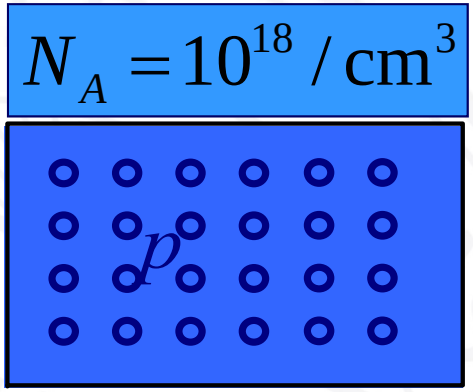
Lecture
Key Concepts of PN Junction

Vincent Chang

Outline

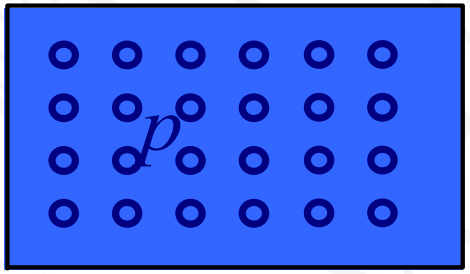
Equilibrium	Energy barrier	Built-in potential
• Diffusion • Build-in field • Drift	• Electrons • Holes	• Derivation • Formulation

Review: p-Type



Review: p-Type

$$N_A = 10^{18} / \text{cm}^3$$

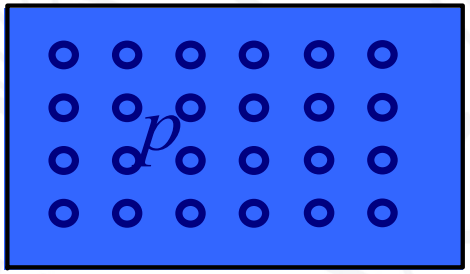


$$p \cong N_A$$

$$n = \frac{n_i^2}{N_A}$$

Review: p-Type

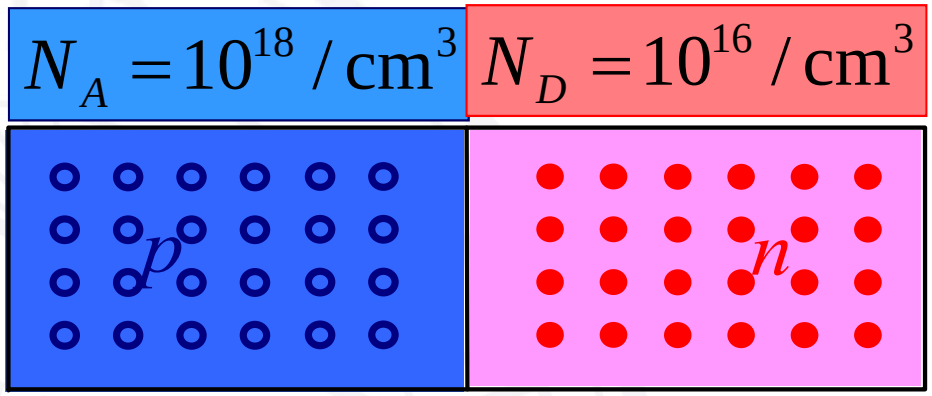
$$N_A = 10^{18}/\text{cm}^3$$



$$p \cong N_A \Rightarrow p = 10^{18}/\text{cm}^3$$

$$n = \frac{n_i^2}{N_A} \Rightarrow n = 10^2/\text{cm}^3$$

Review: n-Type



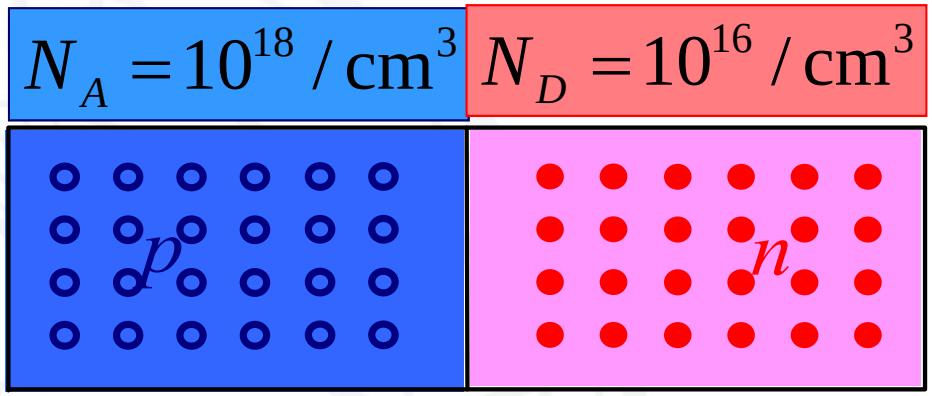
$$p = 10^{18}/\text{cm}^3$$

$$n = 10^{2}/\text{cm}^3$$

$$n \cong N_D$$

$$p = \frac{n_i^2}{N_D}$$

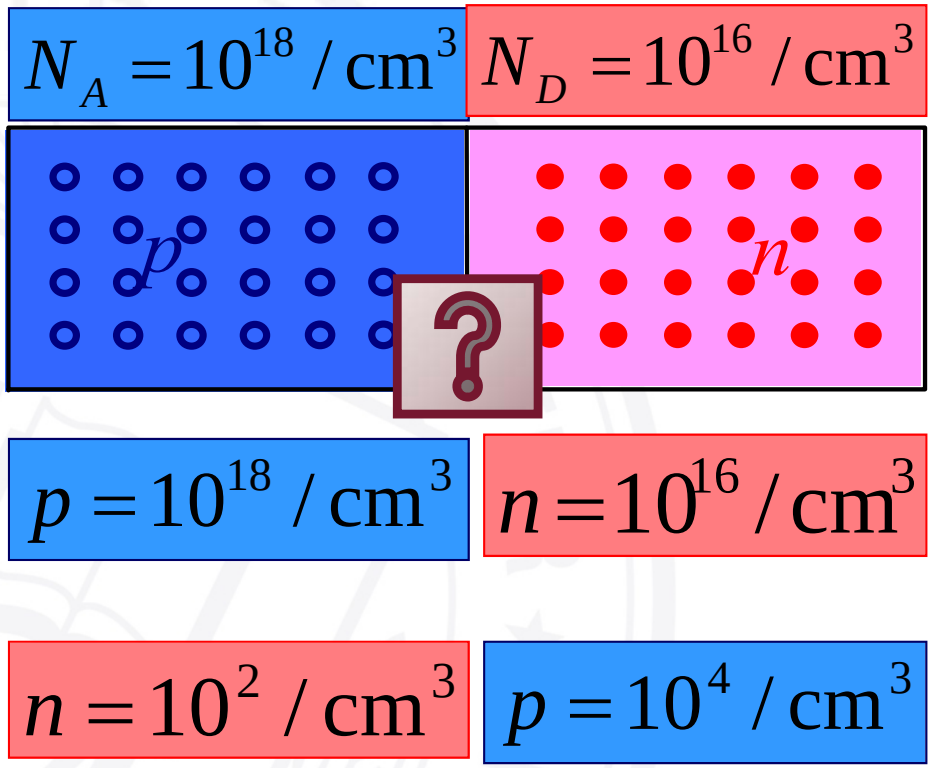
Review: n-Type



$p = 10^{18}/\text{cm}^3$ $n = 10^{16}/\text{cm}^3$ $\Leftarrow$ $n \cong N_D$

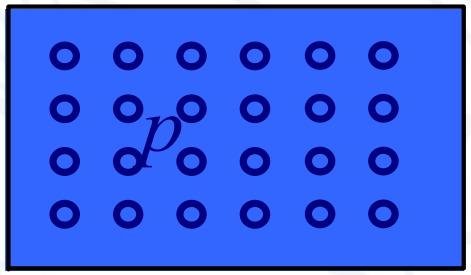
$n = 10^{2}/\text{cm}^3$ $p = 10^{4}/\text{cm}^3$ $\Leftarrow$ $p = \dfrac{n_i^2}{N_D}$

pn Junction

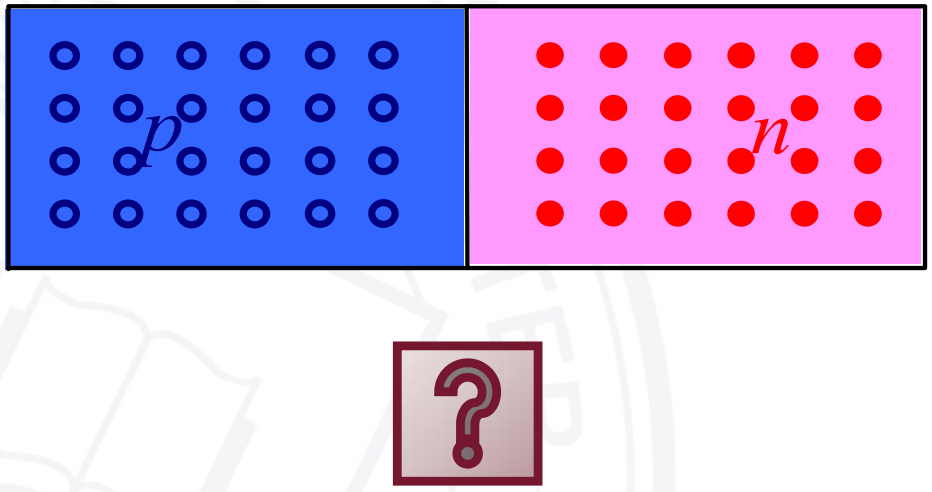

$N_A = 10^{18}/\text{cm}^3$
$N_D = 10^{16}/\text{cm}^3$
p
n
?
$p = 10^{18}/\text{cm}^3$
$n = 10^{16}/\text{cm}^3$
$n = 10^{2}/\text{cm}^3$
$p = 10^{4}/\text{cm}^3$

Charles River, Boston

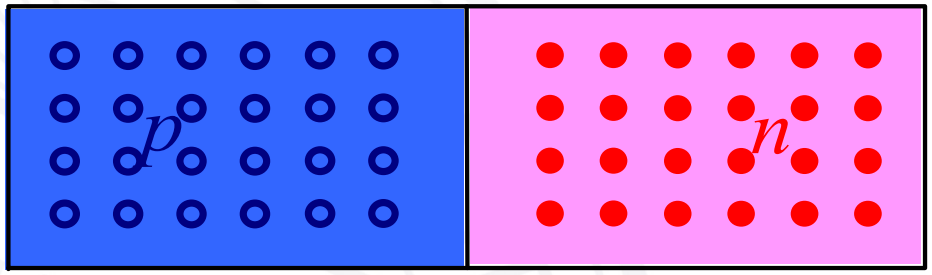
Thermal Equilibrium



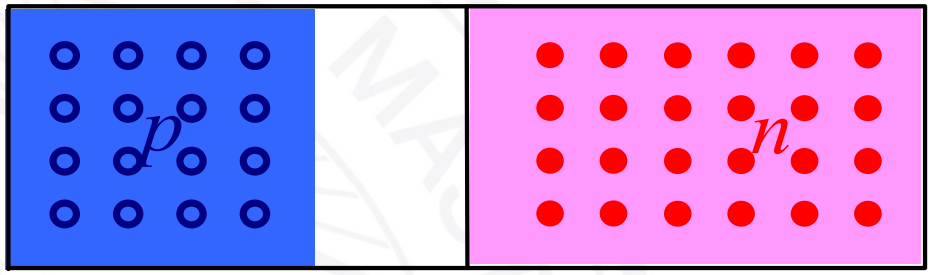
Thermal Equilibrium



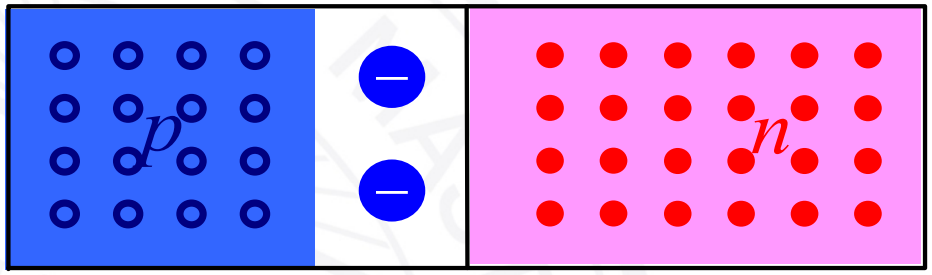
Diffusion



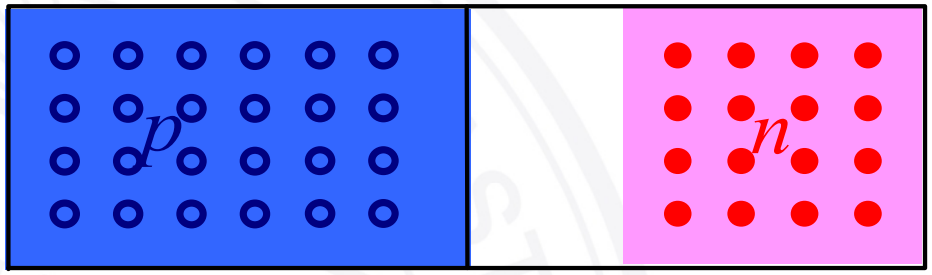
Acceptor Ions



Acceptor Ions

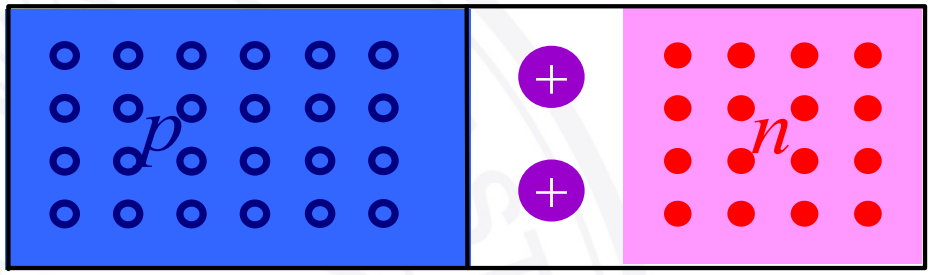


Donor Ions

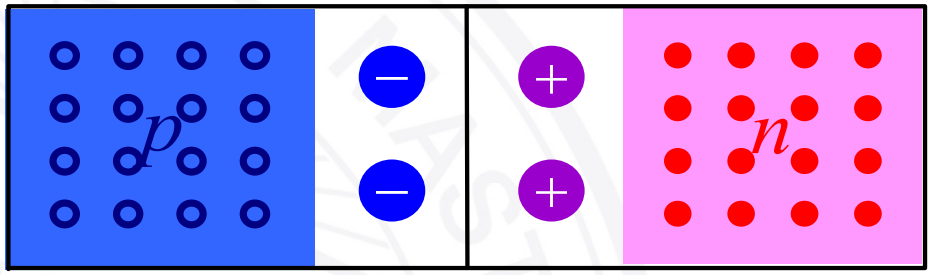


Diffusion

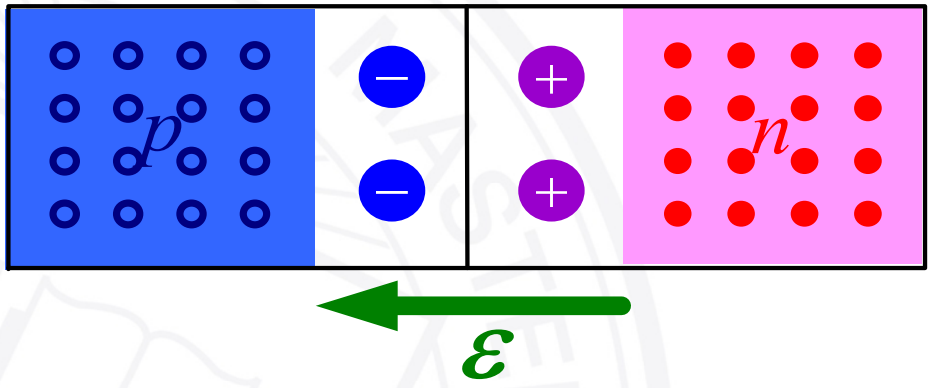
Donor Ions



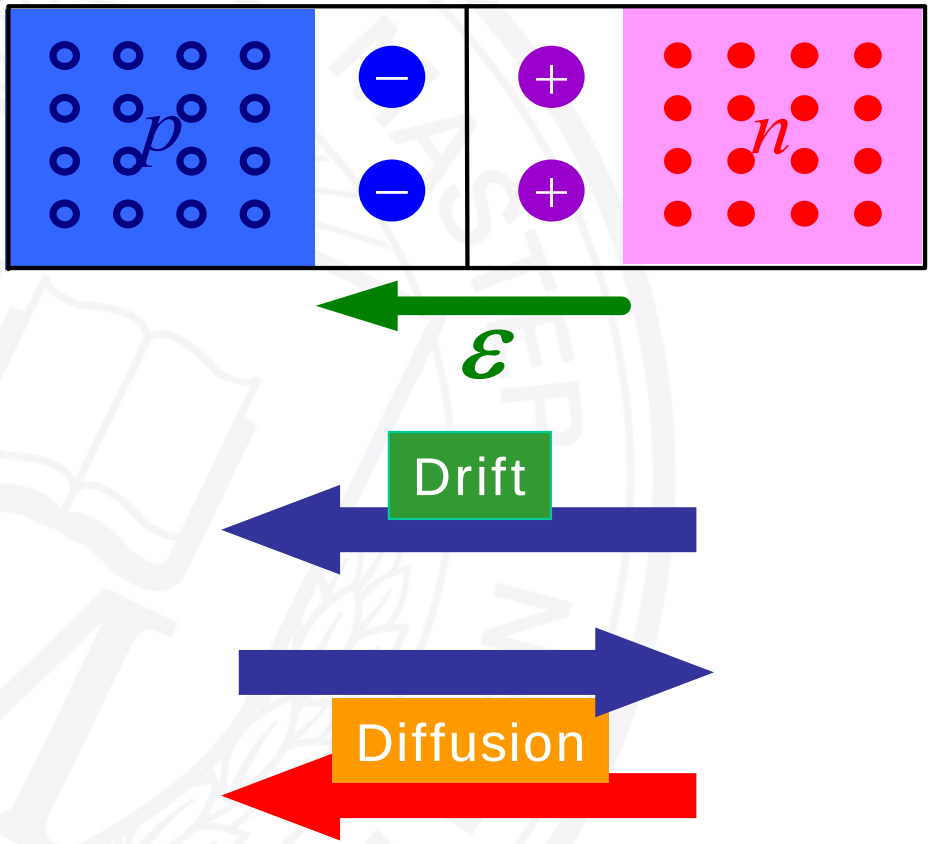
Charge Separation/Storage



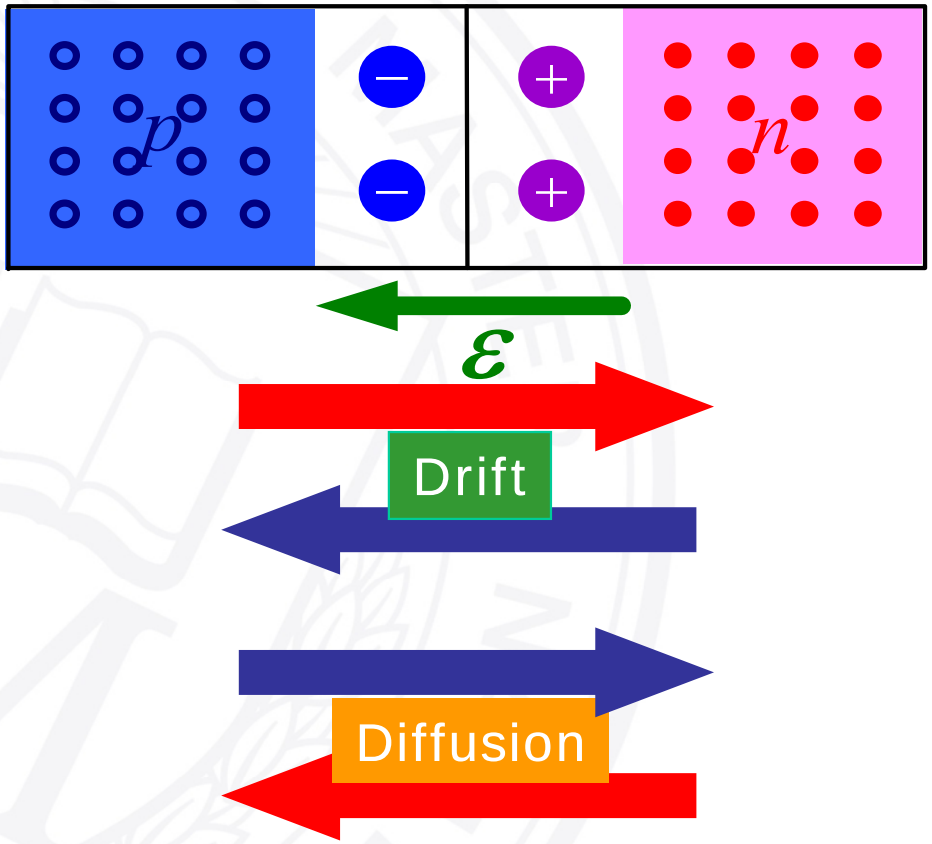
Built-in Electric Field



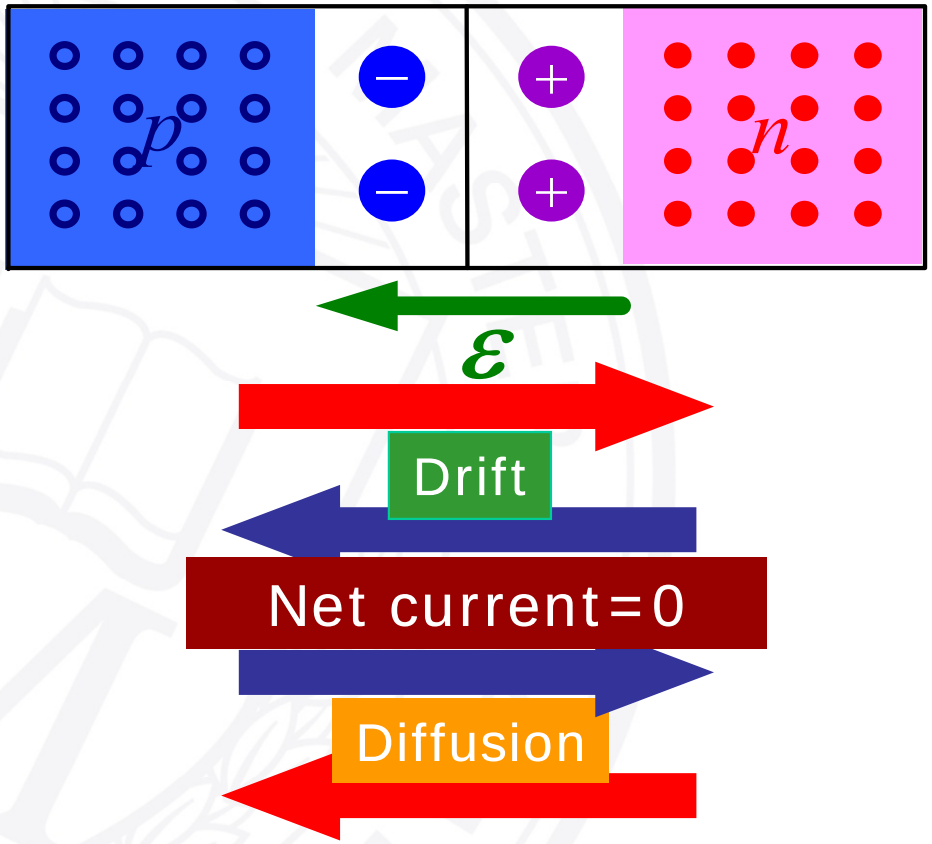
Drift



Drift



Zero Net Current



Outline

Equilibrium

- Diffusion
- Build-in field
- Drift

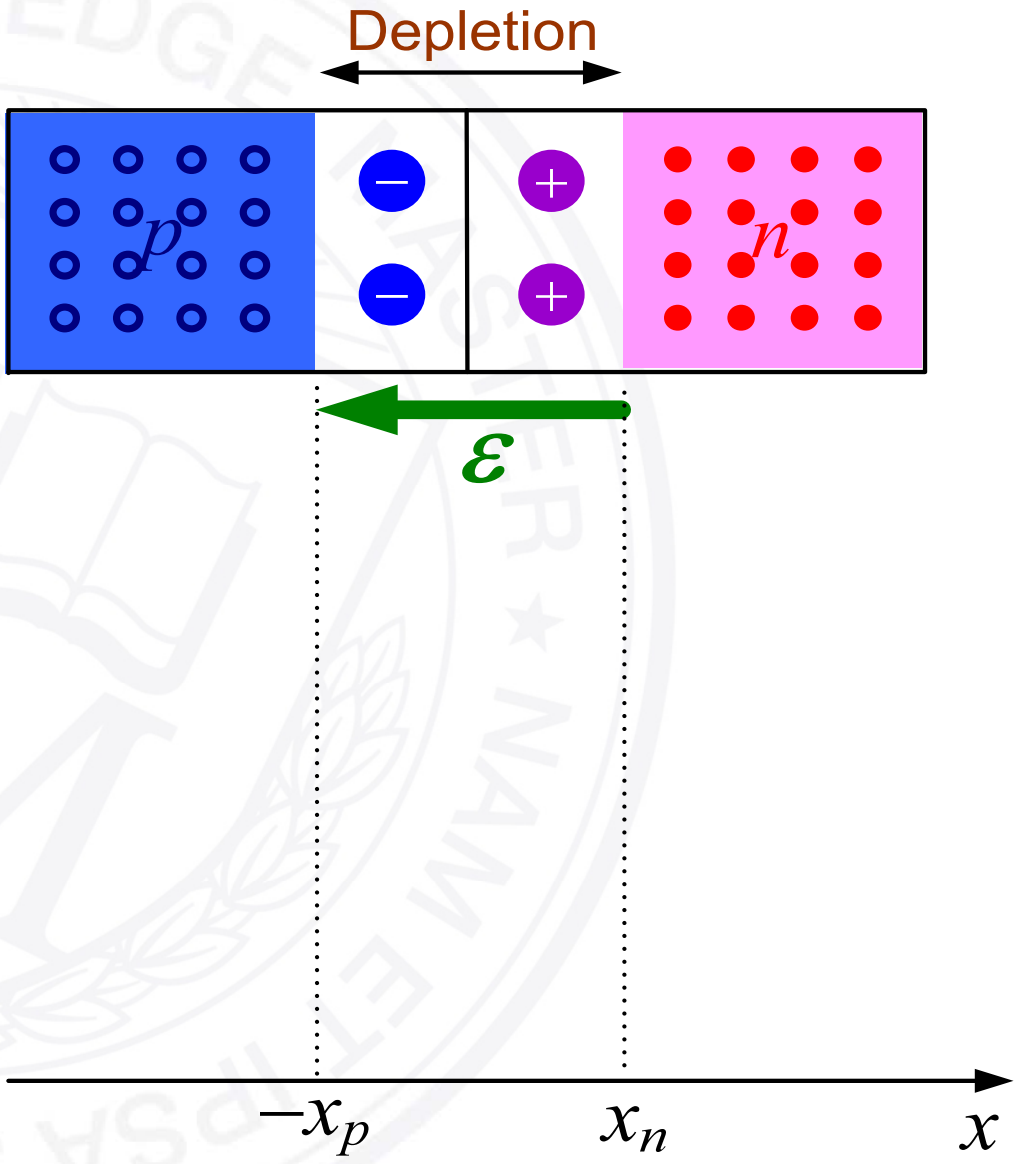
Energy barrier

- Electrons
- Holes

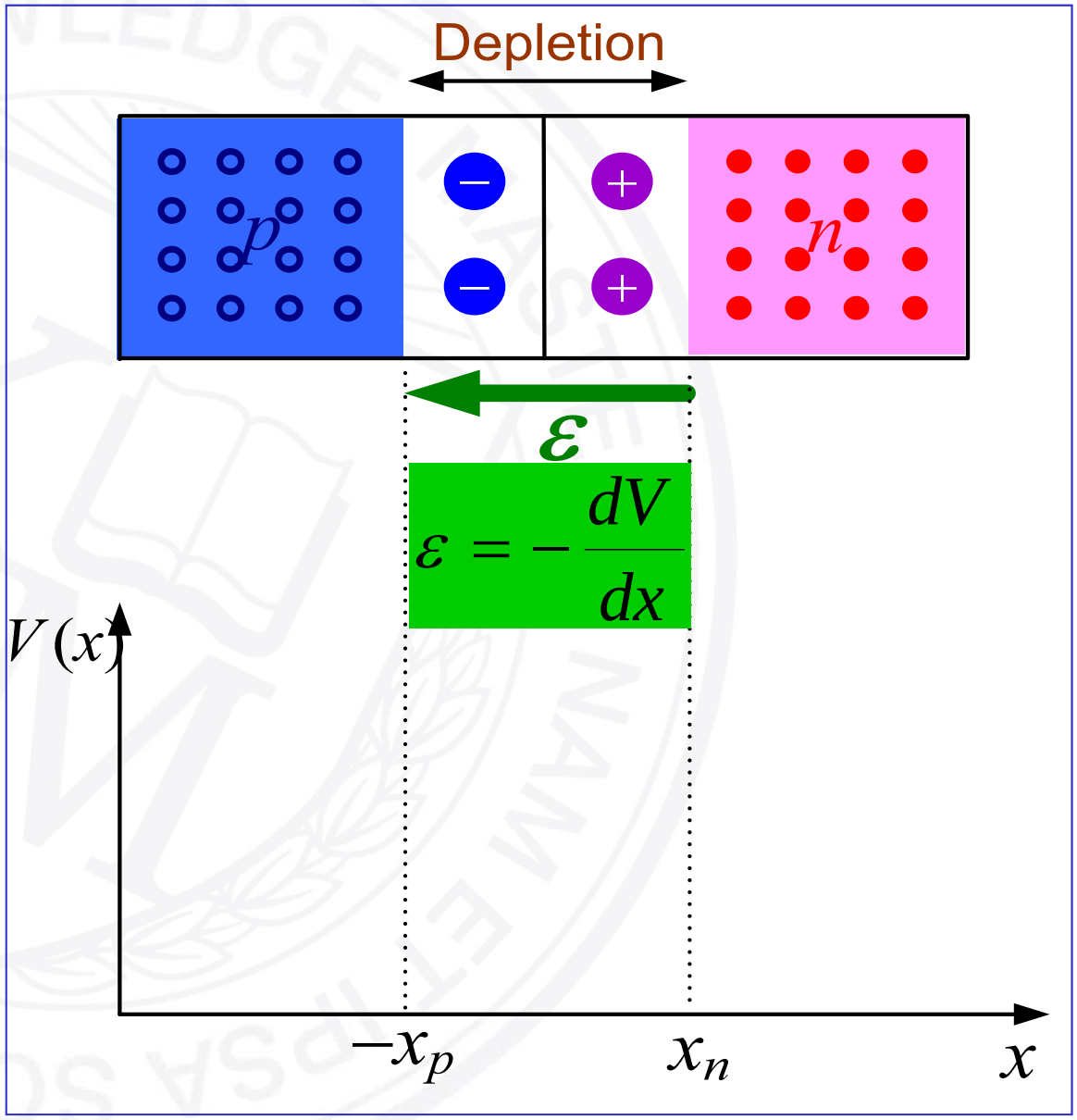
Built-in potential

- Derivation
- Formulation

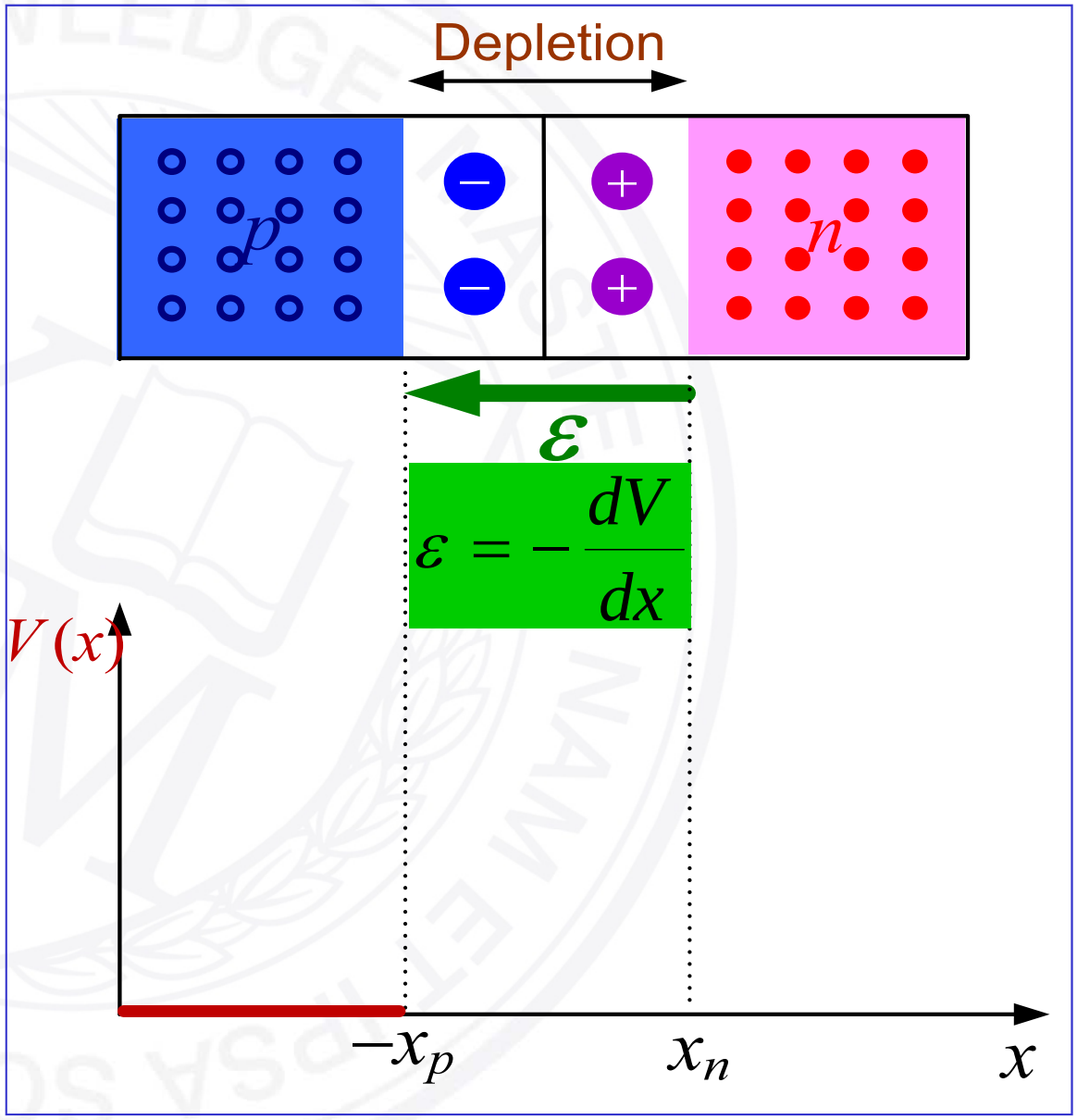
Depletion Layer



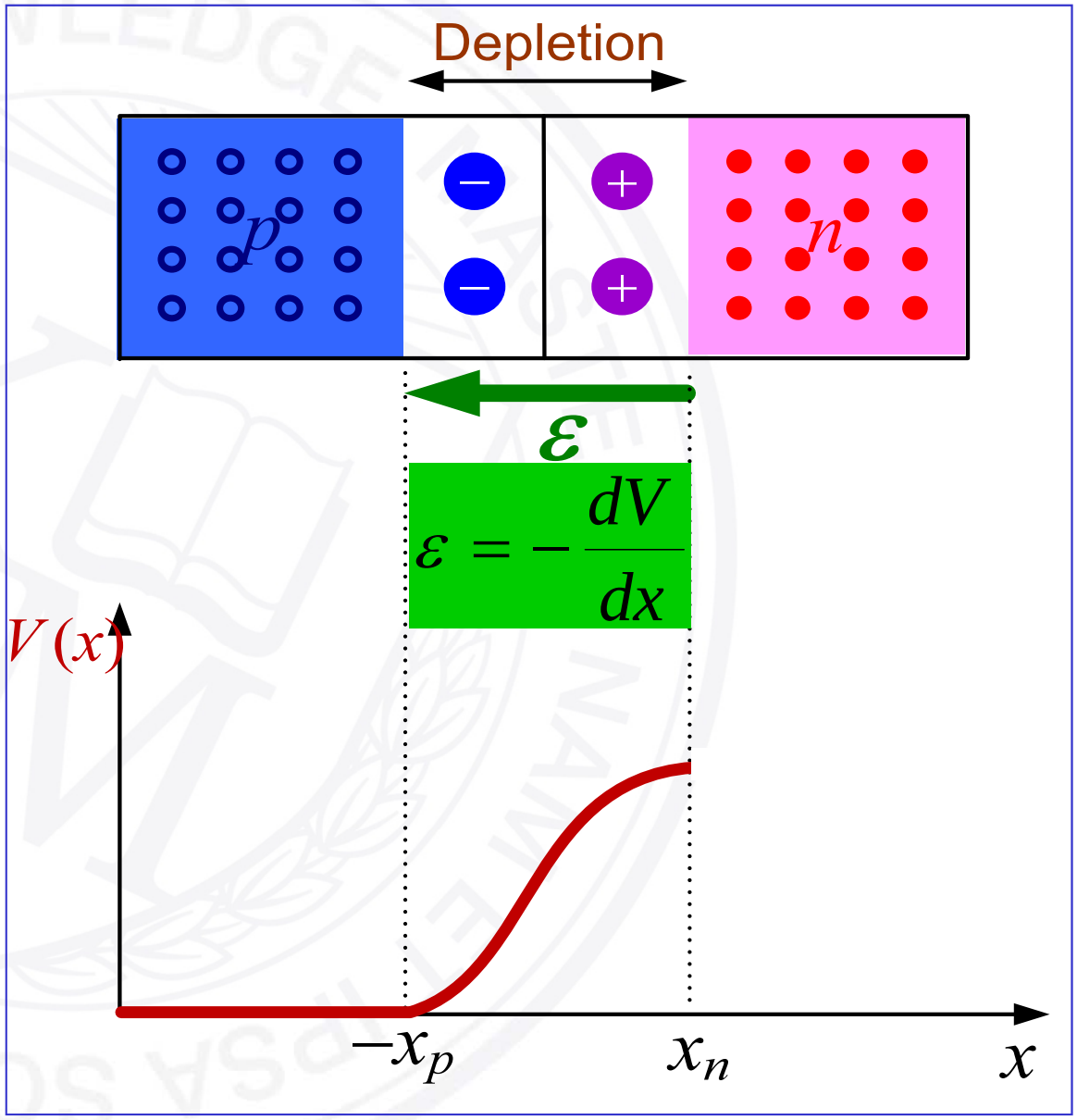
Electric Field vs. Potential



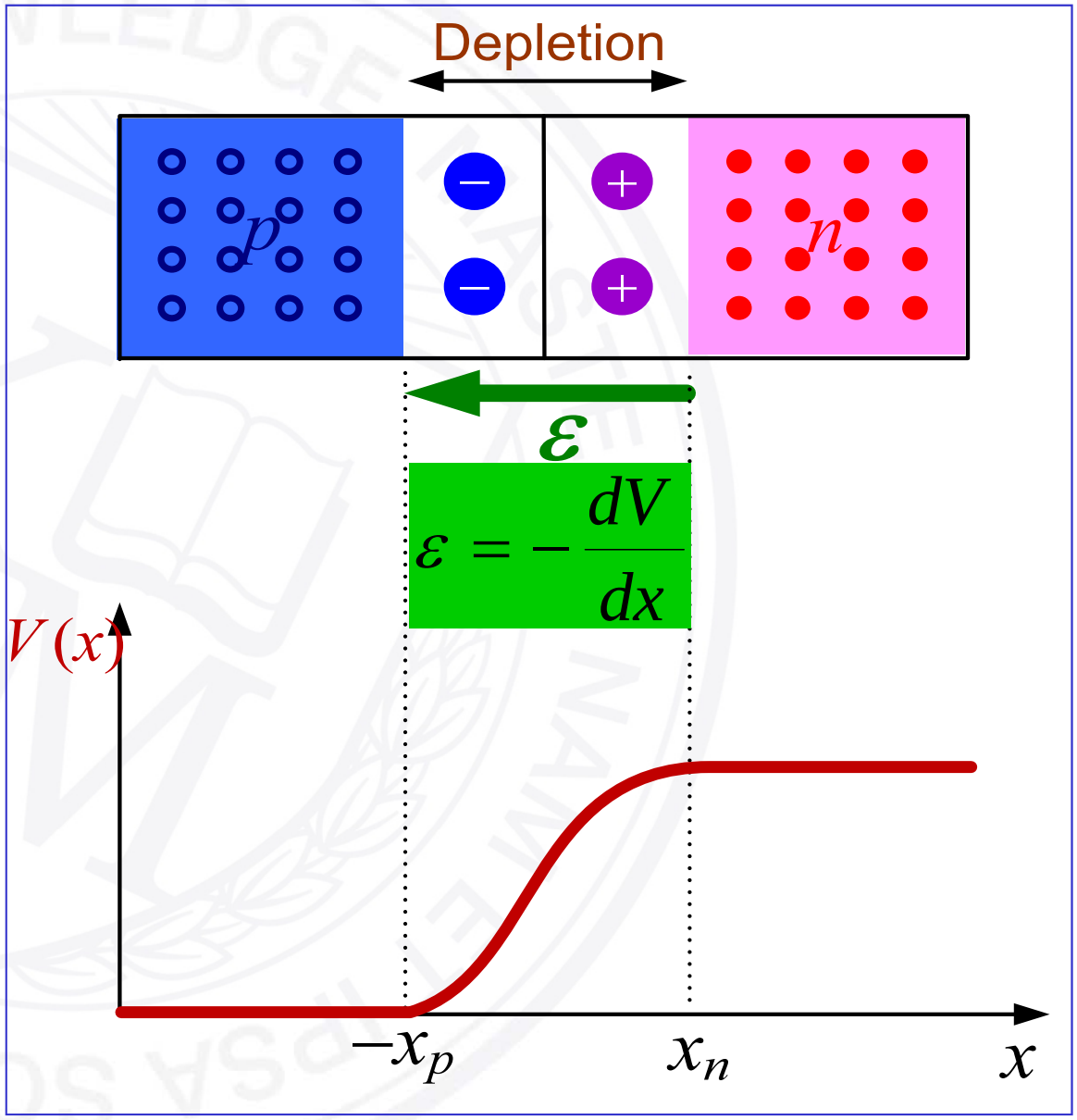
Electrostatic Potential Distribution



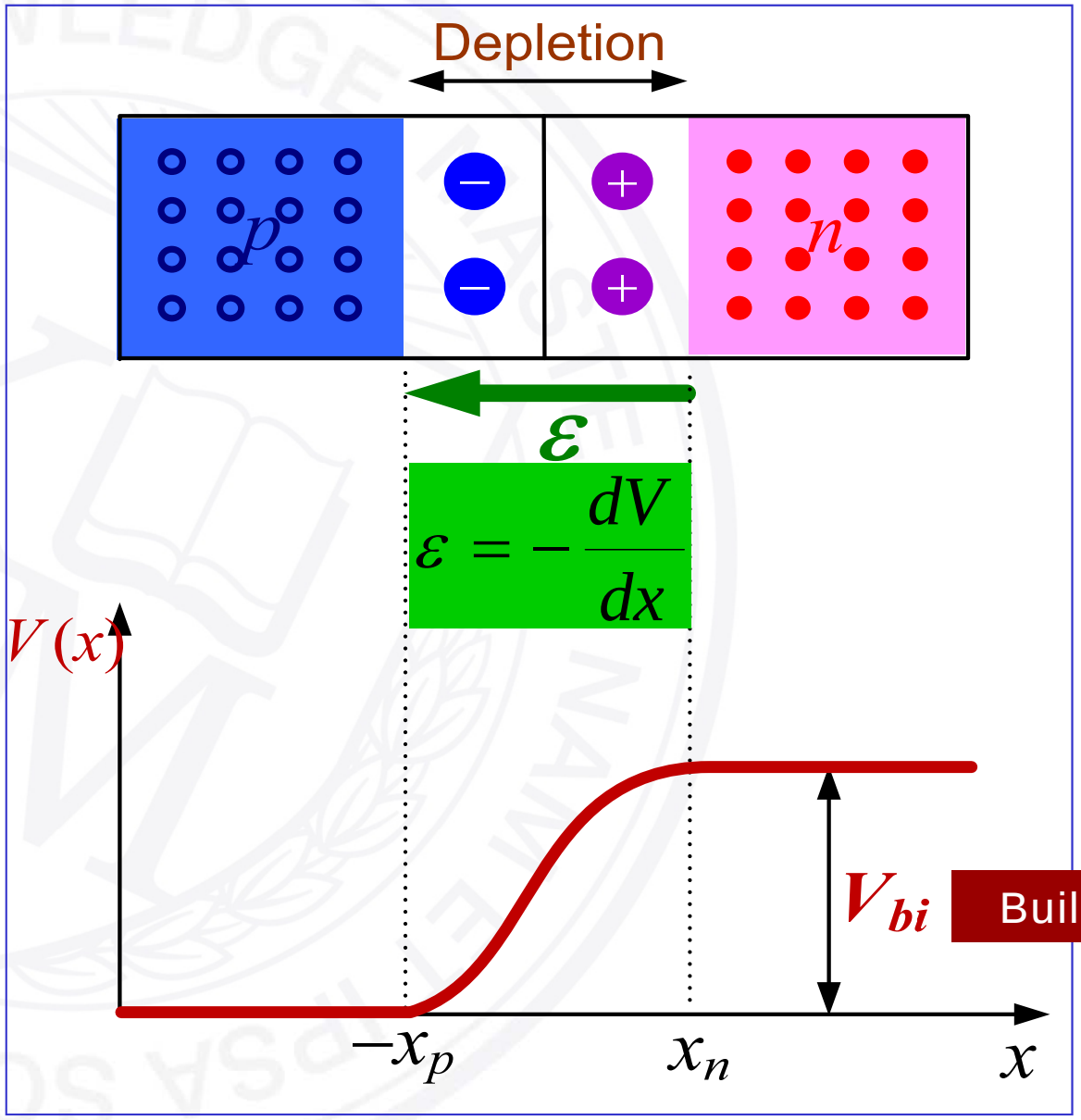
Electrostatic Potential Distribution



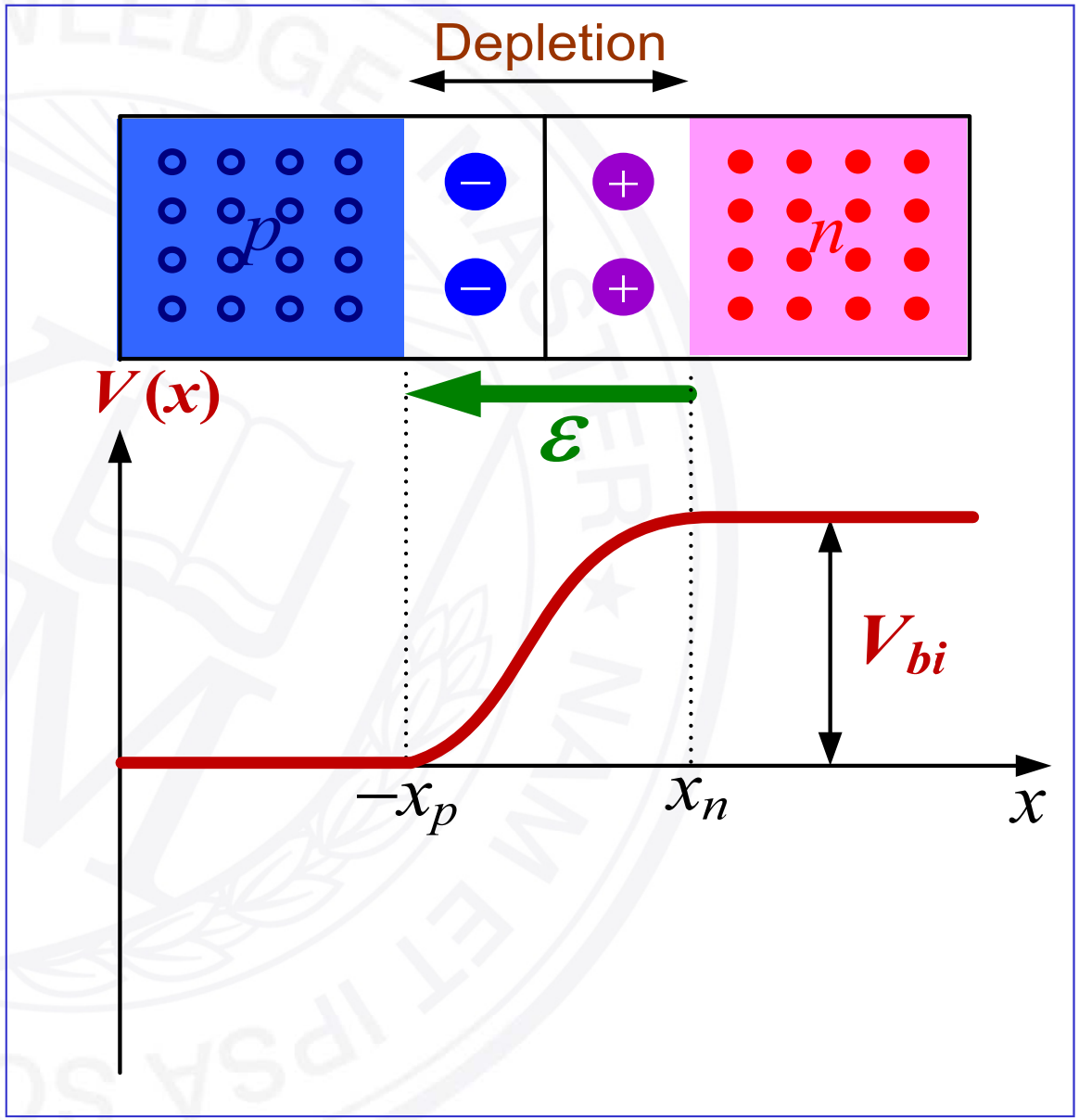
Electrostatic Potential Distribution



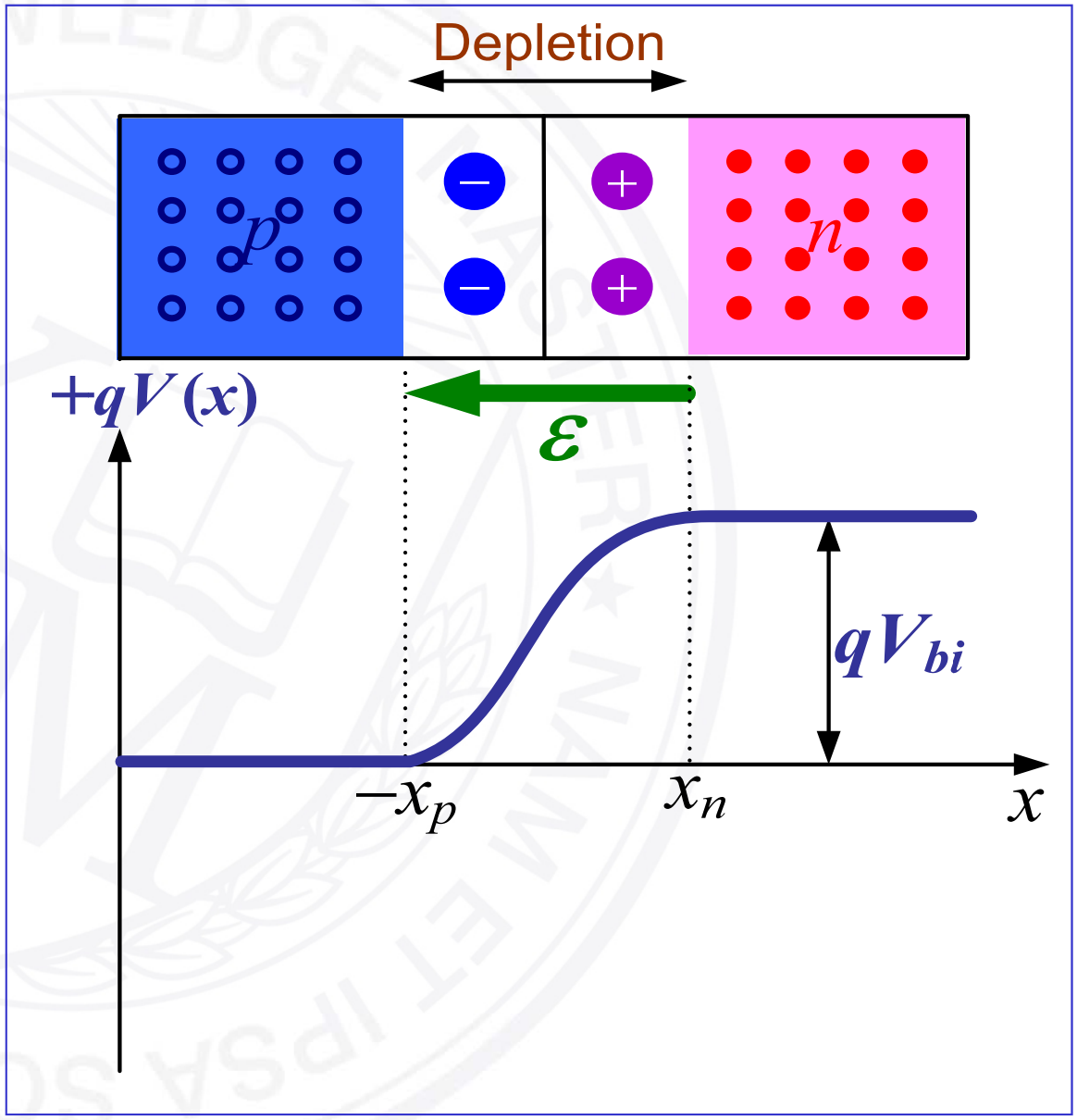
Built-in Potential



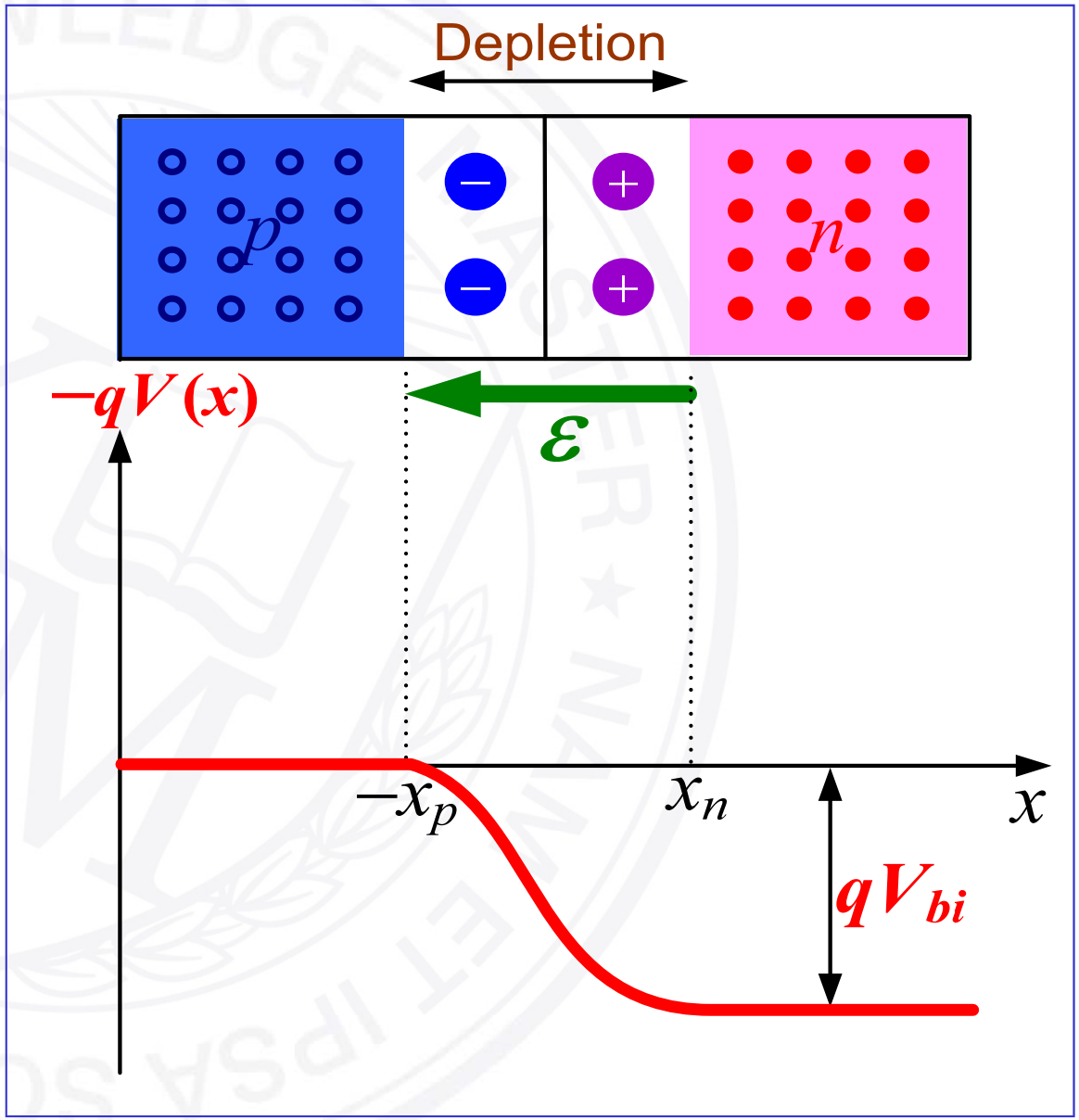
Concept of Energy Barrier



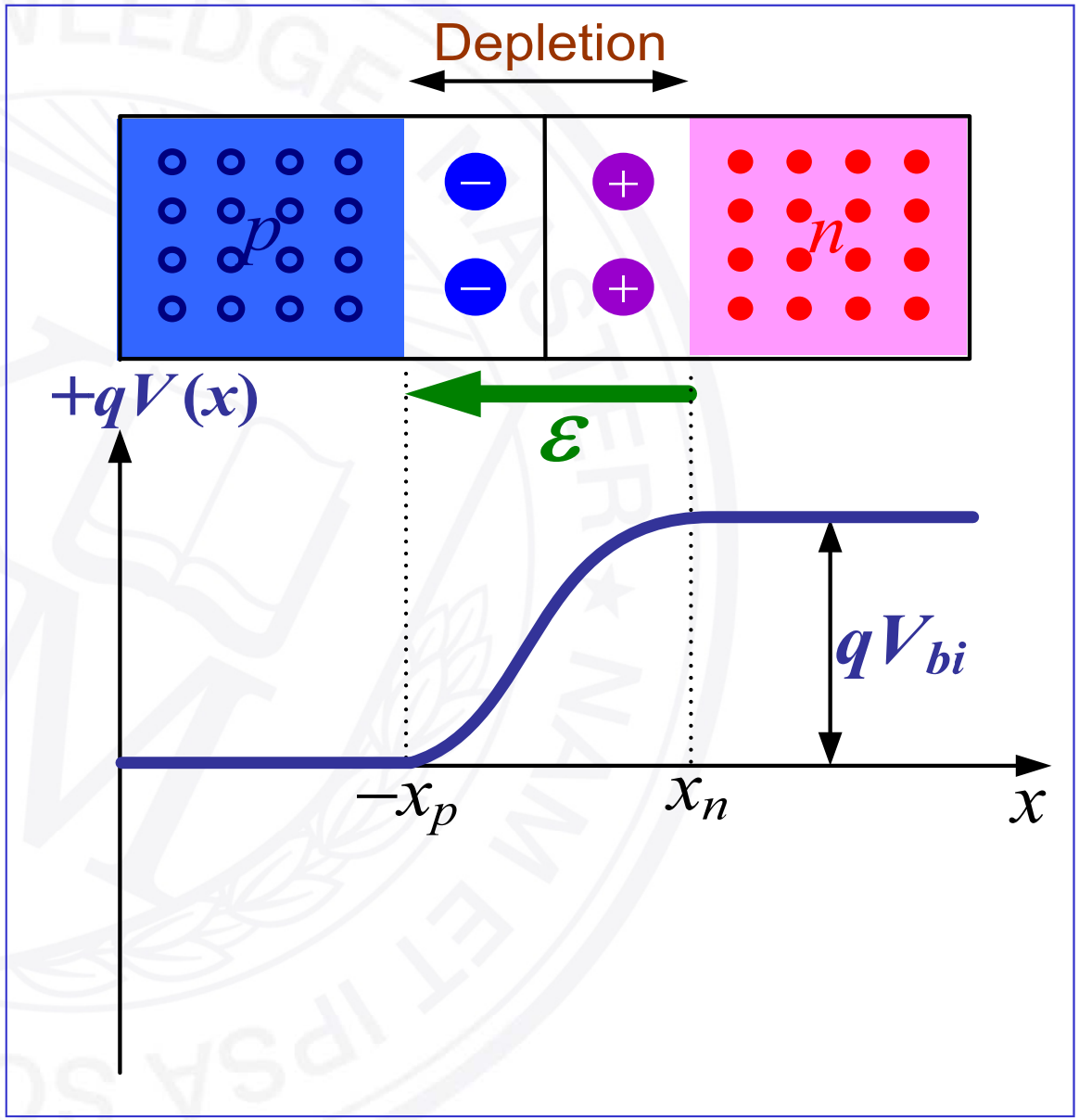
Potential Energy for Hole



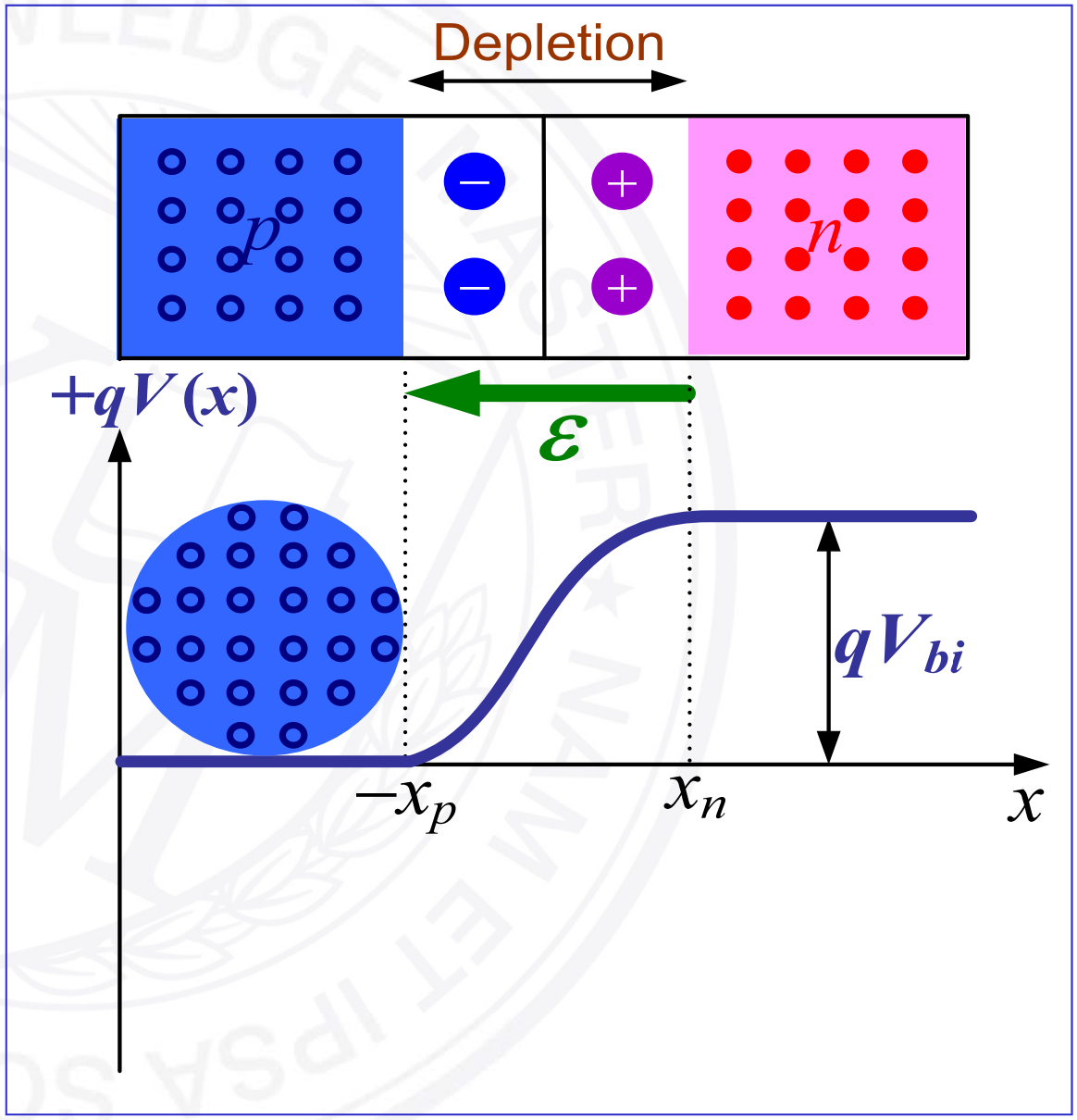
Potential Energy for Electron



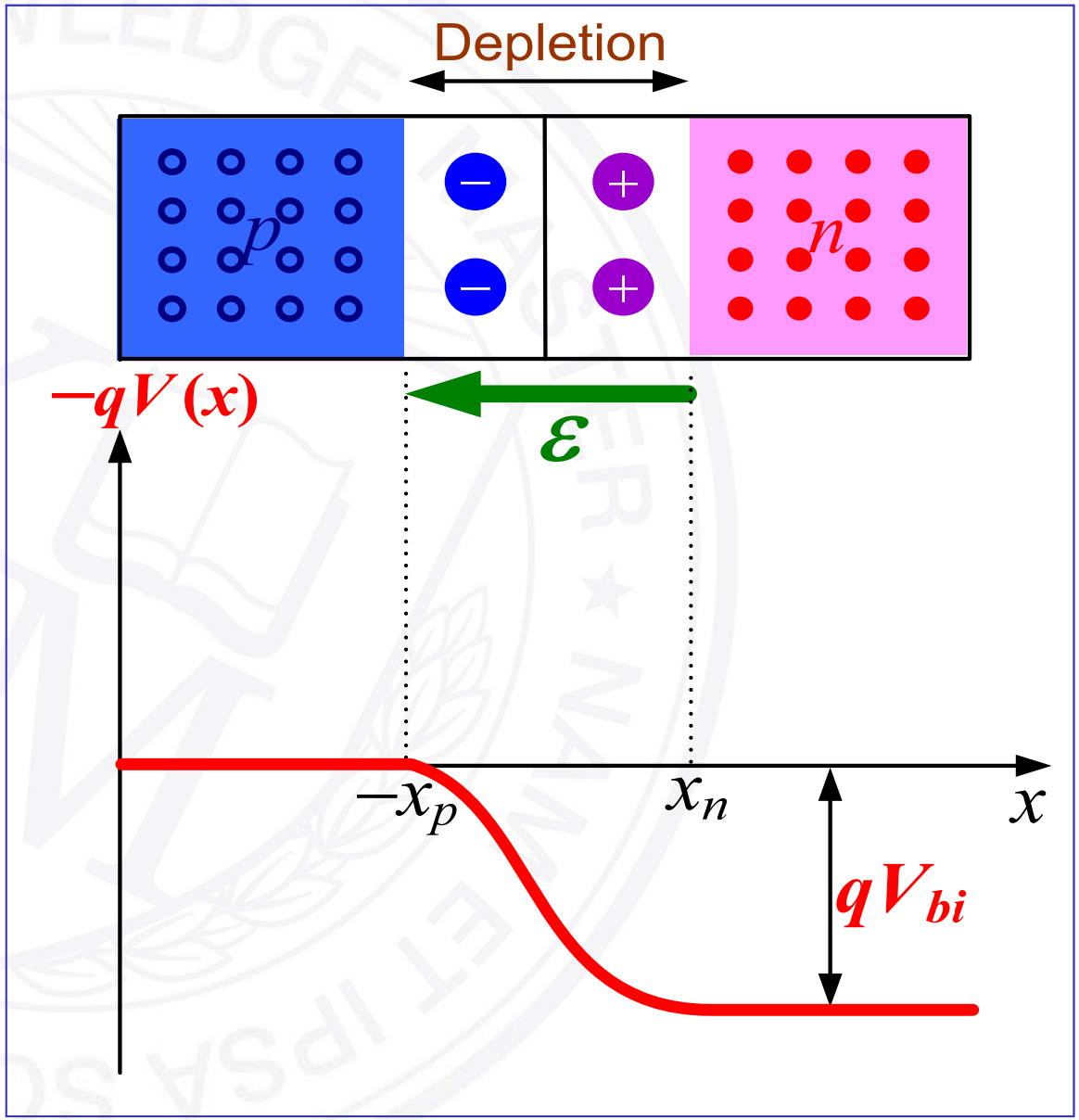
Potential Energy for Hole



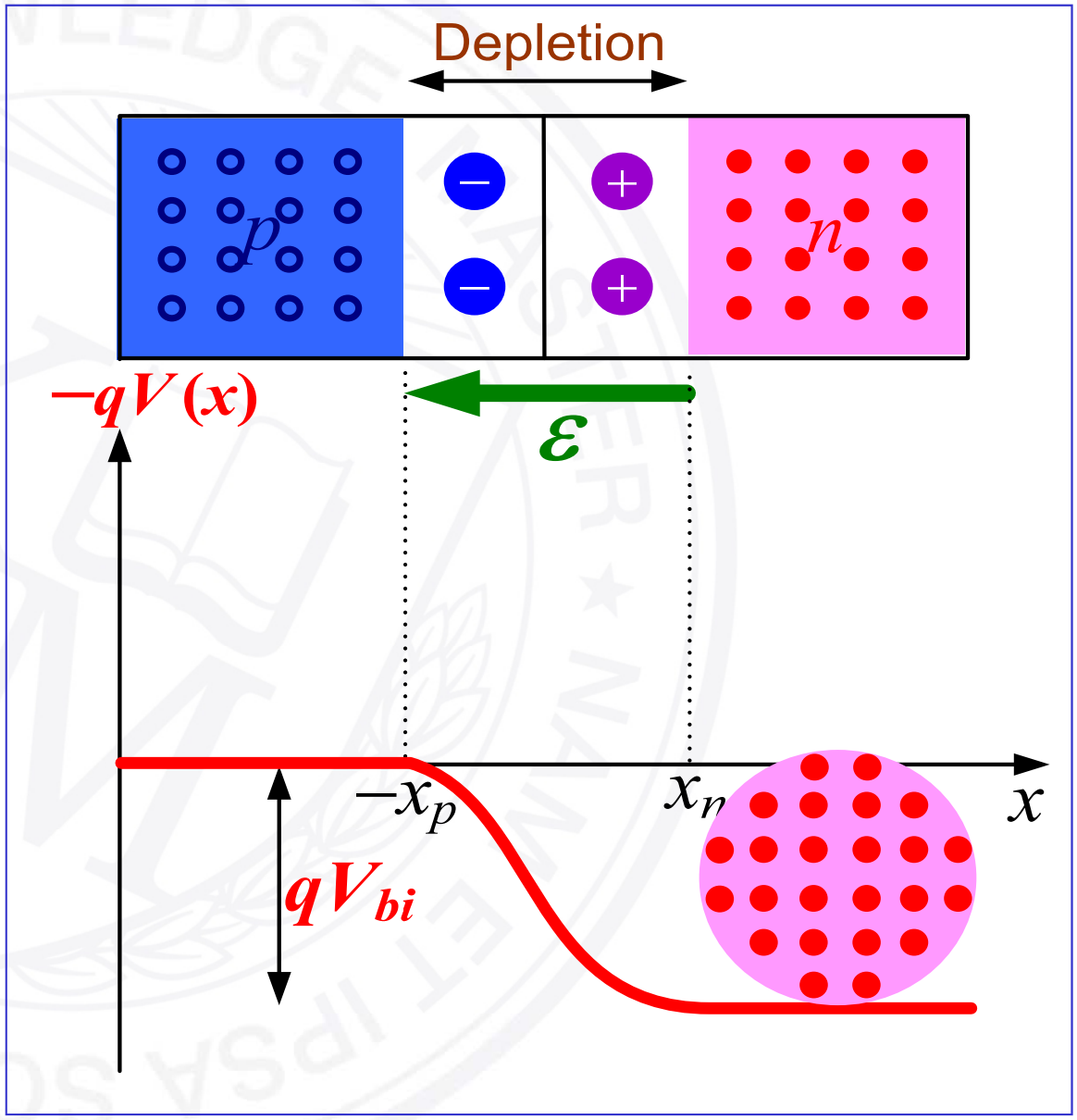
Energy Barrier Against Hole



Potential Energy for Electron



Energy Barrier Against Electron



Outline

Equilibrium	Energy barrier	Built-in potential
• Diffusion • Build-in field • Drift	• Electrons • Holes	• Derivation • Formulation

Net Current Density

Net electron current density

$$J_n = nq\mu_n\varepsilon + qD_n\frac{dn}{dx}$$

Net hole current density

$$J_p = pq\mu_p\varepsilon - qD_p\frac{dp}{dx}$$

Zero Net Hole Current Density

$$J_{p(net)} = pq\mu_p\varepsilon - qD_p\frac{dp}{dx} = 0$$

Net electron current density

$$J_n = nq\mu_n\varepsilon + qD_n\frac{dn}{dx}$$

Net hole current density

$$J_p = pq\mu_p\varepsilon - qD_p\frac{dp}{dx}$$

Einstein Relation

$$J_{p(net)} = pq\mu_p\varepsilon - qD_p\frac{dp}{dx} = 0$$

$$\frac{D_p}{\mu_p} = V_T$$

Einstein relation

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{kT}{q} = V_T$$

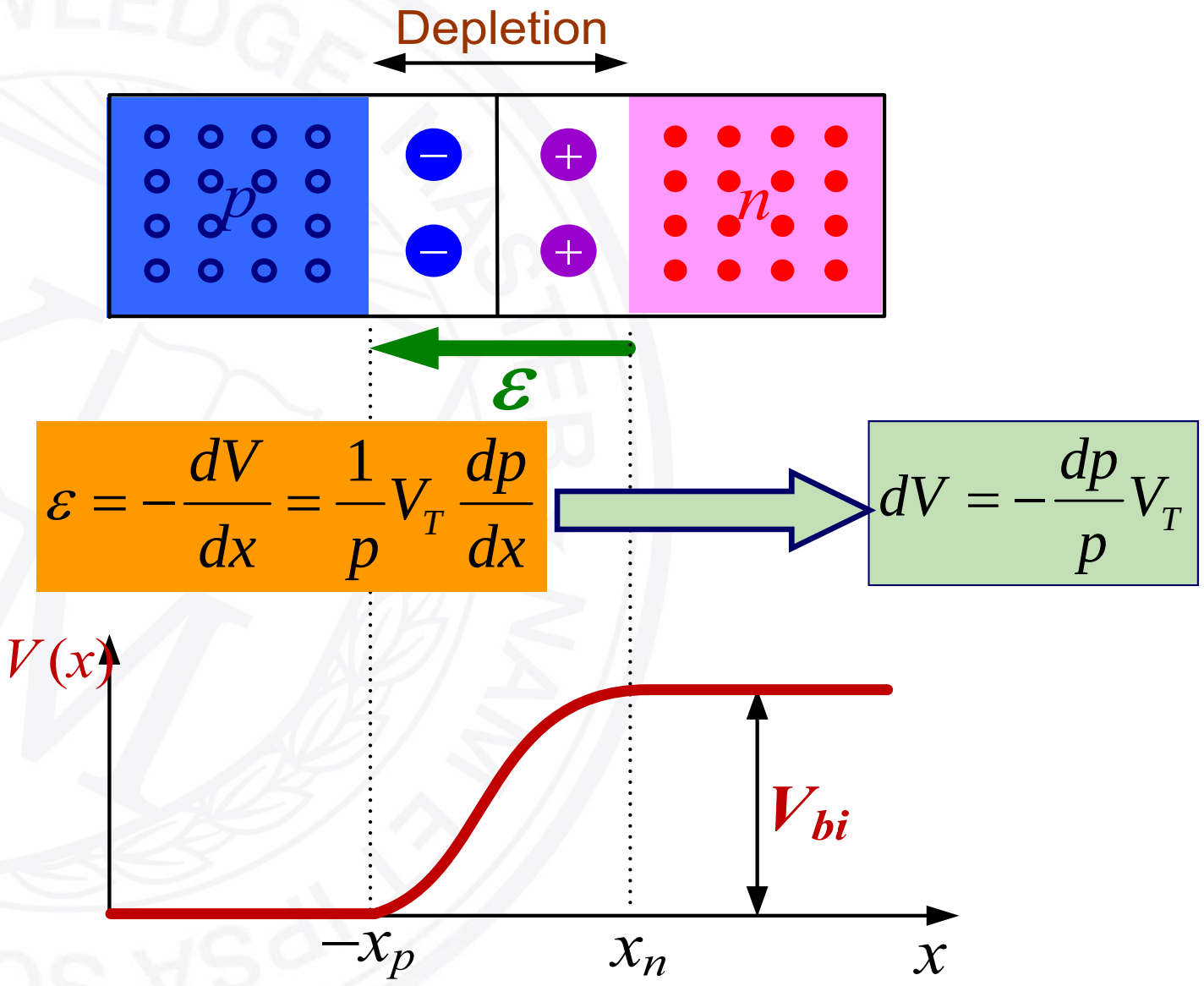
Einstein Relation

$$J_{p(net)} = pq\mu_p\varepsilon - qD_p\frac{dp}{dx} = 0$$

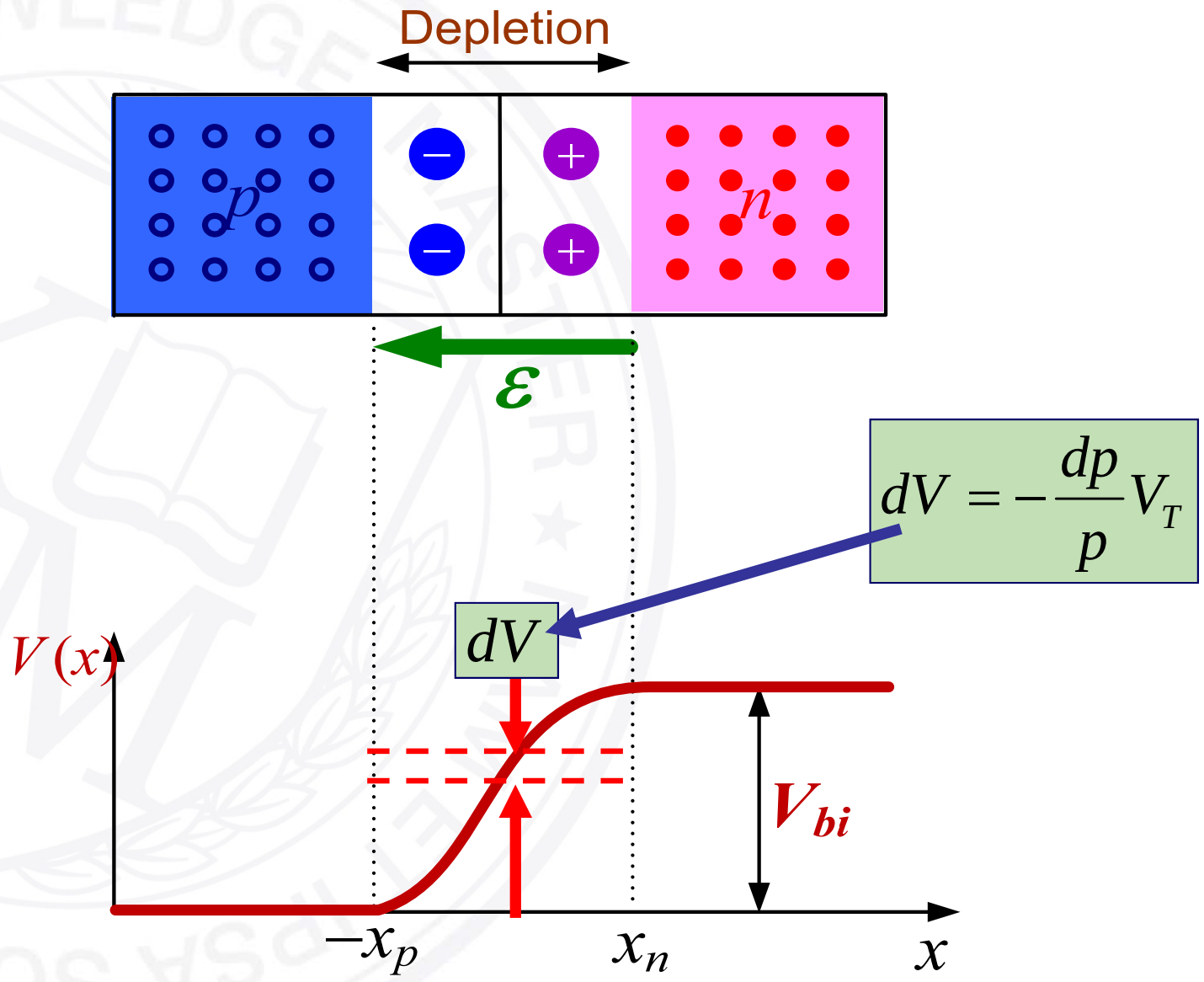
$$\frac{D_p}{\mu_p} = V_T$$

$$\varepsilon = -\frac{dV}{dx} = \frac{1}{p}V_T\frac{dp}{dx}$$

Differential Potential



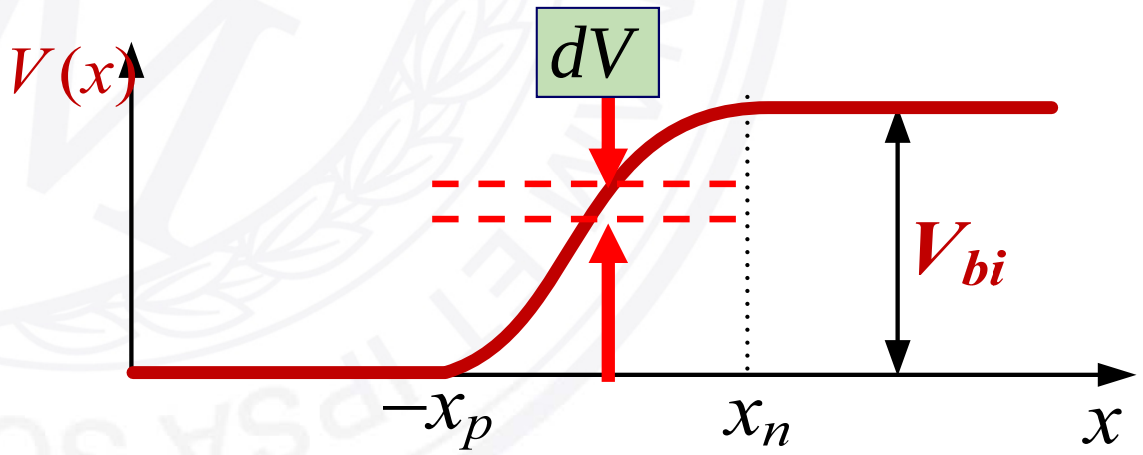
Differential Potential



Integration of Differential Potential

$$V_{bi} \triangleq \int_{-x_p}^{x_n} dV = -V_T \int_{-x_p}^{x_n} \frac{dp}{p}$$

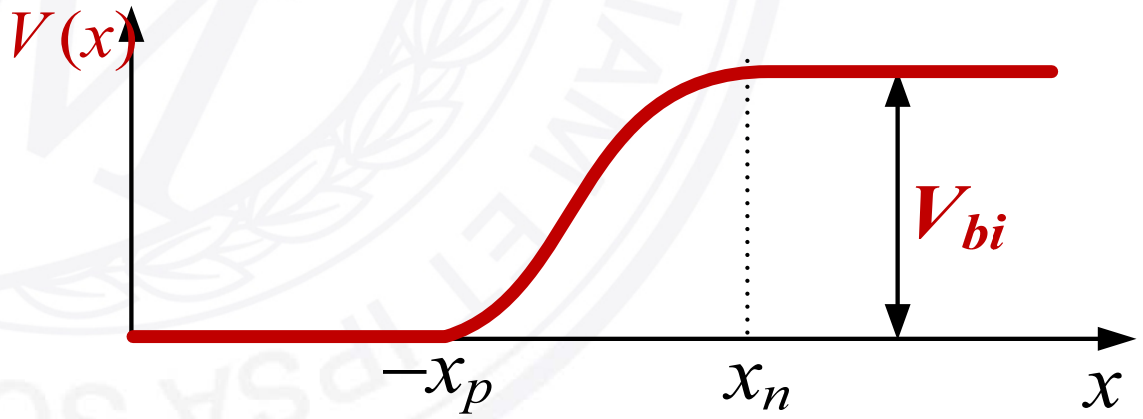
$$dV = -\frac{dp}{p} V_T$$



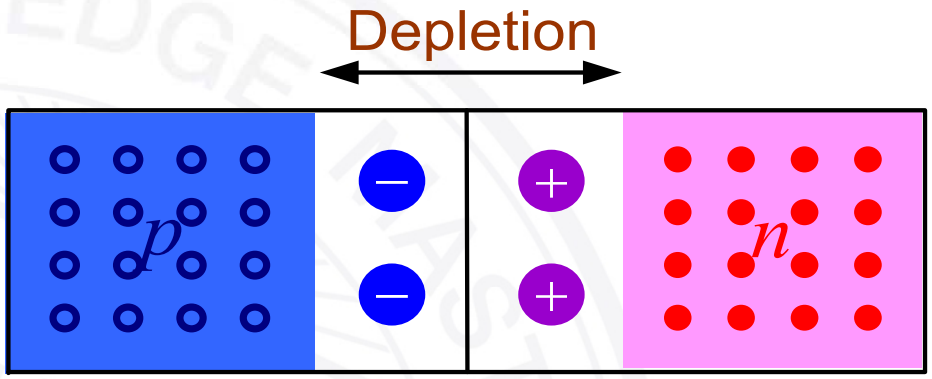
Built-in Potential

$$V_{bi} \triangleq \int_{-x_p}^{x_n} dV = -V_T \int_{-x_p}^{x_n} \frac{dp}{p}$$

$$V_{bi} = -V_T \ln \frac{p(x = x_n)}{p(x = -x_p)} = V_T \ln \frac{p(x = -x_p)}{p(x = x_n)}$$

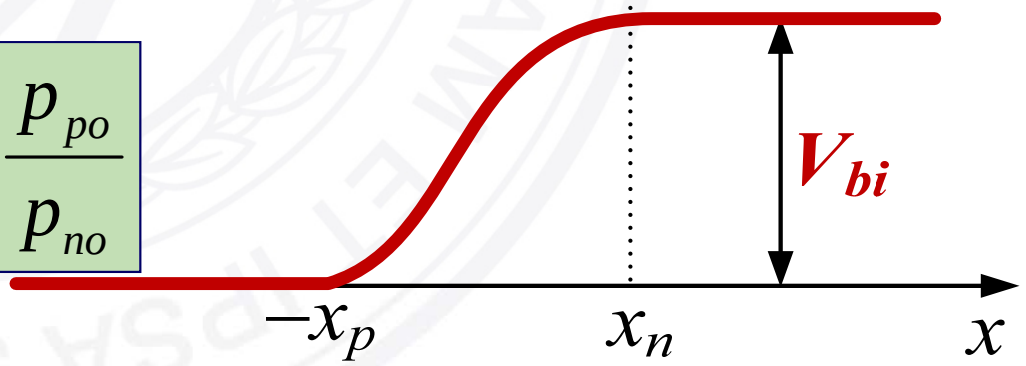


Built-in Potential

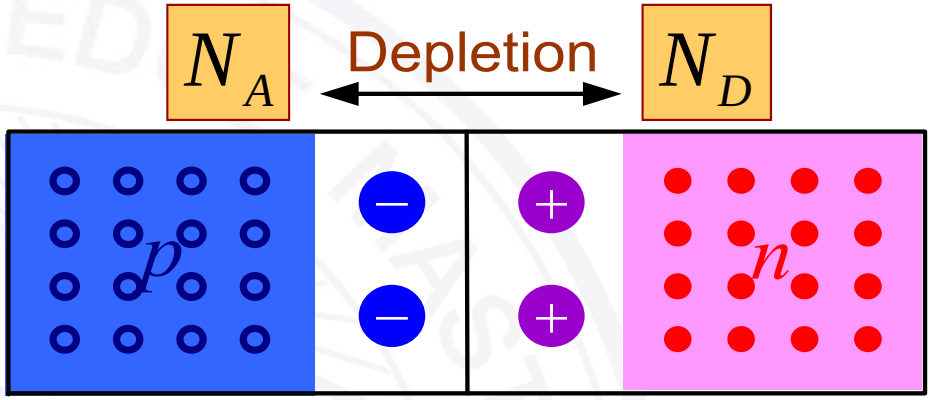


$$V_{bi} = -V_T \ln \frac{p(x = x_n)}{p(x = -x_p)} = V_T \ln \frac{p(x = -x_p)}{p(x = x_n)}$$

$$V_{bi} = V_T \ln \frac{p_{po}}{p_{no}}$$



Built-in Potential

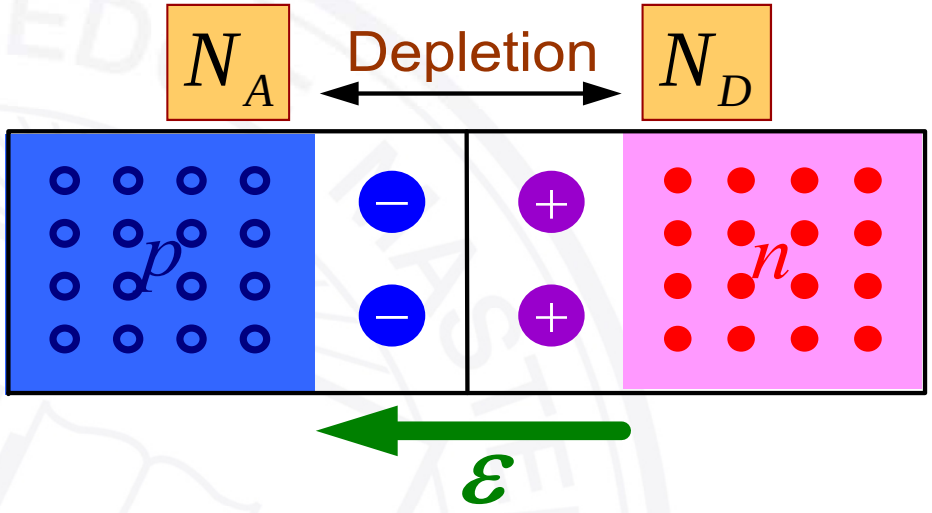


$$p_{po} \cong N_A \qquad n_{no} \cong N_D$$

$$n_{po} = \frac{n_i^2}{N_A} \qquad p_{no} = \frac{n_i^2}{N_D}$$

$$V_{bi} = V_T \ln \frac{p_{po}}{p_{no}} \Rightarrow V_{bi} \cong V_T \ln \frac{N_A}{n_i^2 / N_D}$$

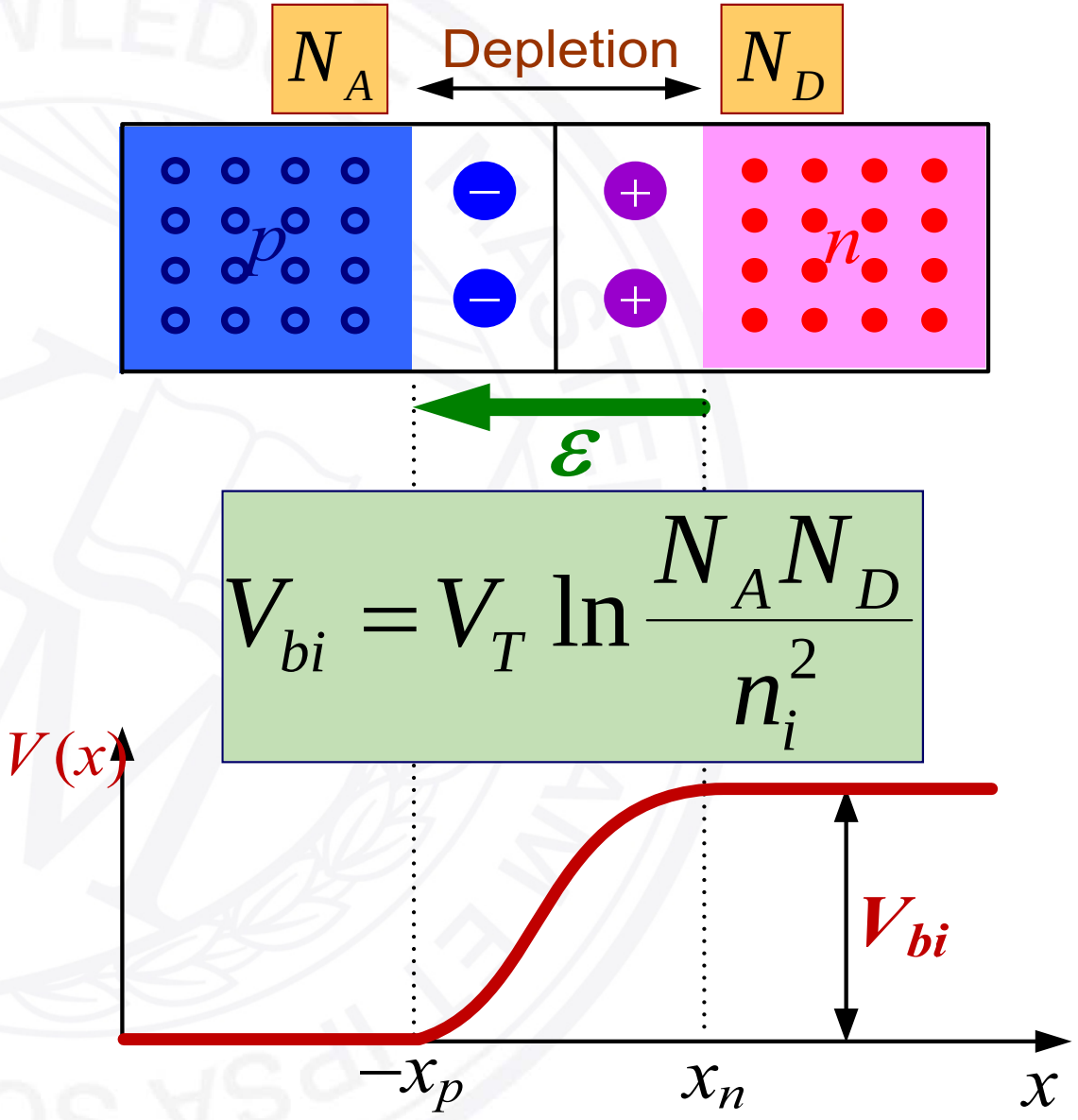
Built-in Potential



$$V_{bi} = V_T \ln \frac{N_A N_D}{n_i^2}$$

$$V_{bi} \cong V_T \ln \frac{N_A}{n_i^2 / N_D}$$

Built-in Potential Vbi



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