DEPARTMENT OF PURE & APPLIED PHYSICS

LAB MANUAL

On

Solid State Physics Lab

B.Sc. VI Semester (Physics)

Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur-495009, Chhattisgarh, India

DEPARTMENT OF PURE AND APPLIED PHYSICS

B.Sc. (Physics)

Academic Year 2023-24

SEMESTER-VI

Core 14: Solid State Physics Lab

LIST OF EXPERIMENTS

1. **Measurement of susceptibility of paramagnetic solution (Quinck`s Tube Method).**

2. **To study of V-I characteristics curves of Light Emitting Diode (LED) device and verification of inverse square law.**

3. **To study of V-I characteristics curves of Light Diode Resistance (LDR) device and verification of inverse square law.**

4. **To study of V-I characteristics curves of Solar cell device and verification of inverse square law.**

5. **To measure the resistivity of a semiconductor (Ge) crystal with temperature by four-probe method (from room temperature to 150°C) and to determine its band gap.**

6. **To determine the Hall coefficient of a semiconductor sample.**

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Department of Pure & Applied Physics

Condensed Matter Physics Practical Experiment Manual

To Determine the Mass Susceptibility of Paramagnetic Solution Using Quincke's Method

1. Introduction

Faraday divided the magnetic materials into three classes:

[a] Diamagnetic Substances:

These substances when placed in a magnetic field are feebly magnetized in a direction opposite to that of the magnetizing field. All closed shell materials are diamagnetic.

[b] Paramagnetic Substances:

These substances when placed in a magnetic field are feebly magnetized in the direction of the magnetizing field. Platinum, Aluminium, manganese, copper sulfate, solution of iron and nickel salts etc are some of the examples of such substances.

[c] Ferromagnetic Substances:

These substances when placed in a magnetic field are strongly magnetized in the direction of the magnetizing field iron, nickel, cobalt and their alloys are some of the examples of such substances.

❖ **<u>Magnetic Susceptibility:</u>**

The magnetic susceptibility 'χ'(read as "chi") of a material is a measure of the ease with which a specimen of that material can be magnetized by a given magnetic intensity. It is defined as the ratio of the magnetization 'M' produced due to the magnetic intensity 'H' i.e.

$$\chi_v = \frac{M}{H} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Here magnetization M is the magnetic moment per unit volume and the, χ_v is known as the "Volume susceptibility ". Note that the volume susceptibility is a dimensionless quantity (irrespective of the system of units used). Let us denote it as χ_v for specifying it as the volume susceptibility. Equation (1) may also be expressed as

$$\chi_v = \frac{\mu_0 M}{B} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where $B = \mu_0 H$ is the magnetic induction corresponding to the magnetic intensity H in vacuum.

If N be the number of atoms/volume and μ as the effective magnetic moment of each of these along B, then

$$M = N\mu \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

2. Experimental Set up

Quincke's tube fitted on stand, Electromagnet capable of producing magnetic field of about 10 K gauss with power supply, Gaussmeter, Travelling microscope and experimental solution.

Experimental Setup of the Quincke's Method

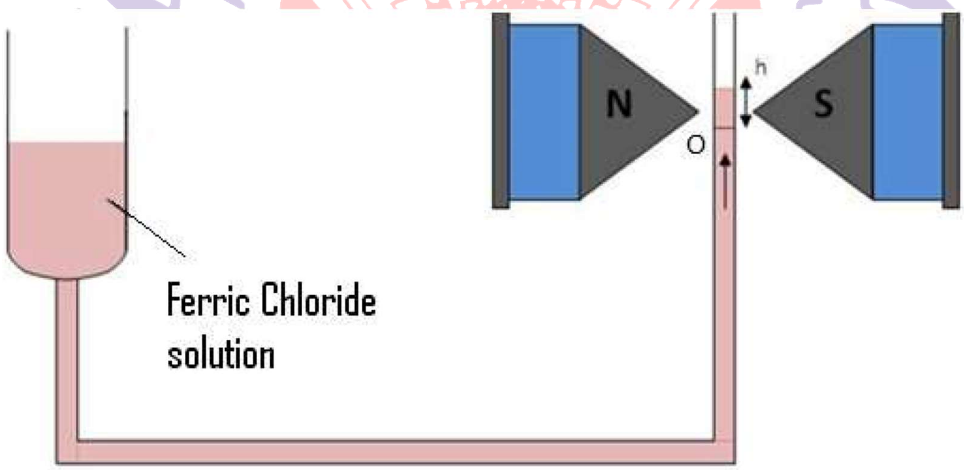

Figure 1. Level of Paramagnetic Liquid rises as we apply external magnetic field.

3. Basic Theory

<u>MEASUREMENT OF SUSCEPTIBILITY:</u>

When a solution of paramagnetic substance of ferromagnetic substance taken in a tube is placed between the poles of a magnet, there is a rise of liquid level. A measurement of this rise in level of the solution in the tube enables us to determine the susceptibility of the substances. We know that the potential energy Ei of an atom of magnetic moment μi, when placed in a magnetic field of strength B (in weber/m^2 or tesla), is given by

$$Ei = \mu_i B = \mu B \text{ .... (4)}$$

Where μ is the effective magnetic moment along the direction of the magnetic field B i.e., Energy of unit volume of a substance with N atoms per unit volume will be E = (Nμ)B = MB (energy/volume) and the force F on the unit volume of the substance, placed in an inhomogeneous magnetic field is

$$F = -\frac{dE}{dx} = -M\left(\frac{dB}{dx}\right) \text{ .... (5)}$$

And using equation (2) we get the force per unit volume

$$F = \left(\frac{\chi_v B}{\mu_0}\right)\frac{dB}{dx} = \left(\frac{\chi_v}{2\mu_0}\right)\frac{d}{dx}(B^2) \text{ .... (6)}$$

i.e., force on the volume V of the substance is

$$F = \left(\frac{\chi_v}{2\mu_0}\right)V\frac{d}{dx}(B^2) \text{ .... (7)}$$

From, Figure 1; let O be a section where the field is negligible and let $'x'$ be the vertical coordinate of O. The force on the element dx of volume adx on the liquid at O is from equation (6)

$$dF = \left(\frac{\chi_v}{2\mu_0}\right)\frac{dB^2}{dx}(a_c\, dx) \text{.............. (8)}$$

Where 'a_c' is the area of cross-section of the narrow limb. The force on the entire liquid above the point O is therefore

$$F = \int_0^{B_1}\left(\frac{\chi_v}{2\mu_0}\right)\frac{dB^2}{dx}(a_c\ dx) = \left(\frac{\chi_v a_c}{2\mu_0}\right)\int_0^{B_1} dB^2 = \left(\frac{1}{2\mu_0}\right)\chi_v\, a_c\, B_1^2 \text{ .... (9)}$$

Where B_1 is the field intensity at the upper level and the force F on the liquid above the point O due to the gravitational field is

$$F = mg = (a_c h)\rho g \text{ .... (10)}$$

where ρ is the density of the liquid. In equilibrium the two forces are equal and opposite thus from equation (7) and (8)

$$F = \left(\frac{1}{2\mu_0}\right)\chi_\nu\, a_c B_1^2 = (a_c h)\rho g \text{ .... (11)}$$

$$\chi_\nu = 2\mu_0 g \frac{h\rho}{B_1^2} \text{ .... (12)}$$

This is the volume susceptibility and is dimensionless. This volume susceptibility divided by density ρ gives the mass susceptibility of the solution

$$\chi_m = \frac{\chi_\nu}{\rho} = 2\mu_0 g \frac{h}{B_1^2}\ (m^3\ kg^{-2}) \text{ .... (13)}$$

Where, $\mu_0 = 4\pi \times 10^{-7}\ V.S/Amp$, g is in m/s^2, B_1 is in Wb/m^2

4. Experimental Procedure

The experimental solution is placed in a Quincke's tube consisting of a wide and narrow limb. The wide limb is placed outside the field and the narrow limb inside the magnetic field provided by an electromagnet as shown in Fig. [1]. The field varies rapidly along the vertical direction due to the wedging of the pole pieces. Thus, the force given by eqn. (5) below on the specimen will be vertical.

1. Put the tube on stand and fix it with clamp.
2. Insert (the narrow limb of the Quincke's tube vertically between the pole pieces of (the electromagnet such that the meniscus is in the central region of the uniform magnetic field or in the centre of the poles and the wide limb is placed outside the field as shown in Figure 1.

3. Illuminate the meniscus level with an ordinary bulb and view it with a travelling microscope. Adjust the horizontal cross wire of the eye piece of microscope on the meniscus and note this reading of the microscope. It will be the initial position of the meniscus. Record this reading in table as shown below.
4. Switch ON the electromagnet power supply and adjust the current say at 0 amp, Bring the cross wire again on the meniscus and also record this reading in table by moving the microscope downwards.
5. Increase the power supply current in steps of 0.5 amp i.e. say 0.5, 1.0, 1.5 ....3.0 and note the corresponding position of the level of the liquid. Note all these readings in table.
6. Repeat the experiment for different concentration of the solution.
7. Finally put the magnetic field sensor b/w pole pieces. Switch on gauss meter and read the magnetic field corresponding to each value of current & note it in the table.

5. Observation Table

Table:1

S.No	Power supply current I (Amp)	Initial position of the meniscus h_1(cm)	Final position of the meniscus h_2(cm)	Change in height h = (h_1-h_2) cm	Mag.Field B_1 (k gauss)	B_1^2 (k gauss)^2
1.						
2.						
3.						
4.						
..						
..						
..						

6. Calculation

Plot a graph (see Figure 2) each for different concentrations between B_1^2 magnetic field in kilo gauss along X-axis and 'h' change in height in cm along Y-axis, which gives a straight line with slope,

$\frac{\boldsymbol{\Delta h}}{\boldsymbol{\Delta B_1^2}} = \frac{\boldsymbol{AB}}{\boldsymbol{OB}}$ cm/kgauss^2 and convert it in m/T^2

Now put above in equation (13) and calculate the mass susceptibility as

$$\chi_m = 2\mu_0 g \frac{\Delta h}{\Delta B_1^2}$$

Similarly calculate the value of mass susceptibility for other concentration of the solution and make table as shown below in Table 2 for the results.

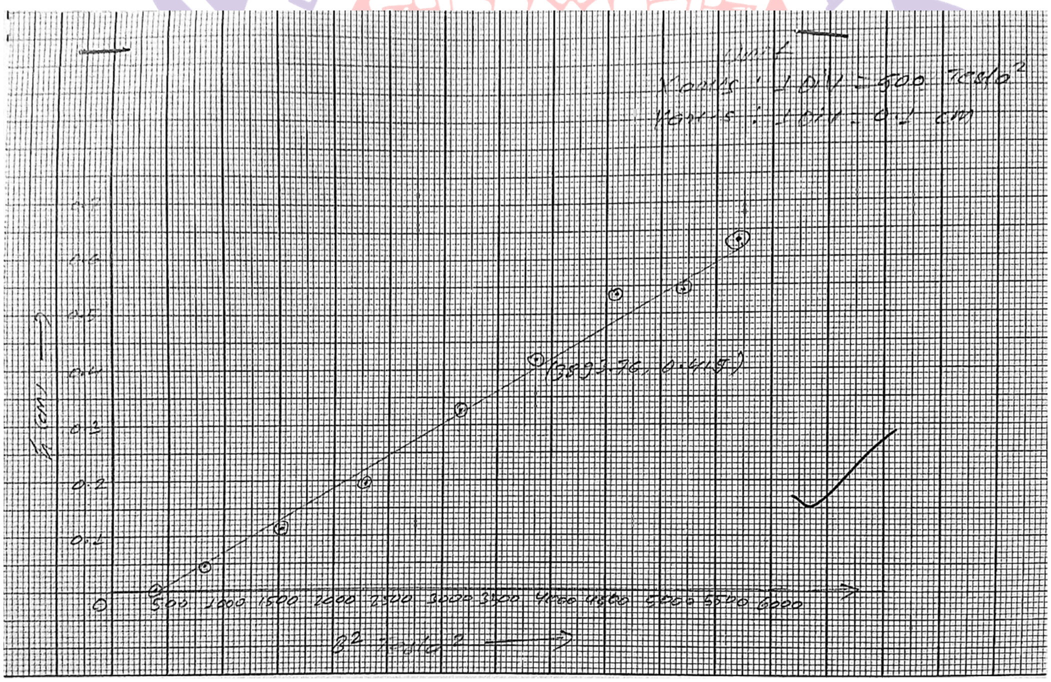

Figure 2. Graph plotted between B_1^2 magnetic field in kilo gauss along X-axis and 'h' change in height in cm along Y-axis to determine mass susceptibility.

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7. Results

Table:2

The table shows the mass susceptibility of the given solution for different concentration.

Sl. No.	Concentration of the solution	Mass susceptibility χ_m
1.	50%	
2.	100%	
…	…	…

8. Precautions

1. Adjust the microscope to get clearer picture of meniscus. B

2. Use lamp and magnifying glass while taking readings.

3. Let the liquid rise and become steady before taking readings of meniscus.

4. Draw best fit straight line while plotting rise in liquid level'h' vs B_1^2.

9. Some constants and conversion factors:

Boltzmann constant, $\mathbf{k} = 1.381\times10^{-23}$ Joule/K

Avogadro's number, $\mathbf{N_A} = 6.0225\times10^{26}$ per kg mole

Bohr magneton, $\boldsymbol{\mu_B} = 9.272\times10^{-24}$ Am^2 or 9.272×10^{-21} erg/gauss

Permeability of free space, $\boldsymbol{\mu_0} = 4\pi\times10^{-7}$ 1 amp.turn/m

Mass susceptibility of water = 9.0×10^{-9} m^3/kg

Molecular weight of $FeCl_3$ = 162.2 g/mole

Density of $FeCl_3$ = 2.9 g/cm^3

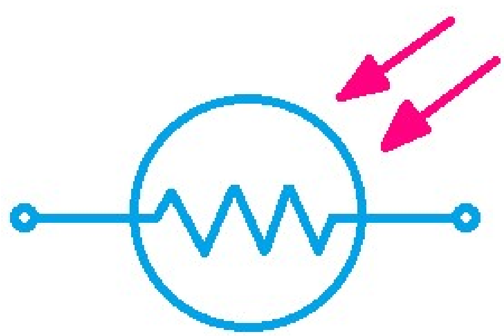
To study the characteristics of opto-electronic devices, light dependent Resistor (LDR), light emitting diode (LED) and Solar cell

Objective - Study the characteristics of opto-electronic devices, light dependent Resistor (LDR) and light Emitting Diode (LED).

Required apparatus: -one DC regulated power supply of 0-3 volts, light dependent Resistor (LDR) and light Emitting Diode (LED). Voltmeter 0-3 volt DC, DC millimeter and one lamp with stand connection wires etc.

Theory:-

A *Light Dependent Resistor* (LDR) or a photo resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices. They are also called as photo conductors, photo conductive cells or simply photocells. They are made up of semiconductor materials having high resistance. There are many different symbols used to indicate a **LDR**, one of the most commonly used symbol is shown in the figure below. The arrow indicates light falling on it



LDR Symbol

A **light dependent resistor** works on the principle of photo conductivity. Photo conductivity is an optical phenomenon in which the materials conductivity is increased when light is absorbed by the material. When light falls i.e. when the photons fall on the device, the electrons in the valence band of the semiconductor material are excited to the conduction band. These photons in the incident light should have energy greater than the band gap of the semiconductor material to make the electrons jump from the valence band to the conduction band. Hence when light having enough energy strikes on the device, more and more electrons are excited to the conduction band which results in large number of charge carriers. The result of this process is more and more current starts flowing through the device when the circuit is closed and hence it is said that the resistance of the device has been decreased. This is the most common **working principle of LDR**.

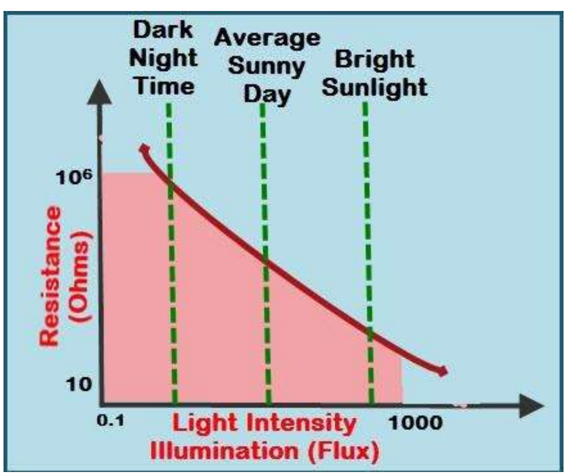


Figure – Graph between resistance and light intensity

Procedure:-

1. Connect the output of DC power supply (0-3 VDC) to the input of the LDR circuit. Also connect voltmeter, current meter and LDR in the circuit through patch cords shown by doted lines.
2. Place the lamp holder and LDR on a graduated wooden stand opposite to each other. Connect the lamp to AC mains and focus the light on LDR. Select the range of current meter to 5mA.
3. Switch on the instrument (power supply unit) using ON/OFF toggle switch provided on the front panel.
4. Now increase the power supply voltage in small step and every time note down the voltage & current in observation table. Calculate the resistance value of LDR by using formula R = V/I
5. Vary the distance (d) between LDR & light source and repeat the experiment again.
6. Plot a graph between resistance (R) vs Distance (d2, SQURE).
7. Also note down the current (mA) for different distances between LDR & light source for fixed voltage.

Observation table for LDR

S,no.	Distance of lamp from LDR d cm	Voltmeter reading v volt	Milliammeter reading (I) mA	Resitance of LDR R = V/R	D2 cm2
1					
2					
3					

Light Emitting Diode (LED).

They are the most visible type of diode that emit a fairly narrow bandwidth of either visible light at different colored wavelengths, invisible infra-red light for remote controls or laser type light when a forward current is passed through them.

The “Light Emitting Diode” or LED as it is more commonly called, is basically just a specialized type of diode as they have very similar electrical characteristics to a PN junction diode. This means that an LED will pass current in its forward direction but block the flow of current in the reverse direction.

Light emitting diodes are made from a very thin layer of fairly heavily doped semiconductor material and depending on the semiconductor material used and the amount of doping, when forward biased an LED will emit a colored light at a particular spectral wavelength.

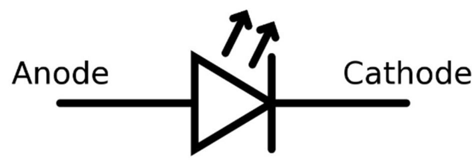


Figure- Symbol of LED

When the diode is forward biased, electrons from the semiconductors conduction band recombine with holes from the valence band releasing sufficient energy to produce photons which emit a monochromatic (single color) of light. Because of this thin layer a reasonable number of these photons can leave the junction and radiate away producing a colored light output.

Light emitting diode construction

LED Construction

Then we can say that when operated in a forward biased direction Light Emitting Diodes are semiconductor devices that convert electrical energy into light energy.

The construction of a Light Emitting Diode is very different from that of a normal signal diode. The PN junction of an LED is surrounded by a transparent, hard plastic epoxy resin hemispherical shaped shell or body which protects the LED from both vibration and shock.

Surprisingly, an LED junction does not actually emit that much light so the epoxy resin body is constructed in such a way that the photons of light emitted by the junction are reflected away from the surrounding substrate base to which the diode is attached and are focused upwards through the domed top of the LED, which itself acts like a lens concentrating the amount of light. This is why the emitted light appears to be brightest at the top of the LED.

However, not all LEDs are made with a hemispherical shaped dome for their epoxy shell. Some indication LEDs have a rectangular or cylindrical shaped construction that has a flat surface on top or their body is shaped into a bar or arrow. Generally, all LED's are manufactured with two legs protruding from the bottom of the body.

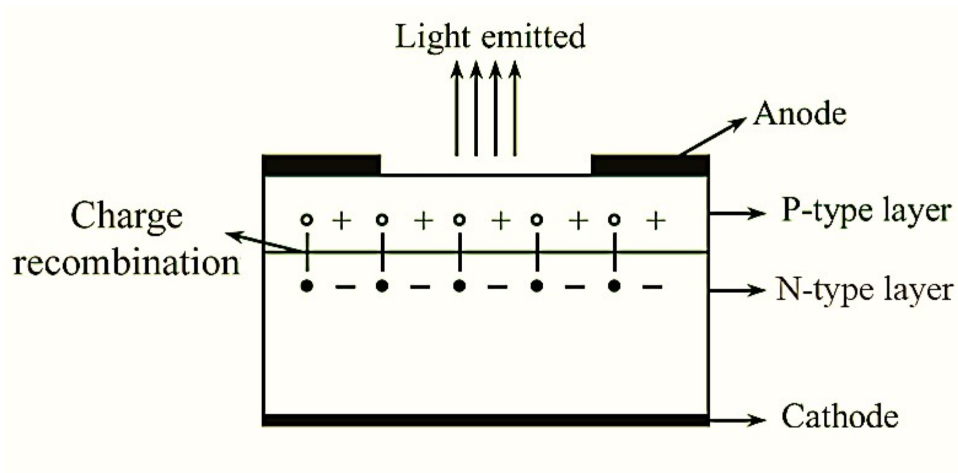


Figure- Construction of LED

Also, nearly all modern light emitting diodes have their cathode, (–) terminal identified by either a notch or flat spot on the body or by the cathode lead being shorter than the other as the anode (+) lead is longer than the cathode (k).
Unlike normal incandescent lamps and bulbs which generate large amounts of heat when illuminated, the light emitting diode produces a "cold" generation of light which leads to high efficiencies than the normal "light bulb" because most of the generated energy radiates away within the visible spectrum. Because LEDs are solid-state devices, they can be extremely small and durable and provide much longer lamp life than normal light sources.

Light Emitting Diode Colors

So how does a light emitting diode get its colour. Unlike normal signal diodes which are made for detection or power rectification, and which are made from either Germanium or Silicon semiconductor materials, **Light Emitting Diodes** are made from exotic semiconductor compounds such as Gallium Arsenide (GaAs), Gallium Phosphide (GaP), Gallium Arsenide Phosphide (GaAsP), Silicon Carbide (SiC) or Gallium Indium

Nitride (GaInN) all mixed together at different ratios to produce a distinct wavelength of colour.

Different LED compounds emit light in specific regions of the visible light spectrum and therefore produce different intensity levels. The exact choice of the semiconductor material used will determine the overall wavelength of the photon light emissions and therefore the resulting color of the light emitted.

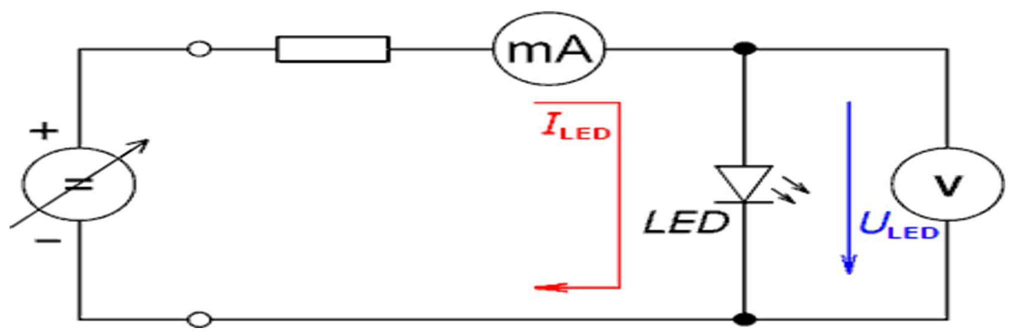


Figure- Circuit diagram of LED

Theory of solar cell :-

The solar cell is a semiconductor device, which converts the solar energy into electrical energy. It is also called a photovoltaic cell. A solar panel consists of numbers of solar cells connected in series or parallel. The number of solar cell connected in a series generates the desired output voltage and connected in parallel generates the desired output current. The conversion of sunlight (Solar Energy) into electric energy takes place only when the light is falling on the cells of the solar panel. Therefore in most practical applications, the solar panels are used to charge the lead acid or Nickel-Cadmium batteries. In the sunlight, the solar panel charges the battery and also supplies the power to the load directly. When there is no sunlight, the charged battery supplies the required power to the load.

A solar cell operates in somewhat the same manner as other junction photo detectors. A built-in depletion region is generated in that without an applied reverse bias and photons of adequate energy create hole-electrons pairs. In the solar cell, as shown in Fig. 1a, the pair must diffuse a considerable distance to reach the narrow depletion region to be drawn out as useful current. Hence, there is higher probability of recombination. The current generated by separated pairs increases the depletion region voltage (Photovoltaic effect). When a load is connected across the cell, the potential causes the photocurrent to flow through the load.

The e.m.f. generated by the photo-voltaic cell in the open circuit, i.e. when no current is drawn from it is denoted by VOC (V-open circuit). This is the maximum value of e.m.f.. When a high resistance is introduced in the external circuit a small current flows through it and the voltage decreases. The voltage goes on falling and the current goes on increasing as the resistance in the external circuit is reduced. When the resistance is reduced to zero the current rises to its maximum value known as saturation current and is denoted as ISC, the voltage becomes zero.

Procedure:-

1. Connect the output of DC power supply (0-3 VDC) to the input of the LED circuit. Also connect voltmeter, current meter in the circuit through patch cords shown by doted lines.
2. Switch on the instrument (power supply unit) using ON/OFF toggle switch provided on the front panel.
3. Now increase the power supply voltage in small step and every time note down the voltage & current in observation table.
4. Plot a graph between voltage and current by taking voltage along X axis and current along Y axis.

Observation table for LED :-

s.no.	**Forward voltage (V)**	**Forward current (I)**
1		
2		
3		
4		
5		

Observation table for LED and solar cell:-

Fixed Distance (cm)	Reverse voltage V_c (Volt)	Reverse current I_c (µA)

Data for resistance R vs D^2 curve

Constant voltage (V)	Distance (cm)	Current (µA)	$(\text{Distance})^2$ Cm^2	Resistance (Ω)

Data for LDR

Distance (cm)	voltage (V)	Current (µA)	Distance (cm)	voltage (V)	Current (µA)

Data for resistance R vs D^2 curve

Constant voltage (V)	Distance of lamp from LDR (cm)	Current (μA)	$(Distance)^2$ Cm^2	Resistance (Ω)

Data for LED

Sl. No	Forward voltage (V)	Current (mA)

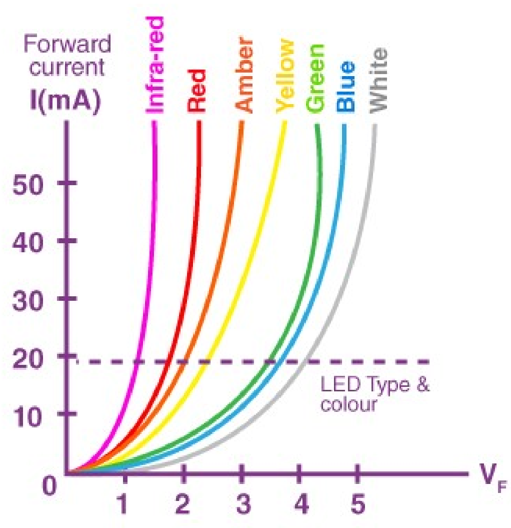


Figure – Forward characteristics of LED

Result: - 1. Forward resistance of LDR is ……………and forward resistance of LED is……..

2 Voltage …… & current ………. LED start Glow, Voltage …… & current ………. LED fully Glow. The nature of R vs D^2 is ………

Precautions:-

1) Firstly read about complete experiment then perform.
2) Connect circuit properly according to diagram.
3) Check connecting wires before use.
4) Connect current meter in series only.
5) Switch OFF the experiment kit after the use.

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Condensed Matter Physics Practical Experiment Manual

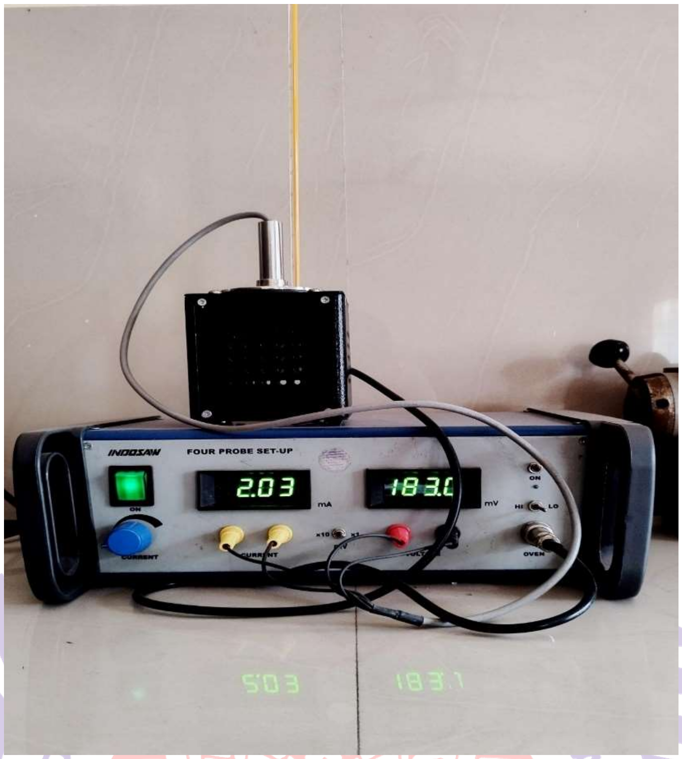
Study of the temperature dependence of Resistivity of a Semiconductor using Four Probe method and to determine the band gap of experimental material (Ge)

1. Historical Background

The four-probe method has its origins in the early 20^{th} century and has been widely used in materials science and semiconductor physics. It was developed to address the limitations of traditional two-probe methods, especially when measuring the resistivity of small and thin samples. The concept of using multiple probes for electrical measurements can be traced back to the work of Walter Kohn and Lu Jeu Sham in the 1950s. They proposed a theoretical framework for understanding the electronic properties of materials, and this laid the groundwork for advanced experimental techniques.

2. Experimental Set up

Four probe apparatus, sample (a Ge crystal in form of a chip), oven, thermometer (260^{o}C) constant power supply, oven power supply, panel meters for measurement of current and voltage.



Experimental Setup of Four Probe method

3. Basic Theory

The 4-point probe set up as shown in Figure 1 is consists of four equally spaced tungsten metal tips with finite radius. Each tip is supported by springs on the end to minimize sample damage during probing. The four metal tips are part of an auto-mechanical stage which travels up and down during measurements. A high impedance current source is used to supply current through the outer two probes; a voltmeter measures the voltage across the inner two probes to determine the sample resistivity. These inner probes draw no current because of the high input impedance voltmeter in the circuit. Thus, unwanted voltage drops (IR drop) at point B and point C caused by contact resistance between probes and the sample is eliminated from the potential measurements. Since these contact resistances are very sensitive to pressure and to surface condition (such as oxidation of either surface).

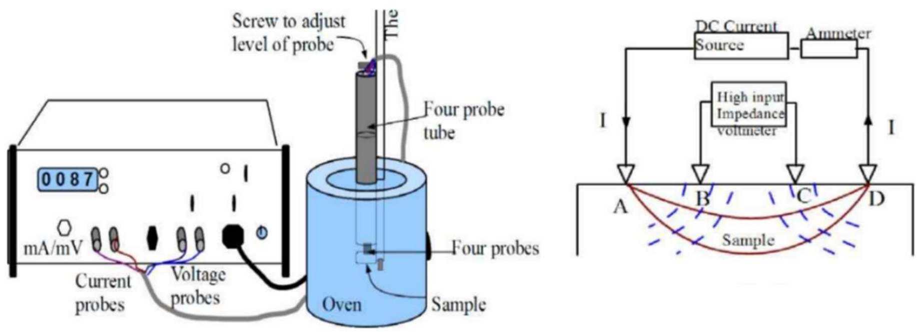


Figure 1. Schematic Illustration of Four Probe set up

Intrinsic semi-conduction is the process, in which thermally or optically excited electrons contribute to the conduction. In the absence of photonic excitation, intrinsic semiconduction takes place at temperatures above 0 K as sufficient thermal agitation is required to transfer electrons from the valence band to the conduction band. The temperature dependence resistivity of a semiconductor sample is inverse of conductivity which is the sum of is the sum of the conductivities of the valence and conduction band carriers, which are holes and electrons, respectively. For a semiconductor material conductivity given by the expression,

$$\sigma = \sigma_e + \sigma_h \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

$$\sigma = e(n_e\mu_e + n_h\mu_h) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2)$$

Where, e is the electronic charge, n_e and μ_e are the electron's concentration and mobility; similarly, n_h and μ_h are the hole's concentration and mobility. Here, mobility determines the average drift velocity in the presence of an applied external field. It also depends on the temperature. The mobility is a quantity that directly relates the drift velocity v_d of charge carriers to the applied electric field E across the material, i.e., $\mu = \frac{V_d}{E}$ ………… (3)

In the intrinsic region the number of electrons is equal to the number of holes, $n_e = n_h = n_i$, so equation (2) implies as $\sigma = en_i(\mu_e + \mu_h)$ ………… (4)

The electron density (electrons/volume) in the conduction band is obtained by integrating (density of states times probability of occupancy of states) from the bottom to top of the conduction band. The detailed calculations reveal that,

$$n_i = NT^{\frac{3}{2}} exp(-\frac{E_g}{2K_BT}) \text{ .... } (5)$$

Substituting the value of n_i in equation (4), we get

$$\sigma = e(\mu_e + \mu_h)NT^{\frac{3}{2}} exp(-\frac{E_g}{2K_BT}) \text{ .... } (6)$$

Whereas for a p-type semiconductor, $\sigma = en_h\mu_h$ .... (7)

Then equation (6) becomes $\sigma = e\mu_h NT^{\frac{3}{2}} exp(-\frac{E_g}{2K_BT})$ .... (8)

Also, $\mu_h = \beta T^{-\frac{3}{2}}$ and substituting this value we get,

$$\sigma = eN\beta \, exp(-\frac{E_g}{2K_BT}) \text{ .... } (9)$$

This shows that conductivity depends on temperature it decreases exponentially with decrease in temperature.

So, the temperature dependency of resistivity can be given by the equation,

$\rho = \frac{exp(\frac{E_g}{2K_BT})}{eN\beta} = \text{A } exp(\frac{E_g}{2K_BT})$ .... (10), where A is constant.

Taking log in both sides, we get $\log\rho = \log A + \frac{1}{2.3026} * \frac{E_g}{2K_BT}$ .... (11)

Rewriting equation (11), $\log\rho = C + \frac{1}{2.3026\times10^3} * \left(\frac{E_g}{2K_B}\right)(\frac{1000}{T})$ .... (12)

Therefore, if a graph is plotted in between $\log\rho$ vs $(\frac{1000}{T})$, it should be a straight line and the band gap will be determined using the slope of it.

Slope = $\frac{AC}{BC} = \frac{1}{2.3026\times10^3} * \left(\frac{E_g}{2K_B}\right)$

$K_B = 8.61733 \times 10^{-5}$ eVK^{-1}

By putting the values

$E_g = 2 \times 8.61733 \times 10^{-5} \times 2.3026 \times 10^3 \times$slope

$= 0.396845 \times$ slope (eV)

4. Experimental Procedure

1. The setting of 4-point probes on the semiconductor chip is a delicate process. So first understand well the working of the apparatus. The semiconductor chip and probe set is costly.
2. Note the values of probe spacing (S) and the thickness (W) of the semiconductor chip. Note the type of semiconductor (germanium or something else).
3. Make the circuit as shown in Figure 1. Put the sample in the oven (normally already placed by lab instructor at room temperature.
4. Pass a milliampere range current (say 5 mA) in the sample using constant current power supply.
5. The reading of the current through the sample is measured using milliammeter provided for this purpose. The voltage is measured by a high impedance milli voltmeter connected to the inner probes. The readings can be taken alternately on digital meter provided for this purpose.
6. Note temperature of sample (oven) using thermometer inserted in the oven for this purpose.
7. The oven temperature is increased a little, and its temperature noted after reaching steady state. Again, the constant current reading (advised to be kept the same) and the corresponding voltage readings are taken.
8. Repeat the procedure for different temperatures. Note the data in the observation table

5. Observation Table

Least count of thermometer = 1^0 c

Least count of milliammeter = 0.01 mA

Least count of digital voltmeter = 0.1×10 mv

Applied Current = _____mA

Distance between the probes (s) = 0.24 cm

Thickness of the sample (w) = 0.05 cm

W/S value = _____ F(w/s) =____________ 2πs =_______

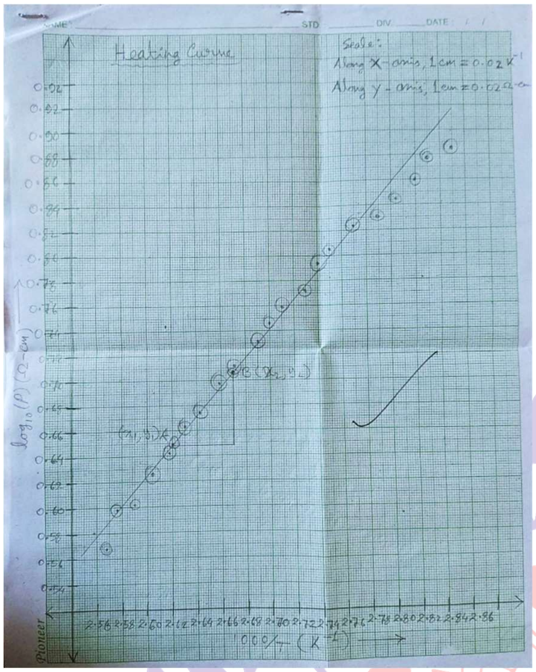
Tabulation:1 (for heating)

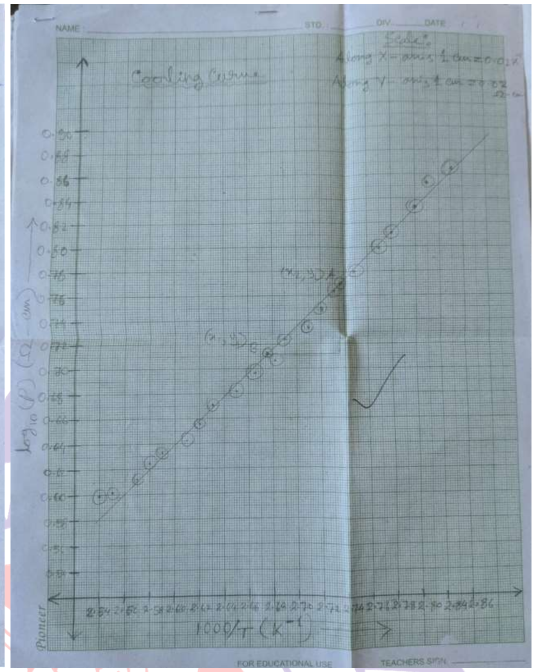
T^0 c	T(k)	V(m,v)	ρ_0 =(v ×2πs)/I Ω-cm	$\rho = \rho_o/f(w/s)$ Ω-cm	$\log_{10}\rho$ Ω-cm	$T^{-1} \times 10^{-3}$ k
80						
82						
84						
86						
118						
120						

Tabulation:2 (for cooling)

T^0 c	T(k)	V(m,v)	ρ_0 =(v ×2πs)/I Ω-cm	$\rho = \rho_o/f(w/s)$ Ω-cm	$\log_{10}\rho$ Ω-cm	$T^{-1} \times 10^{-3}$ k
120						
118						
116						
82						
80						

Model graph:





6. Calculation

For heating

Slope = AC/BC = $(Y_2 - Y_1)/(X_2 - X_1)$ = ________

E_g = __________eV

For cooling

Slope = AC/BC = $(Y_2 - Y_1)/(X_2 - X_1)$ = ________

E_g = __________eV

7. Results

1) We obtain the energy band gap of p-type Gesample as

   For heating E_g =_________

   For cooling E_g =_________

2) Resistivity decreases with increase in the temperature

8. Percentage error

$$\text{Percentage (\%)error} = \frac{(Experimental\ value - Standard\ value)\ \times 100}{Standard\ Value}$$

9. Precautions

1. Current should be constant while performing the experiment
2. The sample should be heated to a temperature near 160^0 C

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Condensed Matter Physics Practical Experiment Manual

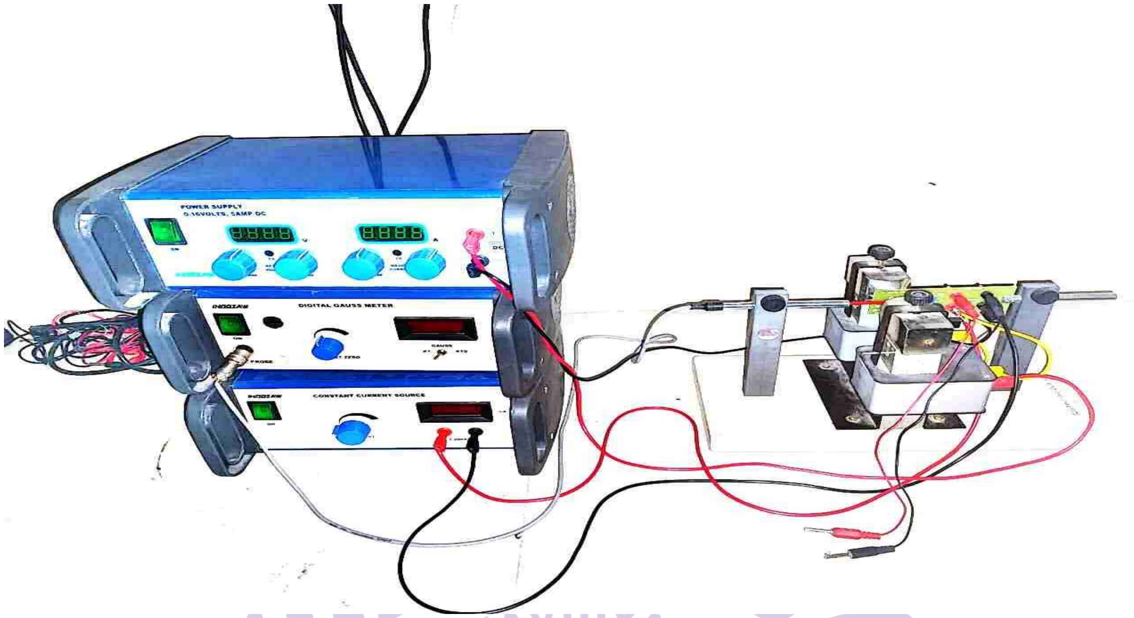
To Determine Hall coefficient (R_H), Hall voltage (V_H), types of charge carriers and Hall angle (θ_H) using Hall Effect experiment

1. Historical Background

In 1879, E.H. Hall discovered this hall effect while working on his doctoral degree at Johns Hopkins University in Baltimore, Maryland. He observed that on placing a current carrying conductor perpendicular to a magnetic field, a voltage is observed perpendicular to both the magnetic field and the current. It was observed that the charge carriers, which were assumed to be electrons experienced a sideways force opposite to what was expected. This was later explained on the basis of band theory. The number of conducting charges and the sign of charge carriers cannot be determined by the measurement of conductivity of a specimen. In metals/conductors, the current carriers are only electrons whereas in semiconductors, both electrons and holes act as current carriers. Therefore, in semiconductor, it is quite necessary to determine whether a material is of n-type or p-type. The Hall effect can be used to distinguish the two types of charge carriers and also to determine the density of charge carriers.

2. Experimental Set up

Gauss meter, supply voltage, current power supply, hall effect experiment apparatus, hall probe, electromagnet, PCB with semiconductor, multimeter.



Experimental Setup of Hall Effect Experiment

3. Basic Theory

When a magnetic field is applied perpendicular to a current carrying specimen (metal or semiconductor), a voltage is developed in the specimen in a direction perpendicular to both the current and the magnetic field. This phenomenon is called Hall effect. The voltage so generated is called Hall voltage. We know that a static magnetic field has no effect on charges unless they are in motion. When the charges flow, a magnetic field directed perpendicular to the direction of flow produces a mutually perpendicular force on the charges. Consequently, electrons and holes get separated by opposite forces and produce an electric field E_H, thereby setting up a potential difference between the ends of a specimen. This is called Hall potential $V_{H.}$

Consider a semiconductor slab in the form of a flat strip with width ‘b’ and thickness ‘t’. Let a current, I flows through the strip along X- axis. P and P' are two points on the opposite faces of a b c d and a' b' c' d' respectively. If a millivoltmeter is connected between points P and P', it does not show any reading, indicating that there is no potential difference setup between these points. But, when a magnetic field is applied along Y-axis, i.e., perpendicular to the direction of current, a deflection is produced in the millivoltmeter indicating that a potential difference is set up between P and P'. This potential difference is known as Hall voltage or Hall potential V_H. If a current is passed along x-axis, then the electrons move along negative direction of x-axis. The force on electron due to the applied magnetic field B along Y axis is given by;

$$\overrightarrow{F_B} = -e(\overrightarrow{v_d} \times \vec{B})\hat{z} \text{ --------------------------------- } (1)$$

$$\overrightarrow{F_B} = -ev_d B\hat{z} \text{ -- } (2)$$

Where, v_d is the drift velocity of electron and e is the charge of electron.

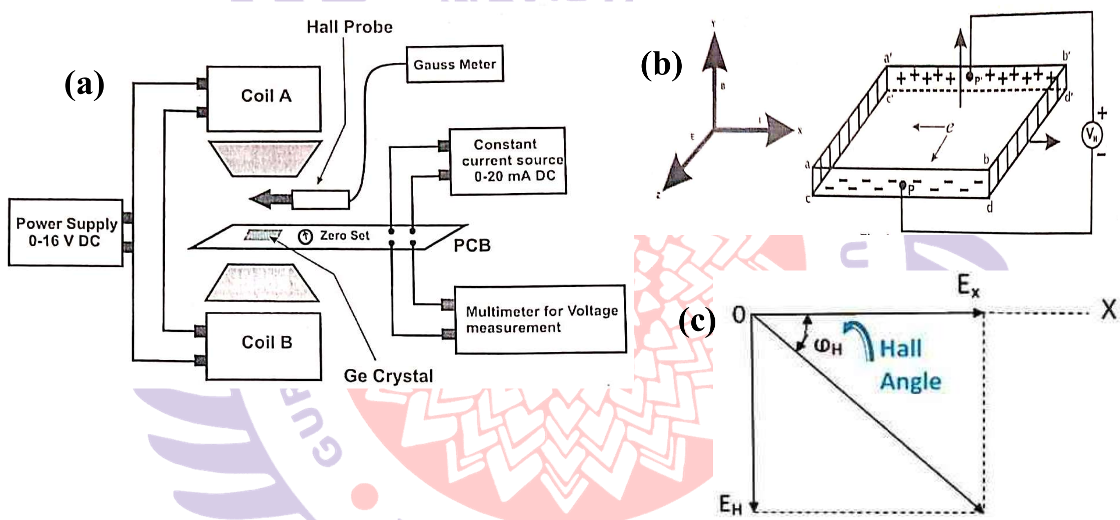


Figure 1. (a) Schematic representation of Hall effect experimental set up, (b) charge carrier motion dynamics under applied magnetic field in a semiconductor material and (c) graphical definition of Hall Angle

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This force along $\hat{z}$ direction deflects the positive charge carriers towards the a' b' d' c' surface of the semiconducting strip. This makes the that surface positively charged while leaving the opposite 'a c d b' surface negatively charged. This accumulation of charges near these two surfaces of the sample leads to the development of a transverse electric field $\vec{E} = E_z\hat{z}$ along the z-direction. Force due to this electric field $e\vec{E}$ opposed the Lorentz force $\overrightarrow{F_B}$ and further precents the charge accumulation. In the steady state condition, these two forces balance out each other and we get,

$eE_z = ev_dB$ ---------------------------------- (3)

Now, the cross-sectional area A = bt, and the current density

$J_x = \frac{I_x}{A} = \frac{I}{bt}$ ----------------------------- (4)

Hall coefficient is defined as the ratio of the electric E_z to the current density J_x multiplied by magnetic field B, that is

$R_H = \frac{E_z}{J_xB}$ ----------------------------- (5)

Now, if n is the charge carrier density i.e., number of charge carriers per unit volume (m^3), then $J_x = nev_d$ ---------------------------- (6)

Using this expression and multiplying both sides of equation (3) by 'bt' we get,

$E_zbt = \frac{J_xbtB}{ne}$ ------------------------------------ (7)

But, $E_zt = V_H$, the voltage across the opposite surfaces known as Hall voltage and $J_xbt = I_H$, then

$V_H = \left(\frac{R_HB}{b}\right) I_H$ ------------------------------------ (8)

With, $\frac{1}{ne} = \left(\frac{V_Hb}{BI}\right)$ --------------------------------(9)

The hall coefficient is given by

$$R_H = \left(\frac{V_H b}{BI}\right) \qquad \text{-------------------------------------(10)}$$

And charge carrier density is given by

$$n = \left(\frac{1}{eR_H}\right) \qquad \text{-------------------------------------(11)}$$

If the condition is primarily due to one type of charge carriers, then conductivity is related to mobility μ_m as

$$\mu_m = \sigma R_H \qquad \text{-------------------------------------(12)}$$

therefore $\mu_m = \left(\frac{R_H}{\rho}\right)$ ------------------------------------- (13)

where, ρ is the resistivity.

There is another interesting quantity called the Hall angle (θ_H), defined by equation, $tan\theta_H = \left(\frac{E_H}{E_x}\right)$ ------------------------------- (14)

but $E_H = V_x B$, hence , $tan\theta_H = \left(\frac{V_x B}{E_x}\right) = \mu_m B$ -----------------------------(15)

4. Experimental Procedure

1. Connect the width wise contacts of the Hall probe to the terminals marked ‘voltage’ and Length wise contacts to terminals marked ‘current’.
2. Switch ‘ON’ the Hall effect setup and adjustment current (say few mA).
3. Switch over the display to voltage side. There may be some voltage reading even outside the magnetic field. This is due to imperfect alignment of the four contacts of the Hall probe and is generally known as the ‘Zero field potential’. In case its value is comparable to the Hall voltage it should be adjusted to a minimum possible (for Hall probe (Ge) only). In all cases the error should be subtracted from the Hall voltage reading.
4. Switch on the constant current power supply at any desired value.

5. Measure the magnetic field between the pole pieces of the electromagnet using digital Gaussmeter and also measure the distance between two pole pieces.
6. The Hall probe is placed in between the pole pieces of the electromagnet and rotate the Hall probe till it becomes perpendicular to the magnetic field so that the Hall voltage will be minimum in this adjustment.

7. Measure the Hall voltage as a function of current in the Hall effect setup keeping the magnetic field constant and plot a graph.

5. Observation Table

Table:1

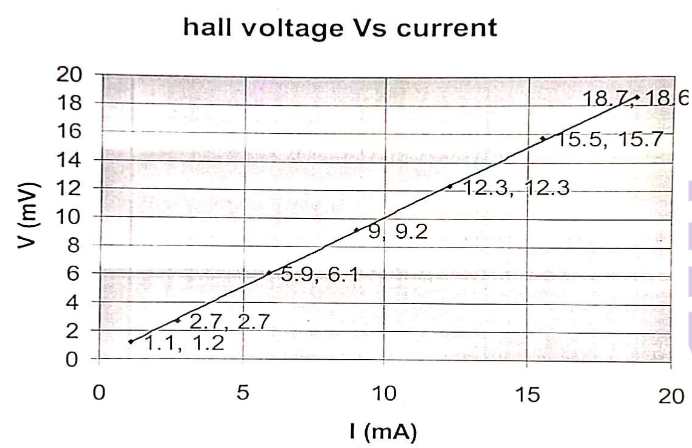
S.no	Current	Reading of millivoltmeter (mV)		Mean value of V_H (mV)	V_H/I (ohms)
		B and I in one direction	B and I in reversed direction		
1					
2					
3					
4					
5					
6					
7					

Table:2

S.No	Current I (mA)	Distance between two points between which potential difference is measured ,l (m)	V_l(mV)	$\rho = V_l bt/Il$ (Ωm)
1				
2				
3				
4				

5				
6				
7				

Model graph:



6. Calculation

1. Mean value of $\frac{V_H}{I}$ = ___ Ω
2. $R_H = \frac{V_H}{I} \times \frac{b}{B}$ = Slope × _____ = _____ m^3c^{-1}
3. $n = \frac{1}{R_H e}$ = _______ carriers m^{-3}
4. ρ = ________ Ωm
5. $\mu_m = \frac{R_H}{\rho}$ = _ _______ $m^3V^{-1}s^{-1}$
6. $\theta_H = \tan^{-1}(\mu_m B)$ = ___°

7. Results

Thus, we obtain the following values through hall experiment,

1. $\frac{V_H}{I}$ = _____ Ω
2. R_H = _____ m^{-3}
3. n = _____ m^{-3}

4. ρ =____ Ωm
5. μ_m =____$m^3v^{-1}s^{-1}$
6. θ_H =____°

8. Precautions

1. Before starting the experiment, check that the gauss meter is showing zero value. For this put the probe away from electromagnet and switch on the gauss meter, adjust its zero-adjustment knob.
2. Ensure that the specimen is located at the centre between the pole pieces and exactly perpendicular to the magnetic field.
3. To measure the magnetic flux the hall probe should be placed at the centre between the pole pieces, parallel to semiconductor sample.
4. For carrying out the experiment, the magnetic flux density should be maximum.
5. The deflection of the hall angle will be within 5^0 from the ideal value 90^0.