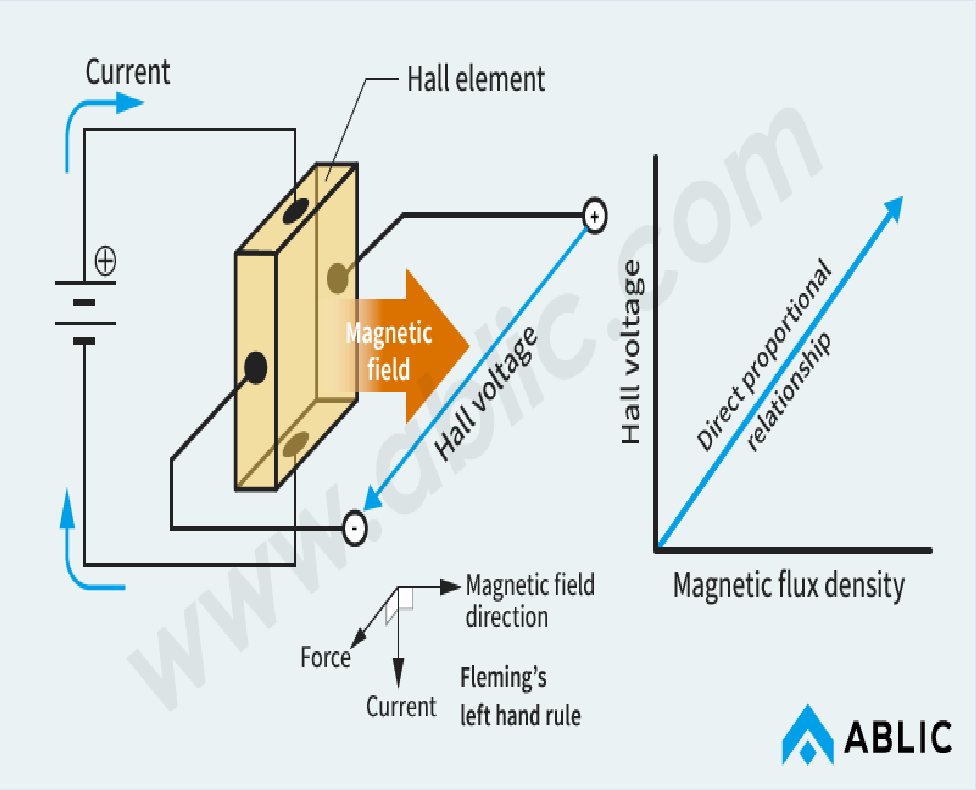
DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

MODULE IV- LECTURE 3

HALL EFFECT

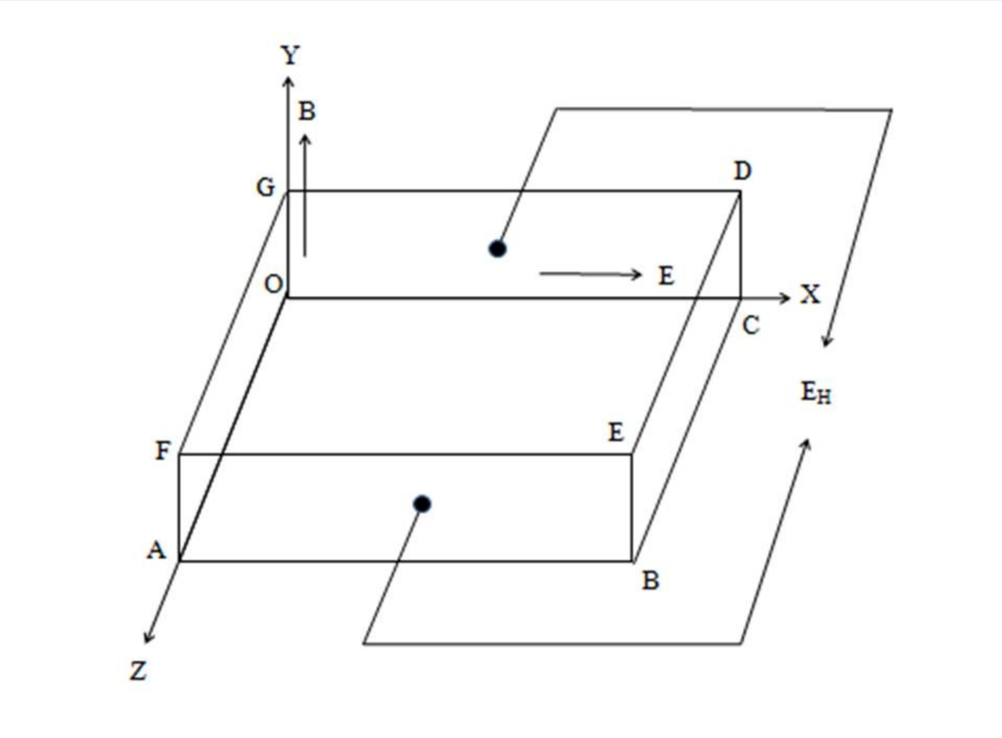
Definition

When a piece of conductor (metal or Semiconductor) carrying current is placed in a transverse magnetic field, an electric field is produced inside the conductor in a direction normal to both the current and the magnetic field. This phenomenon is known as the Hall Effect and the generated voltage is called the Hall voltage.



Explanation:

Consider a conventional current flow through the strip along OX and a magnetic field if induction B is applied along axis OY.



Case – I If the Material is N-type Semi- Conductor (or) Metal

- If the strip is made up of metal or N-type semiconductor, the charge carriers in the strip will be electrons.
- As conventional current flows along OX, the electrons must be moving along XO. If the velocity of the electrons is ‘v’ and charge of the electrons is ‘-e’, the force on the electrons due to the magnetic field is,
- F= - Bev, which acts along OZ. This causes the electrons to be deflected and so the electrons accumulate at the face ABEF.

- Thus, face ABEF will become negative and the face OCDG becomes positive. A potential difference is therefore established across faces ABEF and OCDG., causing a field E_H.
- This field gives rise to a force of ‘ $-eE_H$’ on the electrons in the opposite direction (i.e, in the negative Z direction).

At equilibrium , $eE_H = Bev$ (or) $E_H = Bv$ (1)

If J is the current density, then , $J= -nev$ (2)

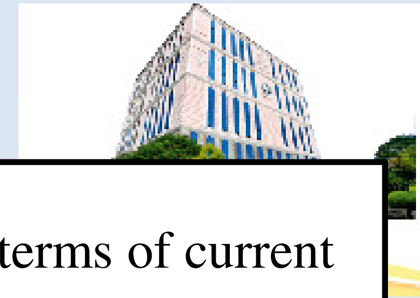
Where 'n ' is the concentration of current carriers,

From equ. (2)

$v= J/-ne$ (3)

Substituting the value of v in equ. (1) we get,

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



- The Hall Effect is described by means of the Hall coefficient ‘R_H ‘ in terms of current density ‘ J’ by the relation,

$$E_H = R_H BJ$$

$$\text{(or) } R_H = E_H / BJ \qquad (5)$$

By substituting the value of E_H from equ. (4) we get,

$$R_H = BJ/ -neBJ = - 1/ne \qquad (6)$$

- Since all the three quantities E_H, J and B are measurable , the Hall coefficient R_H and hence the carrier density ‘n’ can be found out.

Case – (ii) If the material is a P-type semiconductor

If the strip is a P- type semiconductor, the charge carriers in the strip will be holes i.e., positively charged particles. The holes will constitute current in the direction of conventional current. Therefore, holes move along the direction of the conventional current itself i.e., along OX. If ‘e’ is the charge of the hole, the force experienced by the holes due to magnetic field is , F= Bev, which acts along OZ. This causes the holes to accumulate on the face ABEF- making it positive and leaving the face OCDG as negative.

Therefore , for a P-type semiconductor, $R_H = 1/pe$ (7)\

Where p= the density of holes.

Determination of Hall Coefficient

The Hall coefficient os determined by measuring the Hall voltage that generates the Hall field.

If ‘w’ is the width of the sample across which the Hall voltage is measured, then

$$E_H = V_H / w \qquad (8)$$

We know that $R_H = E_H / BJ$ (9)

Substituting the value of E_H in the above equation, we get,

$$R_H = V_H / wBJ$$

(or)

$$V_H = R_H \, w \, BJ \qquad (10)$$

If the thickness of the sample is ‘t’ , then its cross sectional area A= wt, and the current density,

$J = I/A = I/wt$ (11)

Substitute the value of ‘ J’ in equation (11) , we get

$V_H = R_H w BJ / wt = R_H I B /t$

(or) $R_H = V_H t / IB$ (12)

V_H will be opposite in sign for P and N type semiconductors

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Experiment

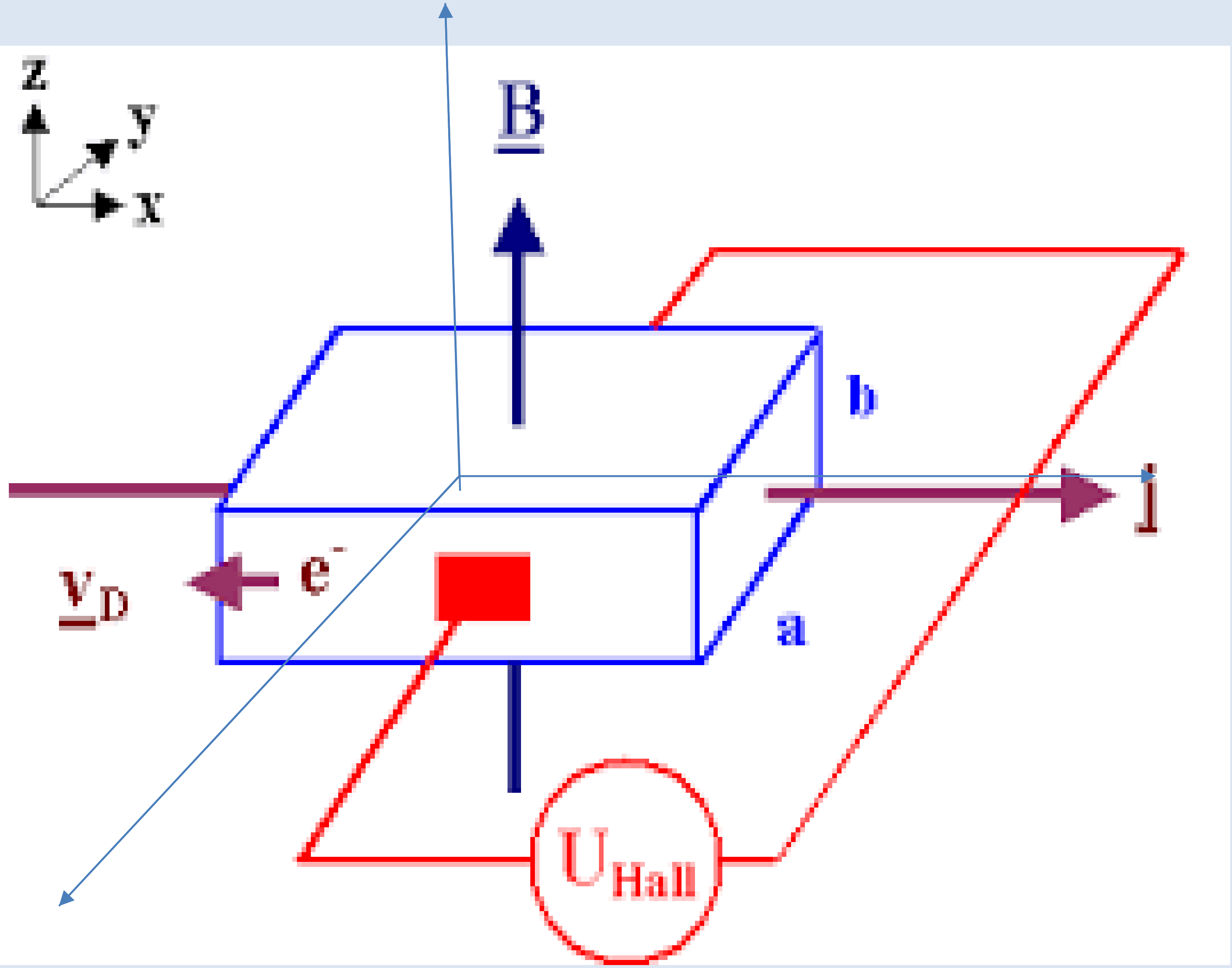
A rectangular slab of the given material having thickness ‘t’ and width ‘w’ is taken . A current of ‘I’ amperes is passed through this sample by connecting it to a battery, ‘Ba’. The sample is placed between two pole pieces of an electromagnet such that the field ‘B’ is perpendicular to I as shown in the experimental setup.

The Hall voltage ‘ V_H’ is then measured by placing two probes at the two side faces of the slab. If the magnetic flux density is ‘B’ and ‘V_H’ is the hall voltage, then the Hall coefficient.

$R_H = V_H \ t / IB$ (m^3 /coulomb)

For n-type material, $\sigma_n = ne\mu_e$ (or) $\mu_e = \sigma_n / ne = - \sigma_n \ . R_H$

For p-type material, $\sigma_p = pe\mu_e$ (or) $\mu_p = \sigma_p / pe = - \sigma_p \ . R_H$


z
y
x
B
b
j
e⁻
v_D
a
U_Hall

Applications of Hall effect:

(1) Determination of type of semiconductor

For a N-type semiconductor, the Hall coefficient is negative whereas for a P-type semiconductor, it is positive. Thus from the direction of the Hall voltage developed, one can find out the type of semiconductor.

(2) Calculation of carrier concentration

Once Hall coefficient R_H is measured, the carrier concentration can be obtained from,

$n = 1/eR_H$ or $p = 1/eR_H$

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(3). Determination of mobility

We know that, conductivity, $\sigma_n = ne\mu_e$ (or) $\mu_e = \sigma_n / ne = - \sigma_n R_H$

Also $\sigma_p = pe\mu_h$ or $\mu_h = \sigma_p / pe = \sigma_p R_H$. Thus by measuring σ and R_H, μ can be calculated.

(4) Measurement of magnetic flux density:

Using a semiconductor sample of known 'R_H' the magnetic flux density can be deduced from $R_H = V_H t / BI$ or $B = V_H t / R_H I$