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# Instruction Manual

# Hall Effect

## Objectives:

1. To study Hall effect and to determine
   (i) Hall voltage $V_H$
   (ii) Hall coefficient $R_H$
2. To determine the type of majority carriers i.e. whether the semiconductor crystal is of n – type or p-type.
3. To determine the charge carrier density or carrier concentration per unit volume in the semiconductor crystal.
4. To determine the magnitude of Poynting Vector.
5. To determine the Hall angle $\theta_H$.

## Introduction:

In 1879, E.H. Hall 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.

## 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 $V_H$.

## Exaplanation:

Consider a semiconductor in the form of a flat strip .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 $V_H$ .

As shown in fig. 1, 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** is given by,

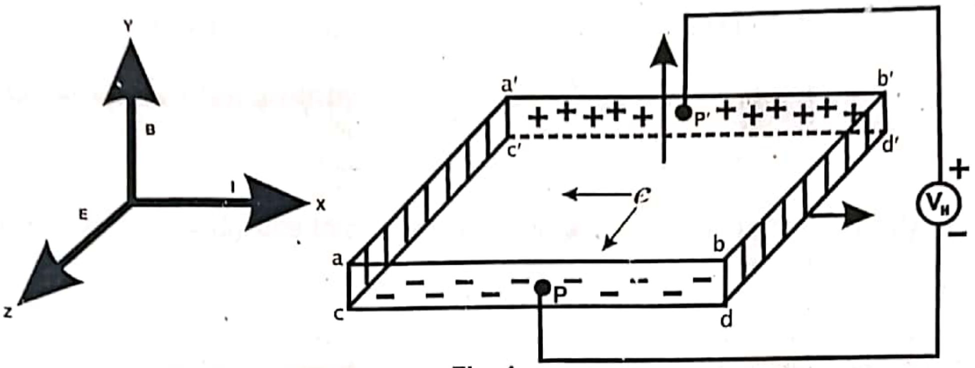


**Fig. 1**

$$F = e(v \times B)$$

$$F = evB \sin 90°$$

Or $F = evB$ ............................................(1)

where, v is the drift velocity of electron and e is the charge of electron.

Using Fleming's left hand rule it is seen that force on the electrons will be directed towards the face a b c d , i.e. along positive Z-axis ,thereby making the face a b c d negative and a′ b′ c′ d′ positive.

If the current is carried by positively charged carriers i.e. holes , the carriers move in the same direction as that of the current . The magnetic force causes the positive charge carriers to move towards the face a b c d., thereby making the face a b c d positive and a′ b′ c′ d′ negative.
Thus, by determining the polarities of the surface of the strip , we can determine the sign of the charge carriers.

At thermal equilibrium ,when the Lorentz force exactly matches the force due to the electric field $E_H$ (the Hall voltage) we have :

$evB = eE_H$ ..................................................(2)

If b be the width and t is the thickness of the specimen (crystal),its cross sectional area A is given by :

$A = bt$ ..................................................(3)

The current density $J = I/A$ .............................(4)

or $I = nevA$ .........................................(5)

where, n is the number of charge carriers per unit volume .

Using above equations we get

$1/ne = V_H b/BI$ ...................................(6)

The Hall coefficient is given by:

$$R_H = V_H b / IB \quad \text{.........(7)}$$

and charge carrier density is given by:

$$n = 1/eR_H \quad \text{.........(8)}$$

If the conduction is primarily due to one type of charge carriers , then conductivity is related to mobility $\mu_m$ as:

$$\mu_m = \sigma R_H \quad \text{.........(9)}$$

therefore,

$$\mu_m = R_H/\rho \quad \text{.........(10)}$$

where , $\rho$ is the resistivity.

There is another interesting quantity called the Hall angle( $\theta_H$) defined by equation

$$\tan\theta_H = E_H/E_x \quad \text{.........(11)}$$

$$\text{but} \quad E_H = v_x B \quad \text{.........(12)}$$

$$\text{hence} \quad \tan\theta_H = v_x B/E_x = \mu_m B \quad \text{.........(13)}$$

**Apparatus:** INDOSAW SK006 Hall effect apparatus.

It consists of :

1. Power supply for electromagnet:
   Specifications: 0-16 V, 5 Amps.
2. Power supply (Constant current source):
   Specifications: 0-20 mA
3. Gauss meter with Hall Probe
4. Semiconductor( Ge single crystal)mounted on a PCB
   Specifications:
   - p-type Ge crystal.
   - Thickness: 0.5 mm
   - Width : 4 mm
   - Length : 6mm
5. Multimeter for measuring Hall voltage

Block Diagram of Experimental set up

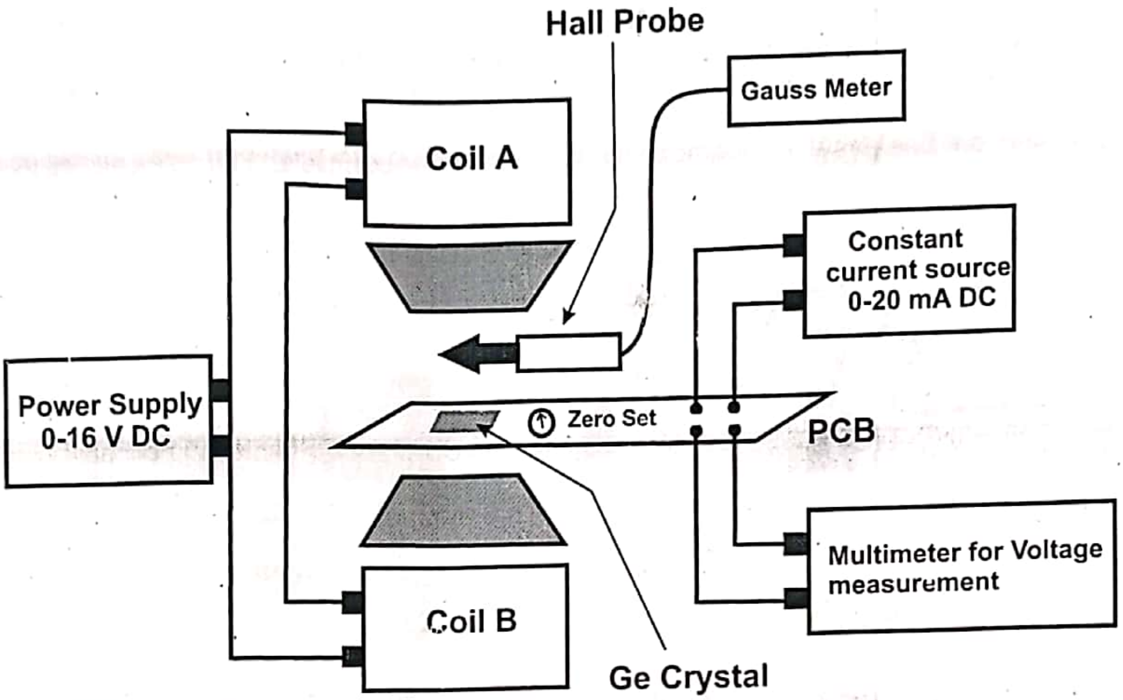


Fig. 2

Fig.2 Shows the block diagram for experimental set up with connections . A p-type Ge crystal is mounted on PCB. PCB is provided with four sockets and a pot to make the Hall voltage zero, when there is no current flowing through the crystal and also when there is no magnetic field .The upper two sockets are connected to a constant current dc source and the lower two to a multimeter/millivoltmeter.

**Formula used:**

(1) Hall coefficient $R_H = V_H b / BI$ $m^3 C^{-1}$
where, $V_H$ = Hall voltage in volts.
b = width of the sample in m.
B = magnetic flux density in Tesla.

(2) Concentration of charge carriers per unit volume
$n = 1/e R_H$ carriers $m^{-3}$
where, $e = 1.6 \times 10^{-19}$ C

(3) Resistivity of the material of the sample
$\rho = V_l b t / I l$ m
Where, $V_l$ =voltage between two points situated l cm apart on one face of sample
b = width of the sample in m .
t = thickness of the specimen in m.

(4) Mobility $\mu_m = R_H / \rho$ $m^2 V^{-1} s^{-1}$

(5) Hall angle $\theta_H = \tan^{-1}(\mu B)$

(6) Magnitude of Poynting vector:

In an electromagnet wave in free space the magnetic field H and the electric field E are perpendicular to each other . A semiconductor placed parallel to E will derive a current I in the semiconductor . The semiconductor is subjected simultaneously to a transverse magnetic field H producing a Hall voltage across the sample. The Hall voltage will be proportional to the product of E and H, which is the magnitude of the Poynting vector of electromagnetic wave. Therefore, Hall effect can be used to determine power flow in an electromagnetic wave and the magnitude of Poynting vector.

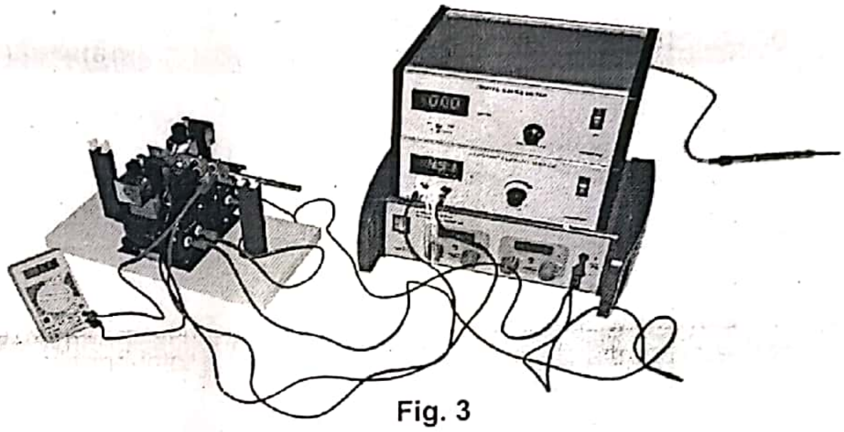

Fig. 3

**Procedure :**

(1) Before starting the actual experiment, check whether the Gauss meter shows the reading to be zero or not. To do this place the Hall probe away from the electromagnet and switch on the Gauss meter as shown in fig.3. It will show Zero value .It may sometimes show some value. Set it at zero or account for it while taking the observations.

(2) Set the current, say at 5 mA in constant current source and keep the magnetic field at zero as recorded by Gauss meter.

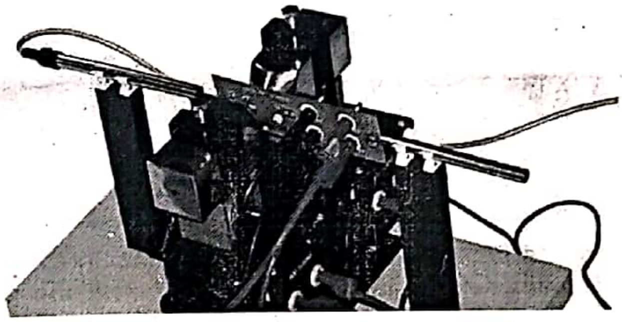

**Fig. 4**

(3) Put the Hall probe at the center in between the pole pieces of electromagnet and parallel to the crystal as shown in figure 4

(4) Ensure that the sample is located at the center in between the pole pieces of the electromagnet and perpendicular to the magnetic field.

(5) Connect the terminals of the constant current source to the sockets provided on the PCB and also connect a millivoltmeter/multimeter to the sockets provided on the PCB.

(6) Set the Hall voltage at zero in the multimeter through the pot provided on the PCB as shown in fig.5, when a current of 5ma from the constant current source is being passed and the Gauss meter shows zero reading.

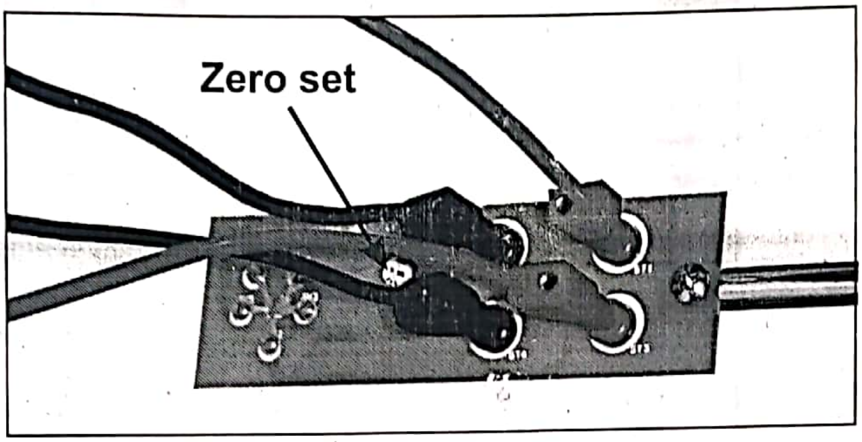


Fig.5

(7) Switch on the power supply of electromagnet (say at about 17 V, 3.5 A).

(8) Measure the magnetic flux density at the center between the pole pieces by placing the tip of the Hall probe there by recording the gauss meter reading.

(9) Do not change the current in the electromagnet i.e. keep the magnetic field constant.

(10) Note the current (mA) from the constant current source passing through the sample and measure the Hall voltage. Record these values in the observation table. Calculate $R_H$

(11) Measure the corresponding Hall voltage by setting the current from constant current source at different values. Record these values in the table.

(12) Change the values of the magnetic field and repeat whole of the experiment.

Observations:

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Width of the specimen, b = 4 mm

= $4 \times 10^{-3}$ m

Length of the specimen, l = 6mm

= $6 \times 10^{-3}$ m

Thickness of the specimen, t = 0.5 mm

= $5 \times 10^{-4}$ m

Magnetic flux density, B = 3110 Gauss

= $3110 \times 10^{-4}$ Tesla

Table for I and V:

| S. No. | Current I (mA) | Reading of millivoltmeter (mV) | | Mean value of $V_H$ (mV) | $V_H/I$ (ohms) |
|---|---|---|---|---|---|
| | | B & I in one direction | B & I in reversed direction | | |
| 1 | 0.48 | 0.9 | 1.1 | 1.0 | 2.08 |
| 2 | 0.99 | 2.0 | 2.2 | 2.1 | 2.12 |
| 3 | 2.01 | 4.1 | 4.5 | 4.3 | 2.14 |
| 4 | 3.01 | 6.2 | 6.9 | 6.55 | 2.18 |
| 5 | 4.04 | 8.3 | 9.2 | 8.75 | 2.17 |
| 6 | 5.14 | 10.5 | 11.7 | 11.1 | 2.16 |
| 7 | 6.02 | 12.3 | 13.7 | 13.0 | 2.16 |
| 8 | 7.02 | 14.1 | 15.9 | 15.0 | 2.14 |
| 9 | 8.12 | 16.2 | 18.3 | 17.25 | 2.12 |
| 10 | 9.11 | 17.8 | 20.5 | 19.15 | 2.10 |
| 11 | 10.06 | 19.2 | 22.7 | 20.95 | 2.08 |
| 12 | 11.21 | 21.0 | 25.2 | 23.1 | 2.06 |
| 13 | 13.20 | 23.8 | 30.2 | 27.0 | 2.05 |
| 14 | 14.01 | 24.9 | 31.6 | 28.25 | 2.02 |

Table for resistivity :

| S. No. | Current I (mA) | Distance between Two points between which potential Difference is measured $\ell$ (m) | $V_\ell$ (mV) | $\rho = V_\ell\, bt / I\ell$ (Ω m) |
|---|---|---|---|---|
| 1 | 0.48 | $0.206 \times 10^{-2}$ | 1.0 | $2.02 \times 10^{-3}$ |
| 2 | 0.99 | $0.206 \times 10^{-2}$ | 2.1 | $2.06 \times 10^{-3}$ |
| 3 | 2.01 | $0.206 \times 10^{-2}$ | 4.3 | $2.07 \times 10^{-3}$ |
| 4 | 3.01 | $0.206 \times 10^{-2}$ | 6.5 | $2.11 \times 10^{-3}$ |

## Calculations :

1. Mean value of $V_H/I$ = 2.09 ohms

2. $R_H = V_H\, b/I \times B$
$= 2.09 \times 0.004 \times 10^4 / 3110$
$= 2.69 \times 10^{-2}\ m^3 C^{-1}$

3. Sign of Hall coefficient is positive, thus the semiconductor crystal is of p-type.*(to check whether a crystal is of p-type or n-type we have first used a crystal of known type)*

4. $n = 1/(1.6 \times 10^{-19} \times R_H)$
$= 2.32 \times 10^{20}$ carriers $m^{-3}$

5. $\rho = 2.0655 \times 10^{-3}\ \Omega\ m$

6. $\mu_m = R_H / \rho = 13.0\ m^2 V^{-1} s^{-1}$

7. In an electromagnet wave in free space the magnetic field H and the electric field E are perpendicular to each other . A semiconductor placed parallel to E will derive a current I in the semiconductor . The semiconductor is subjected simultaneously to a transverse magnetic field H producing a Hall voltage across the sample. The Hall voltage will be proportional to the product of E and H, which is the magnitude of the Poynting vector of electromagnetic wave. Therefore, Hall effect can be used to determine power flow in an electromagnetic wave and the magnitude of Poynting vector .

8. The Hall angle $\theta_H = \tan^{-1}(\mu_m B)$
$= 76.10^\circ$

**Sources of error :**

The experiment has the potential to have systematic errors which could skew the final calculations. This may be due to slight misalignment of the magnetic field, irregularity in the grain of germanium crystal, stray magnetic fields generated by nearby electrical equipments

**Check Points :**

- Before starting the experiment, check the Gauss meter is showing zero value. For this put the probe in separate place and switch on the Gauss meter, it will show zero value.
- Ensure that the specimen is located at he center between the pole pieces and exactly perpendicular to the magnetic field.
- To measure the magnetic flux the Hall probe should placed at the center between the pole pieces, parallel to semiconductor sample.
- Check th direction of electromagnet coils so that it generates the maximum magnetic field, this can be checked by placing a soft iron near the generated magnetic field. If soft iron attracts forcefully, the magnetic field is strong.

**Viva - voce questions :**

1. What is Hall effect ?
2. What is the cause of Hall effect ?
3. What is Hall coefficient ?
4. What are the factors on which Hall coefficient depends ?
5. Explain the meaning of positive and negative Hall effect ?
6. What are the units of Hall coefficient ?
7. Which shows stronger Hall effect , metallic conductors or semiconductors ?
8. Can you identify whether a given sample is p-type or n-type using Hall effect ?

9. What is the significance of Hall effect ?
10. Name some practical applications of Hall effect ?
11. How can you find the charge carrier concentration and the mobility using Hall effect ?
12. Can you study Hall effect using Si sample instead of Ge sample ?
13. Should you prefer Ge or Si ?
14. Which has higher resistivity Ge or Si ?
15. What happens if the current is not perpendicular to the magnetic field applied ?
16. On what factors the sign of Hall potential depends?
17. Write down the dimensional formula of Hall coefficient?
18. What do you mean by charge carrier density?
19. Define mobility?
20. Write down the units of mobility and its dimensional formula?
21. Should you use ammeter or milliammeter in this experiment?

Applications of Hall effect :

1. The Hall effect can be used to determine whether the semiconductor is of n-type or p-type.
2. The Hall effect can be used to determine the carrier concentration.
3. The Hall effect can be used in magnetic flux density meter.