HALL EFFECT

❖ Introduction:

❖ The Hall effect was discovered in 1879 by Edwin Herbert Hall while he was working on his doctoral degree at Johns Hopkins University in the USA.

❖ His measurements of the tiny effect produced in the apparatus he used were an experimental tour de force, accomplished 18 years before the electron was discovered and published under the name "on a New action of the magnet on electric currents."

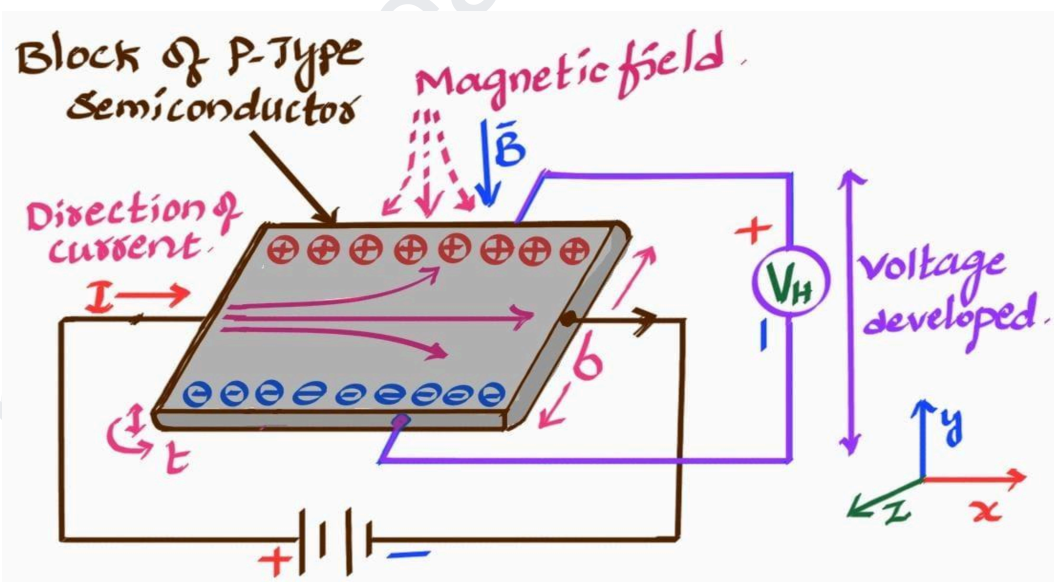
❖ Hall effect:

❖ When a current-carrying conductor is placed in a magnetic field, a voltage develops across the conductor, perpendicular to both the direction of the current and the magnetic field. This phenomenon is known as the Hall effect. The resulting voltage is called the Hall voltage(**V_H**).

❖ Experimental Arrangement & procedure:

❖ Let us consider a rectangular block of P-type semiconductor. A current 'I' is passed through the semiconductor block along the X-direction.The charge carriers will follow a linear path from one end of the block to the other.

❖ This movement of the charge carriers leads to the creation of a magnetic field (B) along the Y-direction and the charge carriers experience a Lorentz force (**F_L**) along the Z-direction as per Fleming's Left-Hand Rule.



❖ As a result of this force (F_L),negatively charged electrons will be deflected to one side of the block and positively charged holes will be deflected to the other side of the block.

- Therefore, a potential difference, called the Hall voltage (V_H), is developed between the two sides of the block. This Hall voltage (V_H) can be measured by connecting the two surfaces to voltmeters. This separation of charge carriers creates a Hall electric field (E_H) in the upward direction.
- When the charge carriers are moving in a magnetic field within the P-Type semiconductor, they experience a Lorentz force.

F_L= eV_dB ------------------- (1) (where F=qvB & V_d - drift velocity)

- The electric force due to the electric field created by the surface charges is

F_H= eE_H--------------------------(2) (where F=eE & E_H - Hall electric field)

- After some time, both forces become equal in magnitude and opposite in direction, and this situation is said to be in equilibrium.
- **<u>At equilibrium:</u>**

$F_H = F_L$

$eE_H = eV_dB$

$E_H = V_dB$ ----------------------- (3)

- But current density $J=neV_d$ (where J=neV)

$\Rightarrow V_d=J/ne$

- Substituting V_d into the equation (3) for E_H

$E_H = (J/ne)B$

$E_H = BJ(1/ne)$ ----------------- (4)

OR

$E_H/BJ = 1/ne$ ----------------- (5)

- **<u>Hall Voltage(V_H):</u>**
- The Hall voltage **(V_H)** is the potential difference (voltage) across the width **(b)** of the P-Type semiconductor due to the Hall electric field**(E_H).**

$V_H = E_H.b$ ----------------- (6)

- **From (4)&(6) => V_H= BJb(1/ne) ----------------(7)**

OR

V_H= Bb(I/A)(1/ne) ----------------(8) (Since J=I/A)

- If 'b' is the width and 't' is the thickness (length) of the P-type semiconductor then Area, A= bt, thus **(8)** becomes

V_H= Bb(**I**/bt)(1/ne)

=> V_H= BI/net ----------------(9)

Hall coefficient (R_H):

- Hall coefficient**(R_H)** is defined as the ratio of the Hall electric field**(E_H)** to the product of the current density**(J)** and the magnetic field strength**(B)**.

=>**R_H= E_H/BJ ------------------ (10)**

- **From (5) &(10)** =>**R_H = 1/ne --------------------(11)**
- **From (6) & (10) =>** $R_H = (V_H/b)/BJ = V_H/bBJ$
- Since J=I/A=I/bt => $R_H = (V_H/b)/B(I/bt) = V_H bt/bBI$

=>**R_H = V_Ht/BI ------------------- (12)**

- **where:** R_H→ Hall coefficient

t→ thickness of sample

B→ magnetic field

I→ electric current

- **NOTE:** For P-type semiconductor →R_H=+1/ne

For N-type semiconductor →R_H=−1/ne

❖ Hall mobility(μ_H):

❖ The drift velocity acquired in a unit electric field is called Hall mobility.

$$\mu_H = V_d/E \text{ ------------------- } (13)$$

❖ We know current density $J=neV_d$ and also $J=\sigma E$. So, $neV_d = \sigma E$

$$\Rightarrow V_d/E = \sigma/ne = \sigma x(1/ne)$$

❖ Sub. V_d/E value in **(13) we get,** $\mu_H = \sigma x(1/ne)$ **------------------- (14)**

❖ **From equations (11) and (14):** $\mu_H = \sigma R_H$ **---------------(15)** (since $1/ne=R_H$ and $V_d/E=\mu_H$)

❖ Hall angle (θ_H):

❖ The net electric field in the semiconductor is a vector sum of E_x (electric field due to current) and E_H (Hall electric field), which acts at an angle θ_H to the x-axis. This θ_H is called the Hall angle. Then:

$$\tan\theta_H = E_H/E_x \text{ --------------------- } (16)$$

❖ And $E_x=J/\sigma$ **------------------ (17)** (since $J_x=J$, and $\sigma=1/\rho$, $E=\rho J= J/\sigma$)

❖ From **(4)& (11) :** $E_H=R_HBJ$ **----------------- (18)**

❖ Substitute E_H **and** E_x values into equation **(16)** $\Rightarrow \tan\theta_H = (R_HBJ)/(J/\sigma)$

$$\Rightarrow \tan\theta_H = \sigma R_H B \quad \text{And From (15)} \Rightarrow \sigma R_H = \mu_H$$

❖ Thus $\tan\theta_H=\mu_H B$ **------------------ (19)**

❖ Drift velocity (V_d):

❖ Since E=voltage/distance => $E_H=V_H/b$ ---------------------- (17) (where b is width)

❖ From (3)=> $V_d=E_H/B$ & From (6) => $E_H = V_H/b$.

❖ **Thus** $V_d= (V_H/b)(B) \Rightarrow V_d= V_H/Bb$ **--------------------- (20)**

❖ Carrier concentration (n):

❖ From equation (11), $R_H=1/(ne)$

❖ Therefore: $n=1/(R_He)$ **----------------------- (21)**

❖ **NOTE:** For N-Type semiconductor $\rightarrow n=-1/(R_He)$ (where $n\rightarrow$ number of electrons)

For P-Type semiconductor $\rightarrow p=+1/(R_He)$ (where $p\rightarrow$ number of holes)

❖ Doping level:

❖ It is possible to estimate the doping concentration N_A from the value of P (hole concentration in p-type material) using the relation: $\mathbf{P_P \approx N_A}$.----------------- **(22)**

❖ Variation of Hall coefficient (R_H) with Temperature (T):

❖ **(i) In metals:** It was found that R_H does not depend on T.

❖ Hence, the concentration of free electrons does not vary with T in metals.

❖ **(ii) In Semiconductors:** The R_H sharply decreases with increasing T.

❖ This indicates that the concentration of charge carriers in semiconductors increases with increasing T.

❖ Applications/Uses of Hall effect:

❖ **(i) Determination of Semiconductor type (SC type):**

❖ If Hall coefficient (R_H) is positive → P-type semiconductor.

❖ If Hall coefficient (R_H) is negative → N-type semiconductor.

❖ **(ii) Calculation of carrier concentration:**

❖ By measuring R_H and V_H, the concentration of electrons in N-type semiconductors and holes in P-type semiconductors can be measured:

❖ For N-type semiconductor $\Rightarrow n = -1/(R_H e)$

❖ For P-type semiconductor $\Rightarrow p = +1/(R_H e)$

❖ **(iii) Determination of Mobility of Charge carriers:**

❖ By calculating conductivity (σ) or resistivity (ρ) and Hall coefficient (R_H), the mobility of charge carriers can be measured as $\mu_H = \sigma R_H$

❖ **(iv) Measurement of Magnetic Flux density (B):**

❖ Hall voltage (V_H) is directly proportional to the magnetic flux density (B) for a given current (I). This principle is used in Magnetic-flux density meters.

❖ **(v) This concept is also used in different devices such as:**

❖ Multipliers

❖ Magnetic field sensors/magnetometers

❖ Automotive fuel level indicators

❖ Position sensing in Brushless DC electric motors.

❖ **(vi) Measurement of power in an electromagnetic wave:**

❖ In an E.M wave, the electric and magnetic fields are mutually perpendicular to each other. The Hall voltage (V_H) is proportional to the product $E_H \times B$, which signifies the power of the wave.