

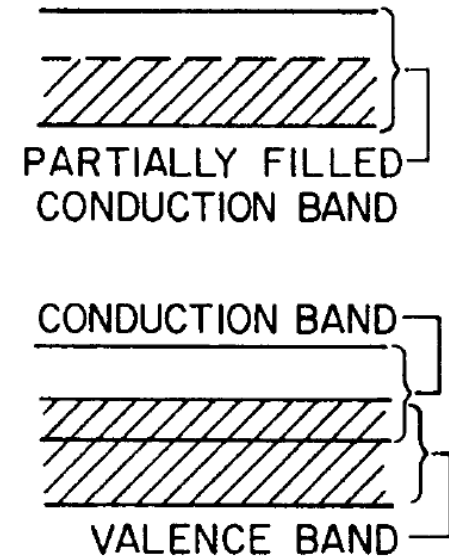
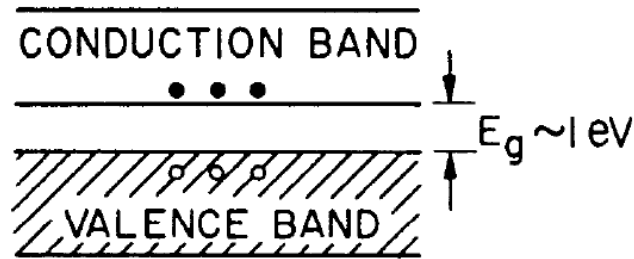
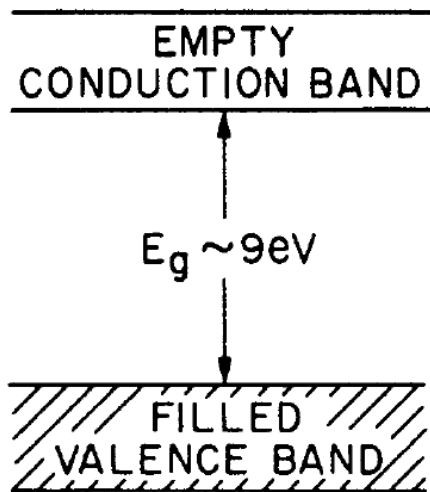
An aerial photograph of a large solar farm. The solar panels are arranged in a grid pattern, with rows of panels extending across the landscape. The panels are dark blue or black, and the grid lines are light gray or white. The perspective is from a high angle, looking down at the panels.

PART 1

Materials

# PHYSICS OF SOLAR CELLS

## Energy band formation

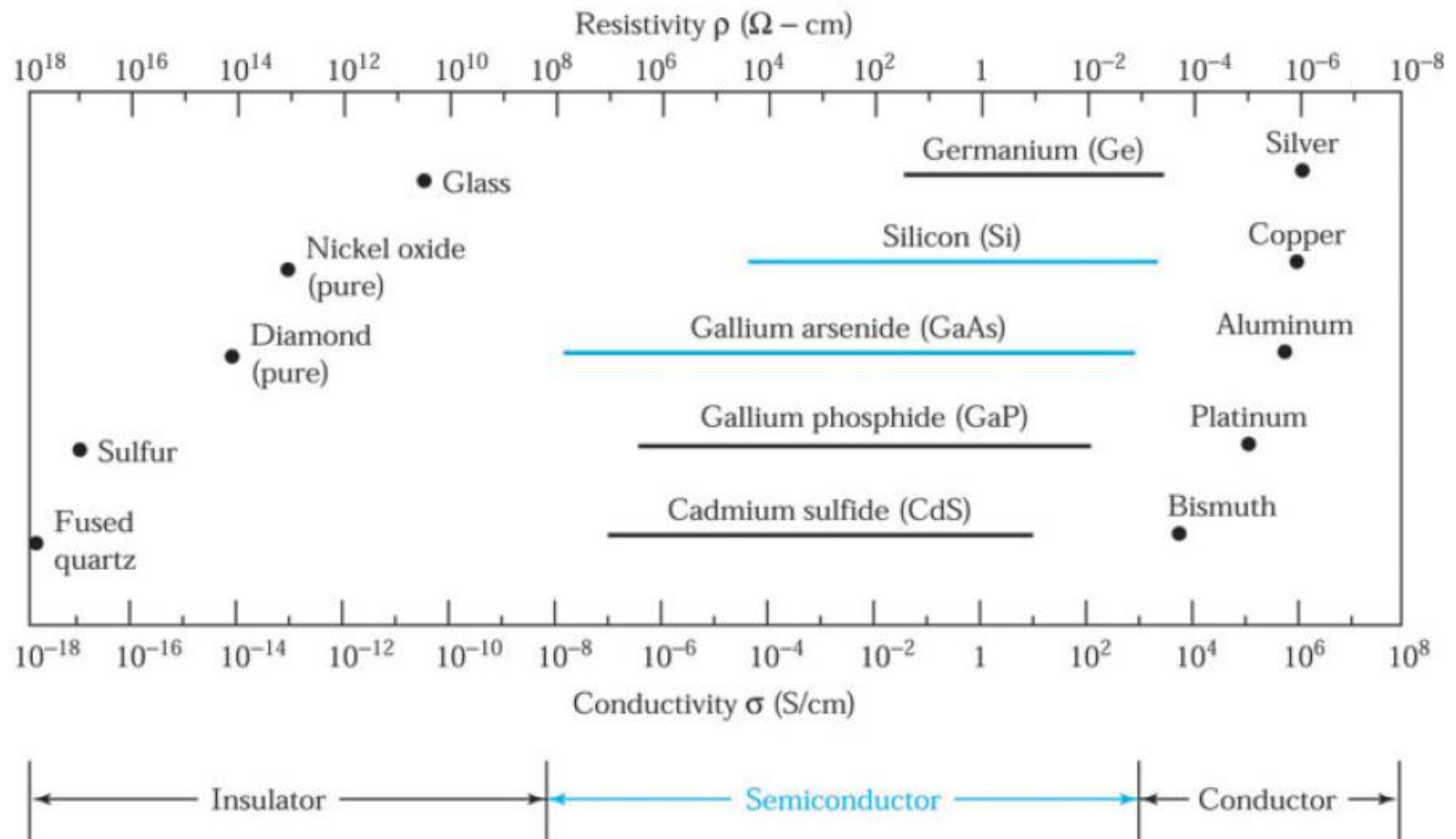


a) Insulator

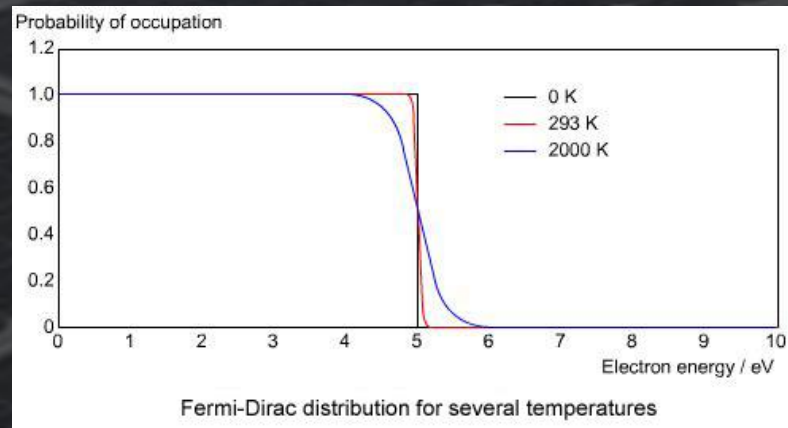
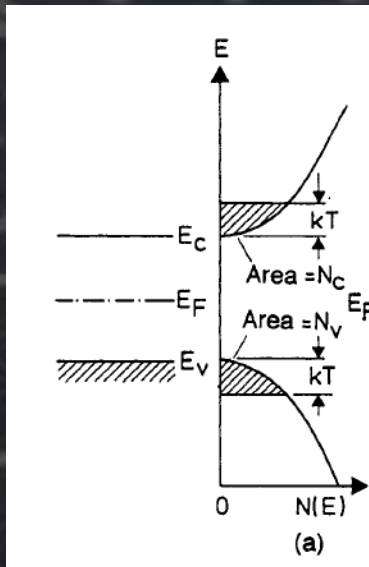
b) Semiconductor

c) Conductor

# PHYSICS OF SOLAR CELLS



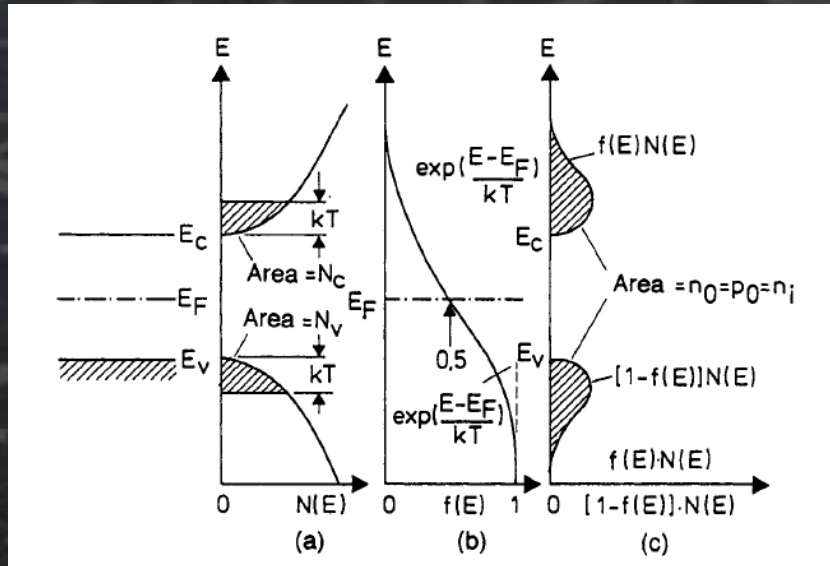
# PHYSICS OF SOLAR CELLS



$$n = \int_{E_c}^{E_{\infty}} f(E) N(E) dE$$



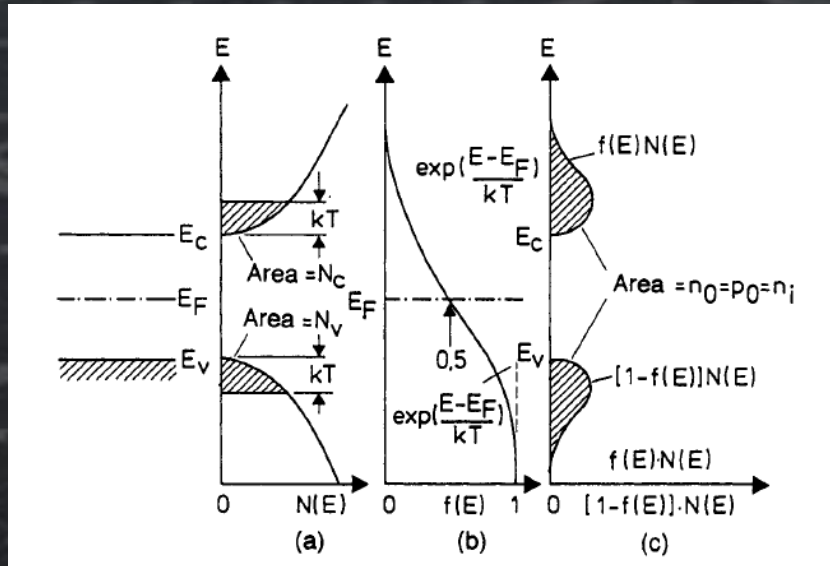
# PHYSICS OF SOLAR CELLS



$$n = \int_{E_c}^{E_{\infty}} f(E)N(E)dE$$

$$n = N_c \exp\left(\frac{E_F - E_c}{kT}\right)$$

# PHYSICS OF SOLAR CELLS



$$np = N_c N_v \exp\left(\frac{E_v - E_c}{kT}\right) = N_c N_v \exp\left(-\frac{E_g}{kT}\right)$$

$$np = n_i^2$$

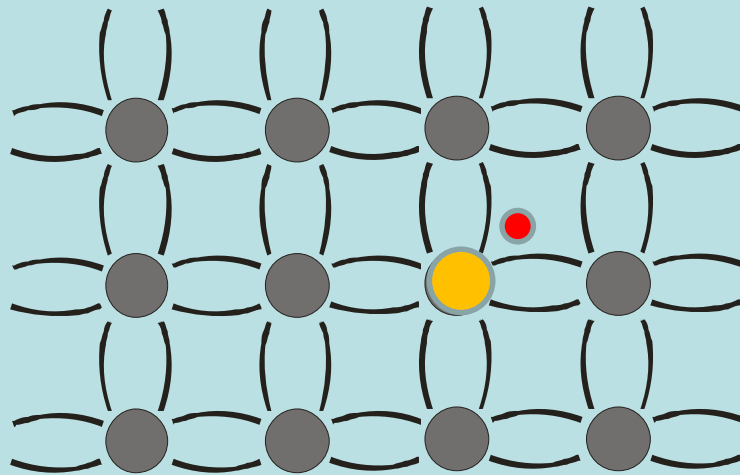
$$N_c = 2.86 \times 10^{19} \text{ cm}^{-3} \quad N_v = 3.10 \times 10^{19} \text{ cm}^{-3} \quad E_g = 1.124 \text{ eV}$$

$$n_i = 1.08 \times 10^{10} \text{ cm}^{-3}$$

Para silício a 300K

# PHYSICS OF SOLAR CELLS

Adding an atom of group V



# PHYSICS OF SOLAR CELLS

$$E_n = -13.6/n^2$$

	Sb	P	As	Ti		C	Pt	Au	O
Si 1.12	<u>0.039</u>	<u>0.045</u>	<u>0.054</u>	<u>0.21</u>		<u>0.25</u>	<u>0.25</u> A		<u>0.16</u>
								<u>0.54</u> A	<u>0.38</u> A <u>0.51</u>
					<u>0.34</u>	<u>0.35</u> D	<u>0.36</u> D	<u>0.29</u> D	<u>0.41</u>
	<u>0.045</u>	<u>0.067</u>	<u>0.072</u>	<u>0.16</u>			<u>0.3</u>		
	B	Al	Ga	In	Pd				



# PHYSICS OF SOLAR CELLS

If we add impurity atoms  $N_D = 10^{16}$  at/cm<sup>3</sup>

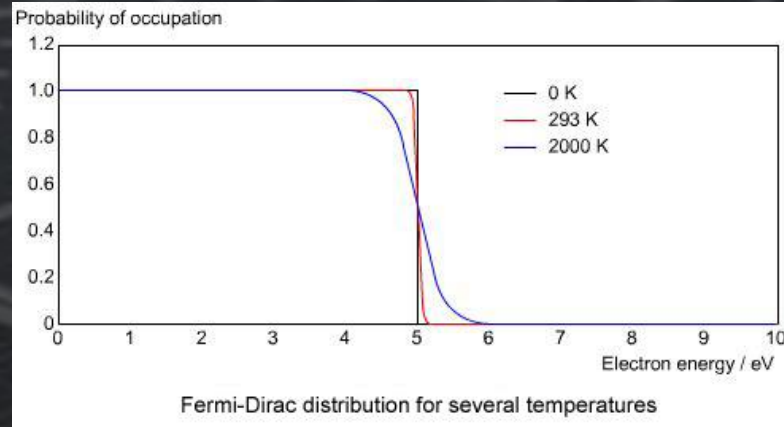
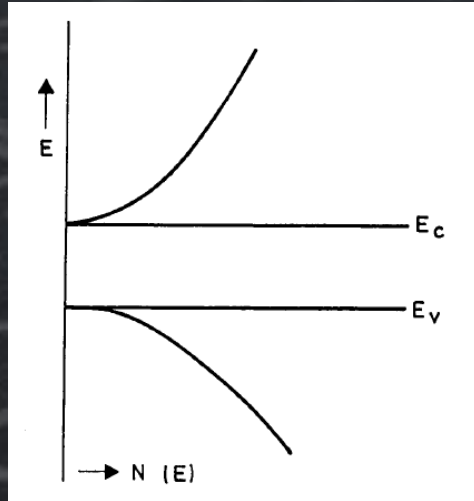
We will have at room temp  $n = 10^{16}$  electrons/cm<sup>3</sup>

$$p = n_i^2 / N_D^+ = 10^4 \text{ cm}^{-3}$$

In this case  $n$  and  $p$  are not equal anymore

Since  $n \gg p$  we call this a  $n$ -type semiconductor

# PHYSICS OF SOLAR CELLS



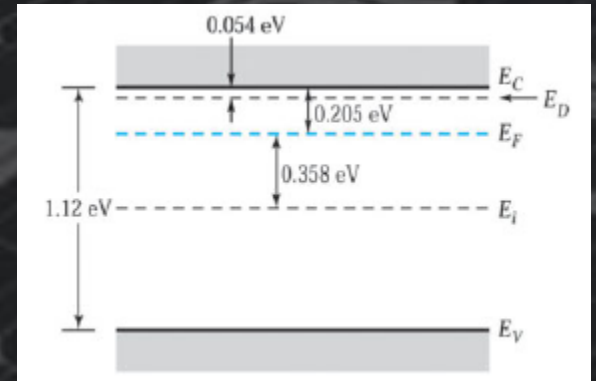
$$n = \int_{E_c}^{E_{\infty}} f(E) N(E) dE$$

$$n = N_C \exp\left(\frac{E_F - E_C}{kT}\right)$$

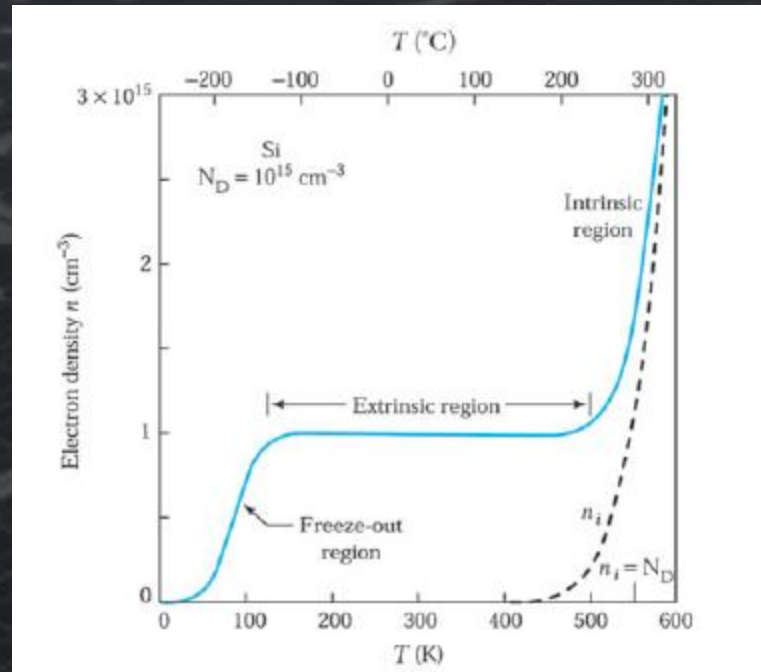
With complete ionization  $n=N_D$

$$N_D = N_C \exp\left(\frac{E_F - E_C}{kT}\right)$$

$$E_F - E_C = kT \ln (N_D/N_C)$$



# PHYSICS OF SOLAR CELLS



# CHARGE TRANSPORT

There are two mechanisms for charge transport

Electric field

Diffusion

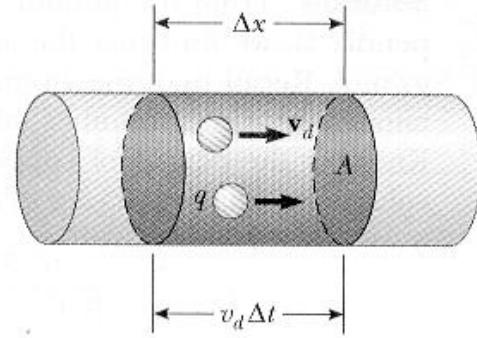


# CHARGE TRANSPORT

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = n q v_{drift} A$$

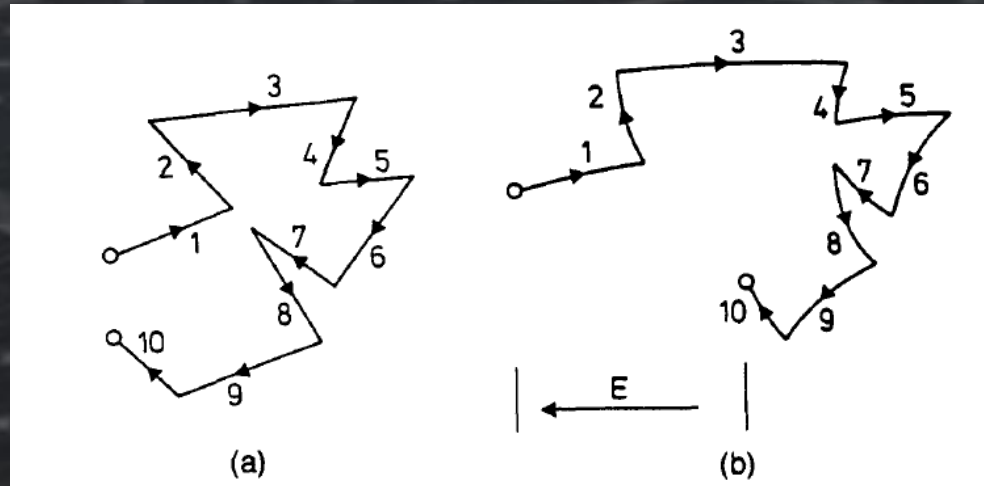
$$j = I_n = n q v_{drift}$$



$$n A \Delta x$$

$$\Delta Q = (n A v_d \Delta t) q$$

# CHARGE TRANSPORT



$$F = qE$$

$$F = ma$$

$$a = qE/m^*$$

$$V_{\text{drift}} = v_0 + a t_{\text{med}}$$

$T_{\text{med}}$  = average time between collisions

$$V_{\text{drift}} = -\frac{1}{2} \frac{q}{m_n^*} E \bar{t}$$

# CHARGE TRANSPORT

$$j = I_n = n q v_{drift}$$

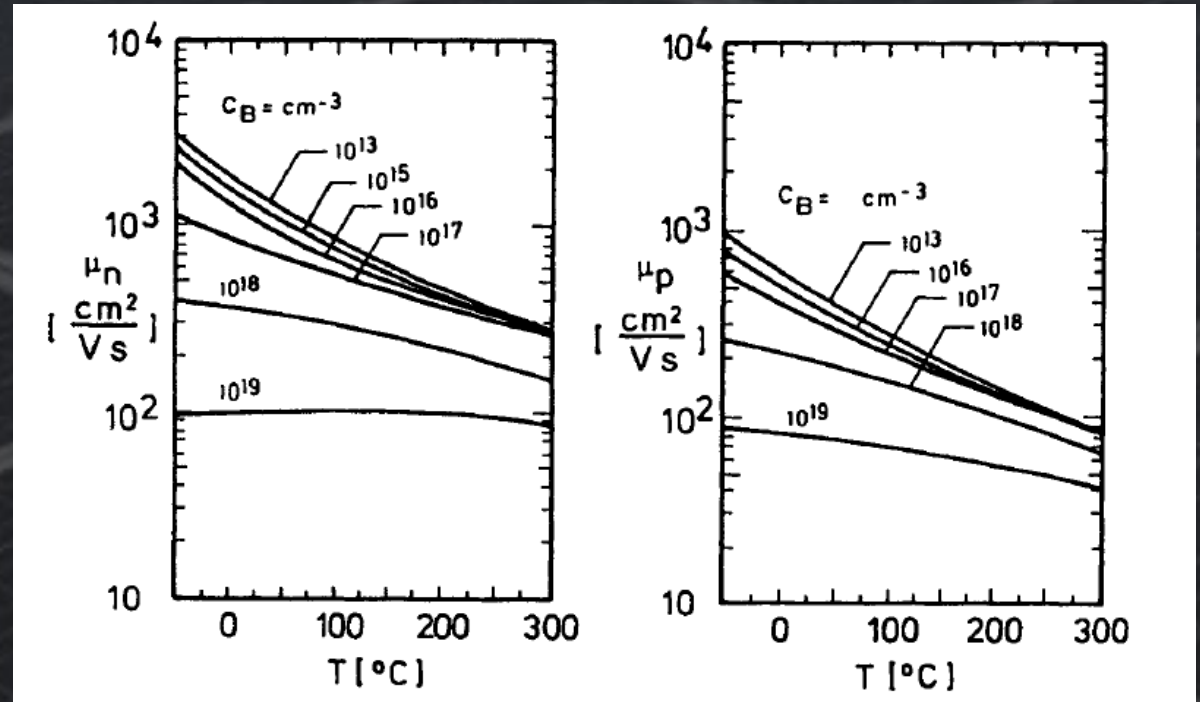
$$\frac{1}{2} \frac{q \bar{t}}{m_n^*} = \mu_n$$

$$I_n = n q \mu_n E$$

$$I_n = \sigma E \quad j = \sigma E$$

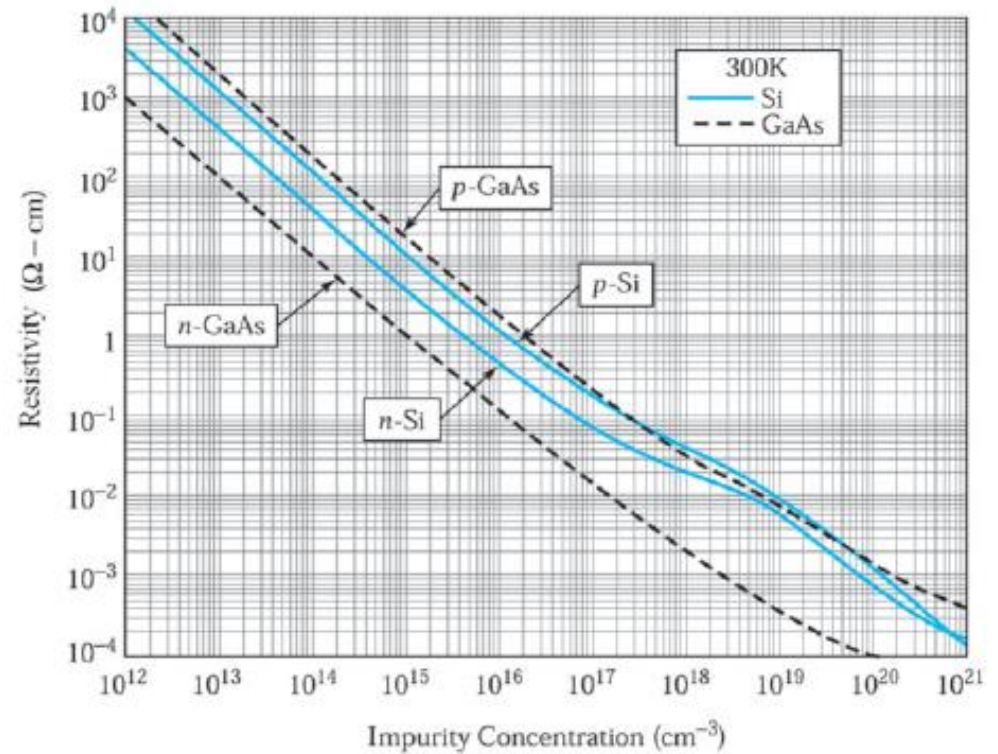
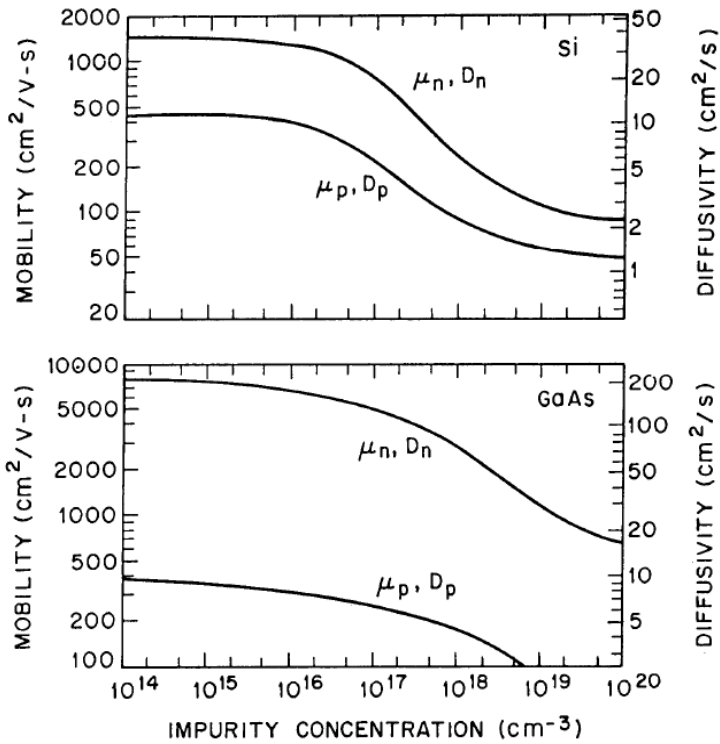
$$\sigma = n q \mu_n$$

$$\sigma = q (n \mu_n + p \mu_p)$$



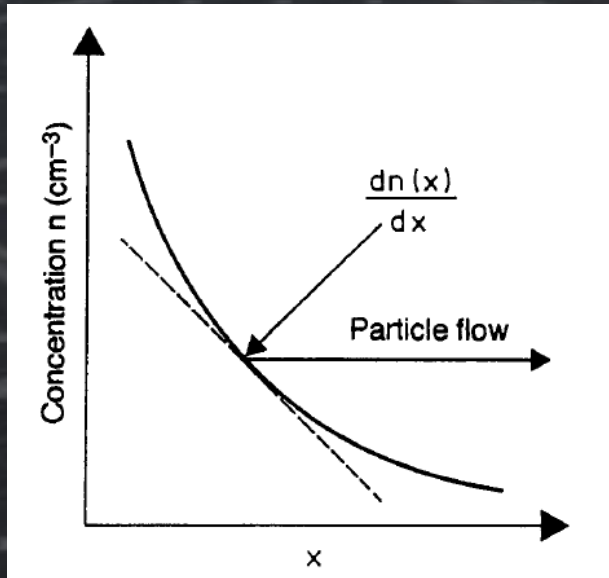
$$\rho = \sigma^{-1} = [q(n\mu_n + p\mu_p)]^{-1}$$

# CHARGE TRANSPORT





# CHARGE TRANSPORT



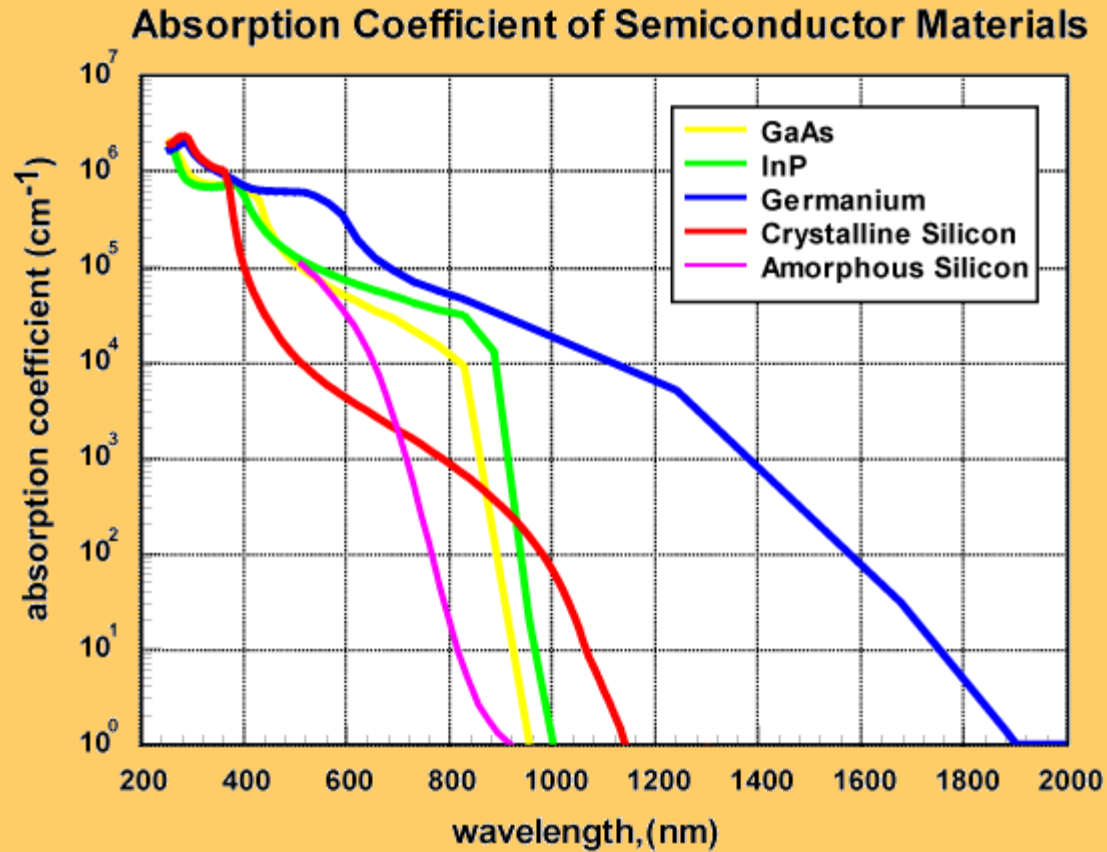
$$\frac{dN}{dt} = -D_n \frac{dn(x)}{dx}$$

$$I_n = -q \frac{dn}{dt} = qD_n \frac{dn(x)}{dx}$$

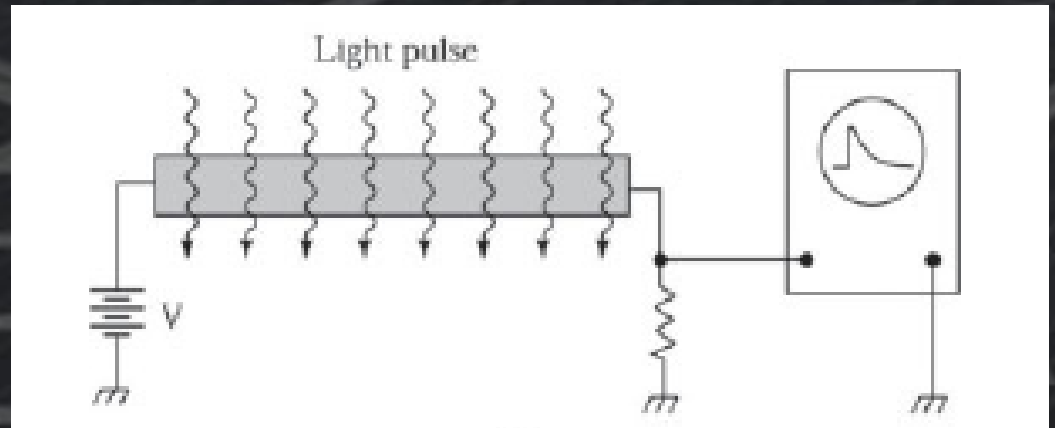
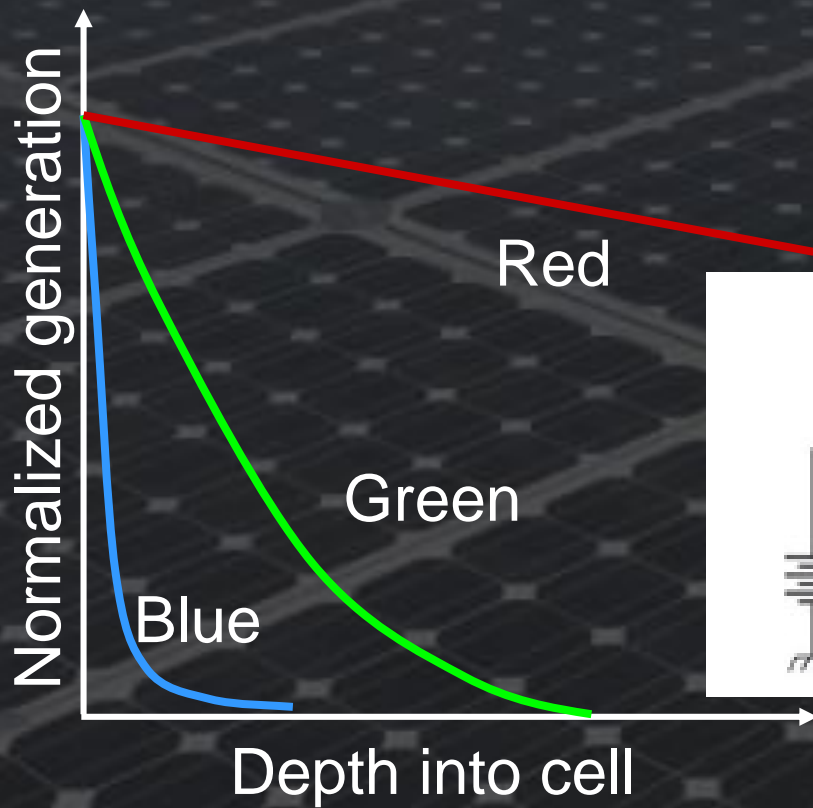
$$I_n = q \left( n\mu_n E + D_n \frac{dn}{dx} \right)$$

$$D = \frac{kT}{q} \mu$$

# GENERATION OF CHARGE

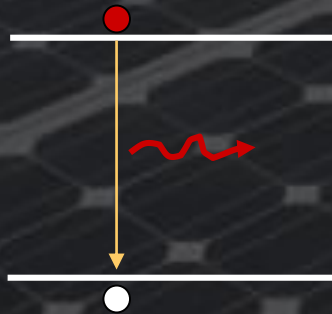


# GENERATION OF CHARGE

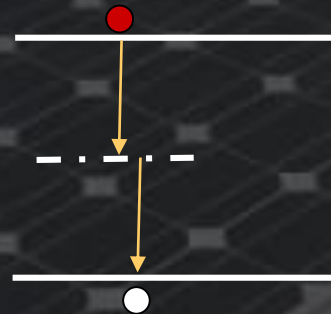


# CHARGE RECOMBINATION

Radiative



Shockley-Read-Hall

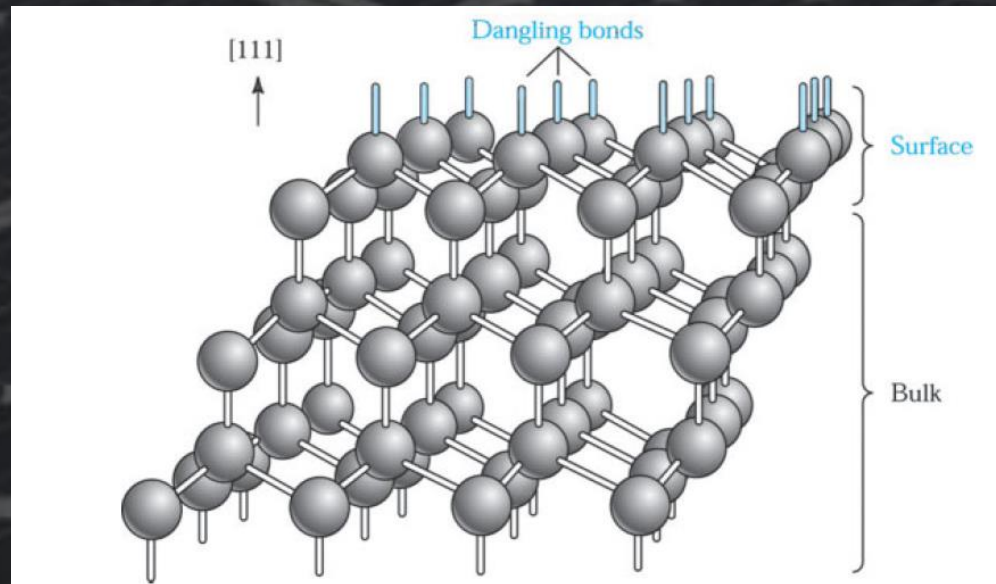
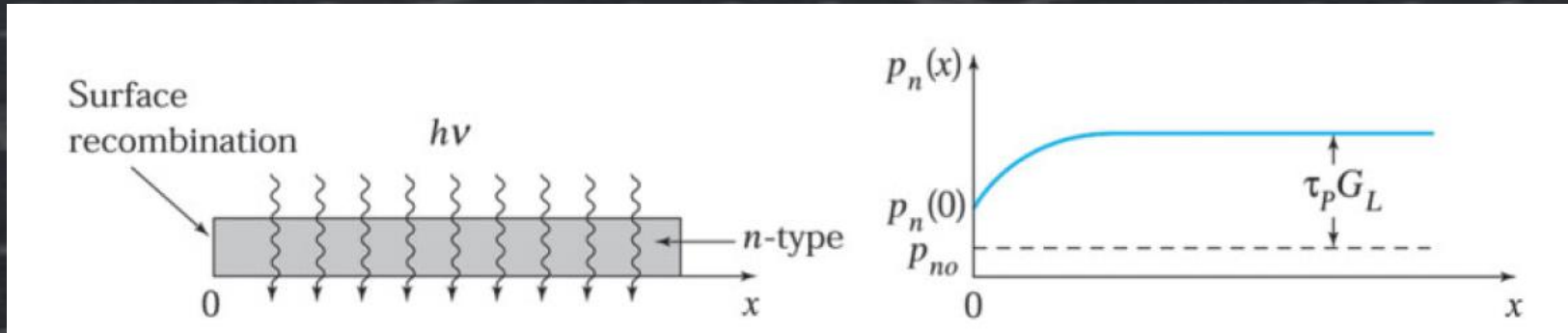


Auger





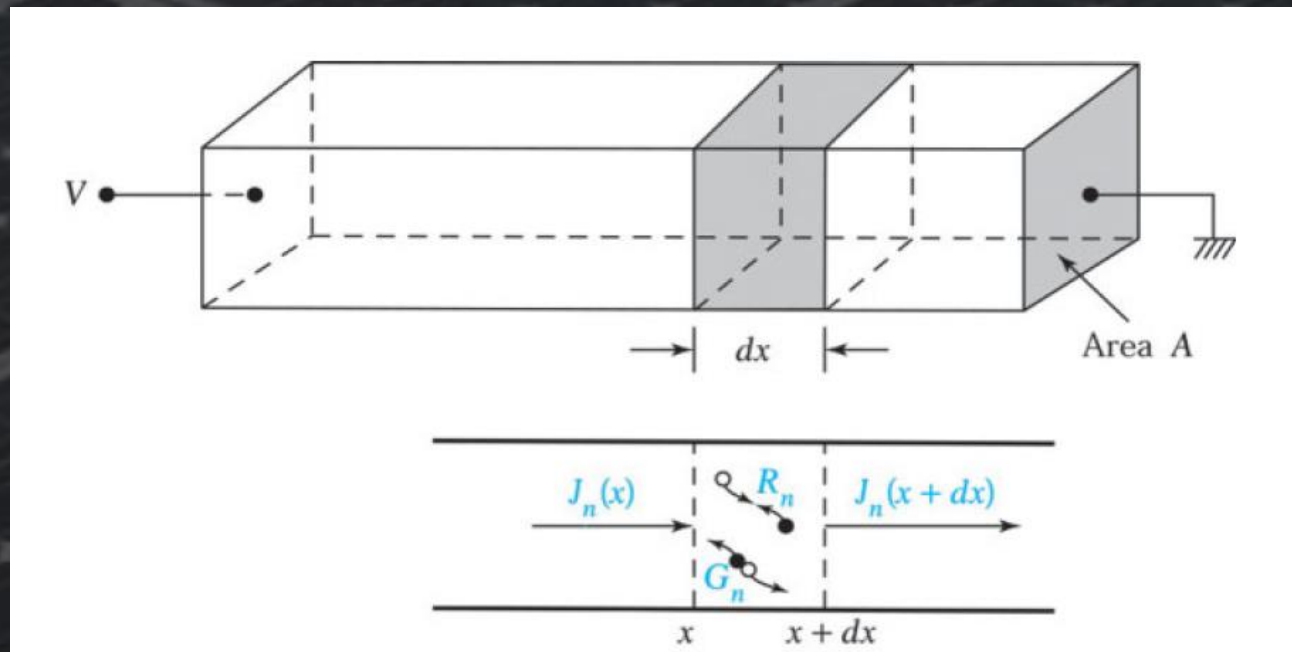
# CHARGE RECOMBINATION



# CHARGE RECOMBINATION

$$\tau = \frac{\Delta n}{R}$$

$$\frac{1}{\tau_{\text{total}}} = \frac{1}{\tau_{\text{radiation}}} + \frac{1}{\tau_{\text{Auger}}} + \frac{1}{\tau_{\text{trap}}}$$



# PHYSICS OF SOLAR CELLS

