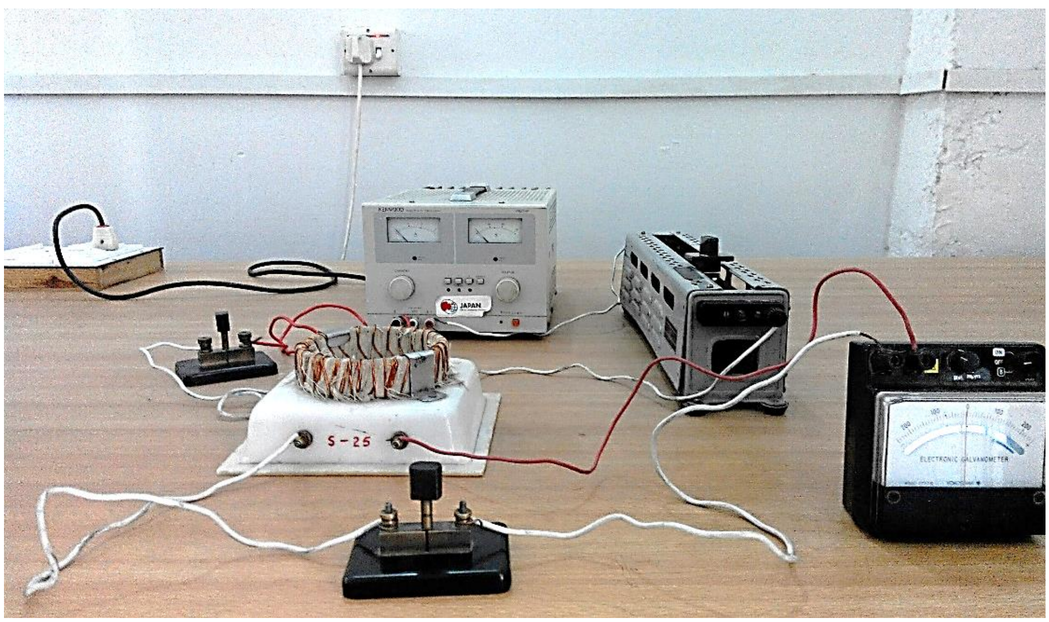
Ans. Since the anode is coated with the phosphor material Zinc Sulfide, the collision of electrons with this material causes the phosphor to excite and when it returns to ground state. It emits photons. As a result, we observe green color.

Q.25 Is it possible to perform this experiment with the help of only earth's magnetic field?

Ans. No, it is not possible perform this experiment with the help of earth's magnetic field, as its value is very small.

Experiment 8

To Draw the B-H Curve of Ferromagnetic Material using Galvanometer



EXPERIMENT 8

To Draw the B-H Curve of Ferromagnetic Material using Galvanometer

Objective

1. To study the properties of magnetic materials by drawing B-H curve of a ferromagnetic material.

Related Concepts

Magnetism, magnetic materials, Hysteresis, electromagnetic induction

Apparatus

- Toroid
- Ammeter.
- Connecting wires.
- Rheostat
- Galvanometer
- Power supply 10V

Experimental Arrangement

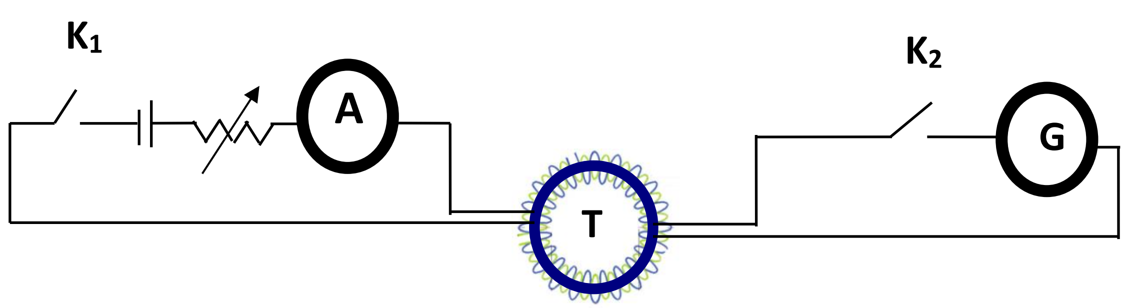


Figure 1. Circuit diagram of experimental setup.

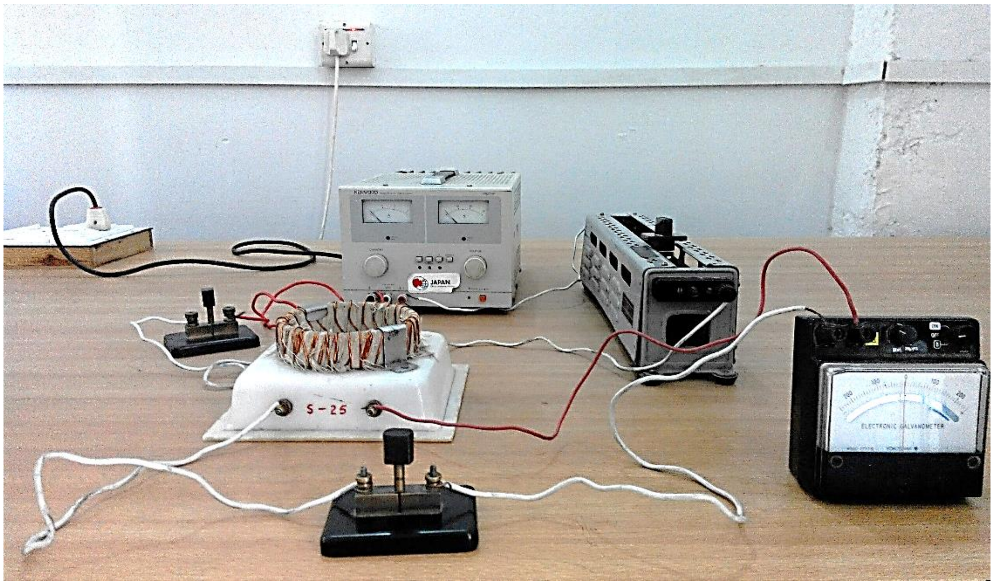


Figure 2: Photographic view of experimental arrangement.

Procedure

1. Make the experimental arrangement as shown in Figure 1 and 2.
2. **G**. is a galvanometer, **T** is a toroid, having primary and secondary windings on iron ring.
3. Set power supply at some suitable voltage i.e. from **8 -10V.**
4. Plug out the key **K2**. Now plug in key **K1** and adjust the current by using ammeter **A** with the help of Rheostat **R**. Note the minimum value of current for initial reading.
5. Plug in key **K2** and note down the deflection in the **G** while plugging out the key **K1**.
6. Repeat steps 4 and 5 by adjusting different values of current with the help of rheostat till a stage is reached when deflection in **G** is constant. Here the material is saturated.
7. Plot a graph between "I" Vs "θ". This is actually the B-H curve / saturation curve /initial curve of the given ferromagnetic material. Here I is α H and θ is α B.

Precautions

1. Make neat and tight electrical connections.
2. Key K2 should be plugged out while current is being changed.
3. Always take readings with increasing current only.
4. Do not use current greater than 2.5 amperes.

Observations and Calculations

Sr. No.	Current **I** (A)	Deflection in Galvanometer **θ** (arb. units)
1.		
2.		
3.		
4.		
5.		
6.		
7.		

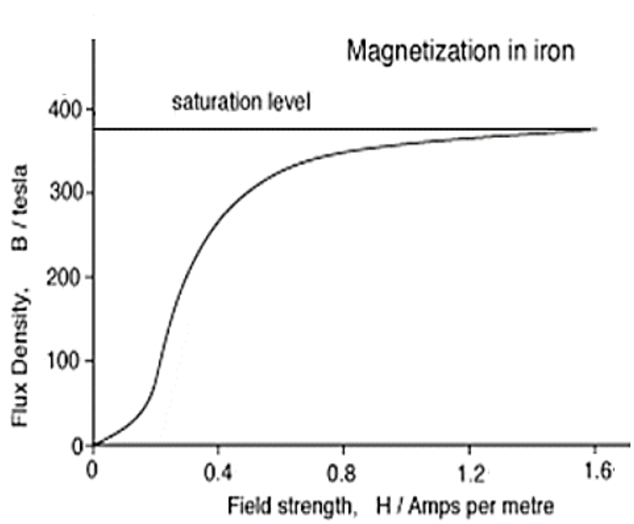


Figure 3: Initial Curve of ferromagnetic material.

Theory

Toroid

A Solenoid bend in circular doughnut form becomes a Toroid. Toroid behaves as an electromagnet. When electric current flows through the toroid wirings, a magnetic field is generated. It is concentrated near (and especially inside) the coil, and its field lines are very similar to those of a magnet. The orientation of this effective magnet is determined by the right-hand rule.

Galvanometer

A galvanometer has a coil which rotates between magnets. It is used to measure quantity of charge rather than currents. The passage of the charge produces an impulse, a momentary torque, which causes the coil then to swing slowly to some maximum position.

$\tau = NIAB\sin\theta$

θ is the angle between coil and magnetic field

$\tau = k\Phi$

$\Phi = NIAB\sin\theta$

N= number of turns

Φ is the deflection i.e. directly proportional to current

Hysteresis Curve

When a magnetic material is subjected to a cycle of magnetization (magnetized first in one direction and later magnetized in opposite direction in a cyclic manner), an energy loss takes place. This energy loss is due to molecular friction in the material. That is, the domains (or molecular magnets) of the material being turned first in one direction and then the other. Energy is thus expended in the material in overcoming this opposition. This loss is in the form of heat and is called **hysteresis loss.**

Hysteresis loss is present in all electrical machines whose iron parts are subjected to cycle of magnetization like transformers, induction motors and other machines operated on ac supply. When an alternating supply is provided to the electrical machines the flux in the iron of these machines change in both direction and value alternatively. During this process energy is lost and this loss constitutes the core loss of the machine. Hysteresis loss also occurs when iron parts rotate in constant magnetic field e.g.- dc machines

The obvious effect of hysteresis loss is the rise of temperature of the machine.

Importance or Significance of B-H Loop

The shape and size of the hysteresis loop largely depends on the nature of the magnetic material. The choice of a magnetic material required for a particular application often depends on the shape and size of the hysteresis loop.

The smaller the hysteresis loop area, the less is the hysteresis loss. For example, the hysteresis loop area for silicon steel is very small, for this reason silicon steel is widely used for manufacturing of transformer cores and rotating machines, subjected to rapid reversals of magnetism. On the other hand, the hysteresis loop of Hard Steel indicates that the material has high retentivity and coercivity (large hysteresis loop area). Therefore, hard steel is quite useful in making permanent magnets.

Magnetic materials

A **magnet** is a material or object that produces magnetic field.

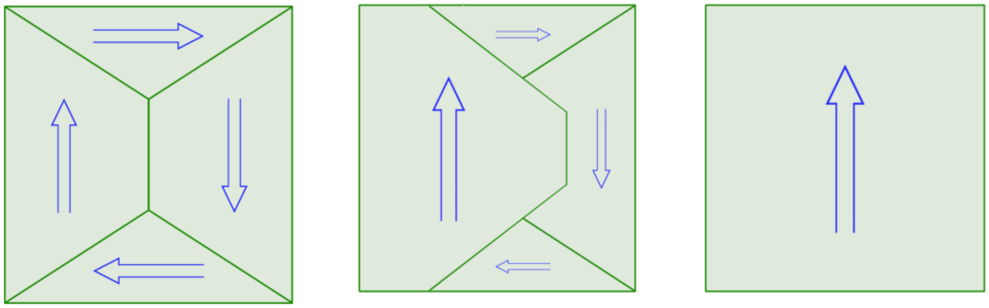
Magnetism is caused by electric charges in motion. Since electrons in atoms are known to move in certain ways, they are able to produce their own magnetic fields. In some types of materials, the motions of atomic electrons are easily aligned with respect to one another, causing an overall magnetic field to be produced by the material.

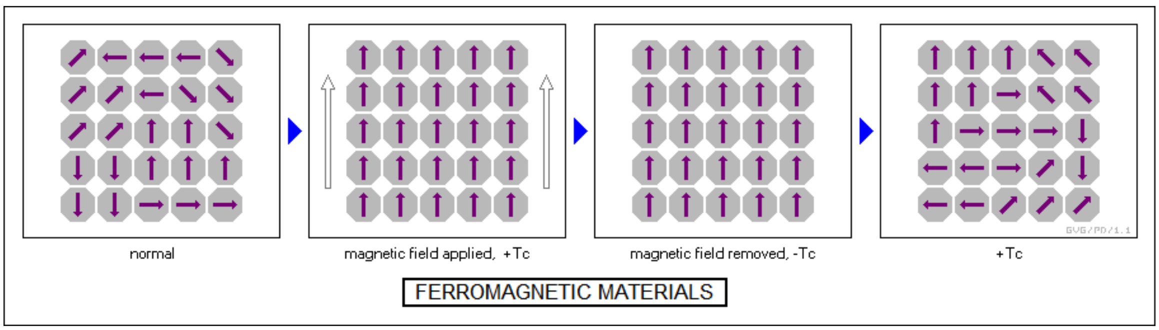
Types of magnetic materials

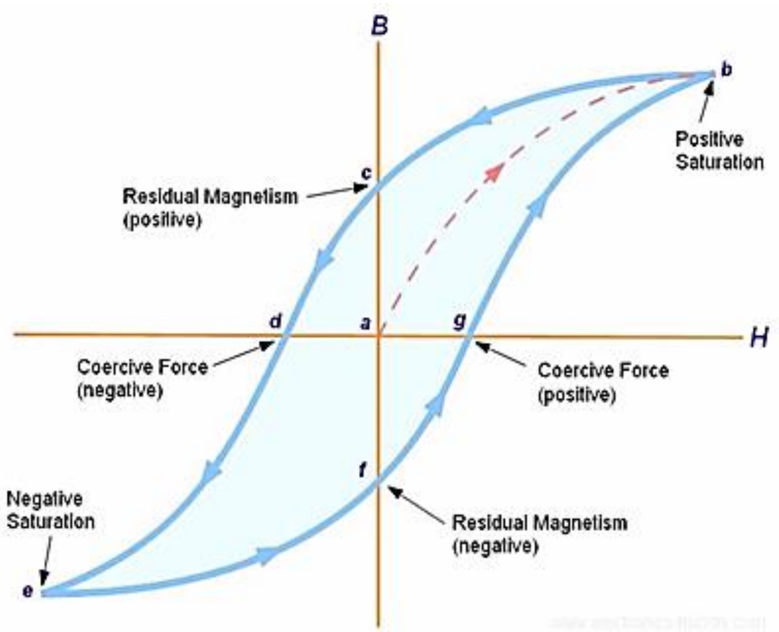
1) Ferromagnetic materials
2) Paramagnetic materials
3) Diamagnetic materials

Ferromagnetic material

Ferromagnetic materials have a large, positive susceptibility. They exhibit a strong attraction to magnetic fields and are able to retain their magnetic properties after the external field has been removed. Ferromagnetic materials have some unpaired electrons so their atoms have a net magnetic moment. They get their strong magnetic properties due to the presence of magnetic domains. In these domains, large numbers of atom's moments (10^{12} to 10^{15}) are aligned parallel. Ferromagnetic materials such as iron, nickel and cobalt.





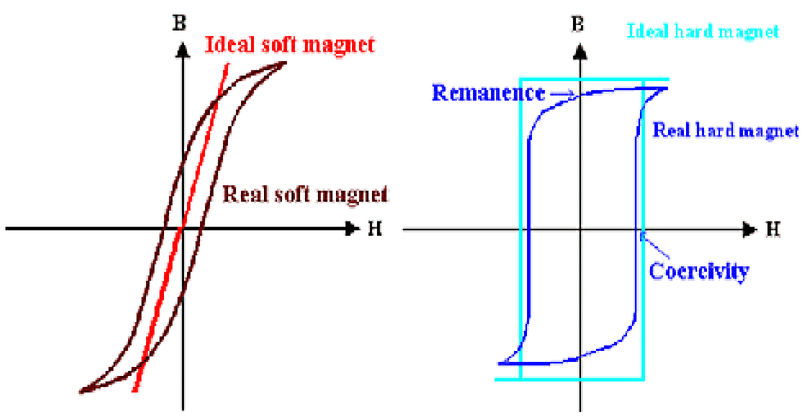


Remanence or **remnant magnetization**

It is the magnetization left behind in a ferromagnetic material (such as iron) after an external magnetic field is removed. The equivalent term **residual magnetization** is generally used in engineering applications. In many other applications, it is an unwanted contamination, for example a magnetization remaining in an electromagnet after the current in the coil is turned.

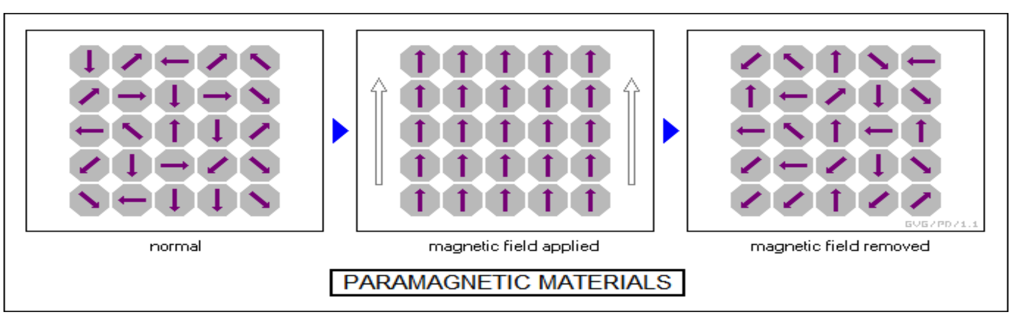
Coercivity, **coercive field** or **coercive force**

It is the intensity of the applied magnetic field required to reduce the magnetization of ferromagnetic material to zero after the magnetization of the sample has been driven to saturation. Coercivity is usually measured in Oersted or ampere/meter units and is denoted H_C. Coercivity measures the resistance of a ferromagnetic material to becoming demagnetized. Depending on the shape of the hysteresis curve and described by the values of the remanence M_R and the coercivity H_C, hard and soft magnetic materials can be distinguished



Paramagnetic material

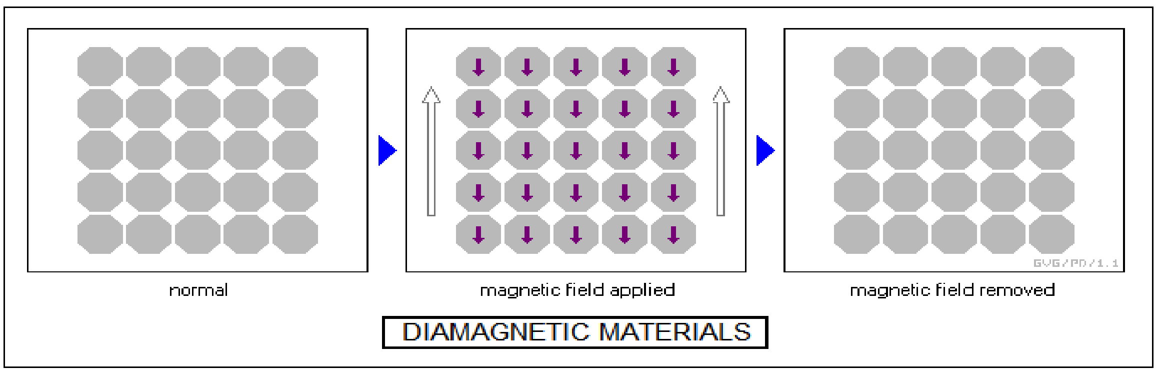
Applying a magnetic field would tend to orient the dipole moments and attains a magnetization. Very high fields would saturate magnetization. Heating the material would tend to disorder the moments and hence decrease magnetization.



Diamagnetic material

Diamagnetism is the property of an object which causes it to create a magnetic field in opposition to an externally applied magnetic field, thus causing a repulsive effect. Specifically, an external magnetic field alters the orbital velocity of electrons around their nuclei, thus changing the magnetic dipole moment. According to Lenz's law, these electrons will oppose the magnetic field changes provided by the applied field, preventing them from building up. The result is that lines of magnetic flux curve away from the material. In most materials, diamagnetism is a weak effect. Diamagnets are materials with a magnetic permeability less than μ_0 (a relative permeability less than 1).

Examples: water, protein, fat.



Faraday's law of electromagnetic induction

Faraday's law of induction is a basic law of electromagnetism relating to the induced electromotive force (emf) in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit

$\text{emf} = -N\Delta\Phi/\Delta t$

The emf is produced by relative motion between a magnet and a coil of wire. The amount of voltage induced across a coil is determined by two factors:

1. The rate of change of the magnetic flux with respect to the coil.

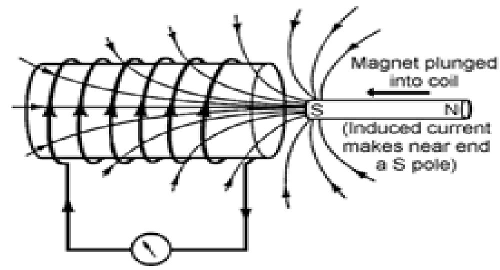
2. The number of turns of wire in the coil

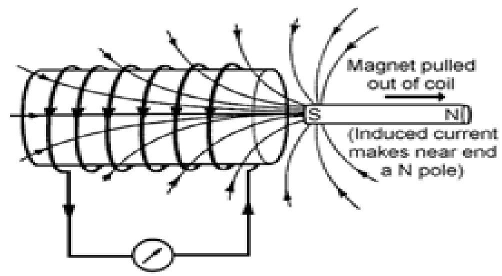
Lenz's law

Lenz's law states that:

"The direction of induced current is always such as to oppose the cause which produces it". That is why a –ive sign is used in Faraday's law.

Lenz's law in fact describes that in order to produce an induced emf or induced current some external source of energy must be supplied otherwise no current will induce.





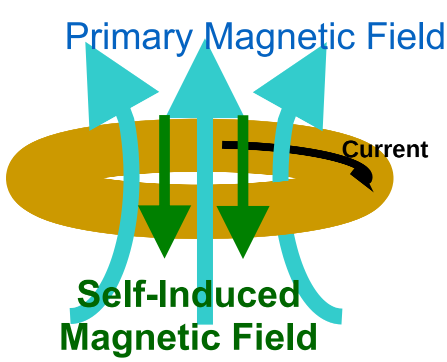
Electromagnetic Induction

An emf is set up in a closed electric circuit located in a magnetic field whenever the total magnetic flux linking the circuit is changing. This is called electromagnetic induction

Types of electromagnetic induction

- **Self-Induction**

When a current is induced by a changing magnetic field, that current itself produces its own magnetic field. This effect is called self-induction.

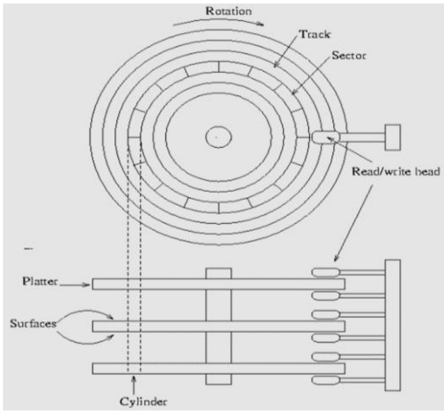
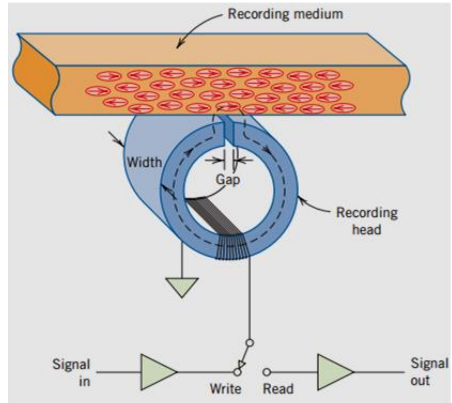


- **Mutual induction**

Two adjacent coils are said to have mutual inductance if a changing magnetic flux (flow of magnetic lines of force) from one of them causes an induced emf in the other.

Applications

- Magnetic materials play a key role in modern life and are present in variety of devices. Engineers and scientists use their knowledge about magnetic materials to select appropriate material for given application based on consideration of cost and performance. **BH curve** is plotted to get useful information about the magnetic materials. Hard magnetic materials are used in permanent magnets that show high resistance to demagnetization and have high energy losses, for instance neodymium iron boron magnets whereas the magnetic materials with less area under the curve are called as soft magnetic materials and are used in devices that are subjected to alternating magnetic fields and in which energy losses must be low, for example an iron-silicon alloy in transformers.
- Magnetic materials have become increasingly important in the area of information storage and **magnetic memory storage** has become a universal technolgy for storage of electronic information as in audio tapes,disk storage media and credit cards.
- A hard drive is a series of disks, made of magnetic material. For data storage purposes, the disks are divided into a series of rings, or tracks like a record, these tracks are then divided into several sectors, (shown in Figure 2).
- Transference to and retrieval from the tape or disk is accomplished by means of an inductive read–write head, which consists basically of a wire coil wound around a magnetic material core into which a gap is produced. Data is introduced ("written") by the electrical signal within the coil, which generates a magnetic field across the gap. This field in turn magnetizes a very small area of the disk or tape within the proximity of the head. Upon removal of the field, the magnetization remains; that is, the signal has been stored. Furthermore, the same head may be utilized to retrieve ("read") the stored information. A voltage is induced when there is a change in the magnetic field as the tape or disk passes by the head coil gap; this may be amplified and then converted back into its original form or character. Both processes are represented in Figure 3.

 **Figure 2:** Top view of Computer hard drive that is divided into tracks and sectors over which magnetic head moves.	 **Figure 3:** Schematic representation showing how information is stored and retrieved using a magnetic storage medium.

- This experiment helps in the characterization of different properties of the palaeomagnetic signal of rocks arises mainly due to the presence of Fe-bearing oxide solid solutions with the spinel crystal structure (such as the titanomagnetites). The ability of these minerals to acquire a strong and stable remnant magnetization in the presence of the Earth's magnetic field is determined to a large extent by their Curie temperature (Tc), saturation magnetization (Ms), coercivity (Hc), and remanence (Mrs). Tc and Ms are determined mainly by the fundamental crystal chemical state of a mineral, which is effected by the processes of cation ordering, magnetic ordering, and subsolvusex solution. Hc and Mrs are determined mainly by the microstructure of the mineral, which is also a function of the cation ordering and subsolvusex solution processes thus other way round one can also find these properties with the help of saturation magnetization, coercivity, remanence and curie temperature.
- The chemical composition is taken into a great care during the manufacturing of the steel magnet. In order to attain required magnetic strength its magnetic properties are monitored at each step of fabrication.
- Magnetic susceptibility measures the 'Magnetizability' of a material. In the natural environment, the magnetizability tells us about field Mapping, the minerals that are found in soils and the field assessment of pollution on building stone.

- Magnetizability is used in detection of bedload (particles in a flowing fluid (usually water) that are transported along the bed moves by rolling, sliding, and/or saltating (hopping).
- B-H curve helps in identification of erratics in drift deposits."Erratics" are large masses of rock, often as big as a house, that have been transported by glacier-ice, and have been lodged in a prominent position in the glacier valleys or have been scattered over hills and plains
- Rocks (basalt, have much higher magnetic susceptibility values than rocks like limestone), dusts and sediments, particularly Fe-bearing minerals are detected through susceptibility. So, the measurements provide information about concentration, classification of materials and create 'environmental fingerprints' for matching materials.
- Magnets can also be used for sorting magnetic material from non-magnetic material. Magnets are used in the material industry to separate metals from ore. Food manufacturers use magnets to prevent small iron particles from mixing with the food. Similarly, vendors use magnets to separate coins from other junk. Magnets are also used to recover ferrous objects from ocean depths.
- Magnetic susceptibility measurements might find a use in passive sensors in reservoirs for distinguishing between formation waters and crude oils (for example, in helping to determine the onset of water breakthrough). Such sensors would provide an environmentally friendly alternative to radioactive tracers. Although viscosity meters might also distinguish between formation waters and crude oils, the magnetic sensors have a further advantage in that they could also rapidly detect small concentrations of ferrimagnetic minerals or migrating fines, such as paramagnetic clays.
- A magnetic rock is one that contains magnetic minerals. The advantage of hysteresis measurements (coercivity, saturation and remanence) is that it can identify multiple mineral components in the same sample, plots of applied magnetic field versus magnetization, where the slope represents the magnetic susceptibility.

- Pure diamagnetic components (quartz and calcite, or reservoir fluids such as crude oils) are characterized by straight lines with negative slope.
- Pure paramagnetic components (clays such as chlorite) give straight lines with positive slope. Mixtures of diamagnetic and paramagnetic minerals can be theoretically modeled and compared with experimental results on the plots.
- The presence of characteristic "kinks" or hysteresis "loops" at relatively low fields enable very small concentrations of ferromagnetic (such as magnetite) to be rapidly identified. Ferromagnetic minerals in a rock is identified by coercivity.
- The electrical resistance of rock formation can be determined from EM induction measurements. Rock formations containing salt water, clay or metallic minerals conduct current readily and therefore has low resistivity, while rocks containing fluids such as oil or gas have high resistivity. These resistivity differences can be used to distinguish between oil and water-saturated sands. Measuring the electrical resistivity near a borehole has long been used to determine production zones in oil and gas fields and to map sand and shale layers. on account of their remanence. Magnetically disordered minerals or the minerals with no iron content are paramagnets and diamagnets. These contribute a weak magnetism and have no remanence. The minerals that can be magnetically ordered are ferromagnets and ferrimagnets. These minerals have a much stronger response to the field and have remanence. These magnetic properties of the minerals can be studied by drawing their B-H curve.
- Earth is littered with magnetic minerals. In magnetic mineralogy, the minerals are classified on account of their remanence. Magnetically disordered minerals or the minerals with no iron content are paramagnets and diamagnets. These contribute a weak magnetism and have no remanence. The minerals that can be magnetically ordered are ferromagnets and ferrimagnets. These minerals have a much stronger response to the field and have remanence. These magnetic properties of the minerals can be studied by drawing their B-H curve. For example, Barite, Borax, Cadmium, Chromferide, Jacobsite, Epsomite are diamagnetic in nature. Maghemite and Magnetite are Ferromagnetic in nature and show strong magnetic field. Whereas, Chromite,

Columbite, Ferberite and Franklinite are the minerals which show paramagnetic behavior or weak magnetic field.

- Magnetic housing of different shapes provide isolation of most equipments from stray magnetic field effects.
- For **static or low frequency magnetic fields**, high magnetic permeability metal alloys, such as sheets of Perm alloy and Mu-Metal, or with nanocrystalline grain structure ferromagnetic metal coatings are used for shielding. These materials draw the field into themselves, providing a path for the magnetic field lines around the shielded volume. The best shape for magnetic shields is thus a closed container surrounding the shielded volume. The effectiveness of this type of shielding depends on the material's permeability, which generally drops off at both very low magnetic field strengths and at high field strengths where the material becomes saturated. So, to achieve low residual fields, magnetic shielding is often designed in such a way that it consists of several enclosures one inside the other, each of which successively reduces the field inside it.
- Similarly, **varying** magnetic fields generate eddy currents that act to cancel the applied magnetic field. The result is that electromagnetic radiation is reflected from the surface of the conductor: internal fields stay inside, and external fields stay outside.

VIVA VOCE

Q. 1 How Lenz's law obeys the law of conservation of energy?

Ans. According to Lenz's law, the induced current will always oppose the change which causes it. Indeed, the induced current has to oppose the change because, otherwise the change which causes the current will persist and the current will continue to flow once it is started. You will then have a supply of energy (in the form of electric current) without any external agency doing any work. This will then violate the law of conservation of energy, which is impossible. So, Lenses law holds good in accordance with the law of conservation of energy.

Q. 2 A bar magnet is released into a copper ring which is directly below it. What about the acceleration of the magnet? Greater than 'g' or equal to 'g' or less than 'g'?

Ans. The acceleration is less than ‘g’ since the falling magnet will generate an induced current in the copper ring and the induced current will oppose the motion of the magnet.

Q. 3 A permanent magnet is a device that retains a magnetic field without need for a power source. what causes permanent magnetism. Explain the cause of permanent magnetism.

Ans. Magnetism is caused by electric charges in motion. Since electrons in atoms are known to move in certain ways, they are able to produce their own magnetic fields. In some types of materials, the motions of atomic electrons are easily aligned with respect to one another, causing an overall magnetic field to be produced by the material.

Q. 4 What two kinds of rotational motion are exhibited by electrons in an atom?

Ans. The spinning motion and the orbital motion of electrons

Q. 5 What effect does the earth's magnetic field have on the intensity of cosmic rays striking the earth's surface?

Ans. Cosmic rays are deflected by the earth's magnetic field, reducing their intensity at the earth's surface.

Q. 4 What is the application of remanence.

Ans. The remanence of magnetic materials provides the magnetic memory in magnetic storage devices, and is used as a source of information on the past Earth's magnetic field in paleomagnetism. In transformers, electric motors and generators a large residual magnetization is desirable.

Q.5 What type of materials are suitable for making permanent magnets?

Ans. The material for a permanent magnet should have the following properties:

- High residual magnetism
- Large coercivity
- It should be able to withstand mechanical ill treatment and temperature changes.
- Large hysteresis loss

e.g, Steel.

Q.6 What properties the material should have to make electromagnets?

Ans.

- Low hysteresis loss
- High susceptibility for low fields
- Large value of intensity of magnetization with compartively small magnetic field

e.g, Soft iron.

Experiment 9

To find the variation of photoelectric current with the intensity of light

EXPERIMENT 9

To Find the Variation of Photoelectric Current with the Intensity of Light

Objective

1. To study the variation in photoelectric current of a photovoltaic cell with the intensity of light.

Related Concepts

Light, absorption of light, photon, Quantum theory of light, photovoltaics

Apparatus

- Tungsten lamp (60 Watt)
- Photodiode
- Micro ammeter
- Box with scale
- 220 V source
- Connecting wires

Experimental Arrangement

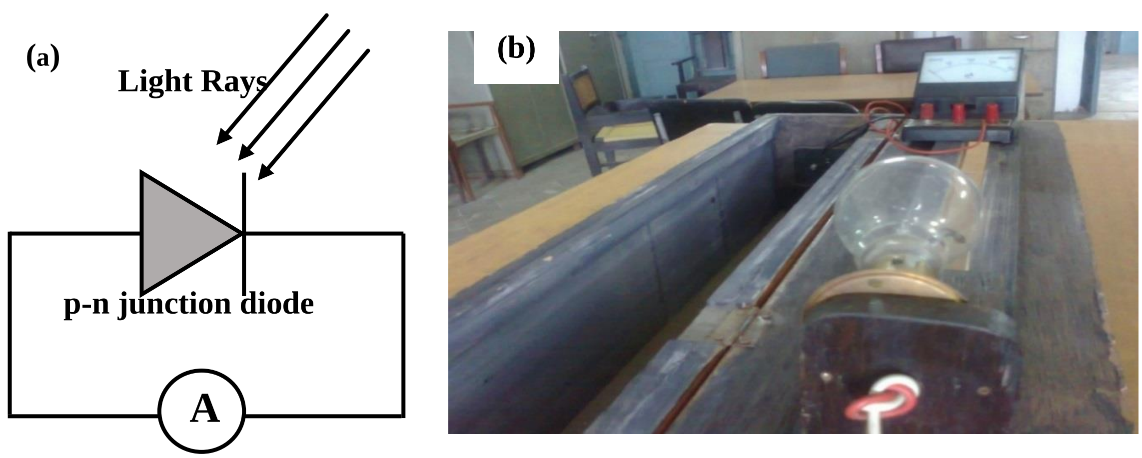


Figure 1: (a) Circuit diagram of a photovoltaic cell and (b) Photographic view of the experiment.

Procedure

1. Give the supply of 220 V to the lamp.
2. Connect micro ammeter with the terminals of photocell.
3. Set appropriate maximum distance between lamp and photocell.
4. Let distance between lamp and photocell is 85 cm, switch on the lamp, there will be a deflection on the micro ammeter. Note down the corresponding value of current.
5. Take several readings of current by decreasing the distance of 5 cm between source and photocell.
6. Calculate Intensity of light I and draw the graph between intensity and photoelectric current on micro ammeter. It is a straight line.

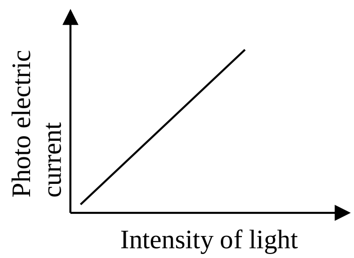


Figure 2. Graph between intensity and photoelectric current

Precautions

1. Make tight connections.
2. Take observations quickly to avoid temperature increase inside the box.

Observations and Calculations

Sr. No.	Distance of lamp from photocell **d** (m)	Intensity of light **I=constant/d²** (m^{-2})	Photoelectric Current **μA**	**I / μA**
1	0.85			
2	0.80			
3	0.75			
4	0.70			
5	0.65			
6	0.60			
7	0.55			
8	0.50			
9	0.45			

Theory

Photoelectric effect

Electrons are emitted from matter (metals and non-metallic solids, liquids or gases) as a consequence of their absorption of energy from electromagnetic radiation of very short wavelength, such as visible or ultraviolet light.

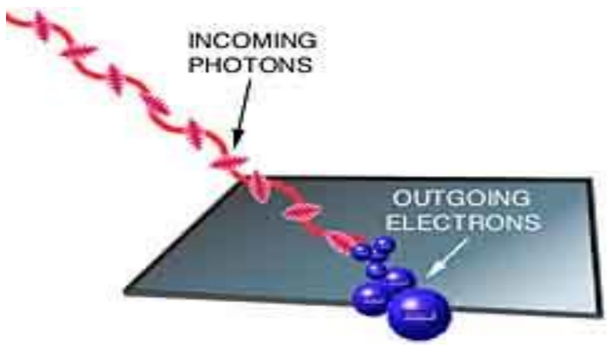


Figure 3 Illustration of Photoelectric Effect

- When light of suitable frequency falls on the metal surface, it emits electrons.
- The number of electrons emitted from the cathode is proportional to the intensity of light.
- The maximum kinetic energy with which the electrons are emitted is independent of intensity of light. It depends on the frequency of light.
- The minimum frequency required for the emission of photoelectrons is called the threshold frequency.
- The photoelectric threshold frequency depends on the nature of metal.
- The minimum energy which an electron should gain to escape from the surface of metal is called the work function.
- If d is the distance between the lamp and the photocell, then the intensity of light I is proportional to $1/d^2$ ($I=constant/d^2$)

Einstein's Equation

Einstein assumed that the radiations were quantized. i.e, the emission and absorption of radiations always occur in quanta (or photons) of energy E=hf, where 'h' is the planks constant and 'f' is the frequency of radiation. The photon remained localized in space as it moves away from the source with a velocity c.

If φ_o is the work function and K_{max} is the maximum kinetic energy with which an electron is emitted from the surface of a metal when radiations of frequency 'f' falls on it then according to the Einstein Equation:

$$hf = k_{max} + \varphi_o$$

Photo Cell

It is a device in which the photoelectric effect is used to produce current when exposed to light or other electromagnetic radiation.

Types of photo cell

(i) Photoemissive cell

It is an electron tube in which the electrons initiating an electronic current originated by photoelectric emission. In its simplest form, it consists of a cathode coated with a photosensitive material (cesium oxide, potassium, rubidium etc.) and an anode.

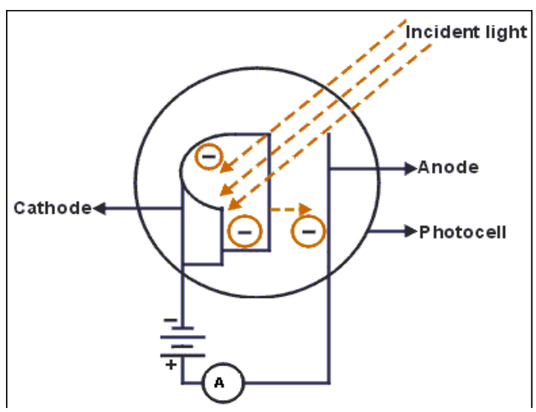


Figure.4 Schematic of photoemissive cell

Light falling upon the cathode causes the liberation of electrons, which are then attracted to the positively charged anode, resulting in a flow of current proportional to the intensity of light falling on the cell. Photoemissive cells may be highly evacuated or may be filled with an inert gas at low pressure to achieve greatest sensitivity.

(ii) Photovoltaic cell

Photovoltaic cell is a junction of semi-conductors (PN junction diode) which generate voltage across its terminals when light fall on it.

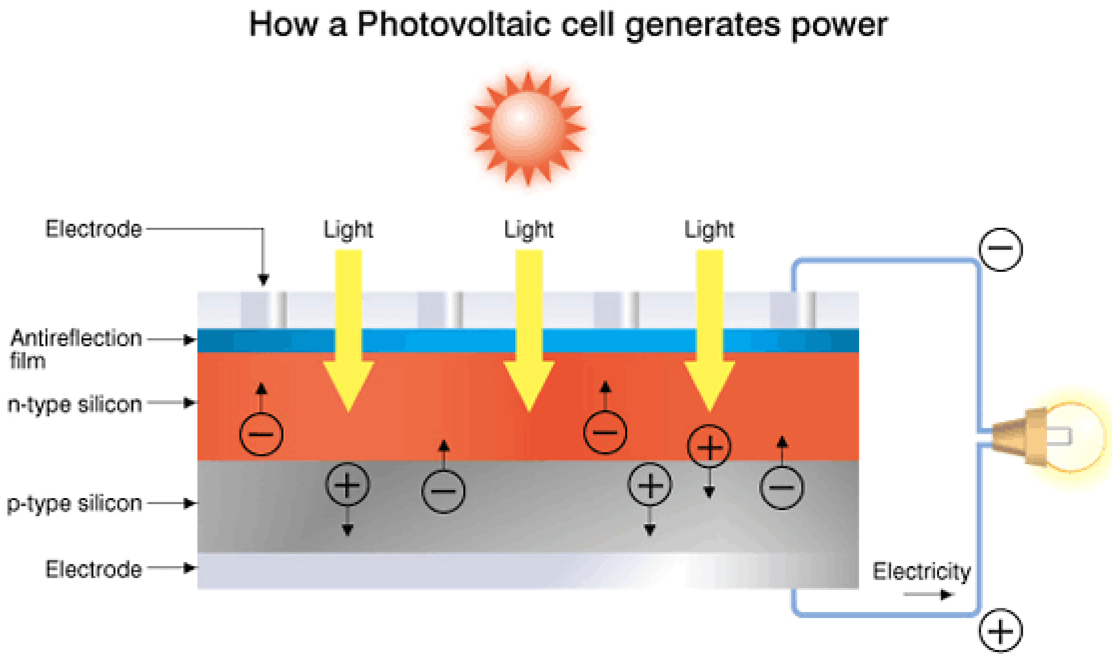


Figure.5 Schematic of photovoltaic cell

The voltage obtained can be increased by increasing the intensity of light. The basics of solar cells are photovoltaic cells, so it converts solar energy into electric energy. These cells are used to light up parks used in solar cars and other electric appliances

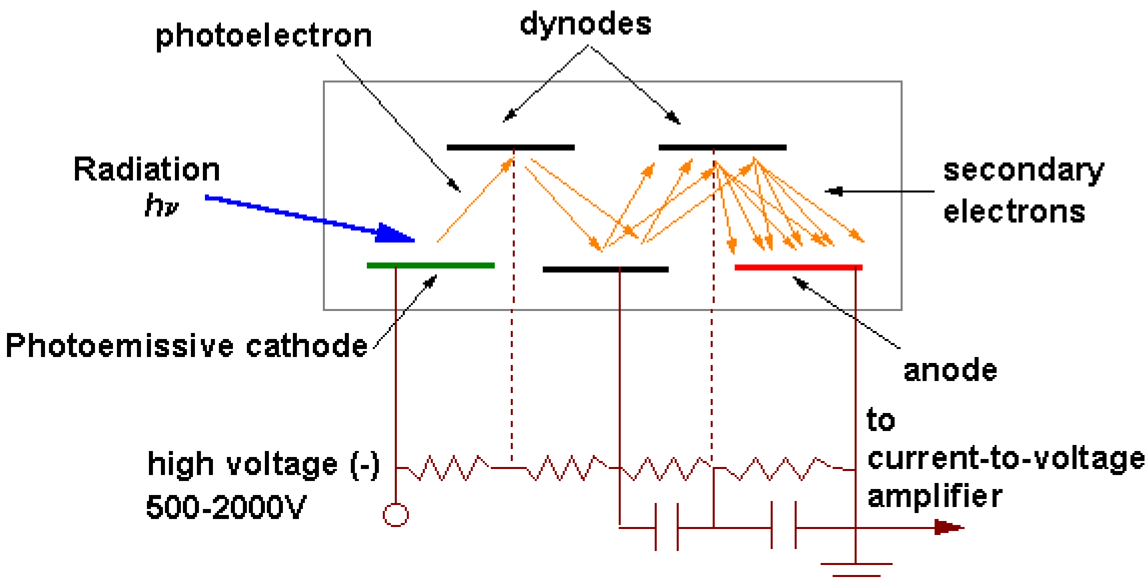
(iii) Photoconductive cell

In this mode diode is connected to a load and a power supply. Photoconductive detectors are used in searching and tracking a source of radiation. Some anti-aircraft missiles search for and track enemy bombers, the engines of which are excellent source of infrared radiation.

Figure.6 photoconductive cell

Photomultiplier tubes (PMTs)

PMTs convert photons to an electrical signal. They have a high internal gain. A PMT consists of a photocathode and a series of dynodes in an evacuated glass enclosure. When a photon of sufficient energy strikes the photocathode, it ejects a photoelectron due to the photoelectric effect. The photocathode material is usually a mixture of alkali metals, which make the PMT sensitive to photons throughout the visible region of the electromagnetic spectrum. The photocathode is at a high negative voltage, typically -500 to -1500 volts. The photoelectron is accelerated towards a series of additional electrodes called dynodes. These electrodes are each maintained at successively less negative potentials. Additional electrons are generated at each dynode. This cascading effect creates 10^5 to 10^7 electrons for each photoelectron that is ejected from the photocathode. The amplification depends on the number of dynodes and the accelerating voltage. This amplified electrical signal is collected at an anode at ground potential, which can be measured. Phototubes are similar to PMTs, but consist of only a photocathode and anode. Since phototubes do not have a dynode chain to provide internal amplification, they are used in less sensitive applications such as absorption spectrometers.



Applications

- **Photodiodes** is a p-n junction or PIN structure. When a photon of sufficient energy strikes the diode, it excites an electron, thereby creating a free electron (and a positively charged electron hole). This mechanism is also known as the inner photoelectric effect. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in electric field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.
- In photovoltaic mode or when used in zero bias or, the flow of photocurrent out of the device is restricted and a voltage builds up. This mode exploits the photovoltaic effect, which is the basis for solar cells – a traditional solar cell is just a large area photodiode.
- In photoconductive mode, the diode is often reverse biased (with the cathode driven positive with respect to the anode). Compared to forward bias, this dramatically reduces the response time at the expense of increased noise, because it increases the width of the depletion layer, which decreases the junction's capacitance. The reverse bias induces only a small amount of current (known as saturation or dark current) along its direction while the photocurrent remains virtually the same. Photo-voltaic cells are

used in active transducers, TV camera, photographic equipments and in light exposure meter.

- A **phototransistor** is a bipolar transistor encased in a transparent case so that light can reach the base-collector junction. The electrons that are generated by photons in the base-collector junction are injected into the base, and this photodiode current is amplified by the transistor's current gain. If the emitter is left unconnected, the phototransistor becomes a photodiode.
- Phenomena of photoelectric effect is the basic working principle of many devices used these days. A photocell is based on the photoelectric effect and are employed directly or indirectly in various devices. Photocells have myriad uses, especially as switches and sensors. They are a common fixture in robotics, where they direct robots to hide in the dark, or to follow a line or beacon (source of guidance).
- A photocell can be used to detect the presence of light. Photocells react to light from a laser pointer (or other laser) and a remote control, and see that information, for example a message can be transmitted by visible and infrared light. An infrared-emitting diode is used to transmit music from an audio source (like a CD player) to the photocell with a speaker connected to it.
- In computer vision system, a photocell array installed in an optomechanical scanning system and is used as the video signal sensor. Such systems are most often used in design of IR vision devices. In scanning systems video signal is formed upon successive commutation of array photo sensors which are shifted as a whole in the direction perpendicular to the photo sensor position in the array. In the course of such scanning each photo sensor forms electric signal whose value is proportional to the radiation flux hitting the photo sensor through the objective. As a result, each photo sensor forms one image.
- In robotics IR vision devices (utilizing photocells) can be an extremely useful source of video information, especially in computer vision systems of specialized mobile robots.

- Sensors operate on the principle of making measurements based on changes in an electrical signal. This signal is then relayed either by wire or wirelessly to an indicator or equipment programmed to respond to changes in the measurement. Changes in light intensity can also be measured by an electronic sensor. These variations in light can be used for devices such as touch keypads, which work like computer keyboards but operate based on changes in voltage when a finger blocks the light on the key.
- The principal of photoelectric effect is used in the Photoelectron spectroscopy. Photoelectron spectroscopy (PES) is a technique used for determining the ionization potentials of molecules. Underneath the banner of PES there are two separate techniques used for quantitative and qualitative measurements. They are ultraviolet photoeclectron spectroscopy (UPS) and X-ray photoelectron spectroscopy (XPS). XPS is known for chemical analysis (ESCA). UPS focuses on ionization of valence electrons while XPS is able to go a step further and ionize core electrons and **pry** them away.
- Photoelectric effect is a very useful phenomenon and its importance can be understood from the following uses of the photoelectric current. Photoelectric current produced as the result of photoelectric effect is used in number of ways e.g. solar light sensitive diodes and solar power such as solar cells.
- Photoelectric current of positive or negative charges is also produced in space craft due to the photoelectric effect. The parts of space craft exposed to the shadow develop a negative current of several kilovolts. On the other hand, the parts exposed to light produce a positive current. The sunlight hits the lunar dust, they get charged due to photoelectric effect. The surface of the moon is lifted off due the repulsion of this charged dust. So, the photoelectric effect is also used to study the surface of the moon.
- Polymer solar cells have been attracting considerable attention due to their unique advantages of being low in cost and lightweight. The active layer of polymer solar cells has good absorption of sunlight. Since 54.3% of the sunlight energy is distributed in the visible region from 380 to 800 nm, an ideal active layer for a polymer solar cell should have a broad and strong absorption spectrum in this range. The active layer

exhibits an almost flat absorption spectrum in the visible range; it has little influence on the color of the transmitted light.

- Solar cell/Photocell design involves specifying the parameters of a solar cell/photocell structure in order to maximize efficiency, given a certain set of constraints. These constraints will be defined by the working environment in which solar cells/photocells are produced. For example, in a commercial environment where the objective is to produce a competitively priced solar cell, the cost of fabricating a particular solar cell structure must be taken into consideration. However, in a research environment where the objective is to design a highly efficient laboratory-type cell, maximizing efficiency rather than cost, is the main consideration.
- Glass packages are commonly used with diodes, and glass seals are used in metal transistor packages.
- Semiconductor packages may include special features. Light-emitting or light-sensing devices must have a transparent window in the package; other devices such as transistors may be disturbed by stray light and require an opaque package.

VIVA VOCE

Q.1 What is photoelectric effect?

Ans. Emission of electrons from a material when light is incident on its surface.

Q.2 What is work function?

Ans. Minimum amount of energy required to eject electron from a material.

Q.3 What is threshold frequency?

Ans. Minimum frequency of light necessary to remove electron from a material.

Q.4 Why light has dual nature?

Ans. The propagation of light follows wave mechanics whereas the absorption/emission of light is quantized. Therefore, it is said that light has dual nature i.e. a wave and a particle.

Q.5 Which type of photocell can be used as a solar cell?

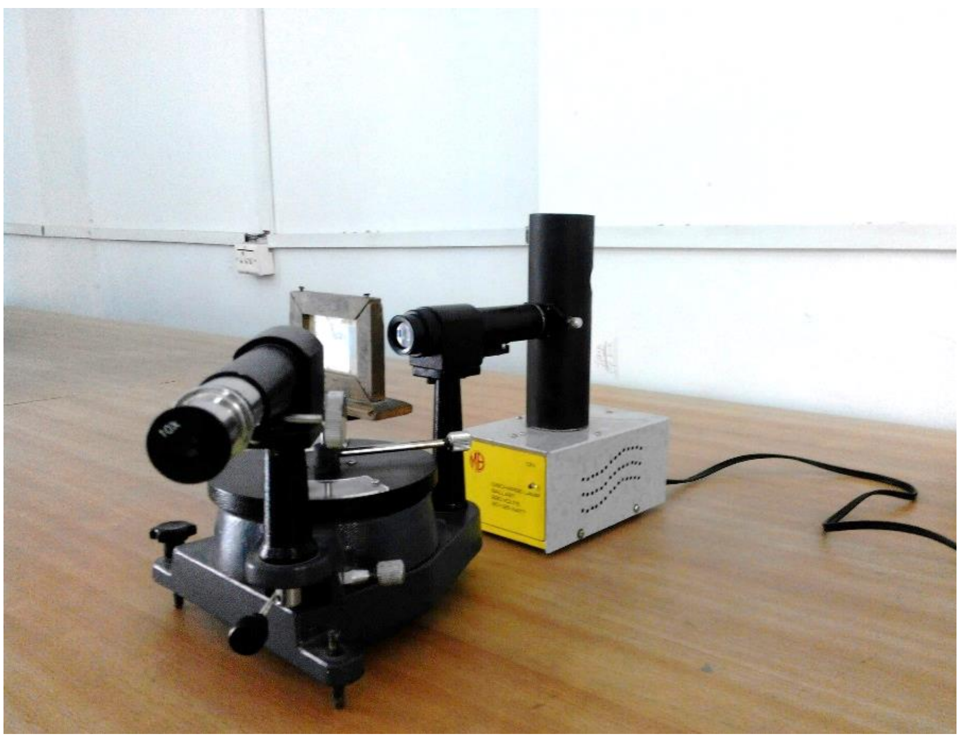
Ans. Photovoltaic

Q.6 If the incident light has energy greater than work function, can we get more number of electrons?

Ans. No because number of emitted electrons depend upon intensity of light and not on its energy. By increasing incident light energy, kinetic energy of electrons increases.

Experiment 10

To Determine the Wavelength of Na Light by Diffraction Grating and Spectrometer



EXPERIMENT 10

To Determine the Wavelength of Na Light by Diffraction Grating and Spectrometer

Objectives

1. To study the emission spectra of sodium using spectrometer.
2. To determine the wavelength of sodium light using diffraction grating.

Related Concepts

Emission of light, Spectrum and its types, diffraction and its types, interference

Apparatus

- Sodium lamp
- Power supply
- Spectrometer
- Diffraction grating

Experimental Arrangement

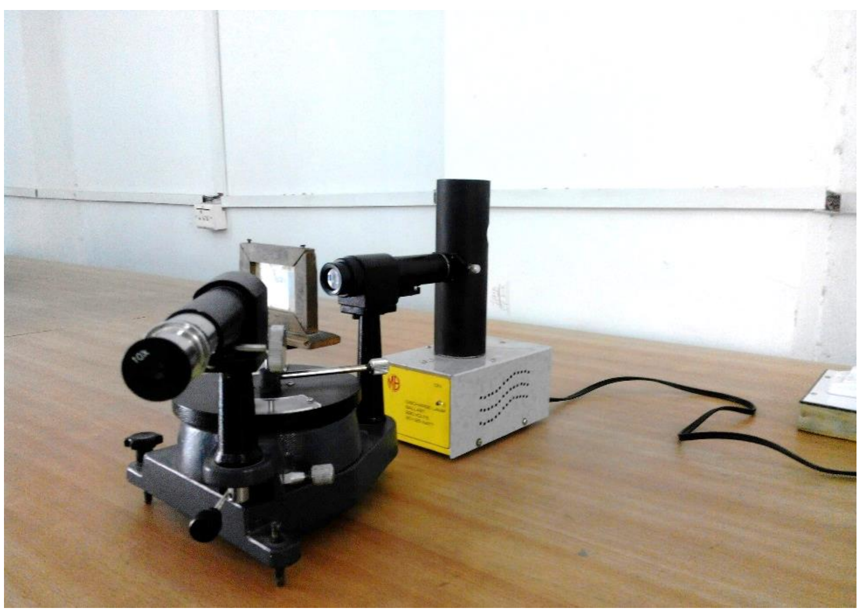


Figure 1. Photograph of experimental setup.

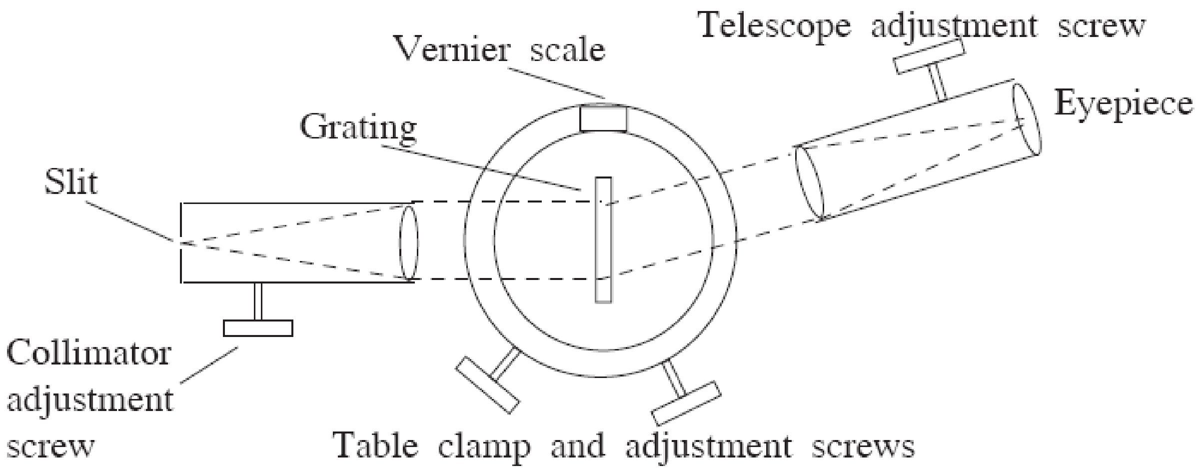


Figure 2. Plane view of the optical spectrometer

Procedure

1. Switch on the sodium lamp and wait till the red light disappears and only yellow light comes out of it.
2. Place the slit of collimator in front of it and adjust the slit width from adjustable knob.
3. Adjust the collimator for parallel rays and focus the telescope at infinity.
4. Place the diffraction grating on the turn table so that its ruled surface should be normal to the axis of the collimator.
5. Adjust the telescope in front of collimator lens and observe directly the slit with it.
6. Bring the slit exactly in the middle of the crosswire by adjusting the telescope with a fine adjustment screw.
7. After above adjustments regarding to telescope and collimator, fix the turn table.
8. Note the direct reading position "I", i.e. zero order diffraction pattern, with the help of telescope when it is in front of the collimator position.
9. Turn and adjust the telescope towards left and right to note down the positions of first and second order diffraction patterns at either side.
10. Calculate the values of θ_1, θ_2, mean θ and $\sin\theta$ and put these values in the formula given below to calculate the wavelength, λ both for 1st and 2nd order diffraction pattern

$$m\lambda = d\sin\theta$$

Precautions

1. The base of the spectrometer and the prism table should be properly leveled using leveling screws.
2. The slit width should be adjusted using adjustable slit, placed at one end of the collimator, so as to get light intensity just sufficient for comfortable observation.
3. Proper collimation of light is achieved by adjusting the distance between the slit and the collimating lens system to bring the slit into the focal plane of the system.
4. The collimator and the telescope should be properly leveled so that the slit image is seen in the center of view of the telescope eyepiece.

Observations and Calculations

No. of lines per inch on the grating = 15000

No. of lines per cm on the grating = 15000/2.54 = 5905.51

Grating element, d =1.69×10^{-6}m

$$L.C. = \frac{Length\ of\ smallest\ division\ on\ circular\ scale}{Total\ divisions\ on\ vernier\ scale} =$$

Least count of spectrometer scale, L.C. =

Sr. No.	Order of spectrum, **m**	Direct reading position **I**	Reading of telescope when it is towards Left side **L**	Reading of telescope when it is towards Right side **R**	Difference **L-I=θ_1**	Difference **R-I=θ_2**	Mean $\theta=\frac{\theta 1+\theta 2}{2}$	**sinθ**	$\lambda = \frac{d\sin\theta}{m}$ nm
1.	1								
2.	2								

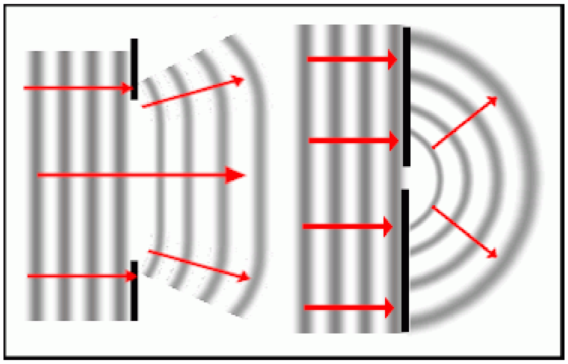
Average value of the wavelength of light from sodium lamp, λ = ______________nm

λ = ______________Å

Theory

Diffraction

Diffraction is the bending or spreading of waves that encounter an object (a barrier or an opening) in their path. Diffraction of light takes place if the size of a slit or an obstacle in the path of the wave is comparable to the wavelength of light. If an obstacle with a small gap is placed in the tank the ripples emerge in an almost semicircular pattern. If the gap is large however, the diffraction is much more limited. Small, in this context, means that the size of the obstacle is comparable to the wavelength of the ripples.



Types of diffraction

Diffraction of light can be divided into two classes:

- Fraunhoffer diffraction or far-field diffraction
- Fresnel diffraction or near-field diffraction

Fraunhoffer diffraction deals with the limiting cases where the light approaching the diffracting object is parallel and monochromatic, and where the image plane is at a distance large compared to the size of the diffracting object.

Fraunhofer diffraction occurs when:

$$F = \frac{a^2}{L\lambda} \ll 1$$

Where,

a - aperture or slit size

λ – wavelength

L - distance from the aperture

Fresnel diffraction is more general case where these restrictions are relaxed, i.e., when the light approaching the diffracting object is monochromatic but not parallel and where the image plane is at a small distance compared to the size of the diffracting object is called Fresnel diffraction.

Fresnel diffraction occurs when:

$$F = \frac{a^2}{L\lambda} \geq 1$$

Diffraction grating

The diffraction grating is a piece of glass with very fine lines etched into it. Grating should be calibrated to find the spacing d between the lines.

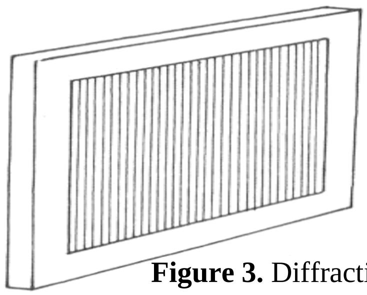


Figure 3. Diffraction grating

<u>Grating element:</u>

The distance between two adjacent slits is known as granting element. Its value is obtained by dividing the length of grating by the by total number of lines ruled on the grating

d=L / N

L=length of the grating, N=number of lines ruled on the grating

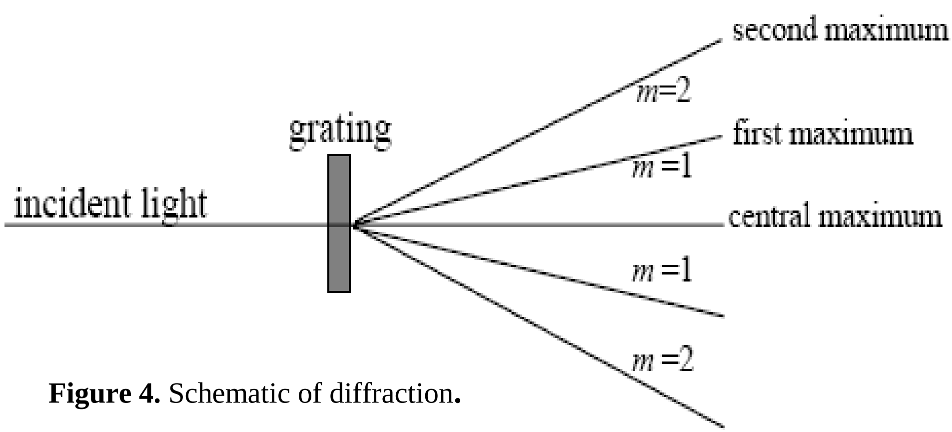


Figure 4. Schematic of diffraction**.**

Optical Spectrometer

A spectrometer is an optical instrument, which is used for observing spectra of light. The function of the spectrometer is to disperse light into its various component wavelengths (or frequencies) and to determine the wavelength of each resolved component. The dispersive element is usually a diffraction grating but it could also be a glass prism.

Figure 5 Photographic View of Spectrometer.

Major parts of spectrometer

i. Collimator

The collimator renders a parallel beam of light through the hollow cylindrical tube. One end of the collimator has a slit through which light enters the tube and falls on lens L situated at the other end.

ii. Turn table/Prism table

Turn table/Prism table is a circular plate fixed over a vertical stand of adjustable height. The free end of stand consists of a circular scale graduated in degrees from 0^o to 360^o along with verniers to enable to read the position of the diffracted spectral lines.

iii. Telescope

Telescope is meant for observing the spectrum and is mounted horizontally on a vertical stand attached to the circular scale. The telescope can be rotated about the Turn table/Prism table. Cross hairs located in the focal plane of the objective lens provide a precise means for locating the direction of these rays.

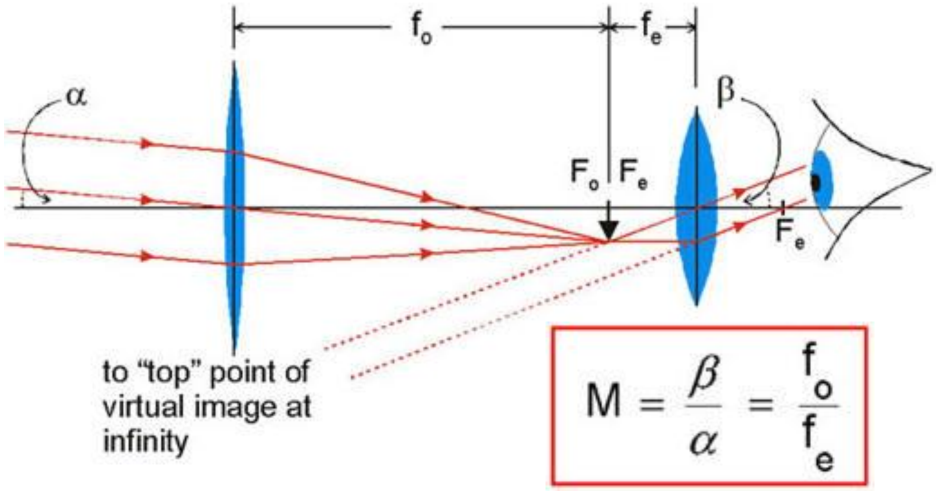


Figure 6. Ray Diagram of astronomical telescope.

How to read spectrometer scale

Spectrometer has two graduated scales given on its circular disk. These scales are main scale and vernier scale. The angular position of the maximas or bright fringes viewed from the telescope is determined by reading both the main and vernier scales. The main scale value is the main scale division that is just below the zero of the vernier scale. The vernier scale value is the vernier scale division that is exactly in line with a division of the main scale. The telescope position is then the main scale value (in degrees) plus the vernier scale value (in minutes).

Interference of light

Young's double slit experiment

The first practical demonstration of optical interference was provided by THOMAS YOUNG in 1801. His experiment gave a very strong support to the wave theory of light. Young's Double Slit Experiment provides a method for measuring wavelength of the light.

Brief description of Young's Experiment

In the early 1800's (1801 to 1805, depending on the source), Thomas Young conducted his experiment. He allowed light to pass through a slit in a barrier so it expanded out in wave fronts from that slit as a light source (under Huygen's Principle). That light, in turn, passed through pair of slits in another barrier (carefully placed the right distance from the original slit). Each slit, in turn, diffracted the light as if they were also individual sources of light. The light impacted an observation screen. Due to interference of waves alternate bright and dark fringes are obtained on the screen.

The path difference between two waves travelling at an angle θ is given by:

$$m\lambda = d\sin\theta$$

Where, $d\sin\theta$ is the path difference between two light rays.

Constructive interference condition

$$d sin\theta = m\lambda \qquad m = 0, \pm 1, \pm 2, \ldots$$

Destructive interference condition

$$d sin\theta = (m + 1/2)\lambda \qquad m = 0, \pm 1, \pm 2, \ldots$$

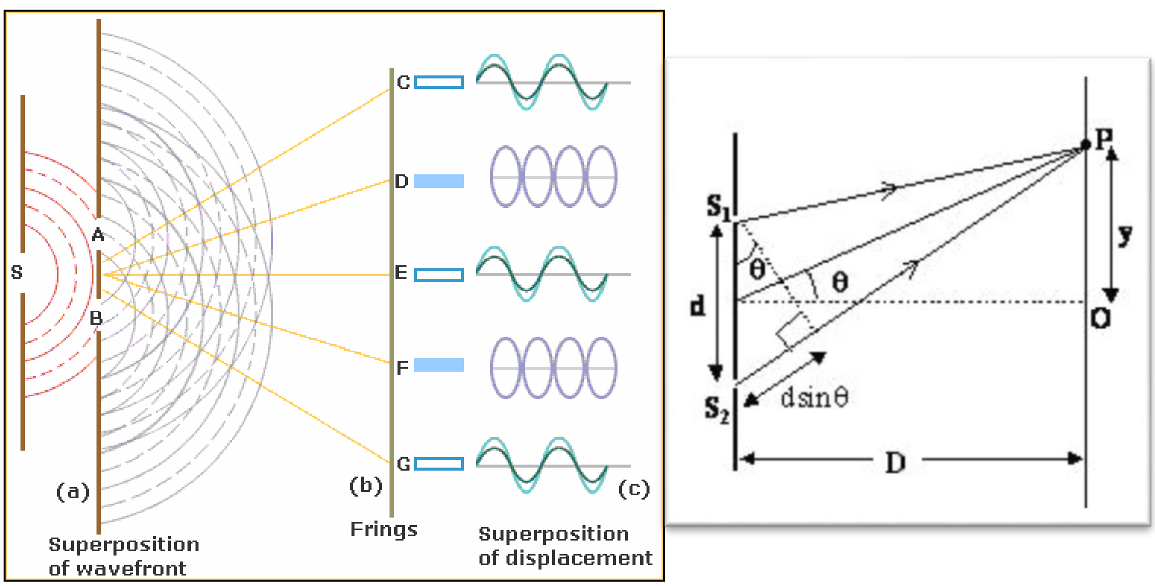


Figure 7 Double Slit Experiment.

Construction and working of Low pressure Na lamp

Low-pressure sodium (LPS) lamps have a borosilicate evacuated glass, gas discharge tube (arc tube) containing solid sodium and a small amount of neon and argon gas as a penning mixture to start the gas discharge with two electrodes across the ends. A high voltage across the electrodes produces an electric discharge that excites the electrons in the atoms, which subsequently de-excite by emitting a dim red/pink light of penning mixture to warm the sodium metal and finally sodium metal vaporizes. Discharge passes through the Na vapors and within a few minutes it turns into a common bright yellow color. The ground state for the sodium's valence electron is designated 3s. Transitions, which principally feature in the sodium emission spectrum are given in the energy level diagram. The transition 3p to 3s is responsible for the yellow sodium D lines of the solar spectrum and the bright yellow color of the sodium flame and of sodium vapor lamps. The intense yellow band is the atomic sodium D-line emission, comprising about 90% of the visible light emission for this lamp type.

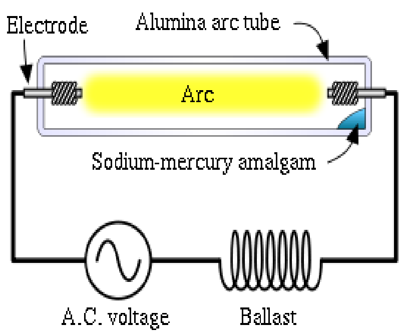


Figure 8. Circuit diagram of Na lamp.

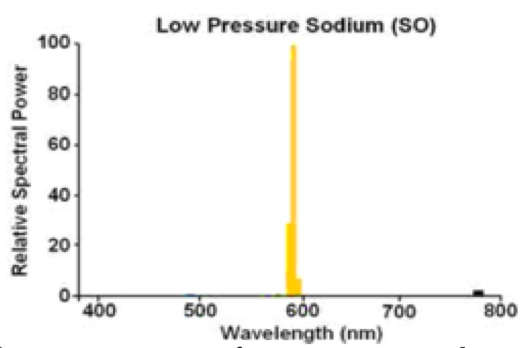


Figure 9. Spectrum of Low-pressure Na lamp

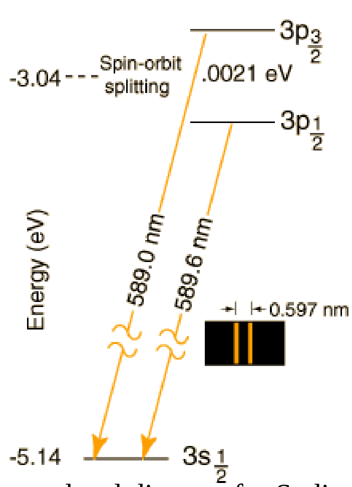


Figure 10 Energy-level diagram for Sodium

Spectrum

When a beam of composite light say white light is passed through a prism or grating the light splits into its constituent colors. The regular arrangement of colors is known as spectrum.

Electromagnetic Spectrum

'The arrangement of different types of electromagnetic radiations in order of increasing wavelengths (and consequently decreasing frequencies) is known as electromagnetic spectrum'.

Types of spectra

The spectra may be divided into principal classes.

(1) Emission spectra

(2) Absorption spectra

The emission spectra are obtained when light coming directly from the source is examined with a spectroscope while the absorption spectra are obtained when light from the source which gives continuous spectrum is passed through a substance, i.e., an absorbing material and the transmitted light is examined with a spectroscope. In absorption spectrum, the absorbing material absorbs all those wavelengths which fall on it. The dark lines in the absorption spectra correspond to the lines which absorbing material would have absorbed.

Both emission and absorption spectra are subdivided into three classes:

1) Line spectra
2) Band spectra
3) Continuous spectra

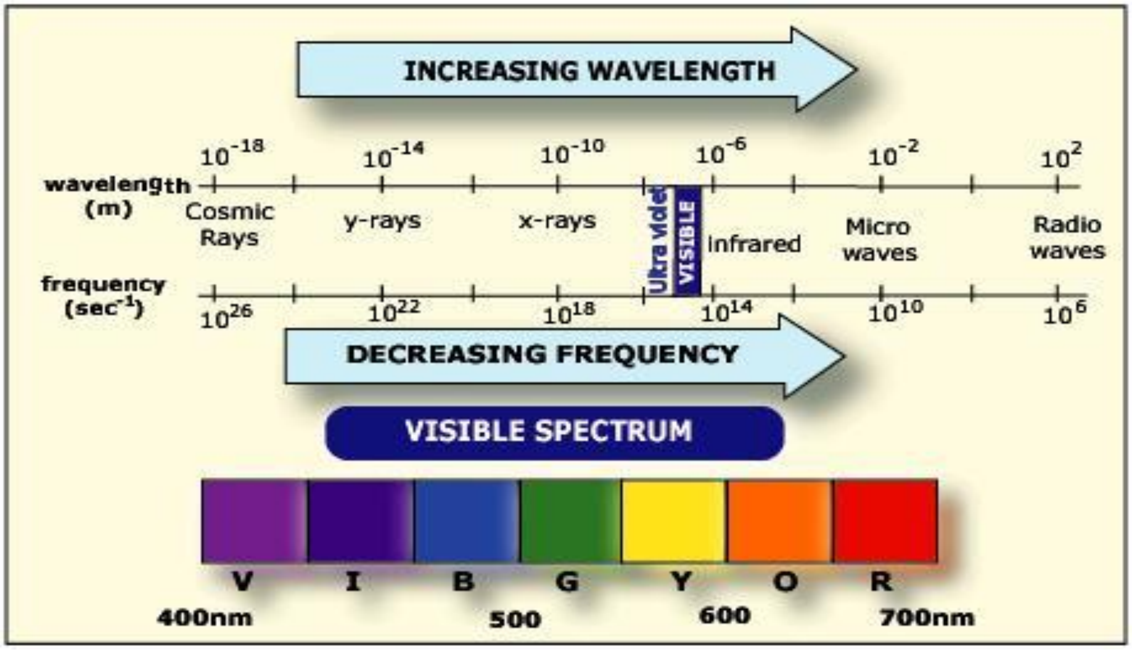


Figure. 11 Electromagnetic Spectrum.

Applications

- The diffraction grating transforms an incident beam of light into a spectrum. This happens because each groove of the grating diffracts the beam, but because all the grooves are parallel, equally spaced and have the same width, the diffracted waves mix or interfere constructively so that the different components can be viewed separately. Spectra produced by diffraction gratings are extremely useful in applications from studying the structure of atoms and molecules to investigating the composition of stars.
- X rays are light waves that have very short wavelengths. When they irradiate a solid, crystal material they are diffracted by the atoms in the crystal. But since it is a characteristic of crystals to be made up of equally spaced atoms, it is possible to use the diffraction patterns that are produced to determine the locations and distances between atoms. Simple crystals made up of equally spaced planes of atoms diffract x rays according to Bragg's Law ($n\lambda = 2d\sin\theta$). Current research using x-ray diffraction utilizes an instrument called a diffractometer to produce diffraction patterns that can be compared with those of known crystals to determine the structure of new materials.

- A hologram (holos—whole: gram—message) can be thought of as a complicated diffraction grating. The recording of a hologram involves the mixing of a laser beam and the unfocused diffraction pattern of some object. In order to reconstruct an image of the object (holography is also known as wave front reconstruction) an illuminating beam is diffracted by plane surfaces within the hologram, following Bragg's Law, such that an observer can view the image with all of its three-dimensional detail.
- Gas/liquid chromatography–mass spectrometry (GC-MS) is a method that combines the features of gas-liquid chromatography and mass spectrometry to identify different substances within a test sample. Applications of GC-MS include drug detection, fire investigation, environmental analysis, explosives investigation, and identification of unknown samples. GC-MS can also be used in airport security to detect substances in luggage or on human beings. Additionally, it can identify trace elements in materials that were previously thought to have disintegrated beyond identification. Liquid chromatography–mass spectrometry (LC-MS, or alternatively HPLC-MS) is used for detection and potential identification of chemicals in the presence of other chemicals (in a complex mixture). Preparative LC-MS system can be used for fast and mass directed purification of natural-products extracts and new molecular entities important to food, pharmaceutical, agrochemical and other industries.
- Absorption spectroscopy refers to spectroscopic techniques that measure the absorption of radiation, as a function of frequency or wavelength, due to its interaction with a sample. Absorption spectroscopy is employed as an analytical chemistry tool to determine the presence of a particular substance in a sample and, in many cases, to quantify the amount of the substance present. Infrared and ultraviolet-visible spectroscopy are particularly common in analytical applications. Absorption spectroscopy is also employed in studies of molecular and atomic physics, astronomical spectroscopy and remote sensing. Spectrophometery is one of the absorption spectroscopy techniques that uses monochromatic light.
- High-pressure sodium lamps provide the highest luminous efficiency of all as much as 150 lumens per watt, which is very high luminous efficiency having extremely long

service life. Sodium Vapor lamps are economical high intensity discharge (HID) lamps used for street lighting, general floodlighting and parking lots due to high-contrast visibility in mist and fog.

- Low-pressure sodium lamps are mercury-free. After ignition, the sodium vapor in the glass tube emits monochromatic yellow light enables a luminous efficiency of up to 178 lumens per watt to be achieved. Low-pressure sodium lamps are preferred around astronomical observatories because the yellow light can be filtered out of the random light surrounding the telescope.
- The minimum impact on night environment is calculated by assuming that the scotopic (vision of the eye under low light conditions) range of human eye sensitivity is near the night vision of fauna (animal life). This is a minimum impact because for instance the insects' vision is much more sensitive below 400nm than the human eye which reaches its detection limit at that range. Particularly, the high-pressure Mercury lamp appears not as bad as in reality because the near UV light emitted, very harmful for insects, is not visible by human beings.
- Low Pressure Sodium lamp is the best light for the protection of night environment and this should remain the common choice near astronomical observatories even if the color rendition is poor.
- While glasses are amorphous and do not themselves give diffraction patterns, there are still manifold uses of diffraction in the glass industry. They include identification of crystalline particles which cause tiny faults in bulk glass, and measurements of crystalline coatings for texture, crystallite size and crystallinity.
- As the microelectronics industry uses silicon and gallium arsenide single crystal substrates in integrated circuit production, there is a need to fully characterize these materials using the XRD. XRD topography can easily detect and image the presence of defects within a crystal, making it a powerful non-destructive evaluation tool for characterizing industrially important single crystal specimens.
- XRD is used mainly in contact trace analysis. Examples of contact traces are paint flakes, hair, glass fragments, stains of any description and loose powdered materials.

Identification and comparison of trace quantities of material can help in the conviction or exoneration of a person suspected of involvement in a crime.

- Stress or stain in a material can cause visible changes in the diffraction pattern of a material. These changes are observed as diffraction peak asymmetry, peak broadening, or peak shifting. The diffraction pattern of a material can be monitored during fabrication or manufacturing to see if these processes are causing any unwanted stress or stain in the material. Discrete samples can be monitored periodically during an industrial process, or diffraction can be measured on-line during sample processing.
- Study of interfaces between fluid phases existing in oil and gas reservoirs is performed by dynamic light scattering. With the spectrometer used for the studies described above, we measure light scattered from thermally excited waves (with amplitude of the order of 1 nm) on the fluid/fluid interface. Interfacial wave components of different wavelengths are probed by measuring scattered light at different scattering angles. Spectrometer is designed to measure scattered light over a relatively large range of scattering angles, giving the opportunity to probe interfacial waves with wavelengths from 5 μm to 500 μm.
- Spectral geology is the measurement and analysis of portions of the electromagnetic spectrum to identify spectrally distinct and physically significant features of different rock types and surface materials and their mineralogy. Spectral data is measured using spectrometer, which record artificially provided radiation reflected from the surface of materials. Wavelength ranges most suitable for the discrimination of geological materials and oil slicks include the visible and near-infrared (VNIR), short-wavelength infrared (SWIR) and the mid or thermal infrared (TIR). Spectral variation is the result of different compositions, the degree of ordering, mixtures and the grain size of different rocks and minerals, because they have multiple valence states.
- Transition elements such as iron (Fe), copper (Cu), nickel (Ni), chromium (Cr), cobalt (Co), manganese (Mn), vanadium (V), titanium (Ti) and scandium (Sc) display the most prominent spectral features in the VNIR wavelength range.

- The SWIR wavelength region between 2000 and 2500 (nm) is particularly suitable for mineral mapping.
- The 2000-2400 nm wavelength region can show many absorption features characteristic of certain hydroxyl and carbonate bearing minerals and mineral groups which are characteristic of hydrothermal alteration. These mineral groups may include pyrophyllite, kaolinite, dickite, micas, chlorites, smectite clays, alunite, jarosite, calcite, dolomite and ankerite.
- There are many different kinds of spectrometers which are ideally suited for mining exploration and mineral identification. These spectrometers cover the UV/VIS/NIR spectra. This makes them supremely reliable in the field. For instance, Transition elements exhibit Visible and Near Infra-Red spectral lines. So that is how their presence can be identified by studying such spectral line.

VIVA VOCE

Q.1 What is light?

Ans. Light is a form of energy.

Q.2 Why it said that light is of dual nature?

Ans. Light propagates as a wave and it is absorbed or emitted from matter in form of photons (packets of radiation).

Q.3 Define wavelength.

Ans. The distance between two consecutive crests or troughs is called wavelength. It is usually measured in nanometer (nm) and angstrom (Å).

Q.4 What is the difference between interference spectrum and diffraction spectrum?

Ans. The intensity of all the peaks is almost same in interference pattern but in diffraction pattern the intensity decreases with increasing order.

Q.5 Why the sodium lamp gives pink color at start when it is switched on?

Ans. It is due to Neon.