8.15 HALL EFFECT

If a piece of conductor (metal or semiconductor) carrying a 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 electric field as the *Hall field.*

Consider a rectangular piece of cunductor carrying a current I in the positive x-direction and subjected to a magnetic flux density B in the positive z-direction (Fig. 8.33). The current carriers will experience a Lorentz force in the negative y-direction. As a result, the carriers are deflected towards the bottom surface of the sample and are accumulated. If the current carriers are electrons, as in the case of an n-type semiconductor, this accumulation will make the bottom surface negatively charged with respect to the top surface. Therefore, an electric field, called the hall field, will be developed along the –ve y-direction. The force on the current carriers due to this Hall field will oppose the Lorentz force. An equilibrium is estabilished when these two forces balance each other. At this stage, no further accumulation of electrons takes place on the bottom surface and the Hall field reaches a steady value.

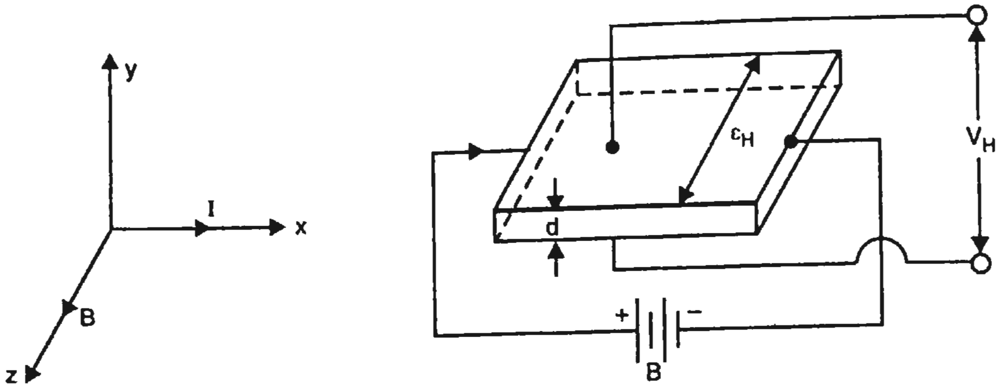

Fig. 8.33 Set up for the measurement of Hall voltage.

If the current carriers are holes, *i.e.*, when the conductor is a p-type semiconductor the accumulation of carriers on the bottom surface will make this surface positively charged relative to the top surface. In this case, the Hall field is produced along the positive y-direction. The force on the holes due to the Hall field opposes the Lorentz force and balances it under equilibrium conditions preventing further accumulation of holes. The Hall field then attains its steady value.

If E_H is the Hall field in the y-direction, the force due to this field on a carrier of charge e is eE_H. The average Lorentz force on a carrier is evB, where v is the drift velocity in the x-direction. In equilibrium these two forces balance, *i.e.*,

$$eE_H = evB \quad ...(62)$$

If J is the current density in the x-direction, we have

$$J = n_c ev \quad ...(63)$$

where n_c is the concentration of current carriers. From eqns. (62) and (63) we get

$$E_H = \frac{BJ}{n_c\, e}$$

The Hall effect is described by means of the Hall coefficient R_H defined in terms of the current density J by the relation

$$E_H = R_H J B \quad ...(64)$$

$\therefore$ We obtain $$R_H = \frac{1}{n_c\, e} \quad ...(65)$$

A vigorous treatement shows that R_H is actually given by

$$R_H = \frac{r}{n_c\, e}$$

where r is a numerical constant. In most of the cases the value of r does not differ much from unity. The error occuring from setting $r = 1$ is, therefore, not large.

If the current carriers are electrons, the charge on the carrier is negative and hence

$$R_H = \frac{1}{ne} \quad ...(66)$$

where n represents the concentration of electrons.

If the current carrier are holes, the carrier charge is positive and therefore,

$$R_H = \frac{1}{pe} \quad \text{...(67)}$$

where p represents the hole concentration.

Thus, the sign of the Hall coefficient tells us whether the sample is an n-type or a p-type semiconductor.

The Hall coefficient is determined by measuring the Hall voltage that generates the Hall field. If V_H is the Hall voltage across a sample of thickness d, then

$$V_H = E_H \, d$$

Using eqn. (64), we can write

$$V_H = R_H \, J \, B \, d \quad \text{...(68)}$$

If w is the width of the sample then its cross-sectional area is dw and the current density J is given by

$$J = \frac{I}{dw} \quad \text{...(69)}$$

where I is the current flowing through the sample.

From eqns. (68) and (69), we get

$$V_H = \frac{R_H \, IB}{w}$$

Hence

$$R_H = \frac{V_H \, w}{IB} \quad \text{...(70)}$$

The polarity of V_H will be opposite for n-type and p-type semiconductors. Therefore, the sign of R_H will be different for the two types of semiconductors.

It will be noticed that the net electric field in the semiconductor, which is the vector sum of applied field (let it be E_x) and Hall field E_H, is not directed allong the axis but it is some angle θ to it, known as **Hall angle** and is given by

$$\tan\theta = \frac{E_H}{E_x}$$

Which using $E_H = \dfrac{BJ}{n_c e}$ and remembering $J_x = \sigma E_x$, gives

$$\tan\theta = \frac{B_z \, J_x}{n_c \, e} \cdot \frac{\sigma}{J_x} = B_z \, \mu_c$$

where μ_c is the mobility of current carriers

or

$$\mu_c = \frac{\sigma}{n_c \, e} = R_H \, \sigma$$

Thus, a simultaneous measurement of R_H and σ can lead to an experimental value for the carrier drift mobility.

8.15.1 Hall Effect in Extrinsic Semiconductors

In above discussion, we have assumed that the conduction process is by means of one type of carrier only. In some semiconductors, *e.g.*, extrinsic material, the assumption is not valid and the Hall coefficient must