

# Physics of Electronics:

## 6. Junction Diodes

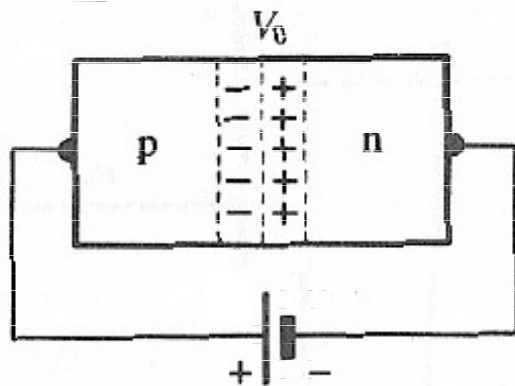
July – December 2009

# Contents overview

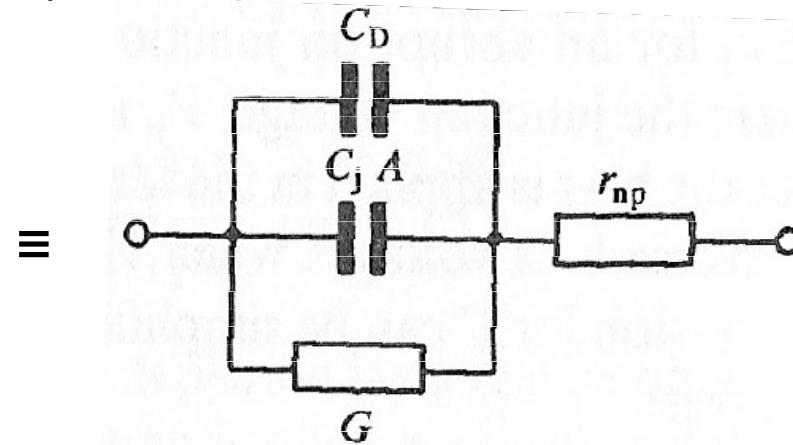
- Metal – semiconductor junctions.
- Zener diode.
- Tunnel diode.
- Bipolar junction transistor

# Equivalent circuit

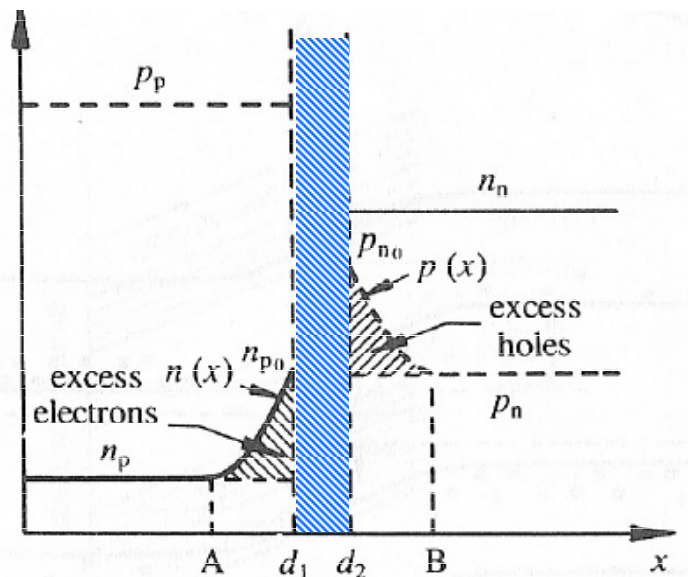
- Forward biased junction:



$$V_{tot} = V + V_1 \exp(i\omega t)$$



$$p_{n0} = p_n \exp\left(\frac{e}{kT}[V + V_1 \exp(j\omega t)]\right)$$



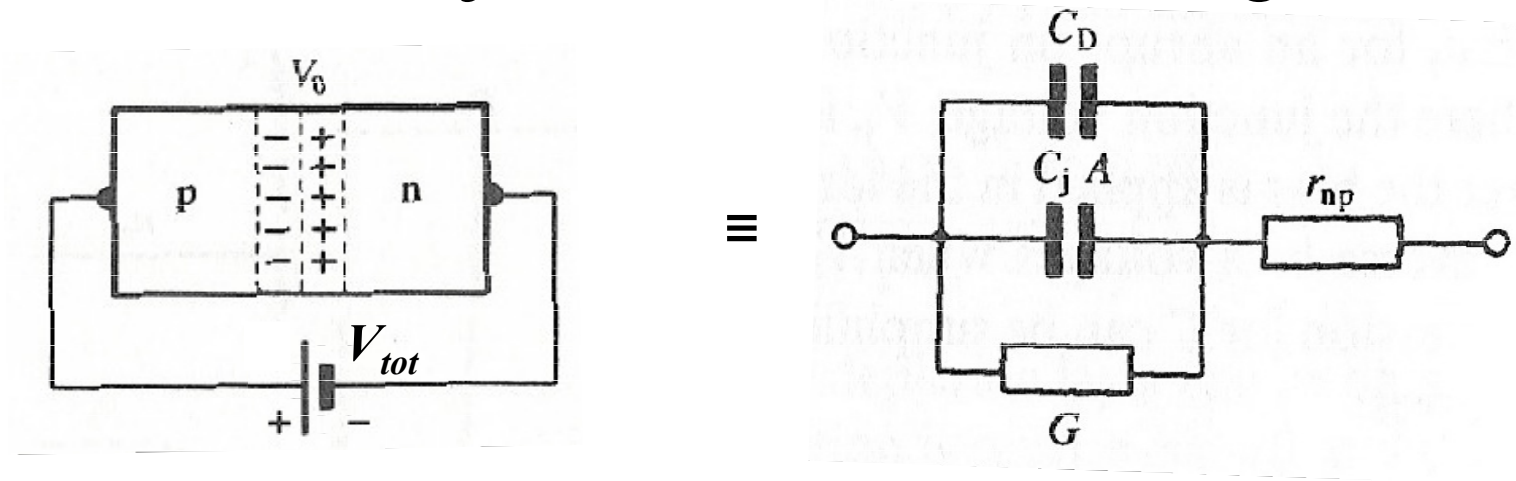
$$V_1 \ll V$$

$$p_{n0} = p_n \exp\left(\frac{eV}{kT}\right) \left(1 + \frac{eV_1}{kT} \exp(j\omega t)\right)$$

$$\delta p = p(x, t) - p_n = p_0(x) + p_1(x) \exp(j\omega t) - p_n$$

# Equivalent circuit

- Forward biased junction with an AC signal:



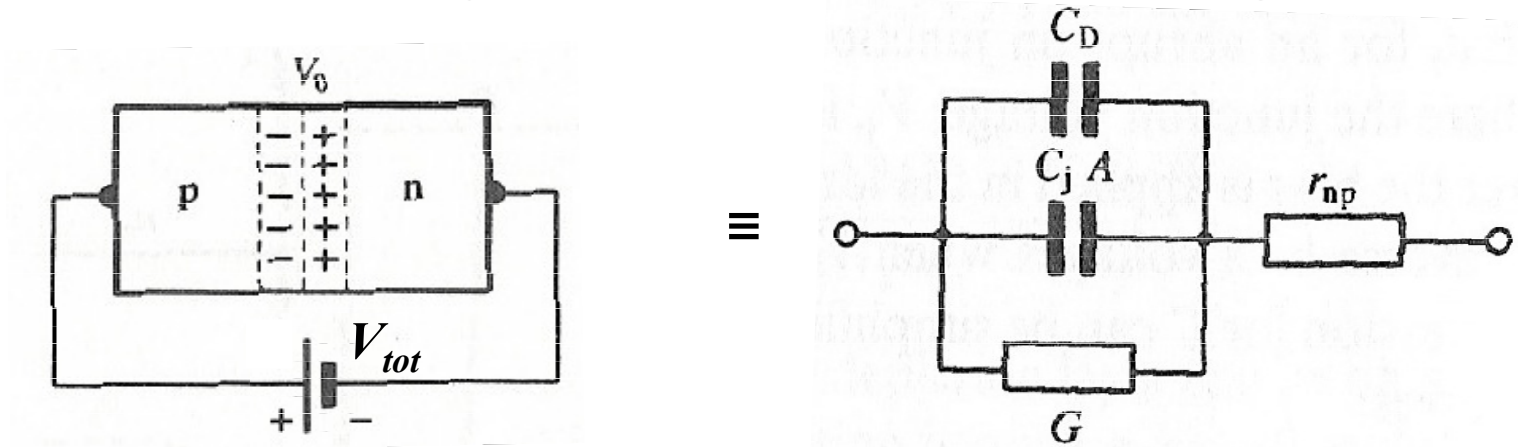
$$\delta p = p(x, t) - p_n = p_0(x) + p_1(x) \exp(j\omega t) - p_n$$

$$\rightarrow \frac{\partial(\delta p)}{\partial t} = -\frac{\delta p}{\tau_{Lh}} + \mu_h E_x \frac{\partial(\delta p)}{\partial x} - D_h \frac{\partial^2(\delta p)}{\partial x^2}$$

$$\rightarrow p_1 = p_n \left( \frac{eV_1}{kT} \right) \exp\left( \frac{eV}{kT} \right) \exp\left( -\frac{(1 + j\omega\tau_{Lh})^{1/2} x}{L_h} \right) \exp(j\omega t)$$

# Equivalent circuit

- Forward biased junction with an AC signal:



- Alternating currents of holes injected into n-region:

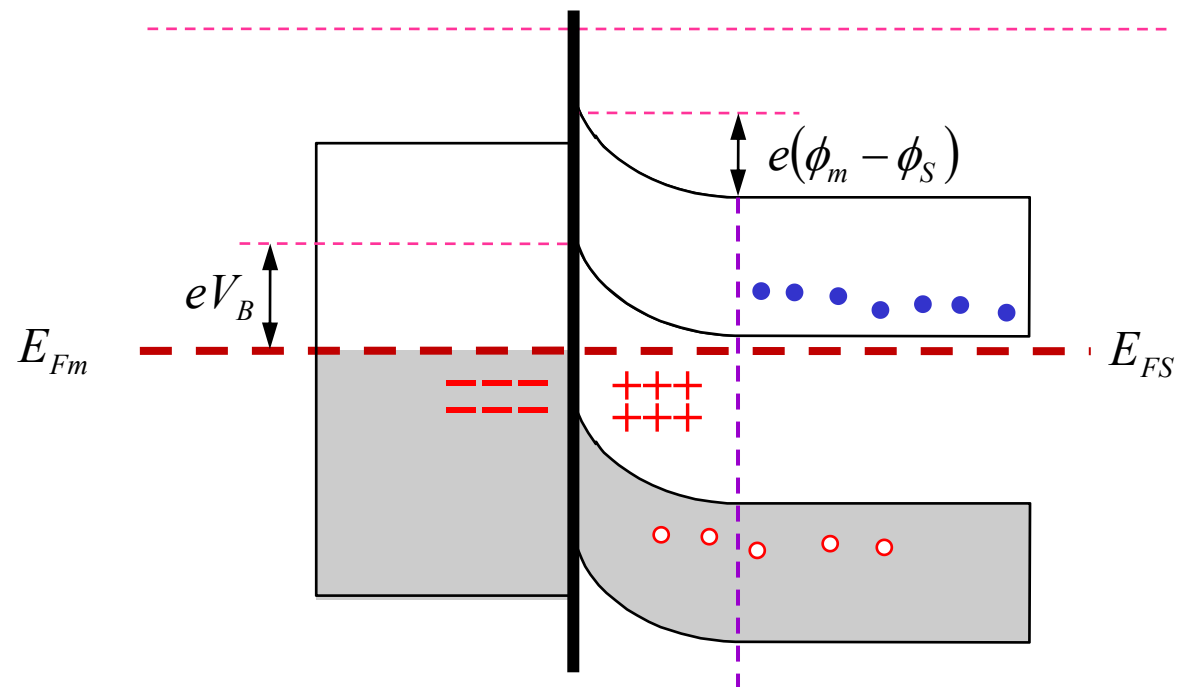
$$J_{h1} = -eD_h \left( \frac{dp(x)}{dx} \right) \Big|_{x=0} = \frac{(1+i\omega\tau_{Lh})^{1/2}}{L_h} \frac{p_n D_h e^2 V_1}{kT} \exp\left(\frac{eV}{kT}\right) \exp(i\omega t)$$

- Alternating currents of electrons injected into p-region:

$$J_{e1} = -eD_e \left( \frac{dn(x)}{dx} \right) \Big|_{x=0} = \frac{(1+i\omega\tau_{Le})^{1/2}}{L_e} \frac{n_p D_e e^2 V_1}{kT} \exp\left(\frac{eV}{kT}\right) \exp(i\omega t)$$

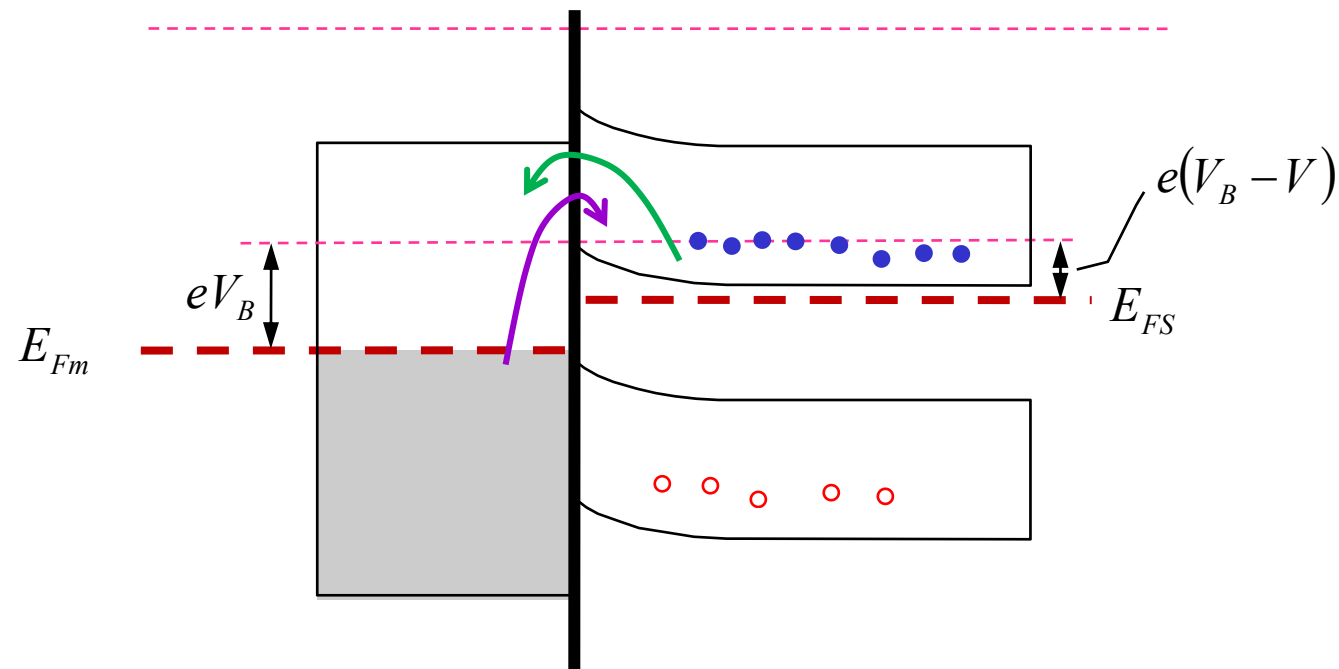
# Metal-sC junctions

- Metal – n-type sC ( $\phi_m > \phi_s$ ):
  - Unbiased junction:



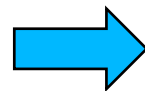
# Metal-sC junctions

- Metal – n-type sC ( $\phi_m > \phi_s$ ):
  - Forward biased junction – Current of majority carriers:



$$J_{mS} \propto \exp(-eV_B/kT)$$

$$J_{Sm} \propto \exp(-e[V_B - V]/kT)$$

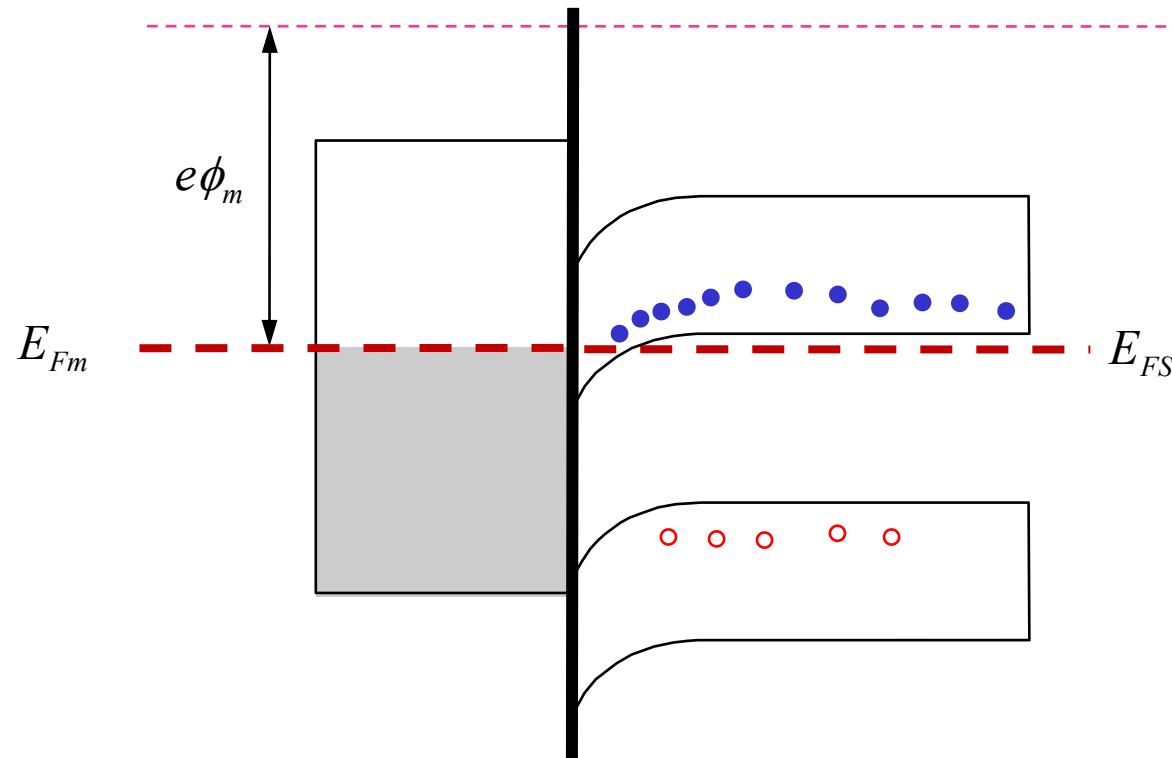


$$J \propto \exp(-eV_B/kT) [\exp(eV/kT) - 1]$$

**Non ohmic contact!!!**

# Metal-sC junctions

- Metal – n-type sC ( $\phi_m < \phi_s$ ):
  - Unbiased junction - after:



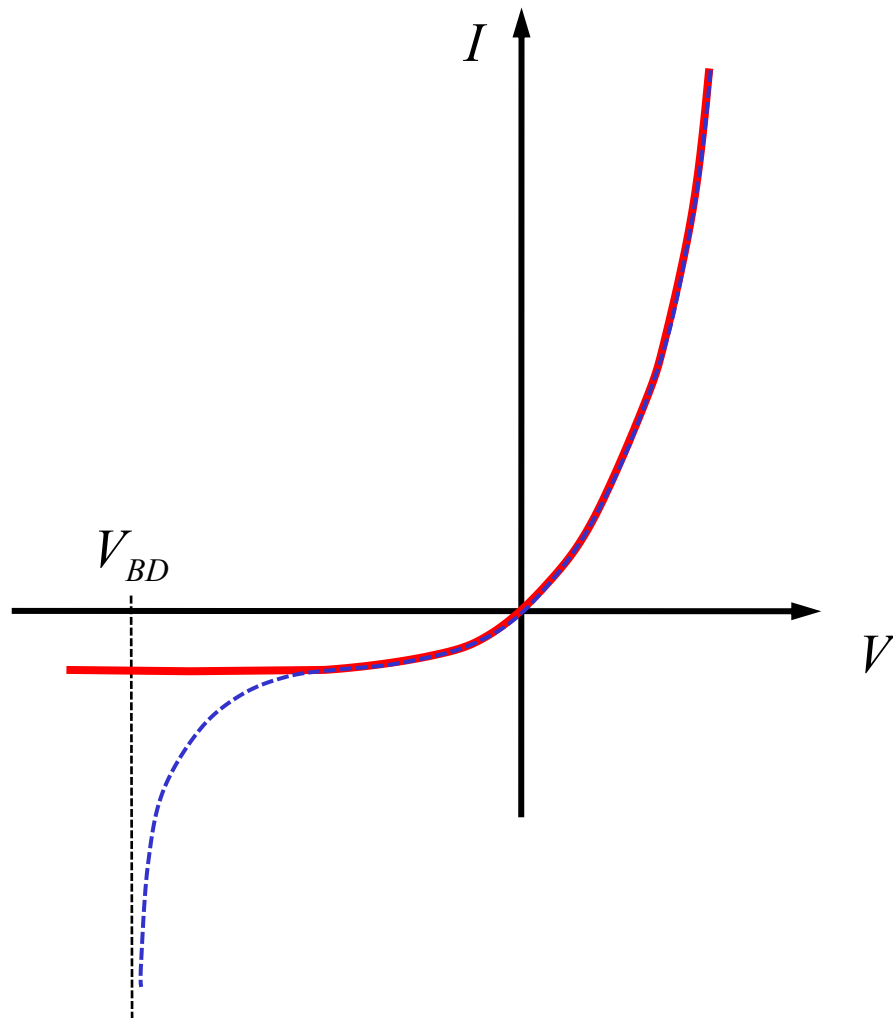
**No barrier formed.  
Ohmic contact!!!**

- Homework: analyze a metal – p-type sC junction.



# The Zener Diode

- Breakdown voltage:



**Ideal diode:** current limited if reversed biased

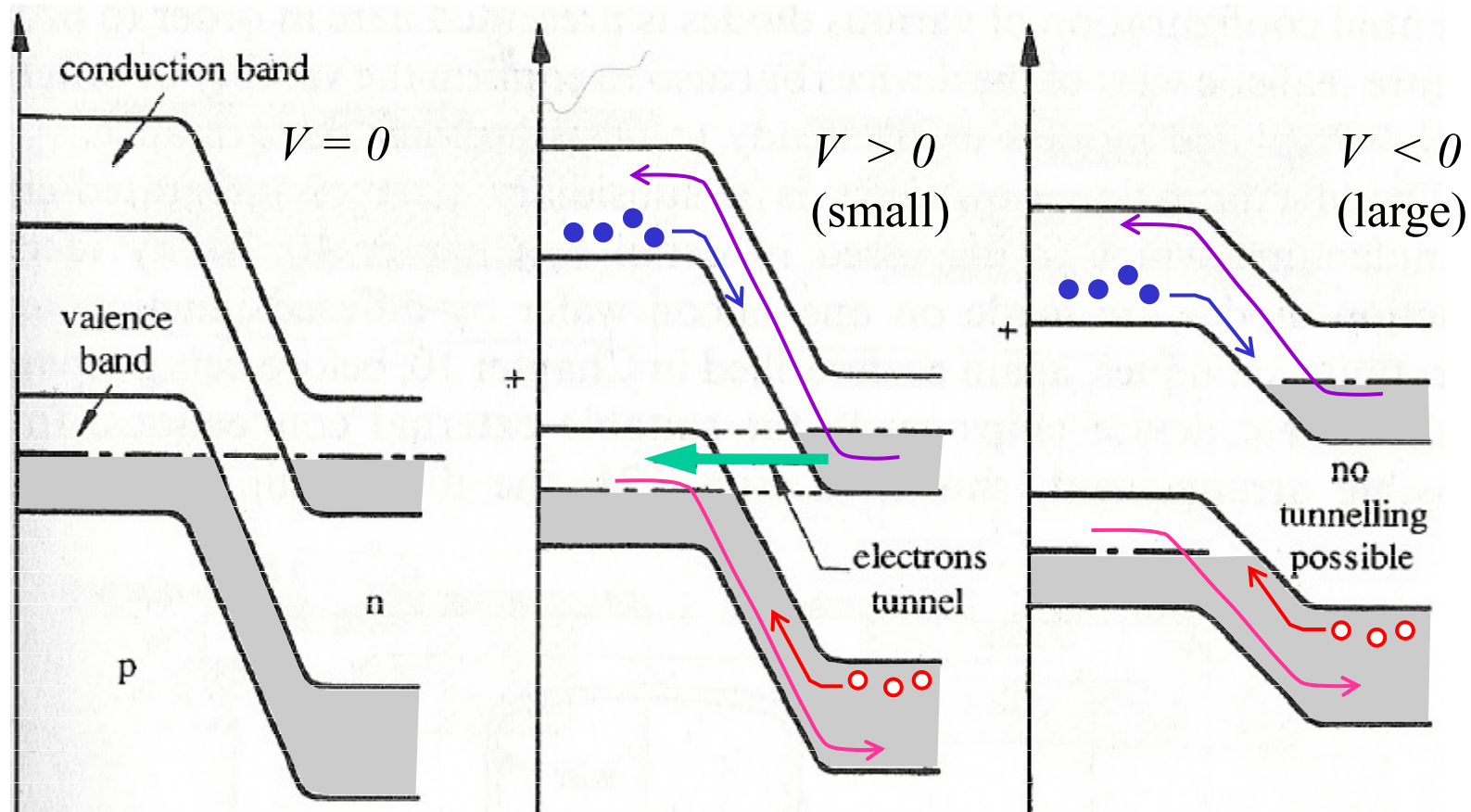
**Real diode:** voltage limited if reversed biased

**Avalanche**

**Tunnel**

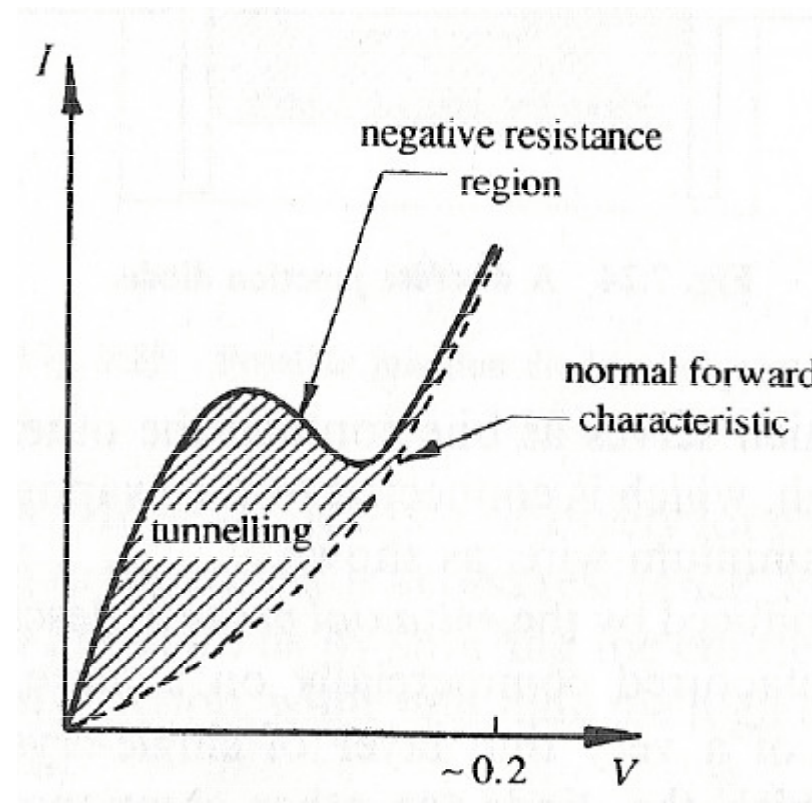
# The Tunnel Diode

- Highly-doped pn junctions ( $V_0$  is large &  $d_p, d_n$  short).
  - Fermi energy cross the bands.
  - Tunneling is favored.



# The Tunnel Diode

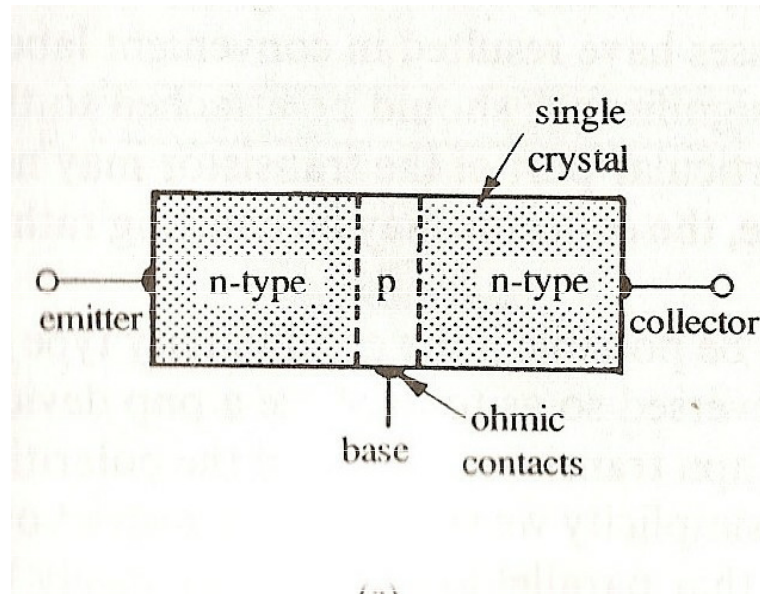
- Highly-doped pn junctions ( $V_0$  is large &  $d_p, d_n$  short).
  - Fermi energy cross the bands.
  - Tunneling is favored.
  - Extra current source at  $V$  small.



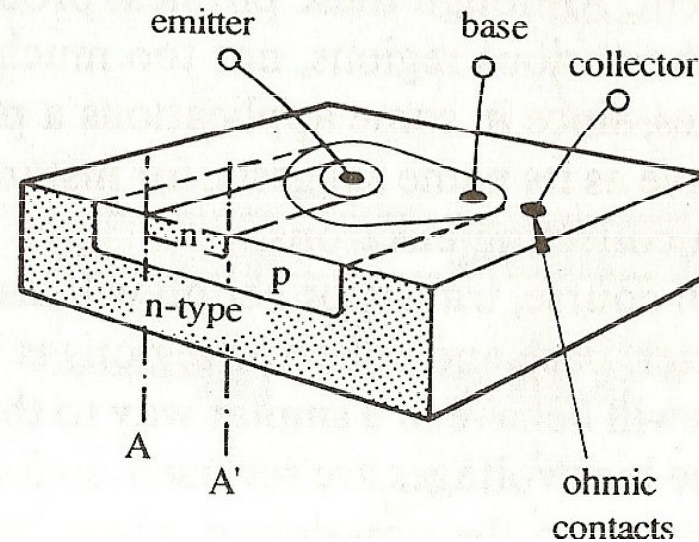
# Ideal Bipolar Junction Transistor

- Basics

Schematic representation



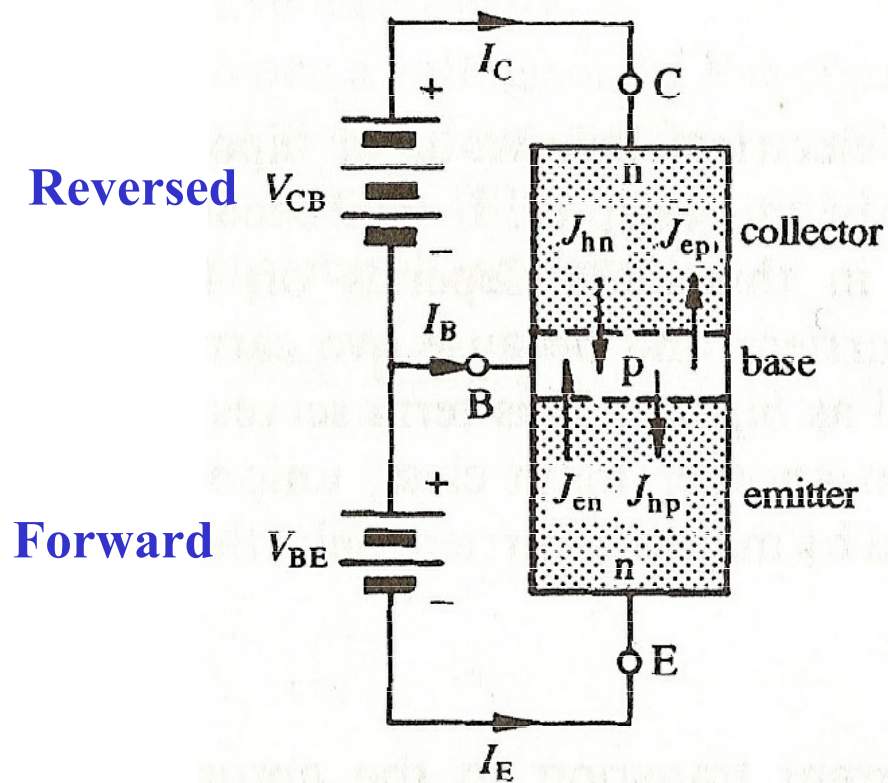
Actual realization



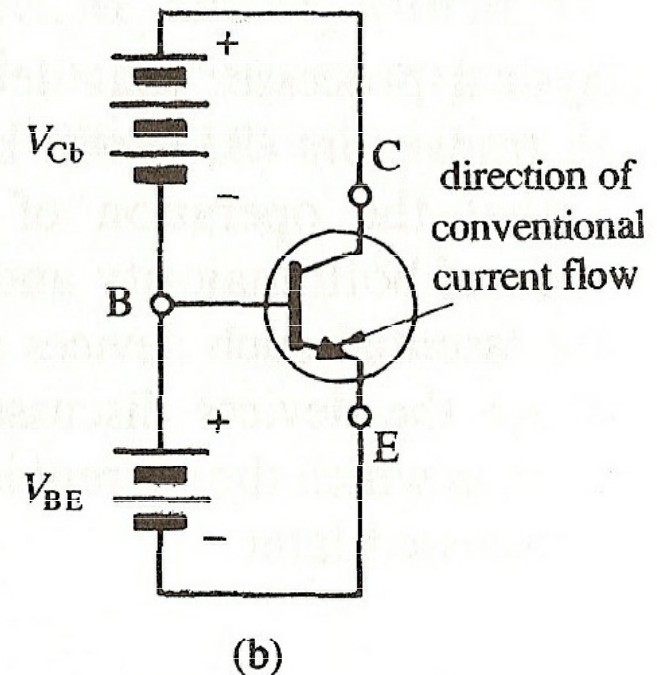
# Ideal Bipolar Junction Transistor

- Basics

Normal biasing

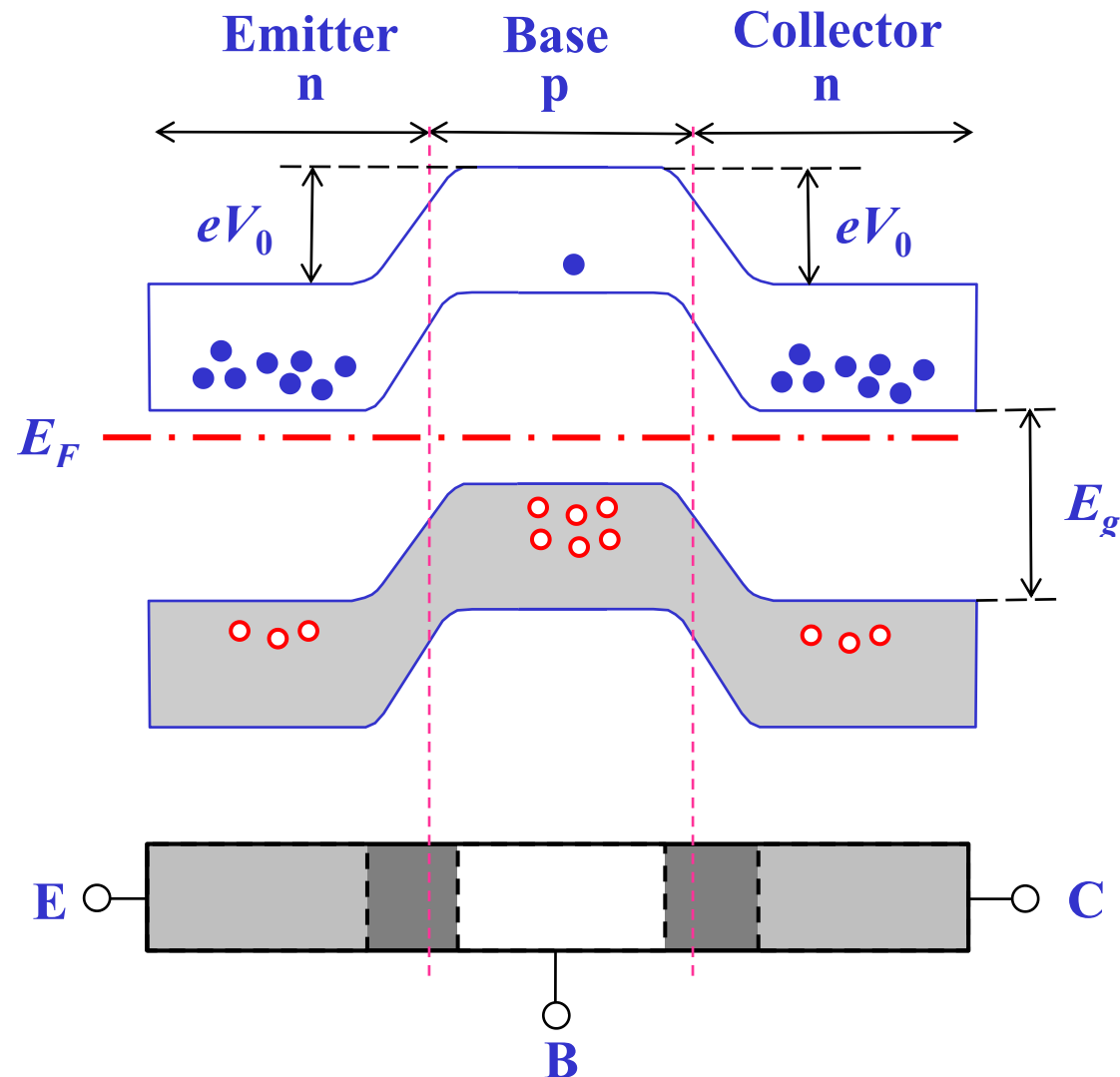


Circuit representation



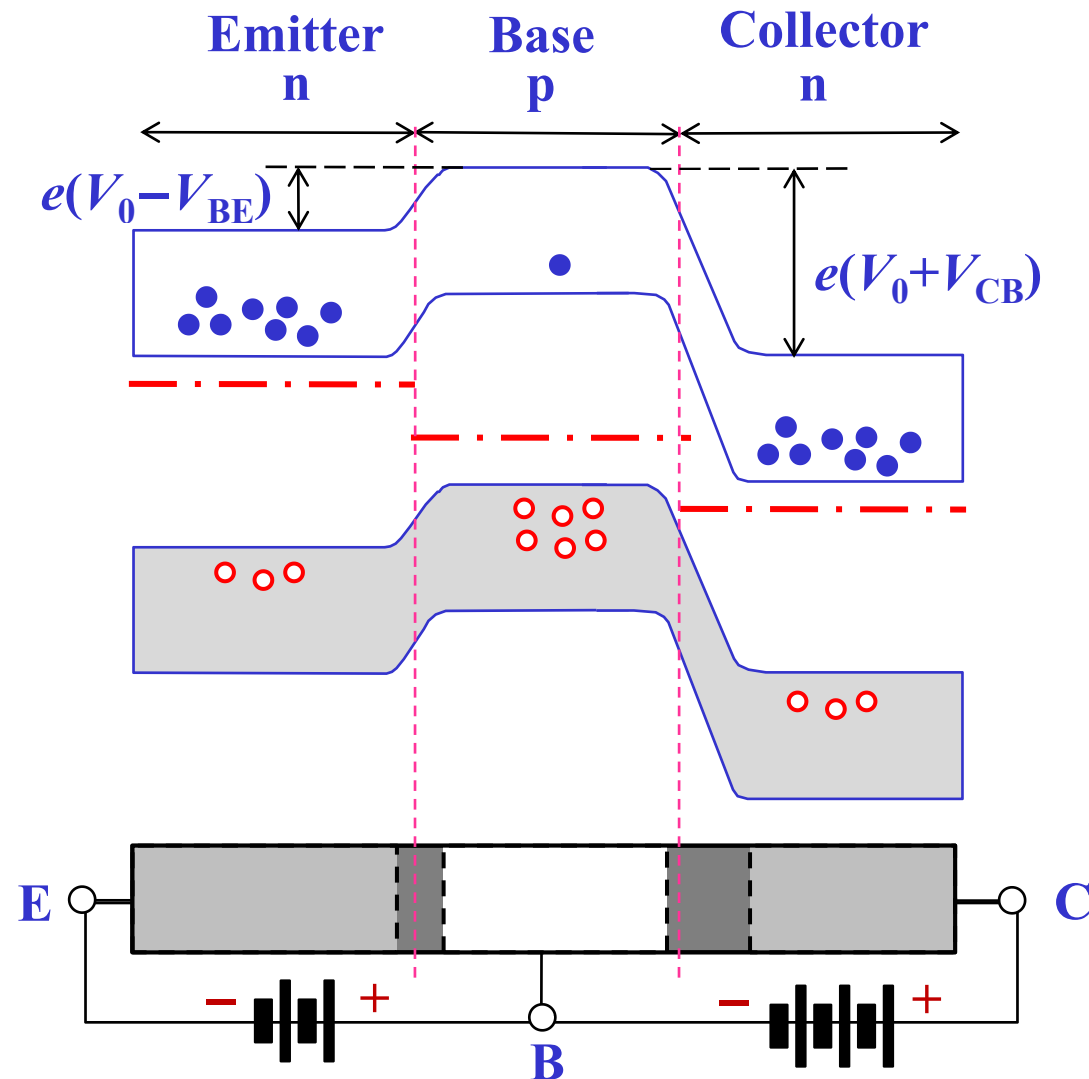
# Ideal Bipolar Junction Transistor

- Phenomenological description - unbiased:



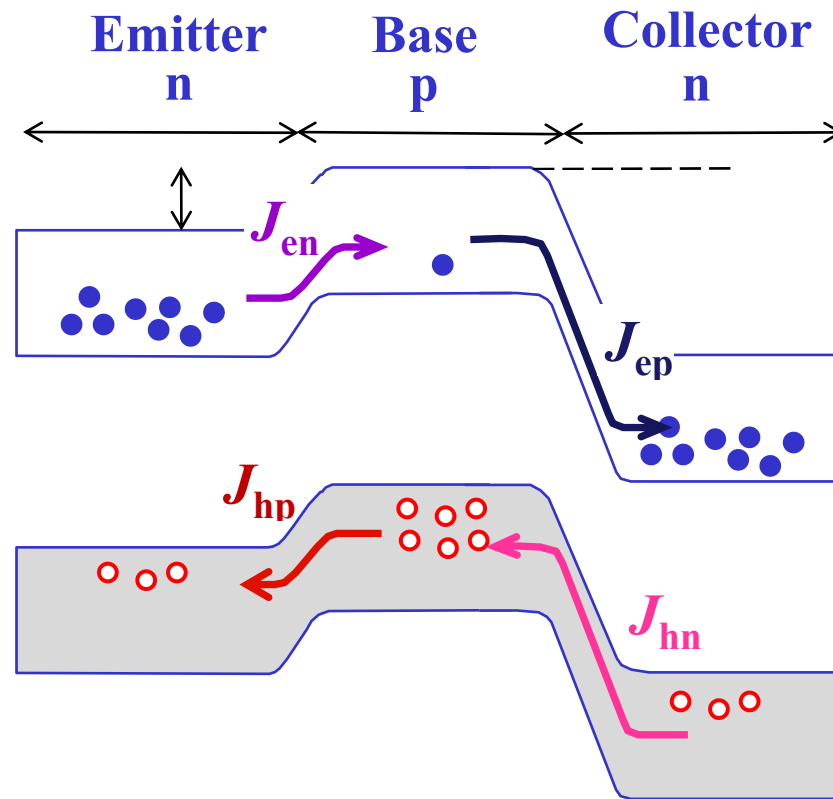
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# Ideal Bipolar Junction Transistor

- Phenomenological description - biased:

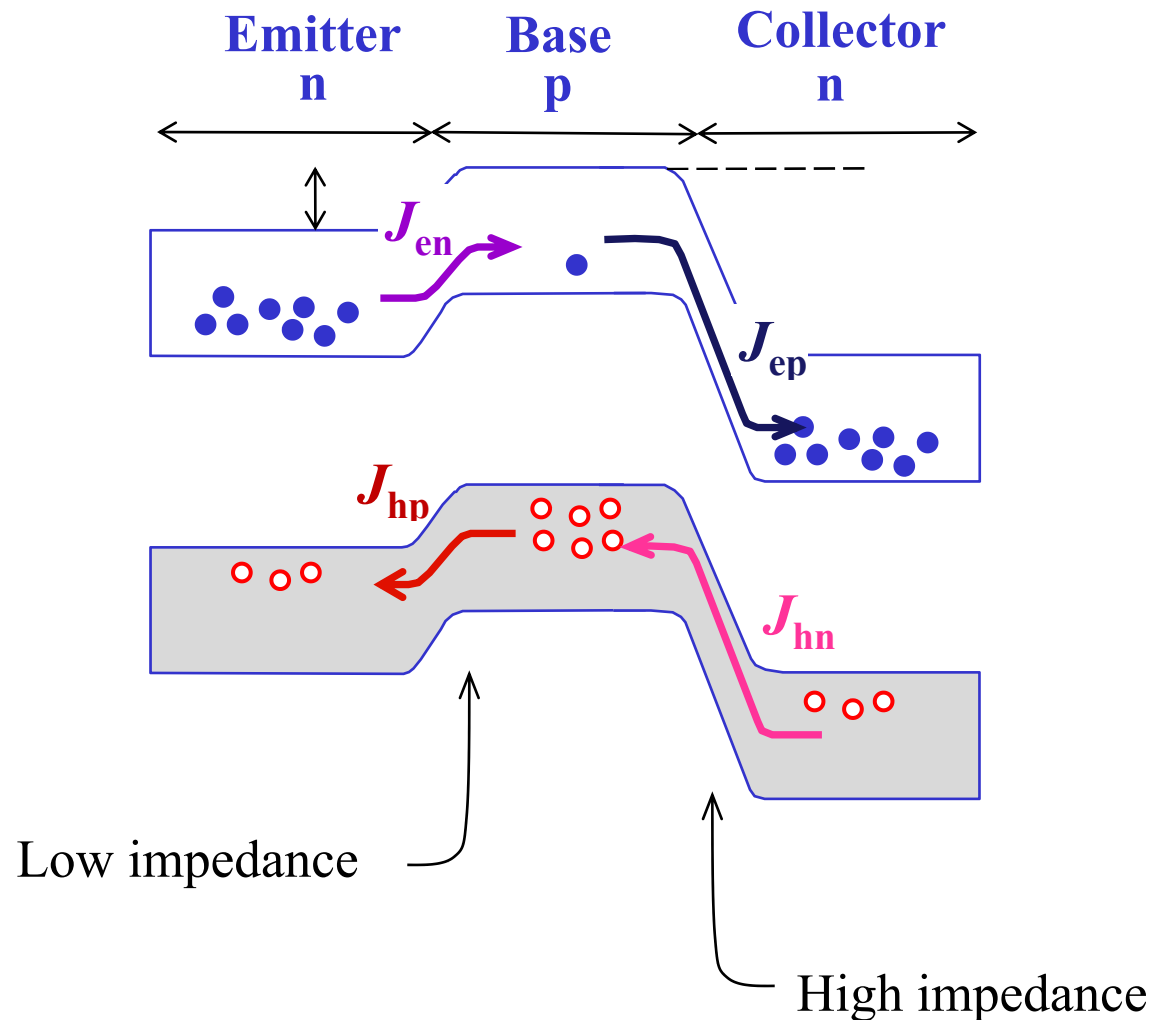


For optimal operation,  $J_{en} \gg J_{hp}$



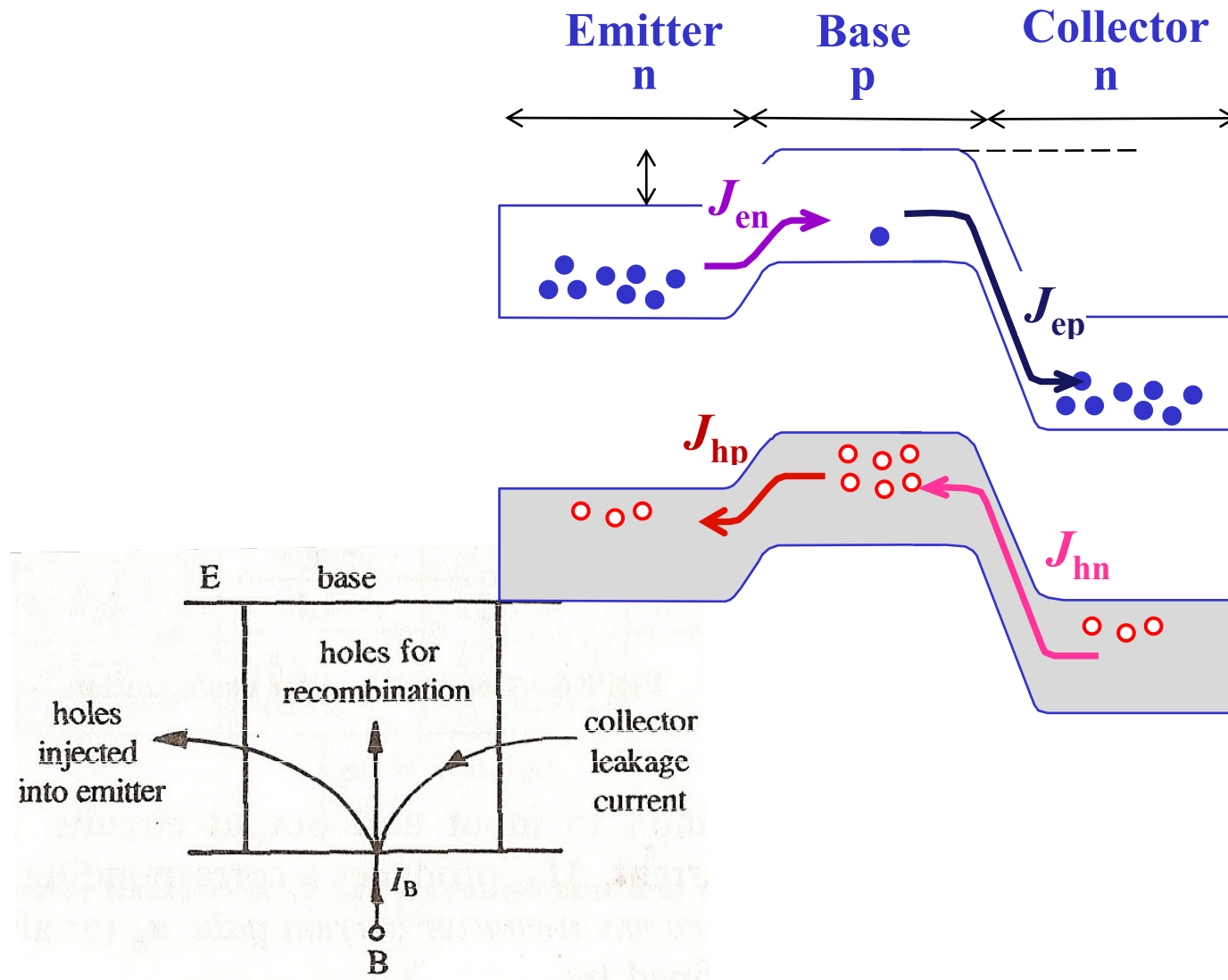
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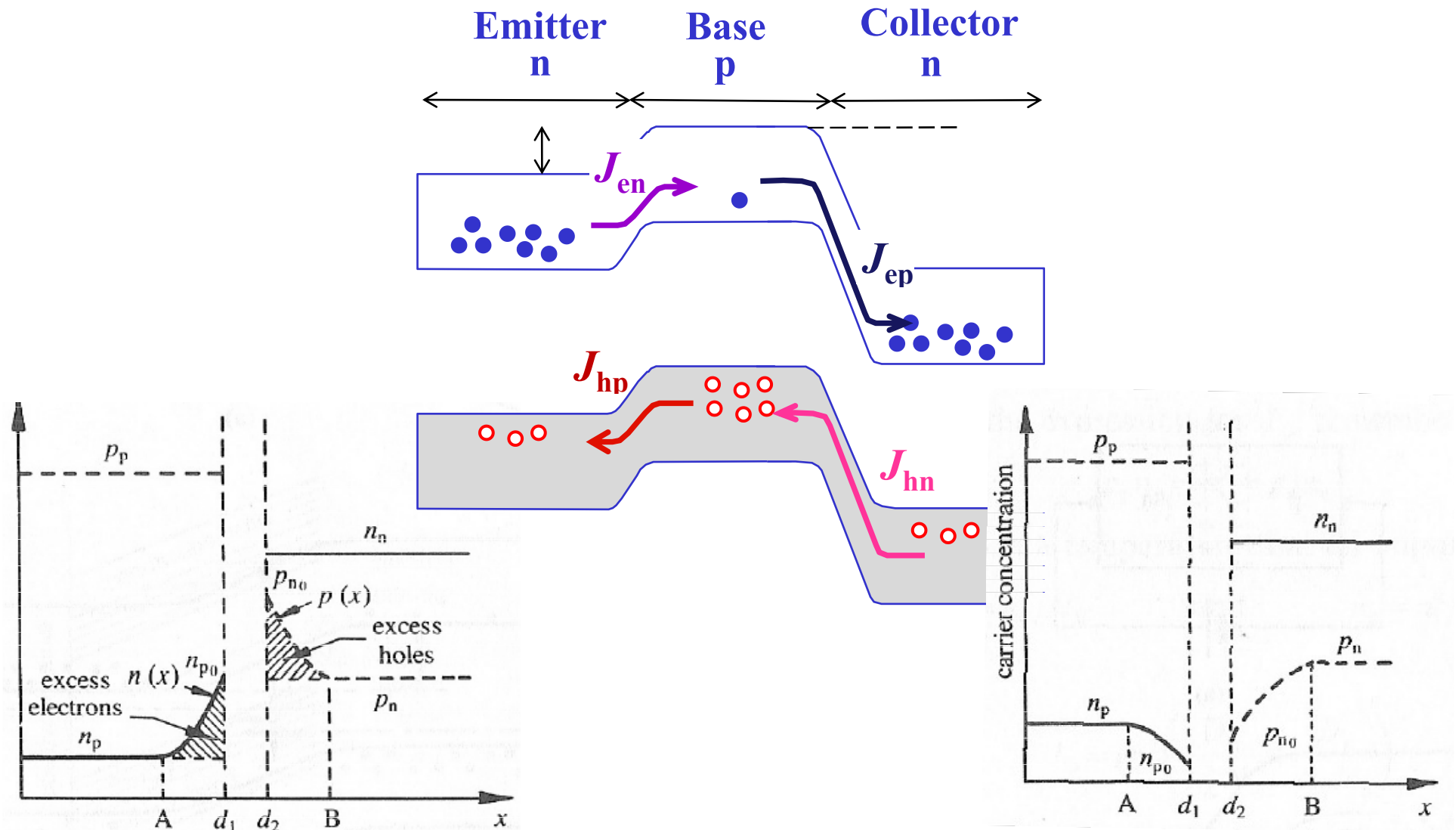
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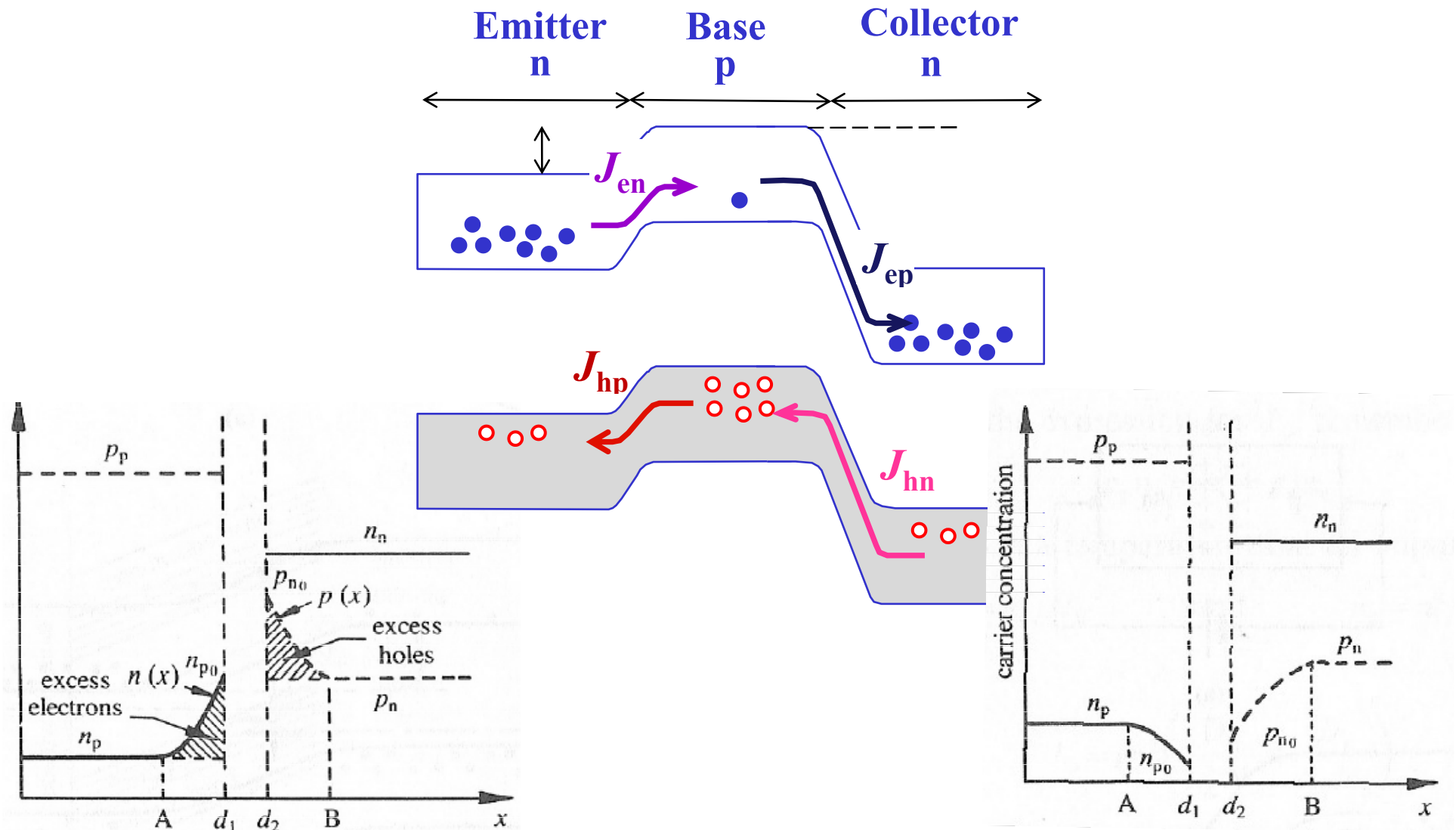
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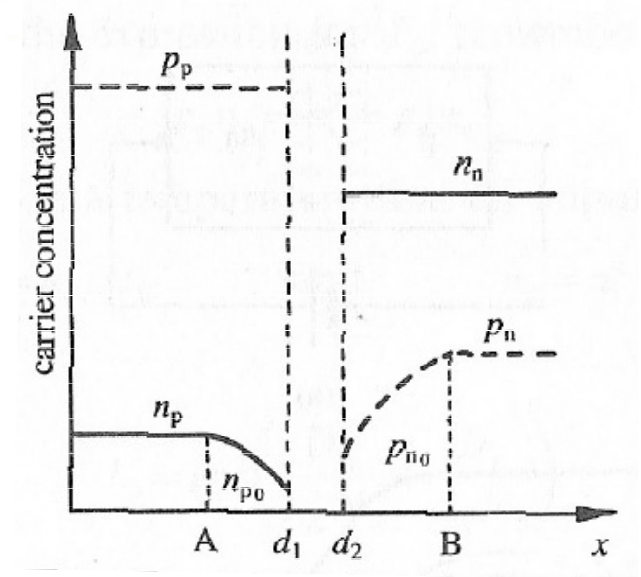
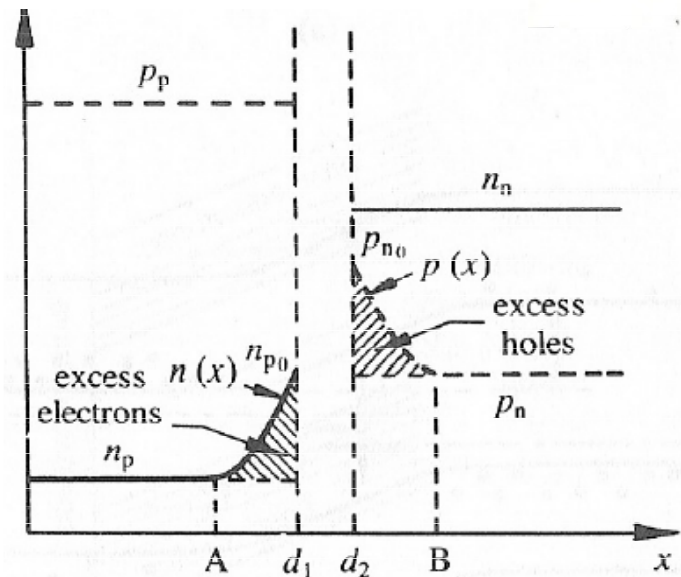
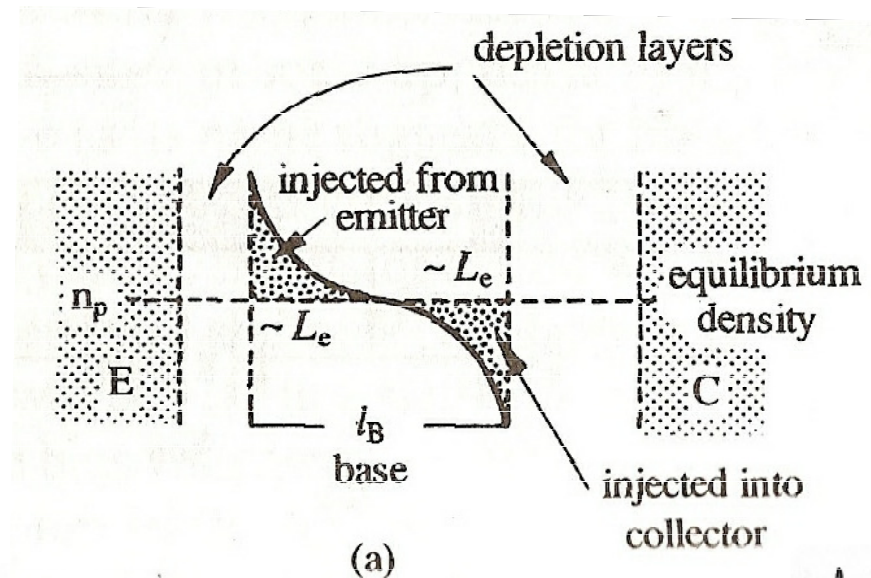
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- Phenomenological description - biased:



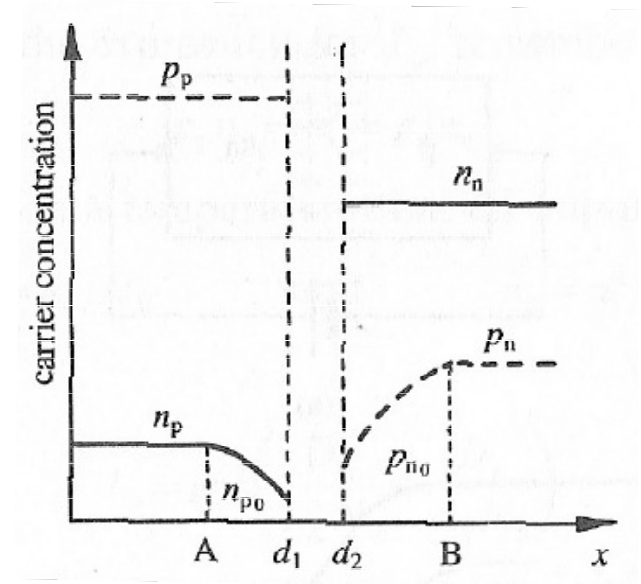
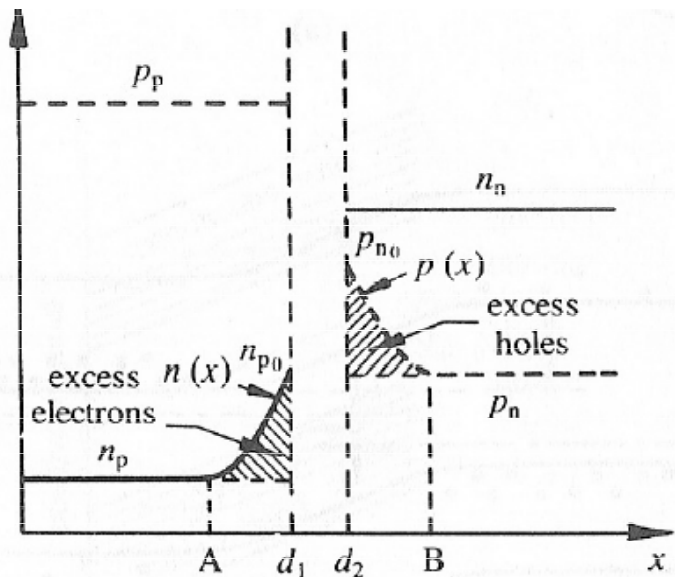
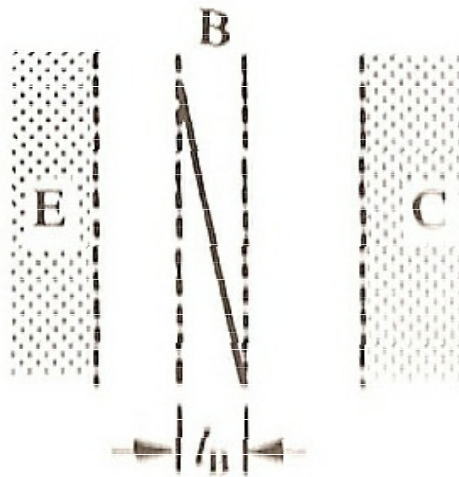
# Ideal Bipolar Junction Transistor

- Phenomenological description - biased:



# Ideal Bipolar Junction Transistor

- Phenomenological description - biased:



# Conclusions

- The BJT was introduced.
- A phenomenological description was made.