Semiconductor Basics: A quick review

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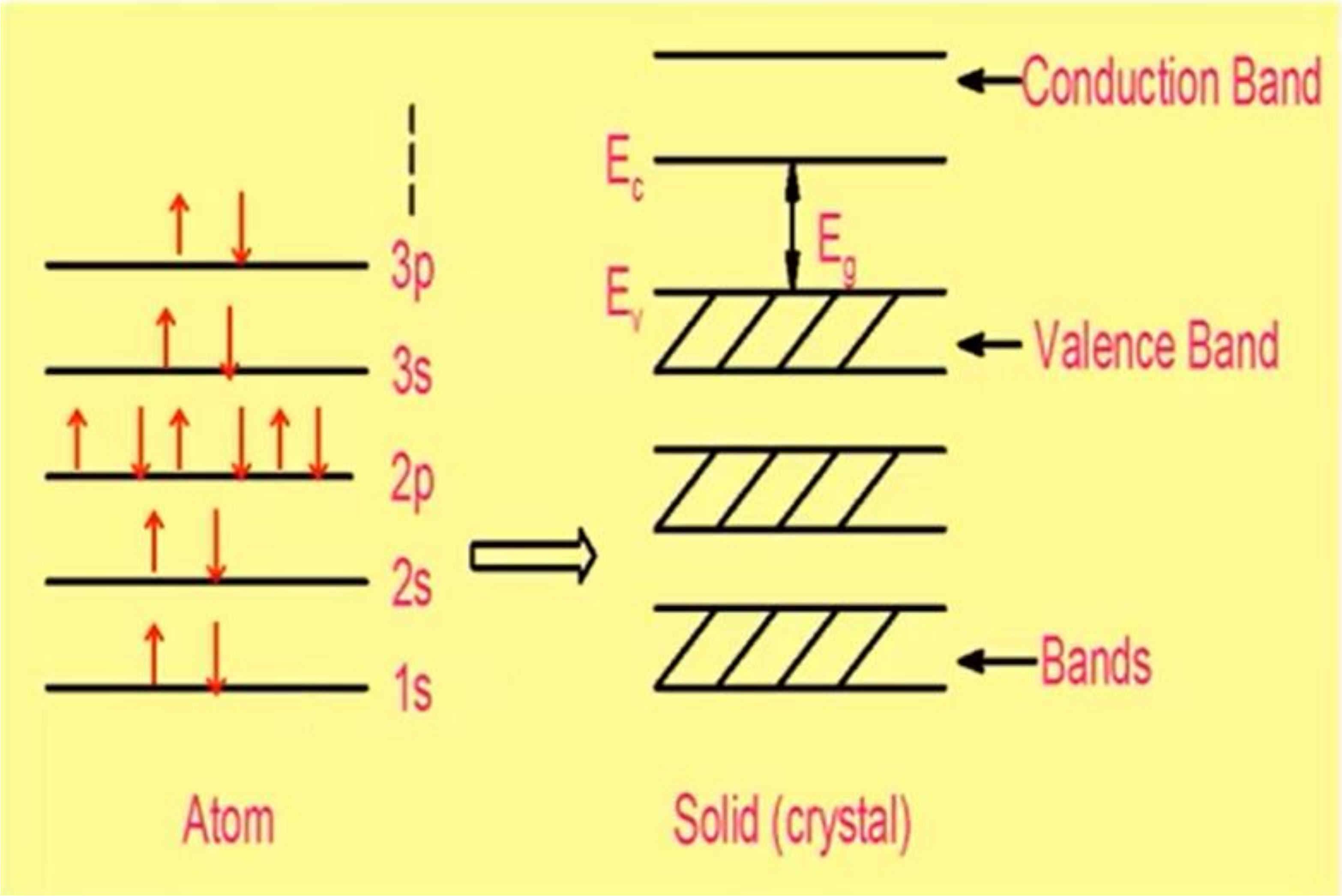
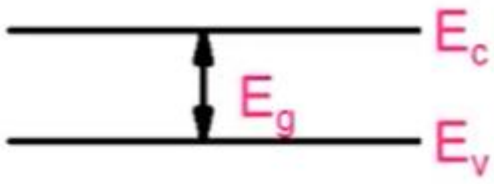
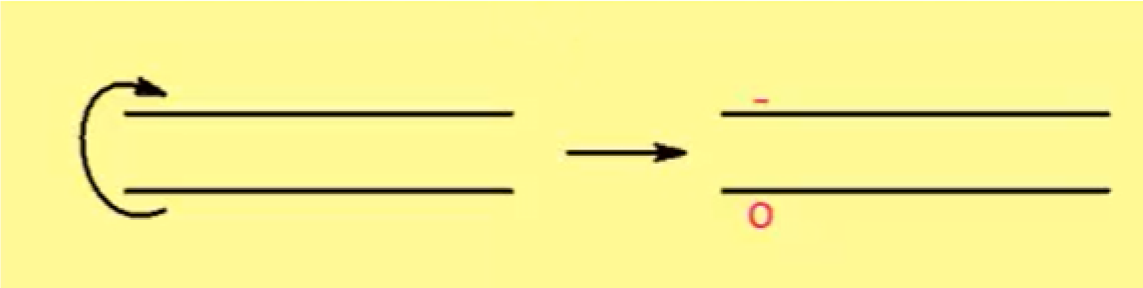
Energy Bands



A completely full band of electrons cannot contribute to current conduction !



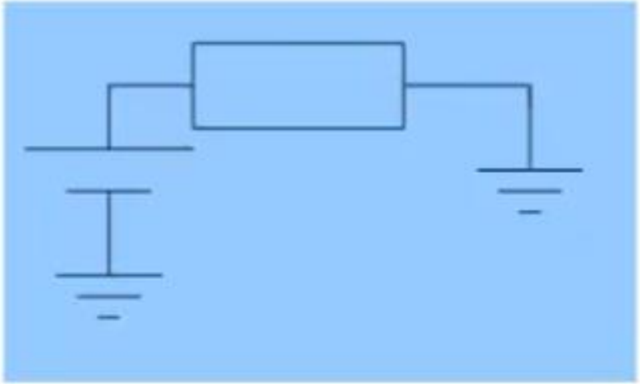
E_g=1.12 eV for Silicon

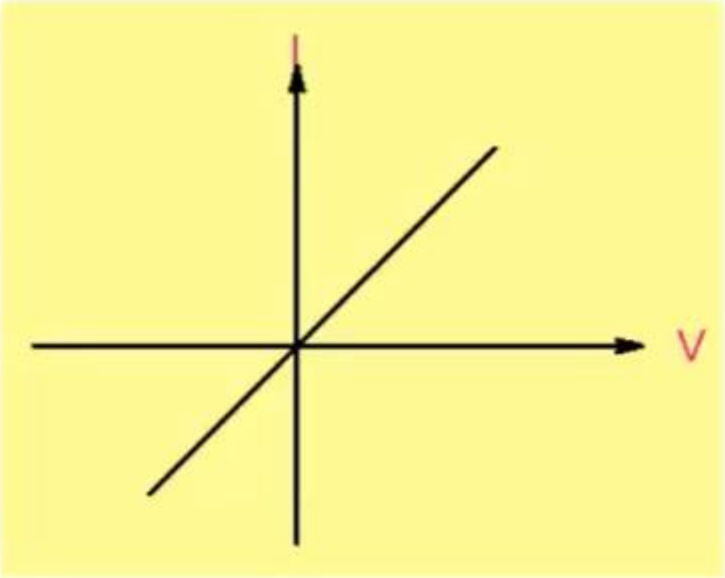


$n = p = n_i$

$n_i = 1.45 \times 10^{10}\ cm^{-3}$ (T = 300K)

$$n_i \propto \exp\left(-\frac{E_g}{2kT}\right)$$





$$J = \sigma E$$

$$I = \frac{V}{R} \; ; \; R = \frac{1}{\sigma} \times \frac{L}{W}$$

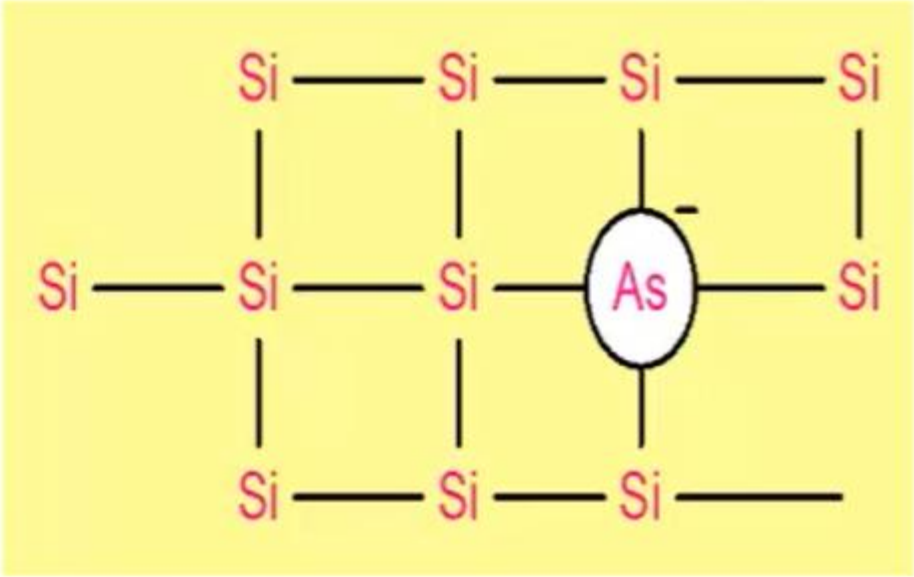
$$\sigma_i = q(\mu_n + \mu_p) n_i$$

$$\sigma_i \approx 4 \times 10^{-6} \, \Omega^{-1} \, cm^{-1}$$

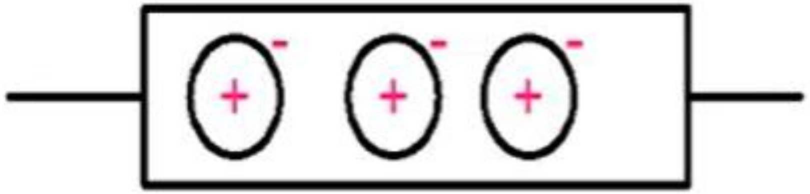
$$\rho_i \approx 2 \times 10^{5} \, \Omega \, cm$$

Doping

N-Type Semiconductor



$$N_D \longrightarrow N_D^{+} + e^{-}$$



$N_D = 10^{16}\ cm^{-3}$

$n \approx 10^{16}\ cm^{-3}$

$p \approx n_i^2/n \approx 2 \times 10^{4}\ cm^{-3}$

$n >> p$

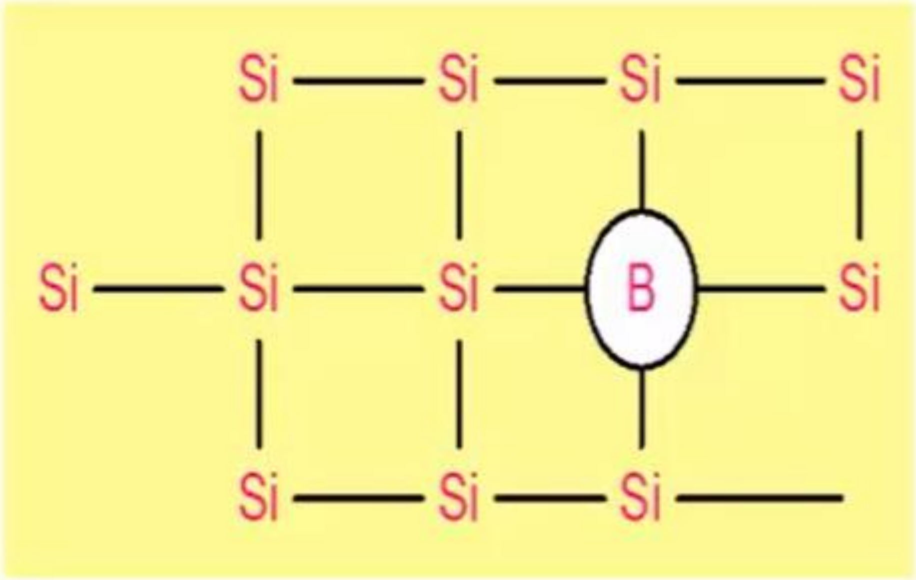
Small amount of impurity results in large change in resistivity !

No. of Silicon atoms / volume = $5 \times 10^{22}\ cm^{-3}$

$$\frac{10^{16}}{5 * 10^{22}} = 2 \times 10^{-7} \quad \text{(0.2PPM)}$$

$$\rho : \quad 2 \times 10^{5}\ \Omega\, cm \xrightarrow{N_D = 10^{16}\ cm^{-3}} \mathbf{1.5}\ \Omega\, cm$$

P-Type Semiconductor



$$N_A + e^- \longrightarrow N_A^- + h^+$$

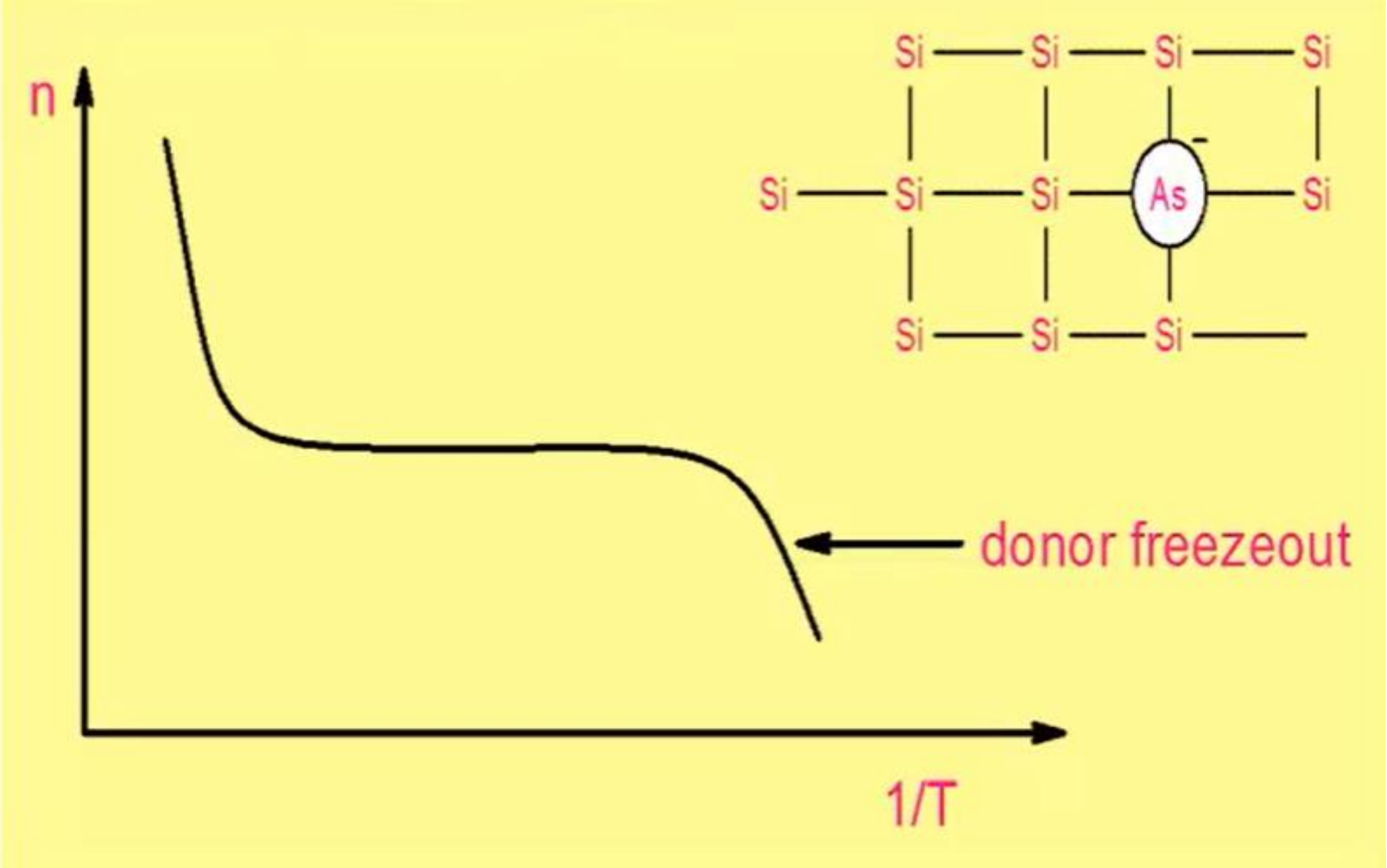
$N_A = 10^{16}\ cm^{-3}$

$p \approx 10^{16}\ cm^{-3}$

$n \approx n_i^2 / p = 2 \times 10^4\ cm^{-3}$

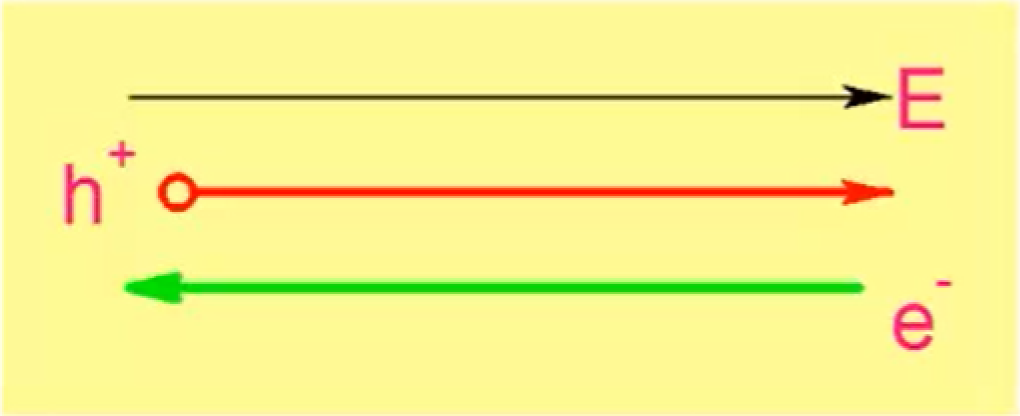
$p >> n$

Number of carriers is dependent on temperature !



Current flow

Drift due to Electric field



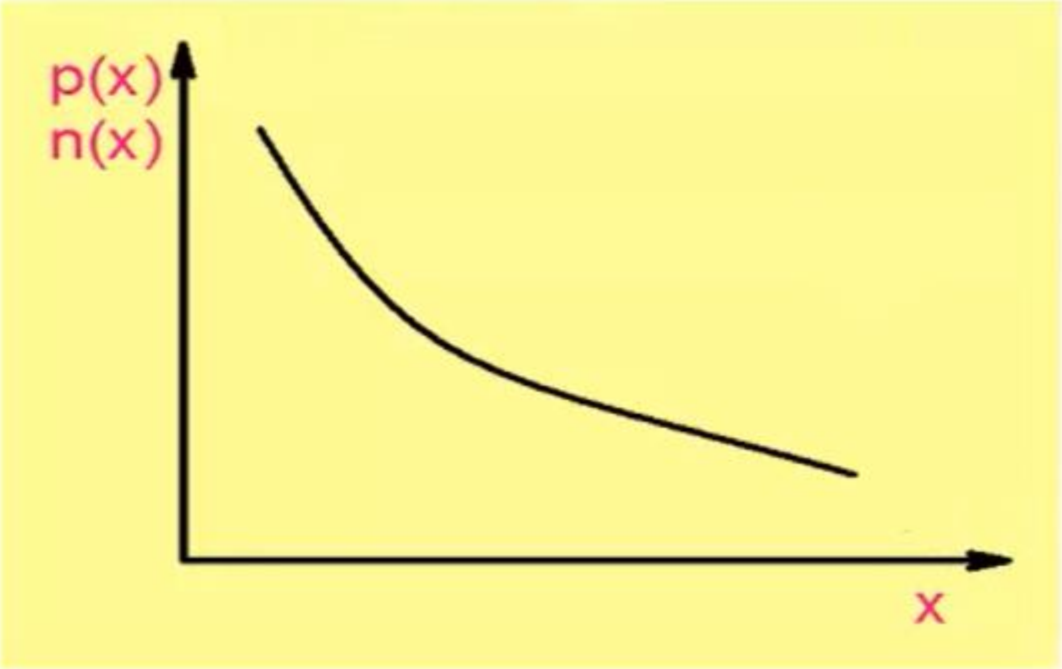
$$J_n = qn\mu_n E$$

$$J_p = qp\mu_p E$$

$$J = J_n + J_p$$

Current flow

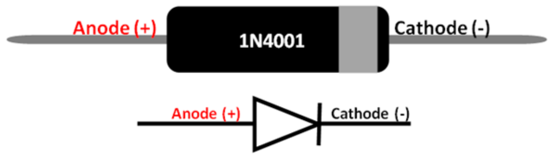
Diffusion to concentration gradient



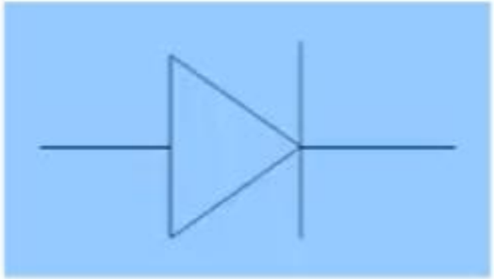
$$J_n = qD_n \frac{\partial n}{\partial x}$$

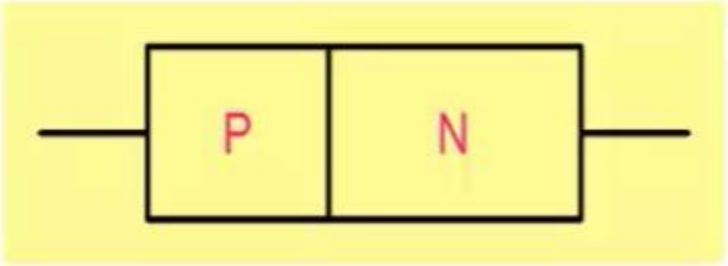
$$J_p = -qD_p \frac{\partial p}{\partial x}$$

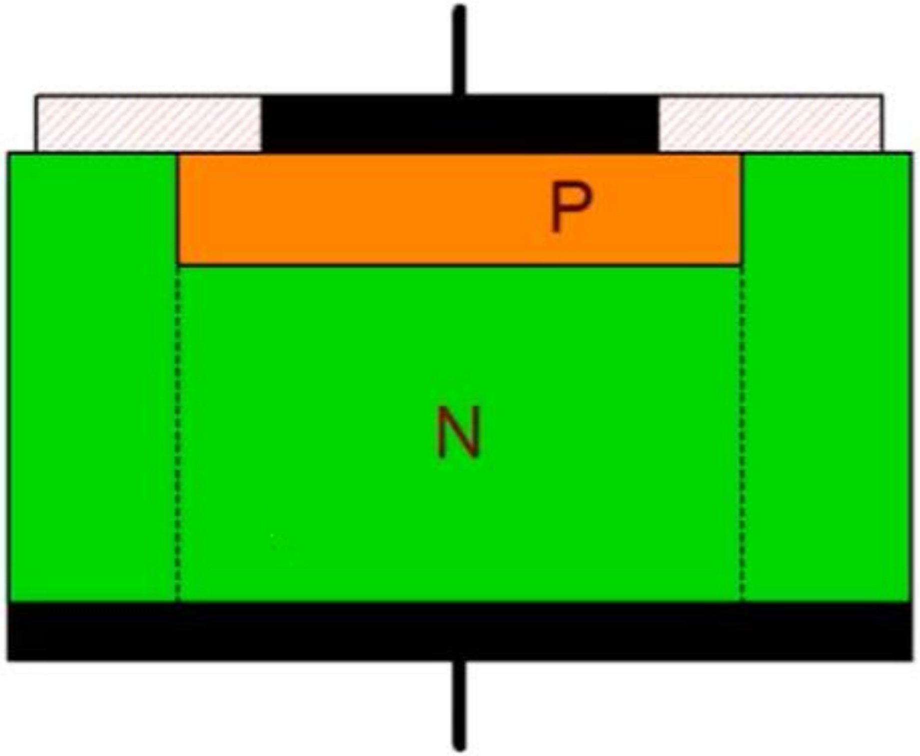
PN Junction Diode



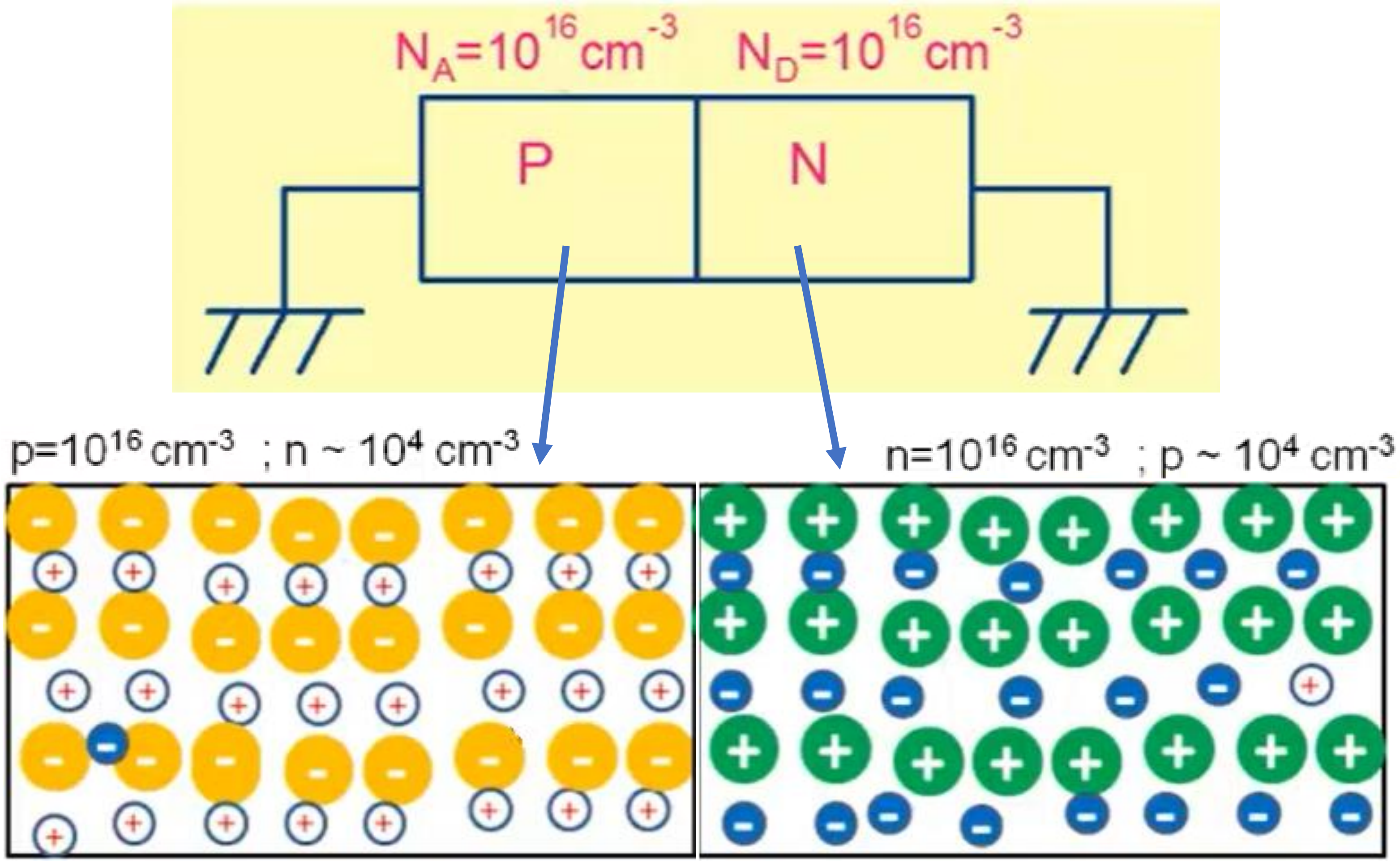
PN Junction Diode



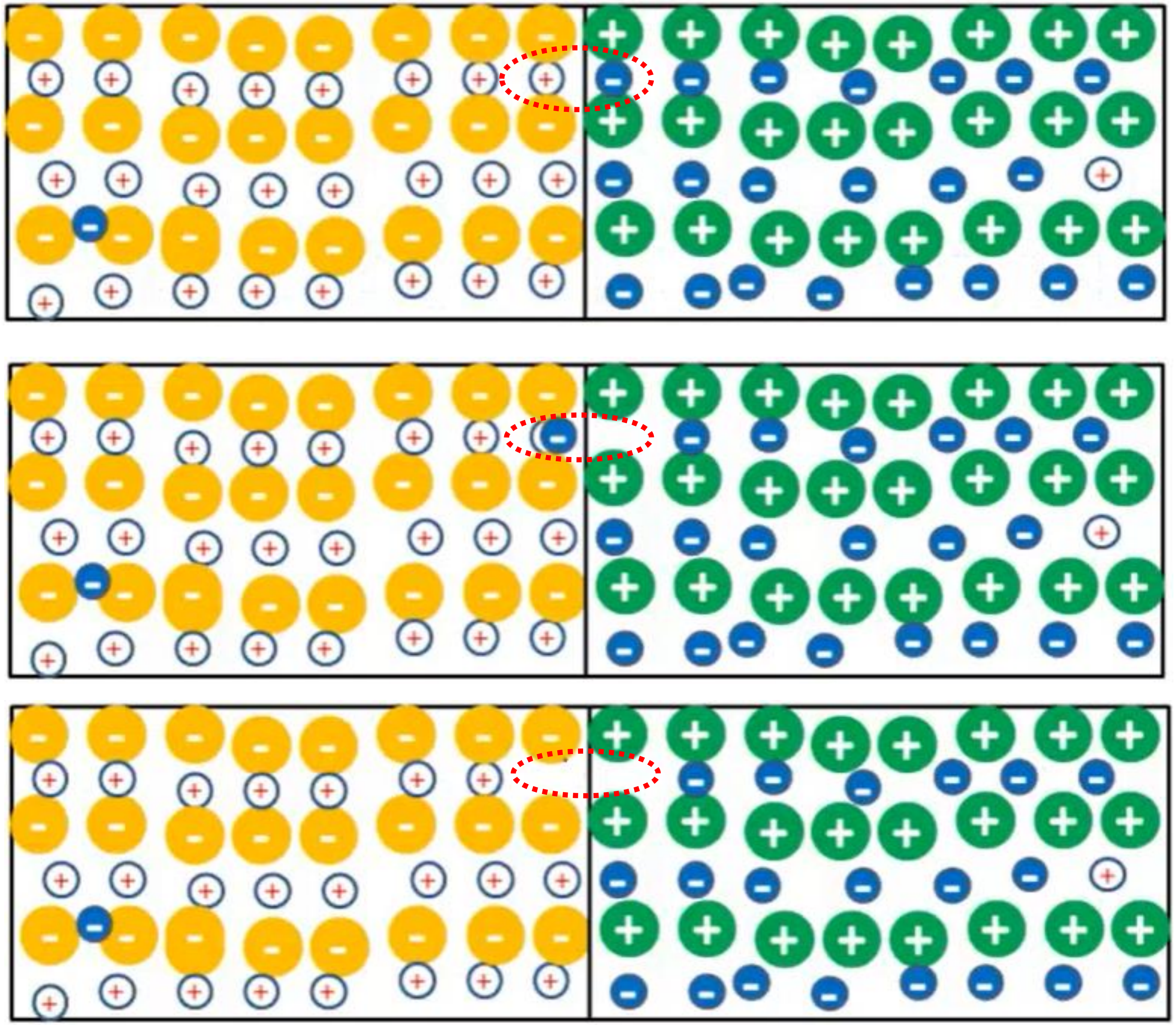


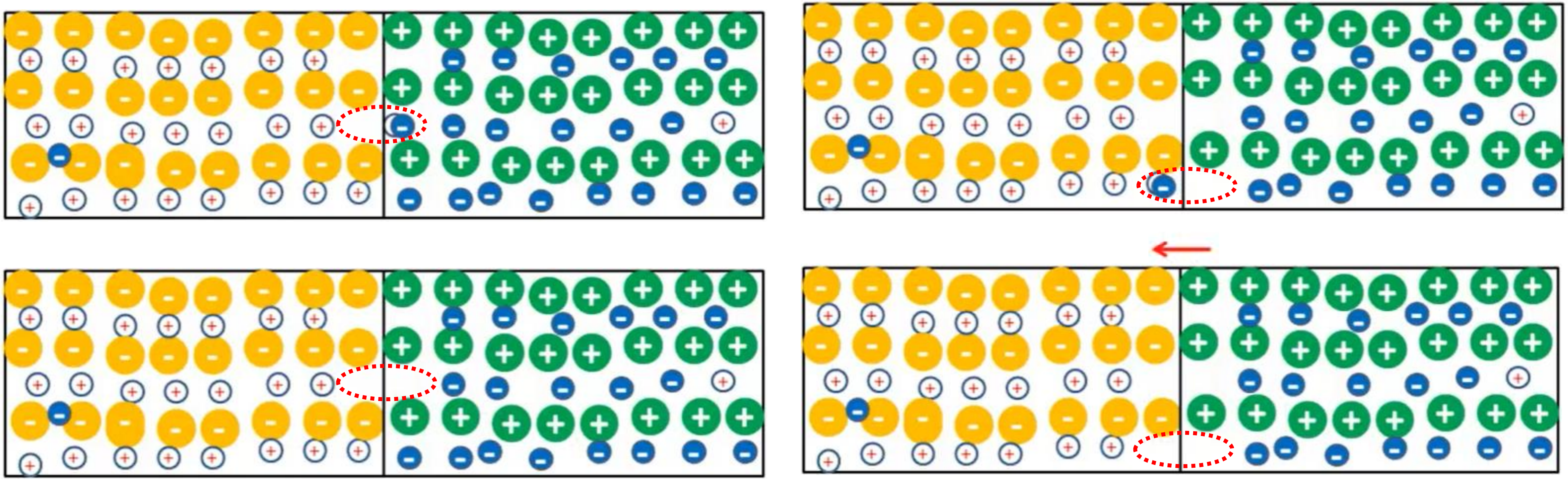


Basic Operation

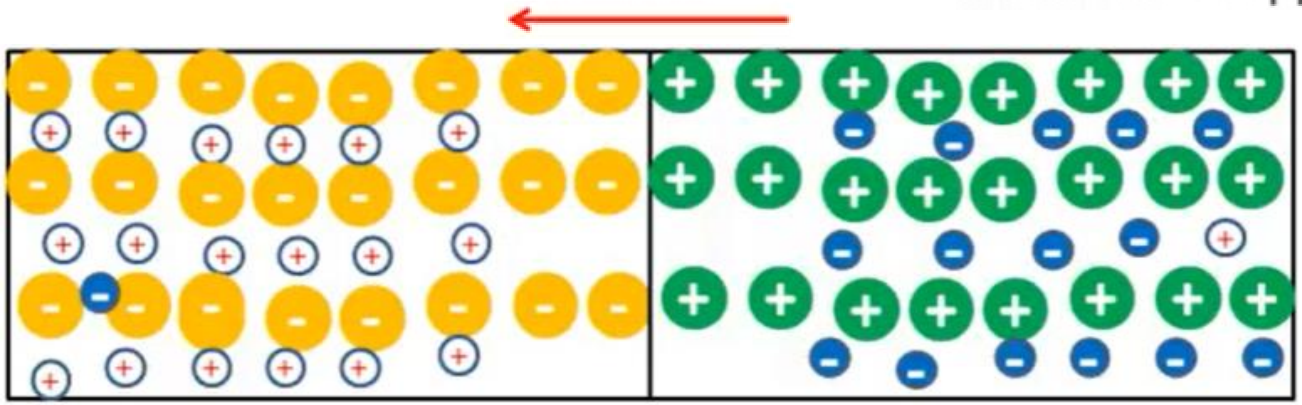


Holes will tend to diffuse from p →n and electrons from n→p



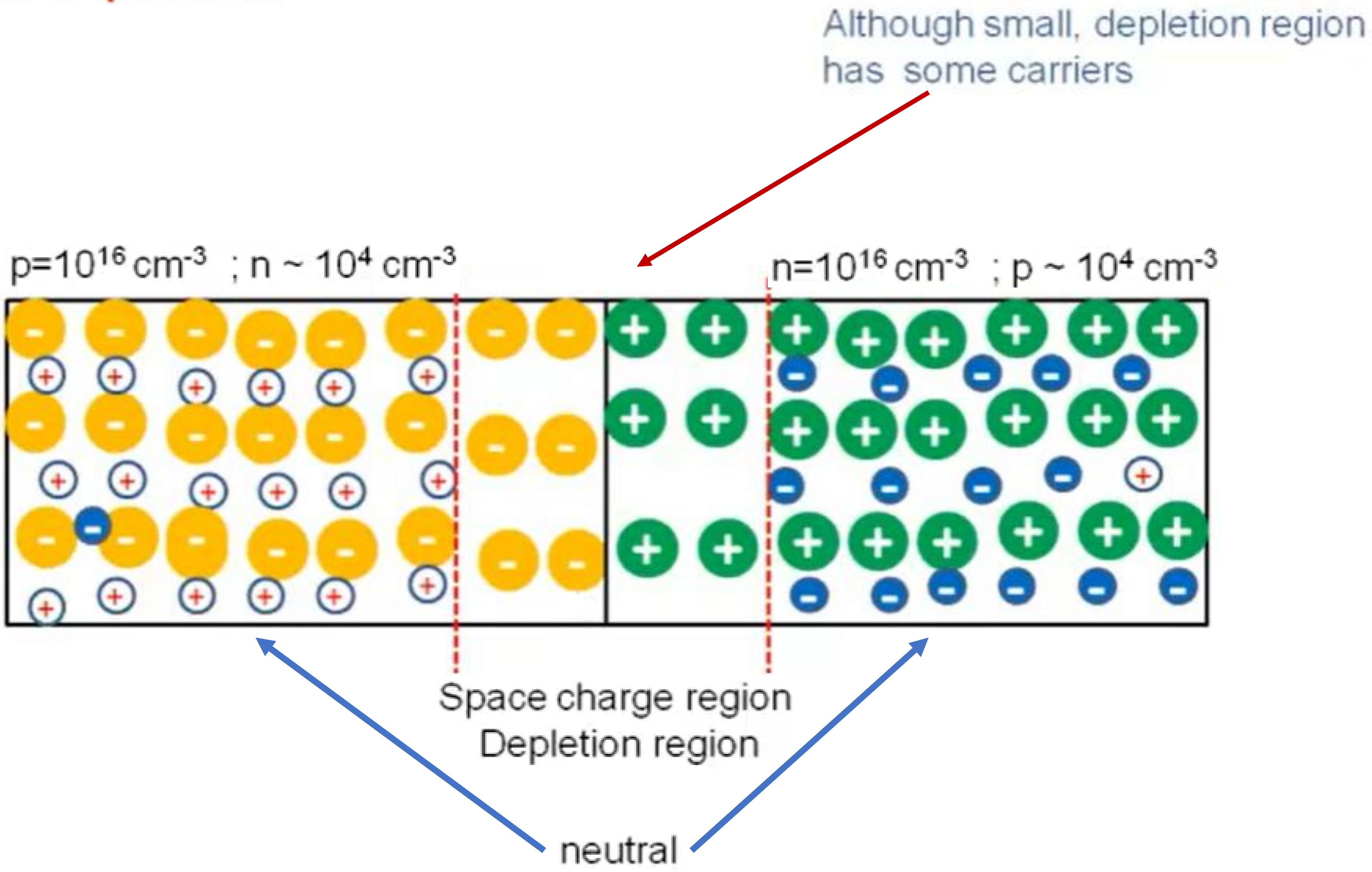


Electric field opposes flow of carriers

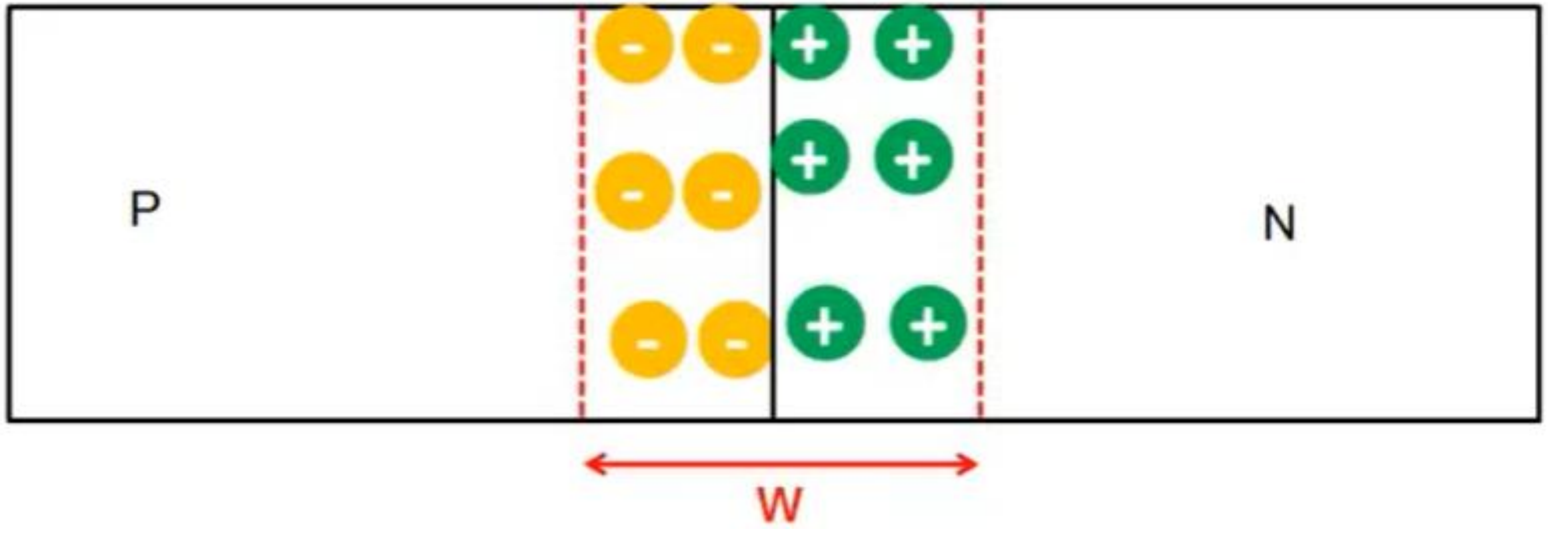


Eventually equilibrium is reached and there is no net flow of carriers across the junction

PN Junction Under Equilibrium



Depletion region



$$W = \sqrt{\frac{2\varepsilon_s}{q} \times \left(\frac{1}{N_A} + \frac{1}{N_D}\right) \times V_{bi}}$$

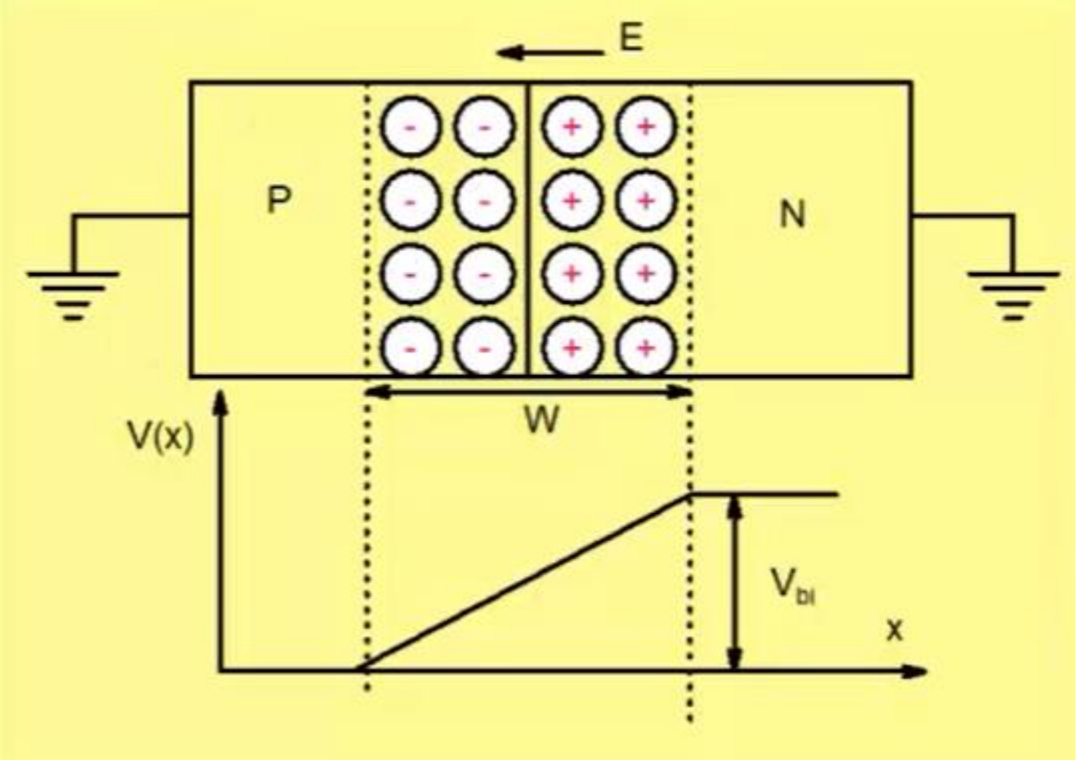
$$\varepsilon_s = 11.7 \times 8.85 \times 10^{-14}\, F/cm;\ q = 1.6 \times 10^{-19}\, C$$

$N_A = N_D = 10^{16}\ cm^{-3}$, $T = 300°K$

$V_{bi} = 0.86\ V$

$$W = 4300\, A^{o}$$

Built-in Potential V_{bi}



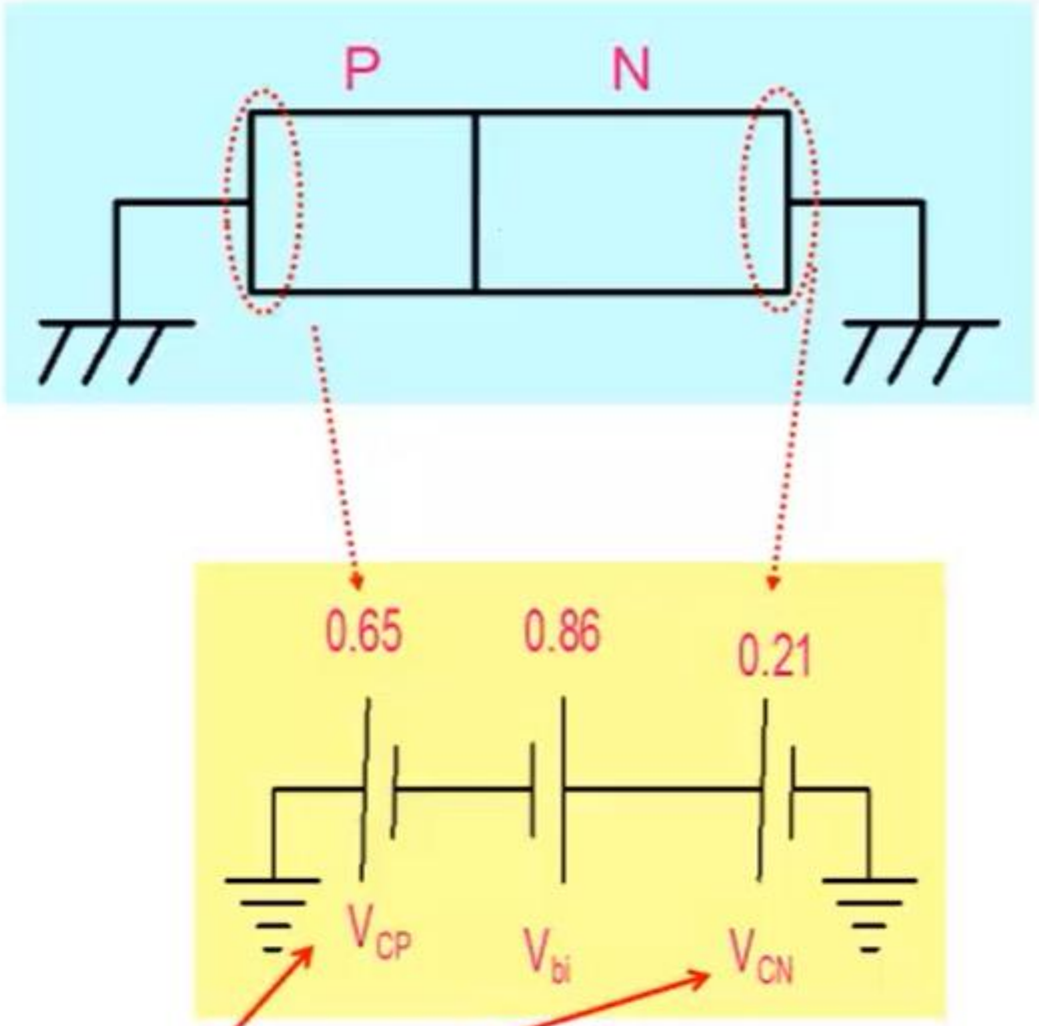
$$V_{bi} = \frac{kT}{q} \ln\left[\frac{N_A N_D}{n_i^2}\right]$$

$N_A = N_D = 10^{16}\,cm^{-3}$, $T = 300°K$

$V_{bi} = 0.86\ V$

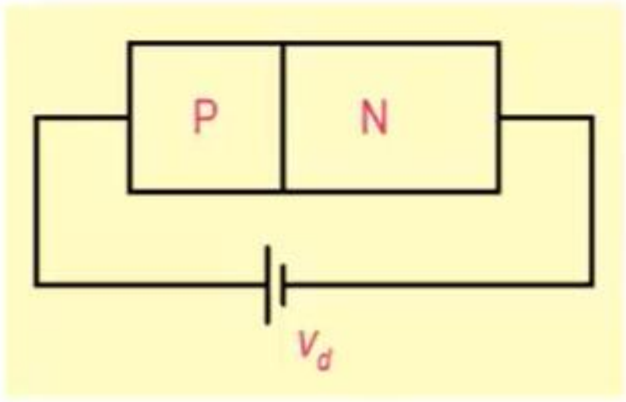
Anytime you put two different materials into contact, a potential develops between them.

Built-in Potential

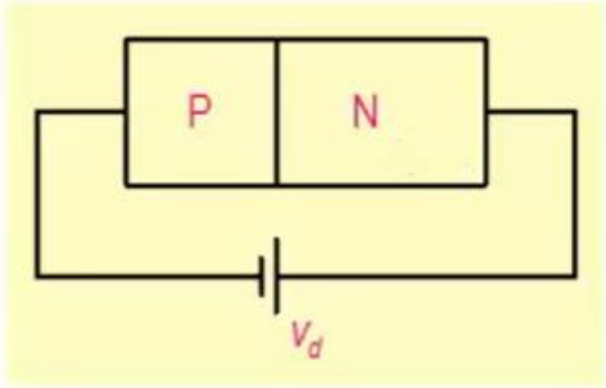


Contact potential

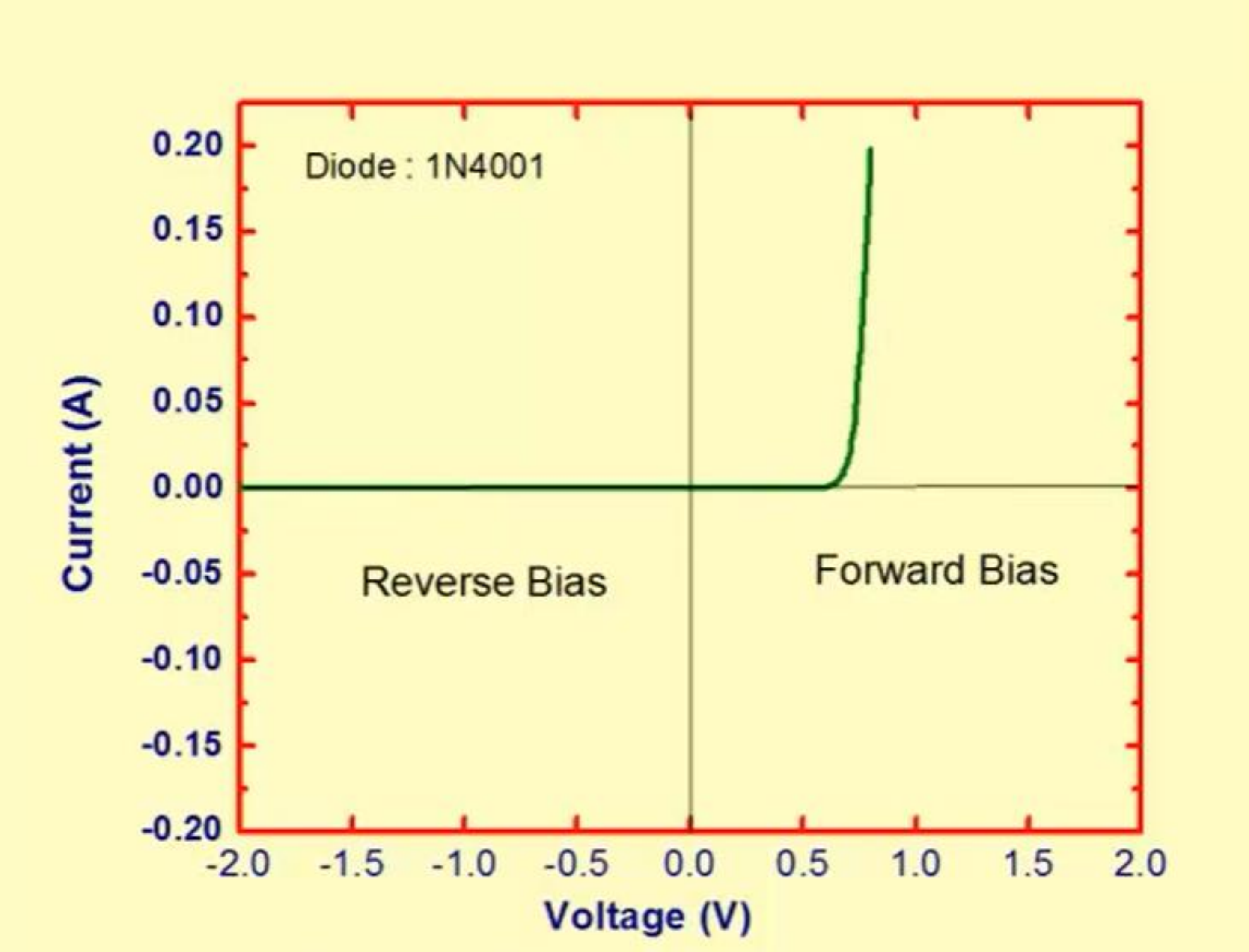
Forward and Reverse Bias



Forward Bias: P is biased at a higher voltage compared to N



Reverse Bias: N is biased at a higher voltage compared to P



The pn junction diode conduct significant current in the forward-bias region