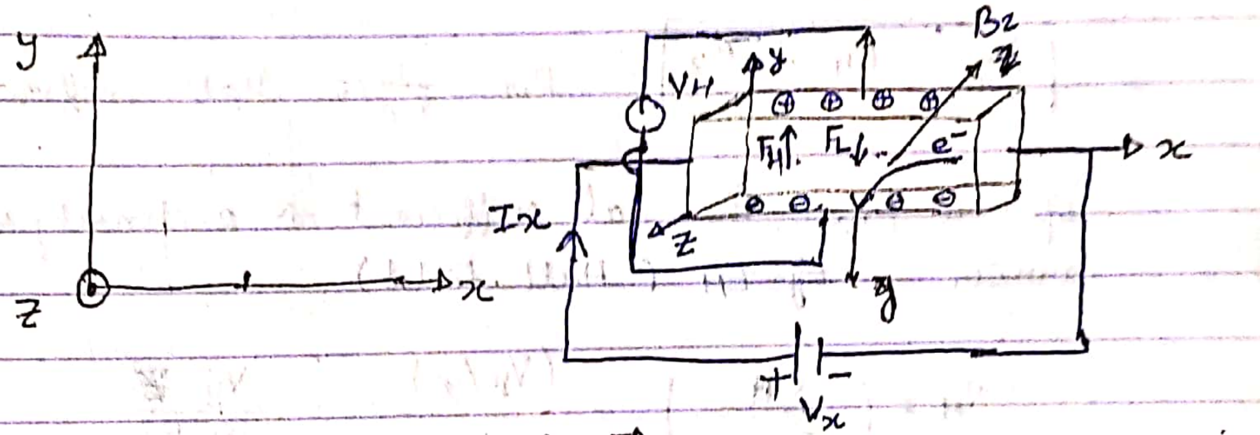
(Hall Voltage, Hall coefficient)

* type of semiconductor (n-type or p-type)
* # density electron / holes
* mobility of electron / holes

Place the extrinsic semiconductor in magnetic field.

$\vec{J} = J_x \hat{i}$ (current flow along +x direction)

$\vec{B} = B_z \hat{k}$ (applied magnetic field direction)




(i) Lorentz force ($q(\vec{v} \times \vec{B})$)

↓

deflection of electron / holes along ±y direction

↓

generate potential / field

↓

force opposite to the Lorentz force.

↓

saturation $\boxed{F_H = F_L}$

(1) n-type semiconductor:

$\vec{J} = \vec{J_x}\hat{i}$

$v = -v_x \hat{i}$ (electron velocity opposite to current)

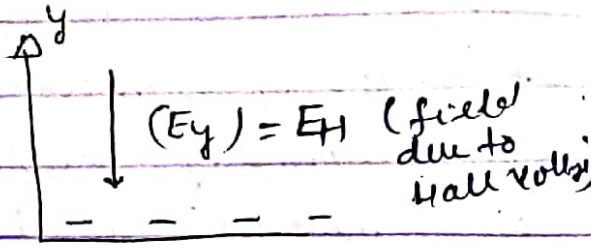
$q = (-ve)$

$F_L = q(\vec{v} \times \vec{B}) = -q(-\vec{v}_x \hat{i} \times B_z \hat{k})$

$= -q(v_x B_z \hat{j})$ deflection of electron in −y direction

$-(q v_x B_z)\hat{j} \Rightarrow$

⇒ a Voltage / field develop into (−y direction)




steady state condition

$$F_H = F_L$$

$$q E_y = q v_x B_z$$

$$E_y = v_x B_z$$

know $J_x$, $B_z$

$$J_x = n e v_x$$

$$E_y = \frac{J_x B_z}{ne}$$

$$\boxed{E_y = R_H J_x B_z}$$

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

if you know the hall coefficient ⇒ # density of carrier. $E_y = E_H$ ( Hall field)

$$R_H = \left(\frac{E_H}{J_x B_z}\right) = \frac{(V_y / y)}{\left(\frac{I_x}{\cancel{z} y}\right) B_z} = \frac{V_y \cancel{z}}{I_x B_z}$$

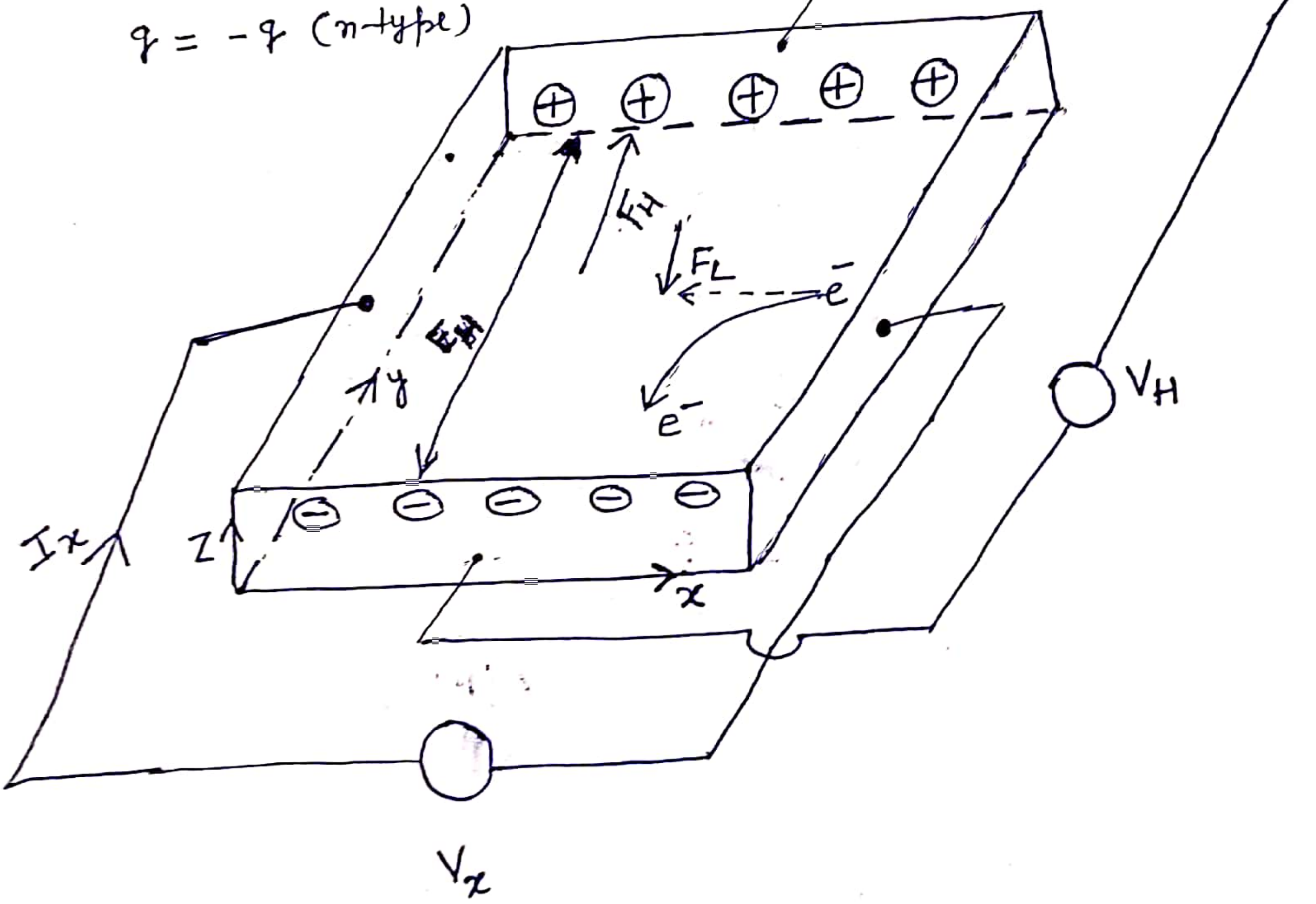
$$\boxed{R_H = \frac{V_y \cancel{z}}{I_x B_z}} \boxed{= \frac{1}{ne}}$$


$\boxed{\mu = R_H \sigma}$ mobility of charge

$\vec{J} = J_x \hat{i}$ ; $\vec{v}_x = -v_x \hat{i}$

$\vec{B} = B_z \hat{k}$

$q = -q$ (n-type)




Arrangement for n-type semiconductor

## 30.25 DRIFT AND DIFFUSION CURRENTS

Under the condition of thermal equilibrium, the electrons and holes are uniformly distributed in the crystal and in the absence of an external stimulus their average velocity is zero and no current flows through the crystal. This is equally true for an intrinsic or an extrinsic semiconductor.

The thermal equilibrium may be disturbed by an external agent and the chaotic motion of charge carriers acquire a directional movement leading to a flow of current in the material. Electric field and concentration gradients are examples of such disturbing agents.

1. **Drift Current**: When an electric field $E$ is applied across a semiconductor, the charge carriers acquire a directional motion over and above their thermal motion and produce drift current.

The electrons drifting in the conduction band produce a current component $J_e$ given by

$$J_e\,(drift) = ne\mu_e E$$

The holes drifting in the valence band cause a current component $J_h$ given by

$$J_h\,(drift) = pe\mu_h E$$

Therefore, the total drift current density is,

$$J_{dr} = J_e\,(drift) + J_h\,(drift)$$

Drift current occurs only when external electric field is present across the solid. Although electrons and holes move in opposite directions, the direction of conventional current flow due to both the carriers is in the same direction.

$\therefore$

$$J_{dr} = e(n\mu_e + p\mu_h)E \tag{30.97}$$

**2. Diffusion Current:** In case of semiconductors, current can also flow without the application of an external electric field. If a spatial variation of carrier density is created in the semiconductor, current flows in it. If we consider an arbitrary surface in the volume of the solid and if there are more charge carriers on its one side than on the other side, we say there is a **concentration gradient**. This concentration gradient causes a directional movement of charge carriers, which continues until all the carriers are evenly distributed throughout the material. Any movement of charge carriers constitutes an electric current, and this type of movement produces a current component known as **diffusion current**.

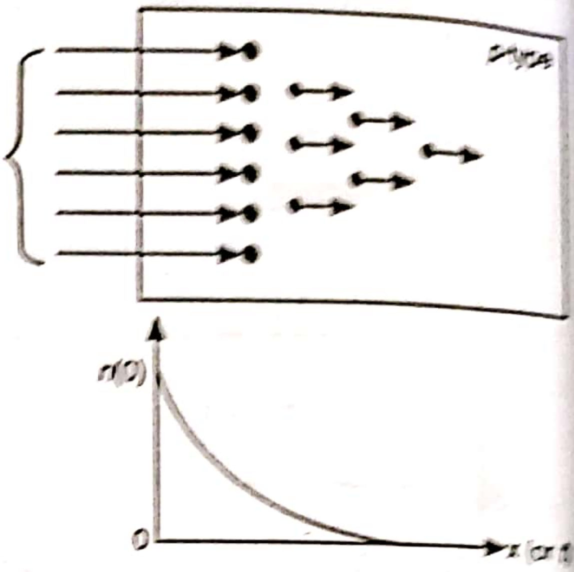



Fig. 30.22

Concentration gradient may be produced in an extrinsic semiconductor by applying heat or light locally at one region. Suppose an external agent such as light or heat acts momentarily at one end of a *p*-type semiconductor, as shown in Fig. 30.22. The external agent generates additional electron-hole pairs leading to a sudden increase in the concentration of charge carriers at that end. In the rest of the volume, the concentration of carriers is at equilibrium value. The difference in the concentration of charge carriers initiates the carriers to diffuse from the region of higher concentration to the region of lower concentration in order to restore the equilibrium condition. As the carriers are charged particles, their migration produces a current flow, which is the diffusion current. The diffusion current strength is proportional to the concentration gradient, i.e. the rate of change of carrier concentration per unit length. In case of electrons moving left to right (see Fig. 30.22), current flows from right to left in the negative *x*-direction.

The current component due to electron diffusion is given by

$$J_e\,(diff) = eD_e \frac{dn}{dx} \tag{30.98}$$

The current component due to hole diffusion is given by

$$J_h\,(diff) = -eD_h \frac{dp}{dx} \tag{30.99}$$

$D_e$ and $D_h$ are *diffusion coefficients* for electrons and holes respectively.

Drift and diffusion currents coexist in semiconductors. The total current density due to drift and diffusion of electrons may be written as

$$J_e = e\left(n\mu_e E + D_e \frac{dn}{dx}\right) \tag{30.100}$$

$$J_h = e\left(p\mu_h E - D_h \frac{dp}{dx}\right)$$

### 30.26.2 Einstein Relations

Although drift and diffusion are two seemingly different processes, the parameters μ, the mobility and $D$, the diffusion length are not independent. There exists a close relationship between them, since both these parameters are determined by the thermal motion and scattering of the free carriers. They are related as follows:

$$\frac{D_h}{\mu_h} = \frac{kT}{e} \tag{30.108}$$

Similar relation holds good for electrons also.

$$\frac{D_n}{\mu_e} = \frac{kT}{e} \tag{30.109}$$

The equations (30.108) and (30.109) are known as **Einstein relations.** From these relations we get

$$\frac{D_n}{D_h} = \frac{\mu_e}{\mu_h} \tag{30.110}$$

**Example 30.17:** *Find the diffusion coefficient of electrons in silicon at 300K if $\mu_e$ is 0.19 $m^2$ /V.s.*

**Solution:** $$\frac{D_n}{\mu_e} = \frac{kT}{e}$$

Therefore, $$D_n = \frac{kT}{e}\mu_e = \frac{1.38\times10^{-23}\,\text{J/K}\times300\text{K}}{1.602\times10^{-19}\,\text{C}}\times0.19\ \text{m}^2/\text{V.s}$$

$$= \mathbf{0.0045\ m^2\ /V.s.}$$