a) Let rate of particle movement (R) by diffusion is directly proportional to concentration (C) gradient i.e.

$$R \propto \frac{dC}{dx}$$

If ē concentration is not uniform, there will be an ē diffusion current, which is proportional to the gradient of electron concentration.

$$J_{n,\,dif} \propto \frac{dn}{dx}$$

$$\Rightarrow \quad J_{n,dif} = -eD_n \frac{dn}{dx}$$

Here $J_{n,diff}$ → diffusion current of electrons
n → electron conc. in semiconductor
e → charge of electron
D_n → electron diffusion constant

Ilkly, holes diffusion current ($J_{p,dif}$) in semiconductor with holes conc. p is,

$$J_{p,\,dif} = -eD_p \frac{dp}{dx}$$

where D_p represents hole diffusion constant

Drift Current

The current density due to drift, $\bar{J}_{drig}$, is defined as charge per second crossing unit area plane normal to direction of current flow.

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$$\vec{J}_{drif} = nq\vec{v}_d \; (= \rho_{drif}\vec{v}_d)$$

If n represents $\bar{e}$ concentration and $\vec{v}_{d.n}$ is electron drift velocity, then drift current density due to electrons $(\vec{J}_{n.\,drif})$ is

$$\vec{J}_{n,\,drif} = n(-e)\,\vec{v}_{d.n}$$

$$\Rightarrow \vec{J}_{n,\,drif} = n(-e)\,(-\mu_n)\vec{E}$$

$$\vec{J}_{n,\,drif} = ne\mu_n\vec{E}$$

$$\therefore \vec{J}_{drif} = e\,(\mu_n n + \mu_p p)\,\vec{E}$$

Current Density

$$J_n = J_{n\,drif} + J_{n.\,diff}$$

$$= en\mu_n E_x + eD_n\frac{dn}{dx}$$

$$J_p = J_{p,\,drif} + J_{p,\,diff}$$

$$= ep\mu_p E_x - eD_p\frac{dp}{dx}$$

Now, Total current density,

$$J = J_n + J_p$$

$$= en\mu_n E_x + eD_n\frac{dn}{dx} + ep\mu_p E_x - eD_p\frac{dp}{dx}$$

~~Total~~

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(b). $$J_n = en\mu_n E_x + eD_n \frac{dn}{dx} = 0$$

$$J_p = ep\mu_n E_x - eD_p \frac{dp}{dx} = 0$$

$$\Rightarrow \quad -n\mu_n E_x = D_n \frac{dn}{dx} \quad \text{——— (1)}$$

$$\Rightarrow \quad p\mu_n E_x = D_p \frac{dp}{dx} \quad \text{——— (2)}$$

we know expression for electron conc. n, in conduction band ie.

$$n = N_c \cdot e^{-\frac{(E_c - E_F)}{k_B T}} \quad \text{——— (3)}$$

$$N_c = 2\left(\frac{2\pi m_n^* k_B T}{h^2}\right)^{3/2} \quad \text{——— (4)}$$

$N_c \rightarrow$ effective density of state.

$$\Rightarrow \frac{dn}{dx} = -\frac{N_c}{k_B T} \cdot e^{-\frac{(E_c - E_F)}{k_B T}} \cdot \frac{dE_c}{dx}$$

$$\frac{dn}{dx} = \frac{-n}{k_B T} \cdot \frac{dE_c}{dx}$$

$$\frac{dn}{dx} = \frac{-n}{k_B T} \cdot eE(x) \quad \text{——— (5)}$$

sub. eq. (5) in (1)

$$-n\mu_n E(x) = D_n \left[-\frac{n}{k_B T} \cdot eE(x)\right]$$

$$\Rightarrow \boxed{D_n = \frac{K_B T}{e} \mu_n}$$

Ilrly for holes $\boxed{D_p = \frac{K_B T}{e} \mu_p}$