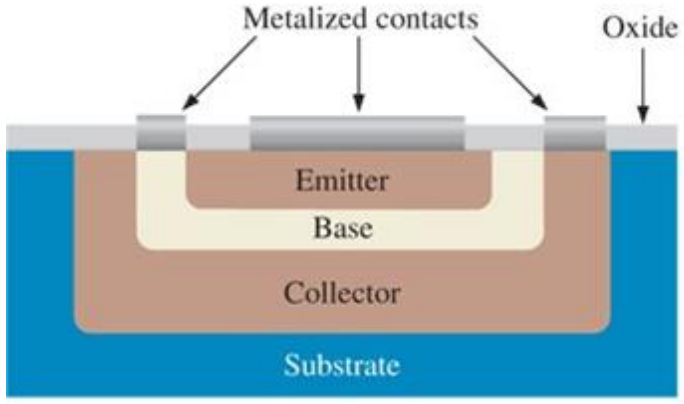
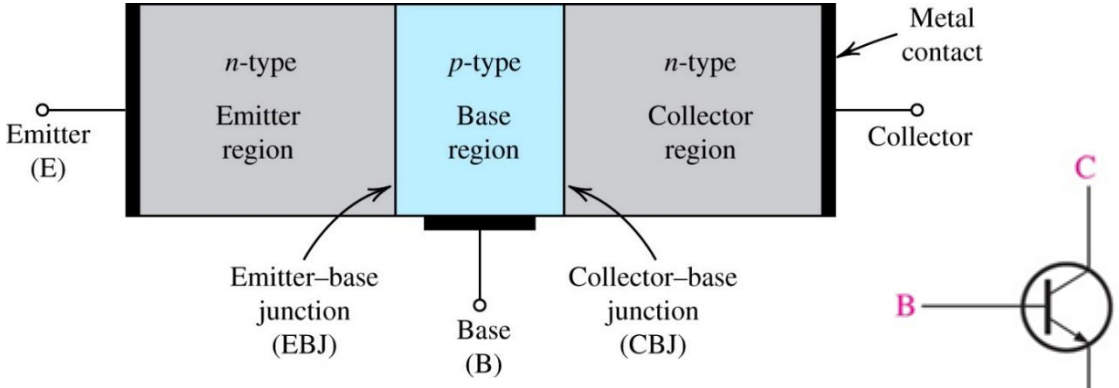
Bipolar Junction Transistors → Chapter 6

- **A three terminal device** *cross section*
- **Invented in 1948 at Bell Telephone Laboratories**
- **Ushered in a new era of solid-state circuits**
- **Replaced by MOSFET as predominant transistors**



- **Simplified structure of the *npn* transistor**



npn symbol

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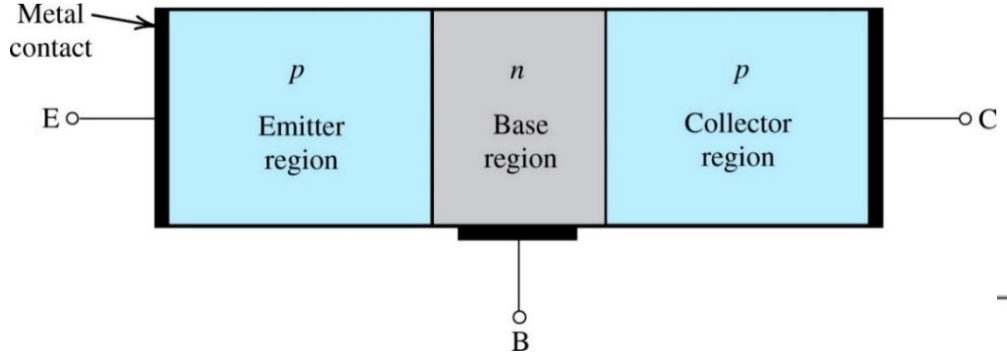
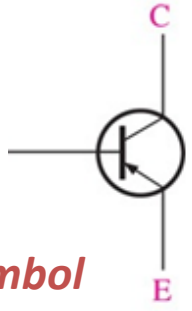




pnp symbol

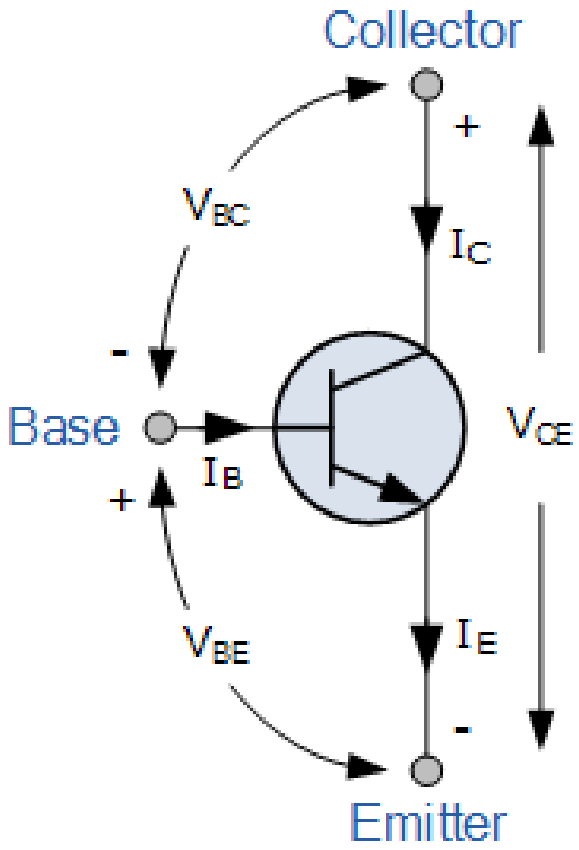
BJT → npn

Voltages are measured with respect to the emitter (lowest potential)

- V_{BE} – base to emitter voltage
- V_{CE} – collector to emitter voltage

Electrons flow from the emitter to the collector terminal

- I_B – base current (in)
- I_E – emitter current
- I_C – collector current



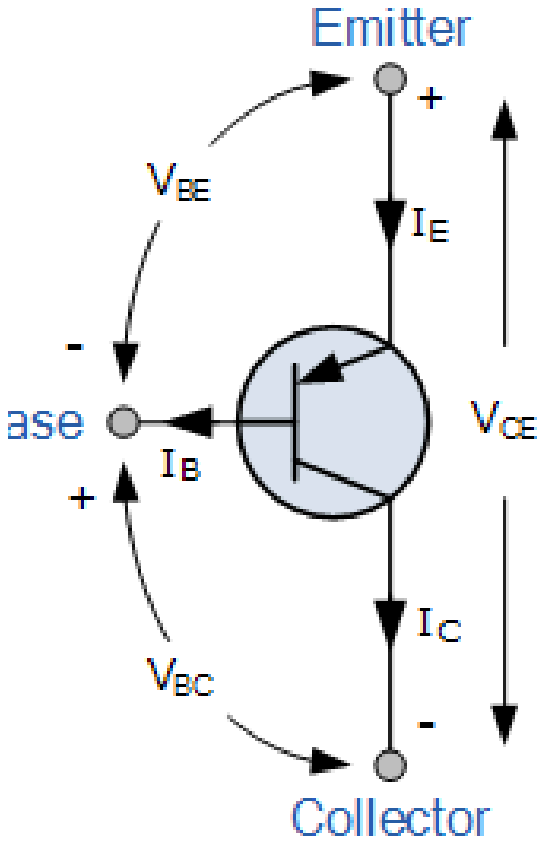
BJT → pnp

Voltages are measured with respect to the emitter (highest potential)

- V_{EB} – base to emitter voltage
- V_{EC} – collector to emitter voltage

Holes flow from the emitter to the collector terminal

- I_B – base current (out)
- I_E – emitter current
- I_C – collector current



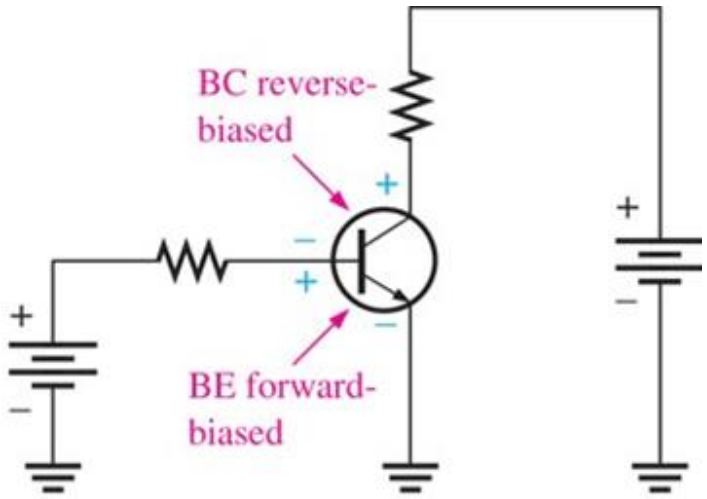
BJT Operation

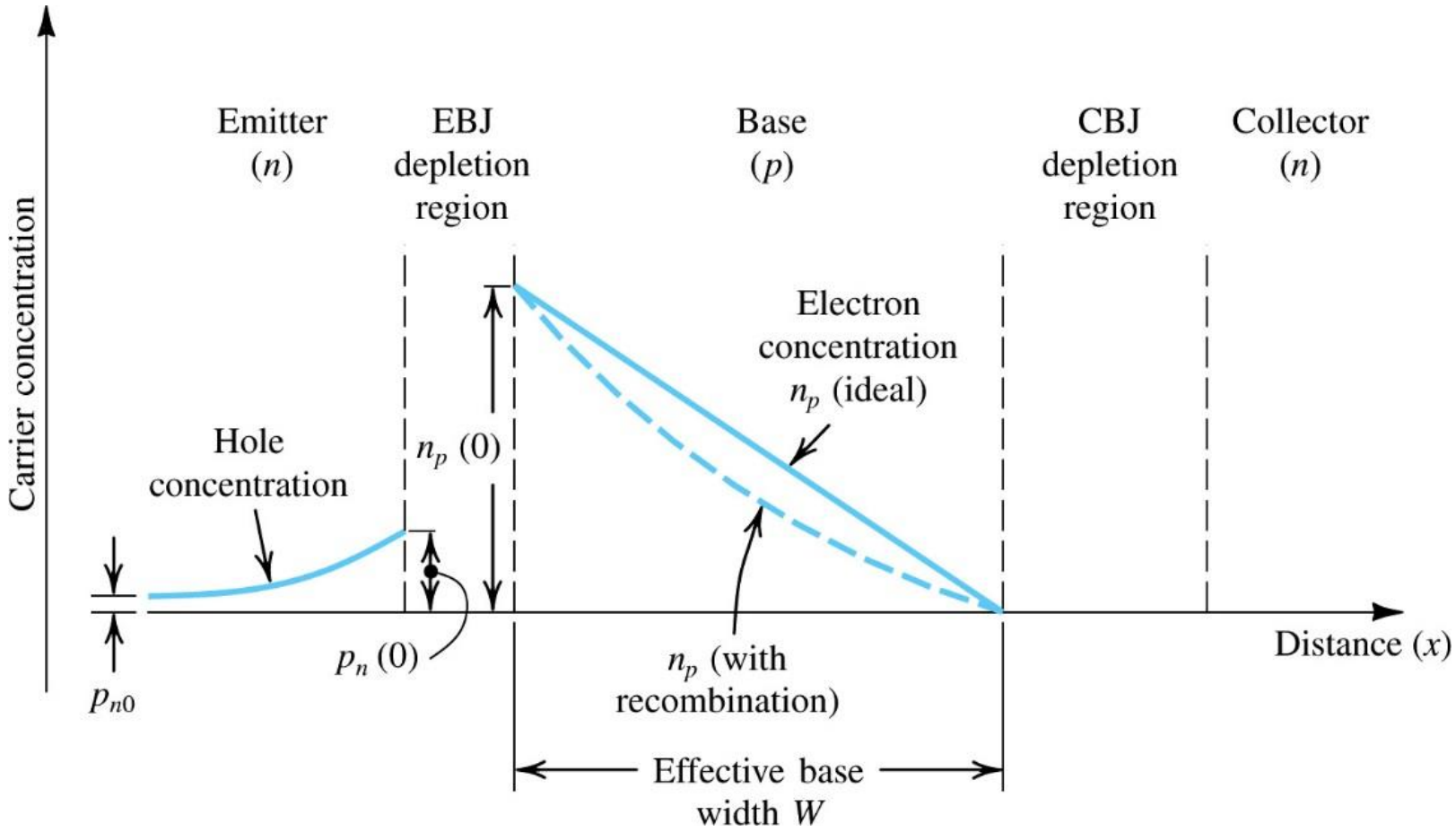
- **Two external voltage sources are required for biasing**
- **Three operation modes:**

used for switching!

1) Cut-Off
2) Saturation
3) Active

used for amplification!





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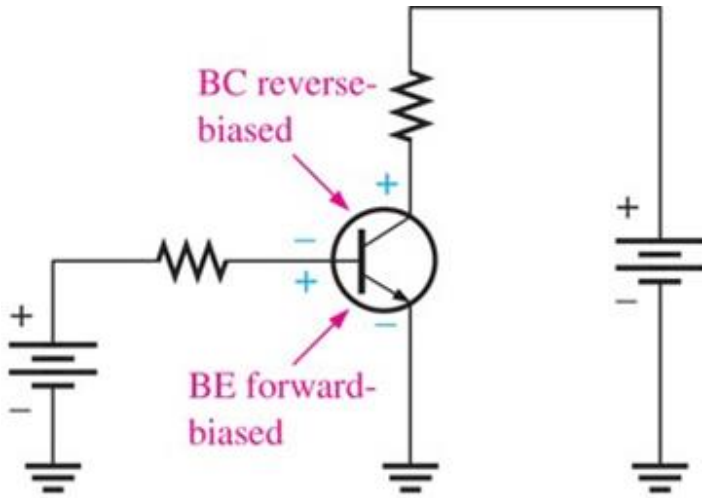
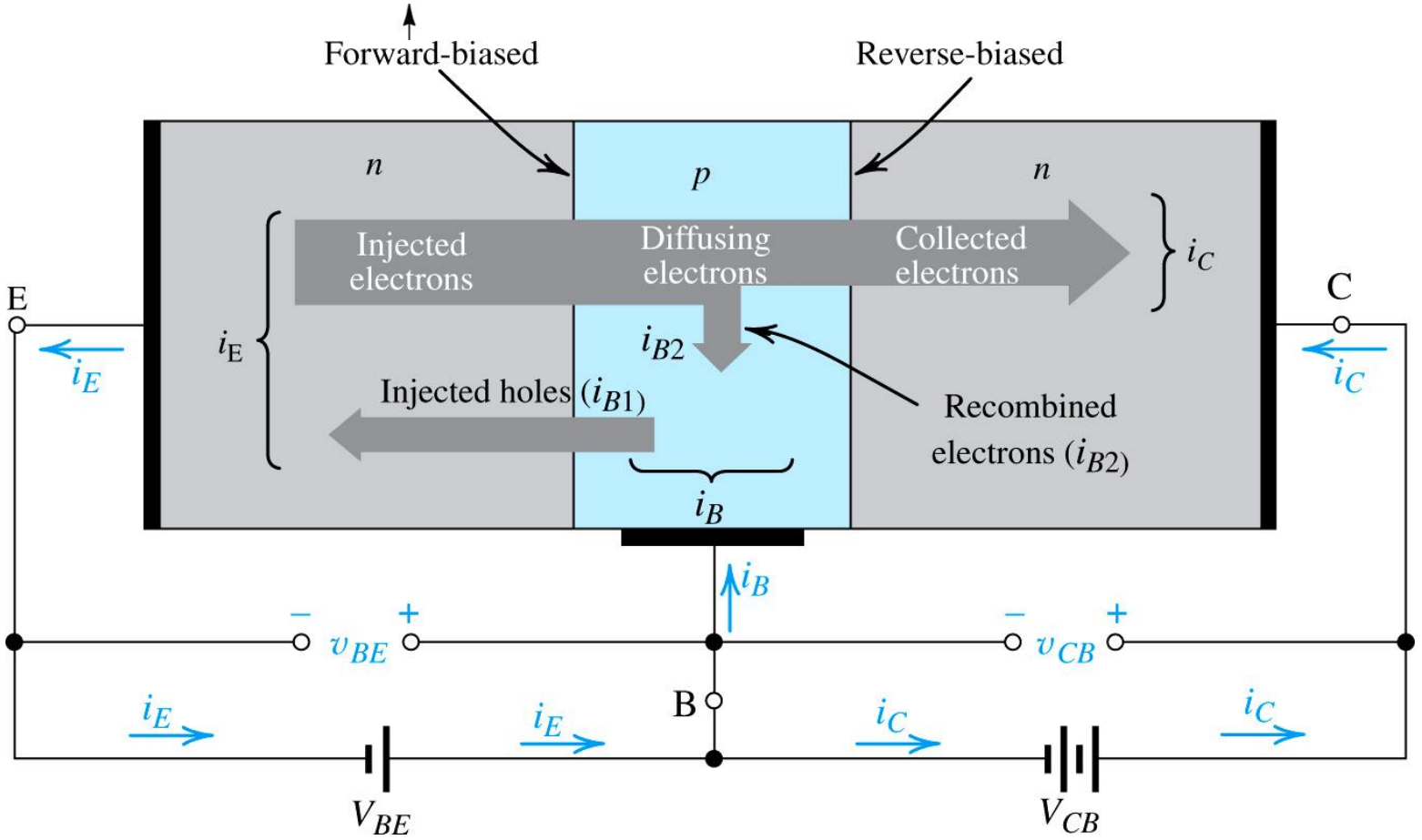
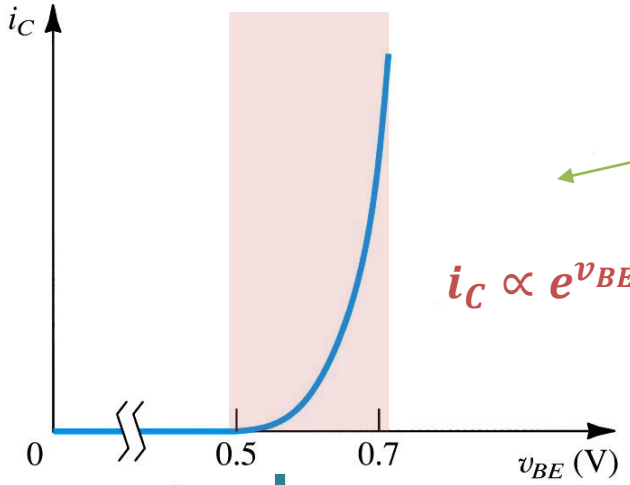




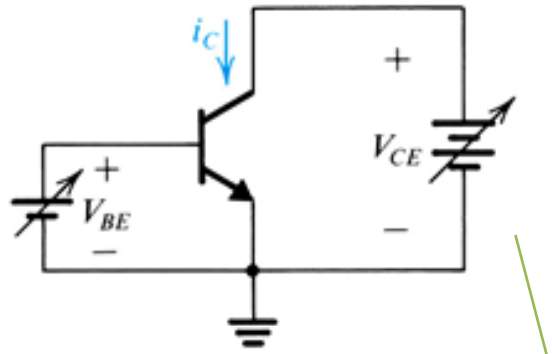
BJT Mathematical Model → Active

9/16/2019

- $i_C = f(v_{BE})$

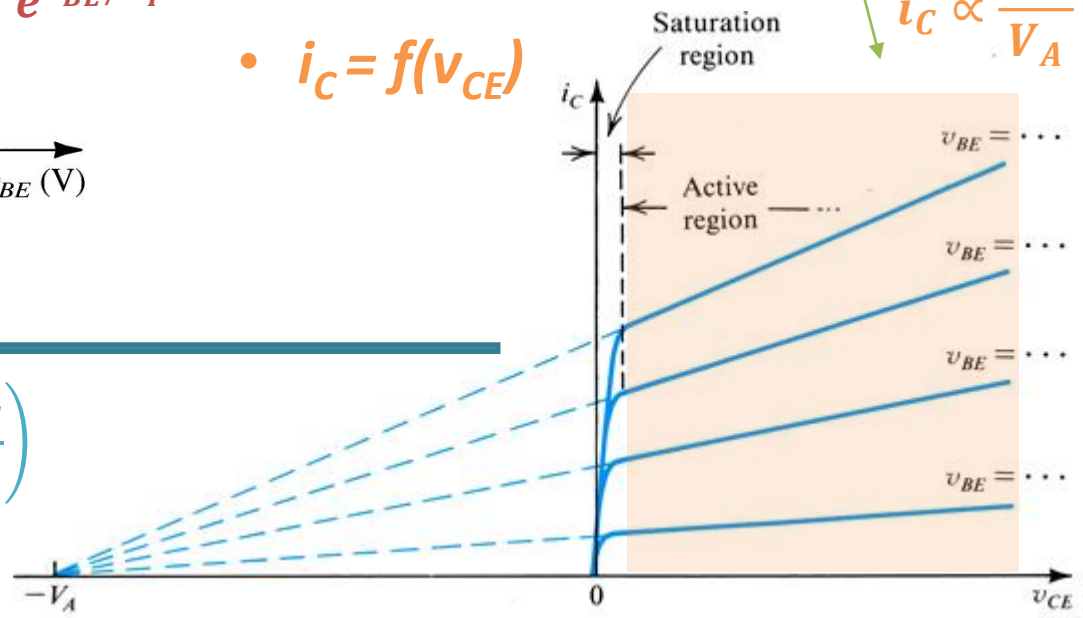


$$i_C \propto e^{v_{BE}/V_T}$$



$$i_C \propto \frac{v_{CE}}{V_A}$$

- $i_C = f(v_{CE})$



Collector Current

$$i_C = I_S e^{v_{BE}/V_T}\left(1 + \frac{v_{CE}}{V_A}\right)$$

$$\approx I_S e^{v_{BE}/V_T}$$

Current & Parameters

$$i_B = \frac{i_C}{\beta}$$

$$i_E = i_B + i_C = \frac{\beta + 1}{\beta} i_C = \frac{i_C}{\alpha}$$

I_S - Saturation Current [10^{-12} - 10^{-18}] A

$$I_S = \frac{A_E q D_n n_i}{N_A W}$$

β - Current Gain [50 - 200] A/A

$$\beta_{forced} = \frac{i_C}{i_B}|_{sat} \leq \beta$$

$\propto$ - Constant

$$\alpha = \frac{\beta}{\beta + 1}$$

V_A - Early Voltage [10 - 100] V

Large Signal Model → npn

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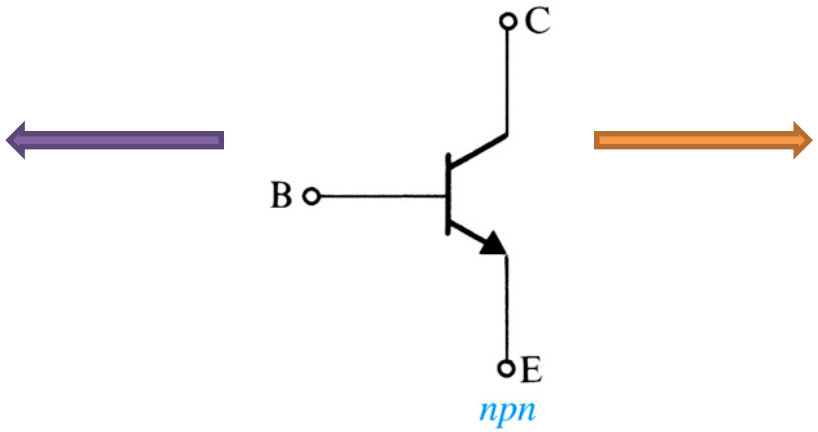
Active Mode

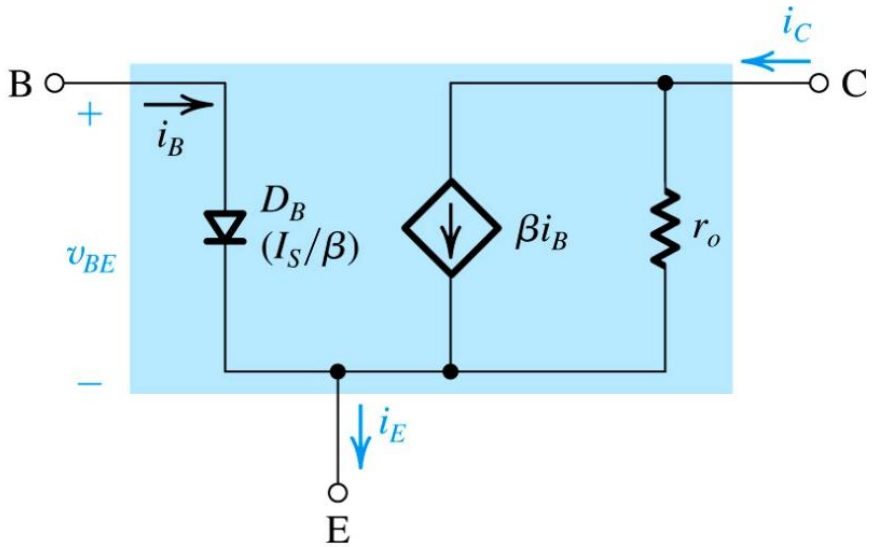
- v_{BE} → forward bias
- v_{BC} → reverse bias
- $v_{CE} > 0.3V$
- $i_C = f(v_{BE})$



Saturation Mode

- v_{BE} → forward bias
- v_{BC} → forward bias
- $i_C \neq f(v_{BE})$
- $i_C / i_B = \beta_{forced} < \beta$

active circuit model



saturation circuit model

Large Signal Model → pnp

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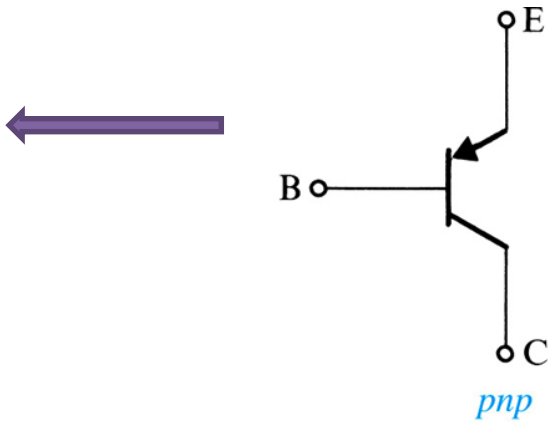

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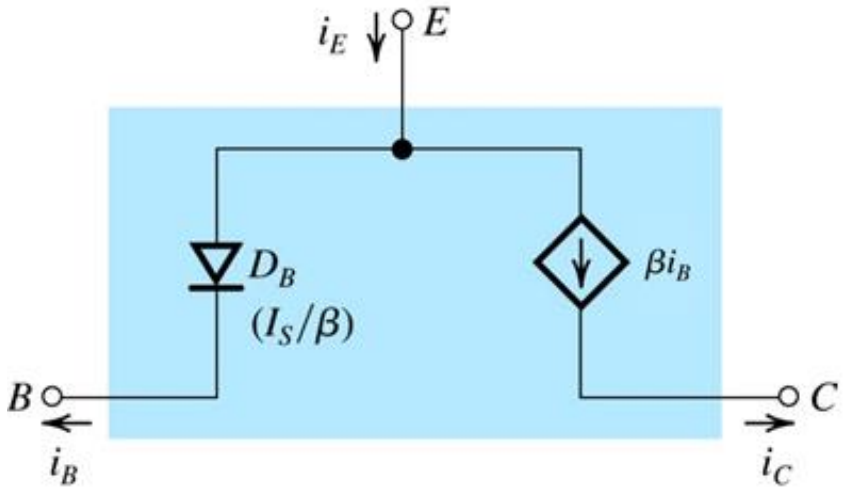

saturation circuit model