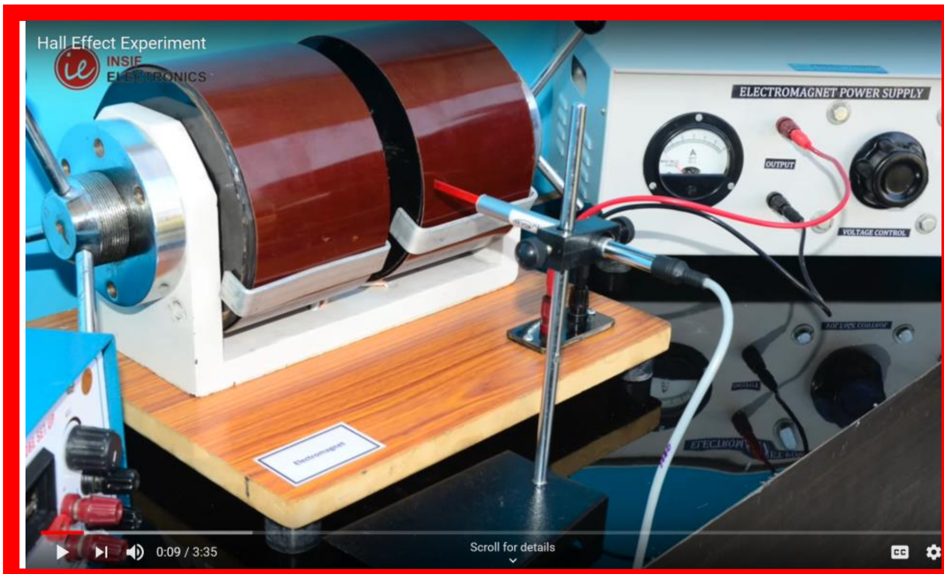
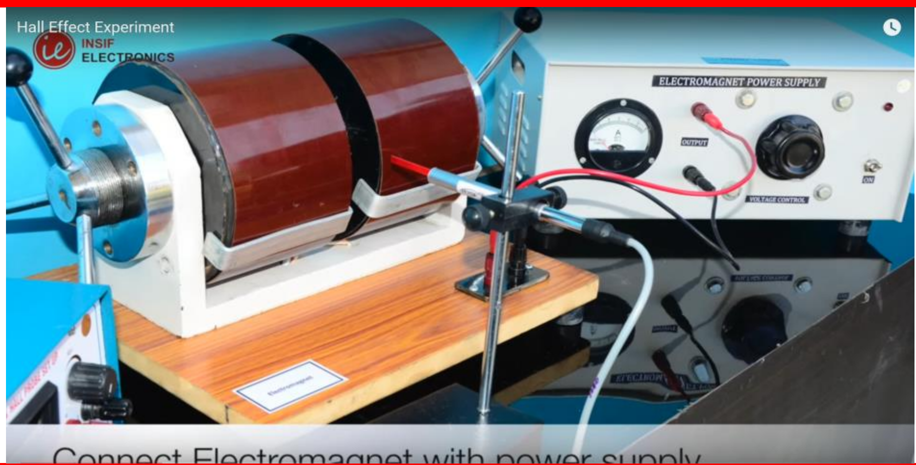
HALL-EFFECT-APPARTUS (AS WE SEE IN LAB IN THE COLLEGE)




INSIF
ELECTRONICS
ELECTROMAGNET POWER SUPPLY
OUTPUT
VOLTAGE CONTROL
ON

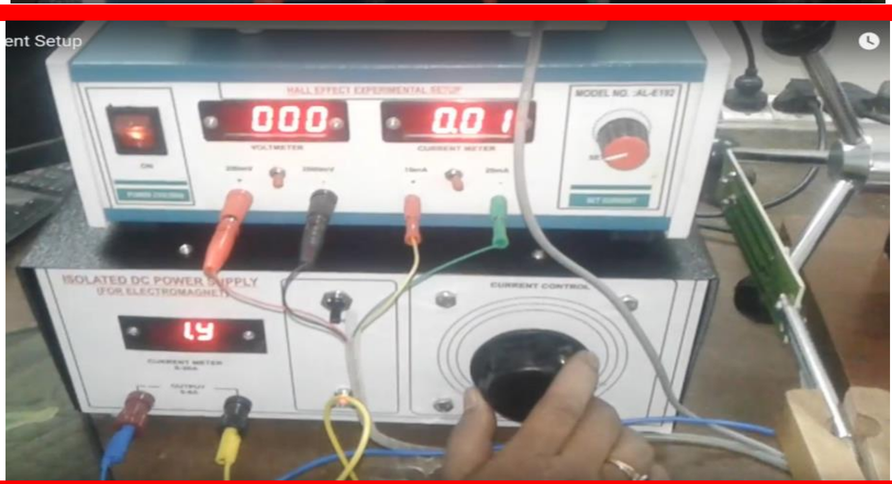

Hall Effect Experiment
INSIF
ELECTRONICS
ELECTROMAGNET POWER SUPPLY
Connect Electromagnet with power supply

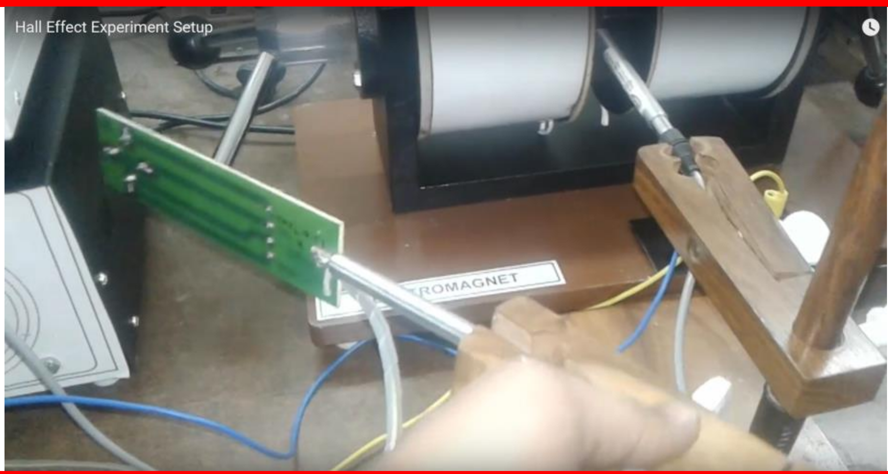

Hall Effect Experiment
INSIF
ELECTRONICS


Hall Effect Experiment
INSIF
ELECTRONICS
ELECTROMAGNET POWER SUPPLY

Or


ffect Experiment Setup
DIGITAL DISPLAY
MODEL NO:AL-E383
RANGE SELECT
DIGITAL GAUSS METER
(FOR HALL EFFECT)
HALL EFFECT EXPERIMENTAL SETUP
MODEL NO. :AL-E192
VOLTMETER
CURRENT METER
SET CURRENT


ent Setup
ISOLATED DC POWER SUPPLY
CURRENT CONTROL


Hall Effect Experiment Setup


Hall Effect Experiment Setup

34.6 HALL EFFECT

The conductivity measurements are not sufficient for the determination of the number density of charge carriers (n) and their mobility (μ). Moreover these measurements do not give any information about the sign of the majority charge carriers. The *Hall effect* supplies all this information.

Consider the action of the magnetic field on electric current flowing in an extrinsic semiconductor. The moment the electric field is switched on, an electric current is established, the density of which is

$$\mathbf{j} = \sigma \mathbf{E} \tag{34.19}$$

The charge carriers acquire a directional velocity v_d (drift velocity) in the direction of the field in case of holes and against the field in case of electrons (Fig. 34.6).

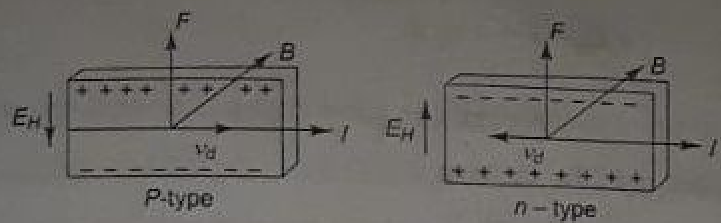


Fig. 34.6

When the magnetic field is switched on, a force perpendicular to both v_d and **B** begins to act on electrons and holes.

$$\mathbf{F} = e(v_d \times \mathbf{B}) \tag{34.20}$$

This is called *Lorentz force* whose direction is given by the Flemming's left hand rule.

***If the thumb, index finger and middle finger of the left hand are held at right angles to each other, and the index finger points in the direction of the magnetic field* B *while the middle finger in the direction of current* I*, then the thumb will indicate the direction of the Lorentz force* F.**

Since for electrons, both e and v_d are negative and for holes both are positive, the Lorentz force is same for both type of carriers, i.e., the *Lorentz force is independent of the charge carrier's sign, being dependent only on the direction of I and B*. In Fig. 34.6 **F** is directed upwards for both n-type and p-type semiconductors, ***i.e. the electrons and holes are deflected in the same direction under the effects of a given electric and magnetic field.***

The opposite faces of the sample will become charged as shown in Fig. 34.6, and as a result an electric field E_H will be established. *This field is called the Hall-field and this phenomenon is called the* ***Hall-effect.*** The value of E_H will continue to grow until the Lorentz force is compensated by the oppositely directed electric force qE_H (or eE_H).

i.e.,
$$eE_H = F \tag{34.21}$$

Note: *Remember that the charge e on the carriers is positive for holes and negative for electrons. Thus while E_H is oppositely directed in p-type and n type semiconductors (Fig. 34.6), the electric force eE_H is in the same direction for both and that is in a direction opposite to that of the Lorentz force.*

Clearly, the Hall field is a function of the applied magnetic field B and the current density j i.e.,

$$E_H \propto jB$$

or
$$E_H = R_H\, jB \tag{34.22}$$

where R_H is the constant of proportionality and is called *Hall Coefficient*.

Thus the Hall coefficient may be numerically defined as the Hall electric field produced by unit current density and unit magnetic field. It is measured in units $\Omega\, m^3$ Weber^{-1} or m^3 coul^{-1}.

From Eqn. (34.20) and (34.21), we have,

$$e\,E_H = F = e\,v_d\,B$$

$$= e\,\mu\,EB \qquad \left(\text{as } \mu = \frac{v_d}{E}\right) \tag{34.23}$$

From (34.22) and (34.23), we have

$$R_H j = \mu E$$

$$R_H = \frac{\mu E}{j}$$

$$= \frac{\mu E}{\sigma E}$$

$$R_H = \frac{1}{ne} \qquad (\text{as } \sigma = ne\mu) \tag{34.24}$$

Here σ and n denote the electrical conductivity and the carrier concentration of the semiconductor respectively.

Experiment 34.2: To study the Hall effect and hence to determine the

(i) Hall coefficient, R_H

(ii) Hall angle, ϕ

(iii) Carrier concentration, *n* and

(iv) The conductivity-type

for the given sample of a semiconductor.

Apparatus: A thin semi-conductor rectangular slab (length > 3 × width), a constant current power supply (0–20 mA), an electromagnet, calibrated fluxmeter to measure the magnetic field, a digital milliammeter, a digital millivoltmeter, a voltmeter, two simple keys and connecting wires.

Theory: Hall effect is a magneto-electric effect as discussed earlier.

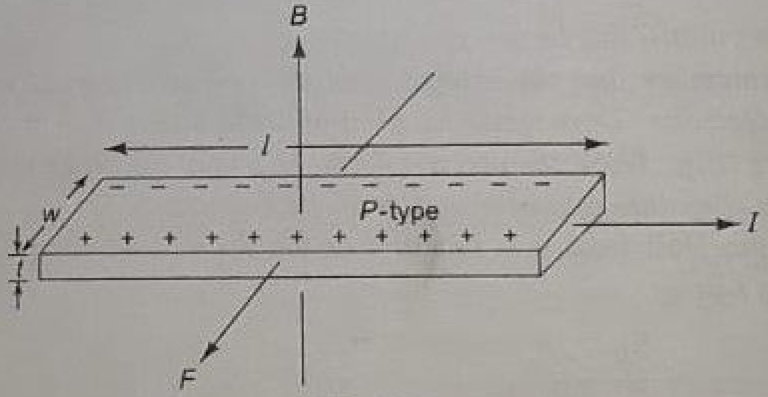


Fig. 34.7

If a current I is passed in x direction of the speciment and magnetic field B is applied in y direction, then a potential difference, called the Hall Voltage V_H is produced in z-direction. The sign of this voltage depends on the nature of the charge carriers, and can be used to find out whether the sample is p-type or n-type.

Hall-coefficient

Suppose, the semiconductor specimen is a slab of length l, width w and thickness t. As already discussed [Eqn. (34.22)], the Hall field is given by, $E_H = R_H jB$ where $j = \frac{I}{wt}$ is the current density and B is the applied magnetic field. R_H is the *Hall coefficient* and is given by,

$$R_H = \frac{1}{ne} \qquad \text{[Eqn. 34.24]}$$

$$\therefore \qquad E_H = R_H \frac{I}{wt} B$$

As wE_H is equal to the Hall voltage V_H, the Hall's coefficiently R_H is given by,

$$R_H = \frac{V_H}{I} \frac{t}{B} \tag{34.25}$$

Since the quantities on the R.H.S. can be found experimentally, the Hall coefficient R_H can be determined.

Hall angle

A charge carrier (electron or hole) in the semiconductor is under the influence of two electric fields simultaneously, applied electric field **E** and Hall field $\mathbf{E}_H$ at right angles to each other. The resultant electric field $\mathbf{E}' = \mathbf{E} + \mathbf{E}_H$ will make an angle ϕ with x-axis or with the direction of the current. The angle ϕ which $\mathbf{E}'$ makes with the direction of current is termed as *Hall angle*. Thus

$$\tan \phi = \frac{E_H}{E} = \frac{V_H/w}{V/l} = \frac{V_H}{V} \frac{l}{w} \tag{34.26}$$

Thus, by measuring V_H and V simultaneously for a given I and B, the Hall's angle may be determined using Eqn. (34.26).

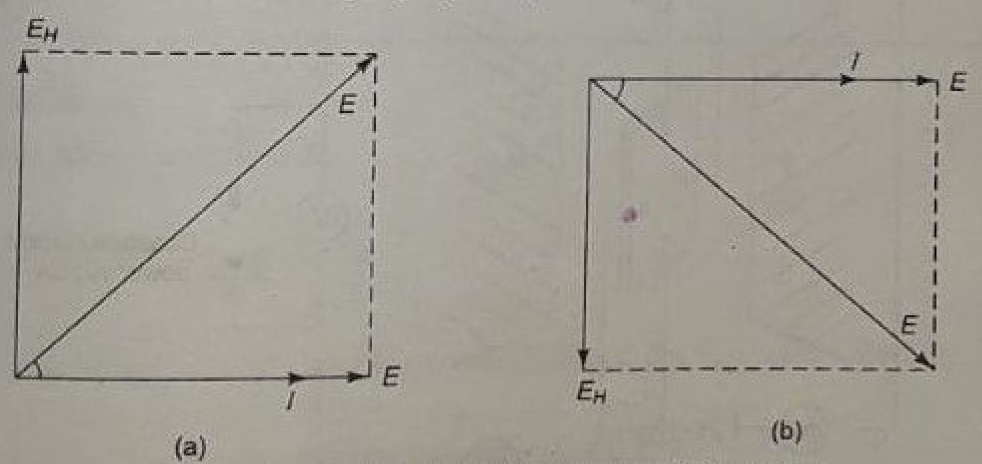


Fig. 34.8 *Hall angle in (a) n-type and (b) p-type*

Carrier concentration

The relation between the carrier concentration n and the Hall coefficient R_H is given by [Eqn. 34.24],

$$R_H = \frac{1}{ne}$$

∴ the carrier concentration

$$n = \frac{1}{R_H e} \tag{34.27}$$

where e is the electronic charge.

Conductivity-type

Conductivity-type (i.e., p or n) is determined from the direction of the Hall voltage developed in the sample on application of the magnetic field B. If we look at Fig. 34.9, the current I flows in upward direction, the magnetic field is directed towards left (from N-pole to S-pole of the magnet), then from the left hand rule, the Lorentz force is directed out of the plane of the paper perpendicular to its surface (from 3 to 4). The carriers are pushed in this direction towards the point 4. So if the contact point 4 in Fig. 34.9 is positive w.r.t. 3, the sample is p-type; and if the point 4 is negative w.r.t 3, it is n-type sample.

Procedure:

1. Place the semiconductor sample at the centre between the pole-pieces of the electromagnet with the help of a stand such that the magnetic field is perpendicular to the face of the sample i.e., B is along the thickness of the sample. Make connections as shown in Fig. 34.9 and switch on the constant current power supply. The current flows along the length of the specimen.

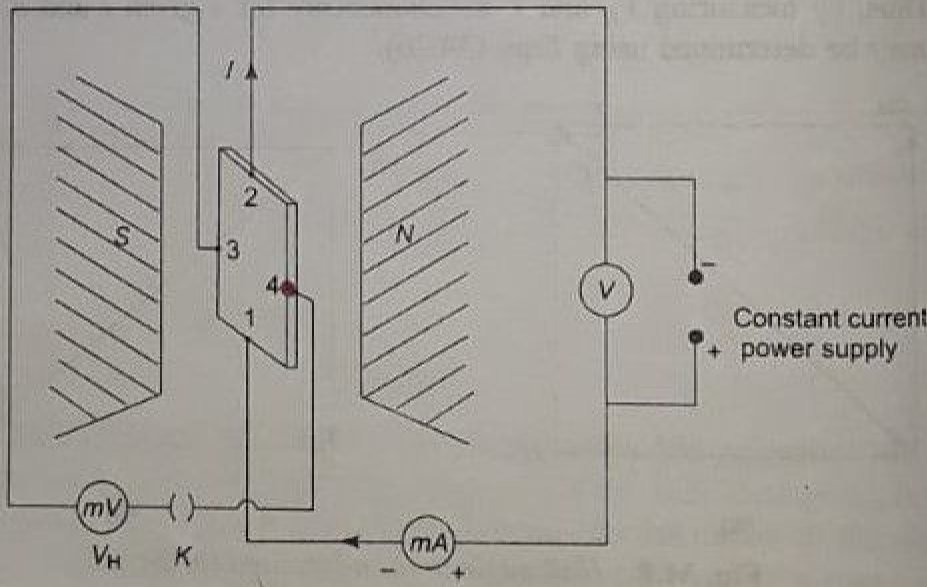


Fig. 34.9

2. Note down the current I through the sample and the voltage V* across it.
3. Close the key K. The voltage appearing along the width of the sample (between the points 3 and 4) is called the offset voltage. Note it down.
4. Open the key K, switch on the electromagnet and wait for 2–3 minutes. Close the key K and measure the Hall voltage developed along the width of the specimen. Subtract the offset voltage from it to get the corrected Hall-voltage V_H. Switch-off the magnet.
5. Increase the current through the sample in small steps and repeat the process to take at least 6–7 observations. Remember that while measuring V, magnetic field should remain off. It should be switched on only for measuring V_H.
6. Measure the magnetic field strength B with the help of a Gauss-meter or flux-meter. Convert it to Weber/m^2 by using the relation 1 Gauss = 10^{-4} Weber/m^2.
7. Measure the length, width and thickness of the specimen with the help of vernier callipers and screw gauge.
8. Plot the following graphs:
   (i) I along x-axis and V_H along y-axis.
   (ii) V along x-axis and V_H along y-axis.

Observations:

Length of the sample l = ... cm = ... m
Width of the sample w = ... cm = ... m
Thickness of the sample t = ... cm = ... m
Magnetic field B = ... Wb/m^2

S. No.	*Voltage V* ($\times 10^3$ mV)*	*Current I (mA)*	*Offset Voltage (mV)*	*Hall Voltage (mV)*	*Corrected Hall voltage V_H (mV)*
1					
2					
3					
4					
5					
6					

Calculations:

(i) For Hall coefficient R_H

$$R_H = \frac{V_H}{I}\frac{t}{B}$$

$\frac{V_H}{I}$ is given by the slope of the straight line in the V_H versus I plot (Fig. 34.10).

$$\therefore \quad R_H = \text{Slope} \times \frac{t}{B} = \ldots\ \Omega\ \text{m}^3\ \text{Wb}^{-1}$$

*The voltage V across the length of the sample is very large in comparison to V_H. Whereas V_H is in millivolts, V is in volts. To avoid error in calculations, multiply it with 10^3 and note it down in millivolts in the observation table.

(ii) For Hall angle* ϕ

$$\tan\phi = \frac{V_H}{V}\frac{l}{w}$$

$\frac{V_H}{V}$ is given by the slope of the straight line in the V_H versus V plot (Fig. 34.11).

$$\therefore \quad \tan\phi = \text{Slope} \times \frac{l}{w} = \ldots$$

or $\quad \phi = \ldots$ degree

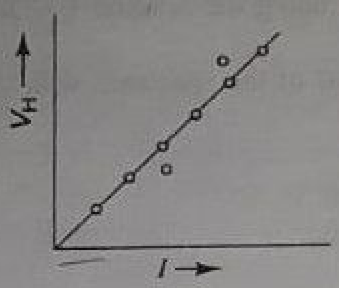


Fig. 34.10

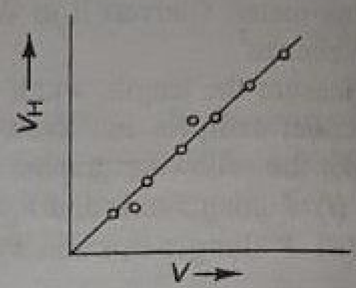


Fig. 34.11

(iii) For carrier concentration

$$n = \frac{1}{R_H e} = \ldots \text{ m}^{-3}$$

where e is the electronic charge in Coulombs and R_H is the Hall's coefficient in Ωm^3 Wb^{-1}.

Result:

(*i*) The Hall coefficient, $R_H = \ldots\ \Omega\ m^3\ Wb^{-1}$ (or m^3/coulmb)
(*ii*) Hall angle, $\phi = \ldots$ degree
(*iii*) Carrier concentration, $n = \ldots\ m^{-3}$ and
(*iv*) The conductivity-type for the given semiconductor sample = ... type.

Precautions and Sources of Error:

1. Hall voltage developed is very small and hence it must be measured very carefully by a high input impedance ($\simeq$ 1 MΩ) device such as electronic digital voltmeter or electrometer.
2. Sometimes V_H is not zero for zero magnetic field. This is due to imperfect alignment between the contacts for measuring V_H. This offset voltage should be taken care of.
3. The theory assumes that all the carriers are moving only lengthwise. Practically it has been found that a closer to ideal situation may be obtained if the length of the sample is at least three times its width.

*The voltage V is in volts where as the Hall-voltage V_H is in millivolts. As a result, the Hall-angle is very small. It's value ranges from a few minutes to a few degrees.

4. Reading for V_H should be taken 2–3 minutes after switching on the magnetic field.
5. While determining the Hall coefficient, variation of V_H with I is preferred over the variation of V_H with B due to the difficulties arising in the accurate determination of B.
6. For no field readings, care should be taken that no remanent field exists in the electromagnet when switched off.
7. The magnetic field should be measured carefully.
8. The current through the sample should not be large enough to cause heating.

Weak Points

The measurement of the field with a gauss-meter is the least accurate measurement in the experiment and might introduce some error. Also the voltage appearing between the Hall probes is not generally the Hall-voltage alone. There are other galvano-magnetic and thermomagnetic effects which can produce voltage between the Hall probes. In addition IR drop due to probe misalignment and thermoelectric voltage due to transverse thermal gradient may be present. All these can be eliminated by taking four readings of V_H, two by reversing the current through the sample and two by reversing the direction of the magnetic field. Taking the average of the four readings would eliminate all the above effects and would give the correct Hall-voltage.

Exercise: To determine the conductivity σ and the mobility μ of a semiconductor from the Hall-measurements.

We can get a rough estimate of the conductivity σ and the mobility μ of a semiconductor from the Hall-measurements done in Exp. 34.2.

For this, plot a graph between the current I through the sample along x-axis and the voltage V across the length of the sample along y-axis. The slope of the straight line obtained gives the resistance R of the sample. Then the conductivity is given by,

$$\sigma = \frac{Il}{Vwt} = \frac{1}{\text{slope}} \times \frac{l}{wt}$$

where l, w and t are respectively the length, width and the thickness of the sample. The mobility, μ is obtained from the relation,

$$\mu = \frac{\sigma}{ne} = R_H \sigma$$

QUESTIONS FOR VIVA

Q. Differentiate between conductors, semiconductors and insulators.

Q. Give two examples each of (i) conductors, (ii) semiconductors and (iii) insulators.

Ans. (i) Copper, silver, (ii) germanium, silicon, (iii) corbon, diamond.

Q. What is the difference between intrinsic and extrinsic semiconductors?

Q. What is the difference between *p*-type and *n*-type semiconductors?

Q. How does a non-conducting crystal becomes conducting when impurities are doped into it?

Ans. Some impurity atoms have extra electrons which makes it conducting. Again,

Q. Define carrier concentration, electrical conductivity and mobility of charge carriers. How are they related?

Q. What are the requisites of a sample used for the determination of Hall coefficient?

Ans. 1. it should be a semiconductor.

2. it's thickness (t) should be very small.

3. it's length should be more than three times its width i.e., $l > 3\,w$.

Q. In Hall measurements, why does the resistance of the sample increase with increasing magnetic field?

Ans. On increasing the magnetic field, the Hall voltage V_H increases. As more carriers move in a direction perpendicular to the direction of the applied potential V, less number of carriers move in the direction of V and less current flows for a given V. Hence resistance of the sample increases.

Q. Give expressions for Hall electric field (E_H). How is it related to the electric field across the sample length (E)?

Ans.

$$E_H = \frac{V_H}{w} = \frac{R_H IB}{tw}$$

where w is the width of the specimen.

$$E = \frac{V}{l} = \frac{IR}{l} = \frac{I}{\sigma wt}$$

where l is the length of the specimen.

$$\therefore \quad \frac{E_H}{E} = \frac{R_H IB}{tw} \times \frac{\sigma wt}{I} = R_H B\sigma = \frac{\sigma B}{ne}$$

$$\therefore \quad E_H = \frac{\sigma B}{ne} E$$

or

$$E_H = \mu BE$$

Q. Why is it desirable to have the length of the specimen much larger as compared to its width?

Ans. This is to reduce the end-effects and to make the electric field uniform throughout the body of the specimen. Also, since $\tan\phi = \frac{V_H}{V}\frac{l}{\omega}$ and $V_H << V$, a large l/w is desirable to make the hall angle ϕ measurable.

Hall Measurements

Q. Define Lorentz force. State the rule which gives the direction of this force.

Q. What is Hall effect? Explain.

Q. How is Hall's coefficient related with carrier concentration?

Ans. $R_H = \frac{1}{ne}$

Q. On what factors does the sign of the Hall's coefficient depend?

Ans. It depends on the majority charge carriers in the semiconductor. It is negative for *n*-type and positive for *p*-type semiconductors.

Q. What is the sign of Hall coefficient for an intrinsic semiconductor.

Ans. It is negative.

Q. Can we measure Hall's coefficient for metals?

Ans. No, as its magnitude is many orders smaller in metals.

Q. Why is the Hall coefficient of semiconductors many orders of magnitude greater than that of metals?

Ans. Because the carrier concentration in semiconductors is much less than that in metals.

Q. How is Hall's coefficient related to the Hall's voltage (V_H) and the thickness (t)? Why should the sample be thin?

Ans. $R_H = \frac{V_H}{I}\frac{t}{B}$

As the Hall voltage $V_H \propto \frac{1}{t}$, a small t would give a large and measurable value of V_H.

Q. What are the units of Hall's coefficient?

Ans. m^3 coul^{-1}.

n→9