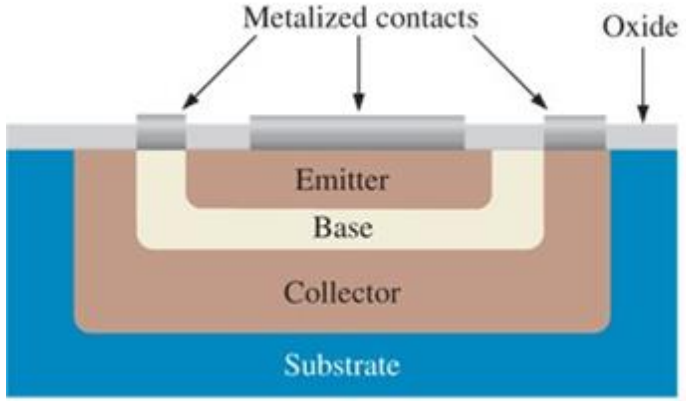
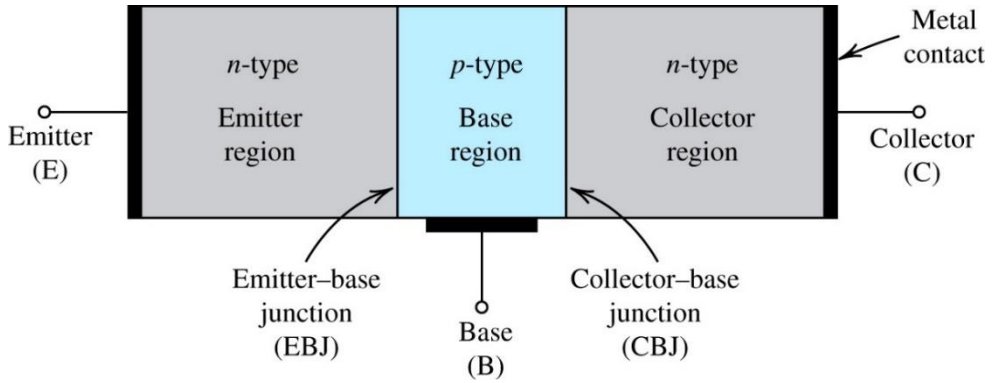
Bipolar Junction Transistors → Chapter 6

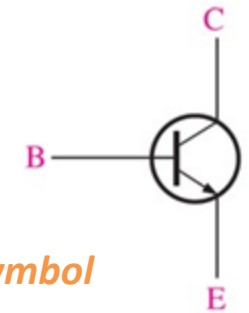
- A three terminal device
- Invented in 1948 at Bell Telephone Laboratories
- Ushered in a new era of solid-state circuits
- Replaced by MOSFET as predominant transistors

cross section



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





npn symbol

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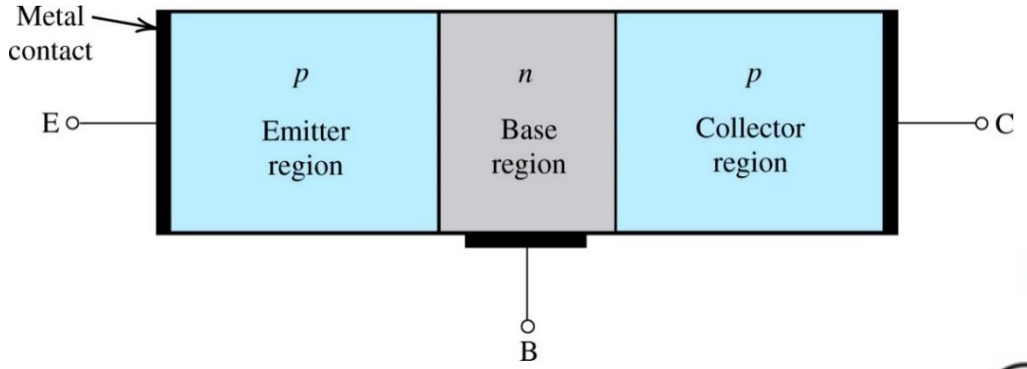
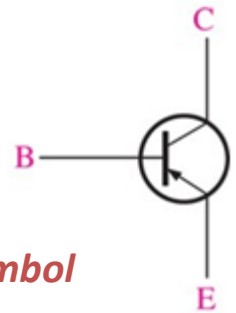




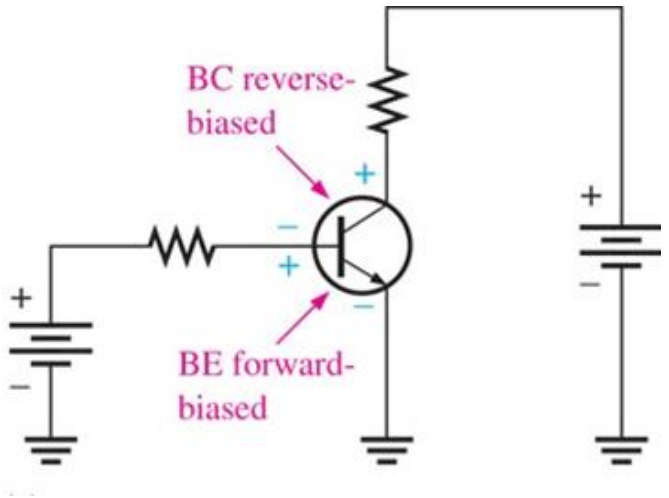
pnp symbol

BJT Operation

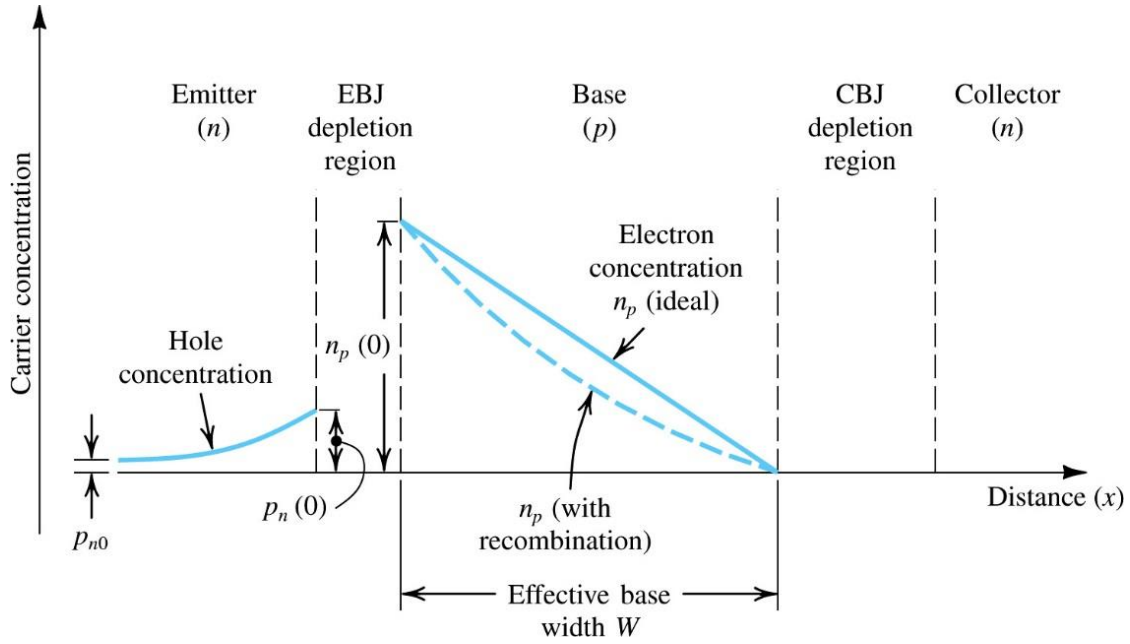
- **Two external voltage sources are required for biasing**
- **Three operation modes:**

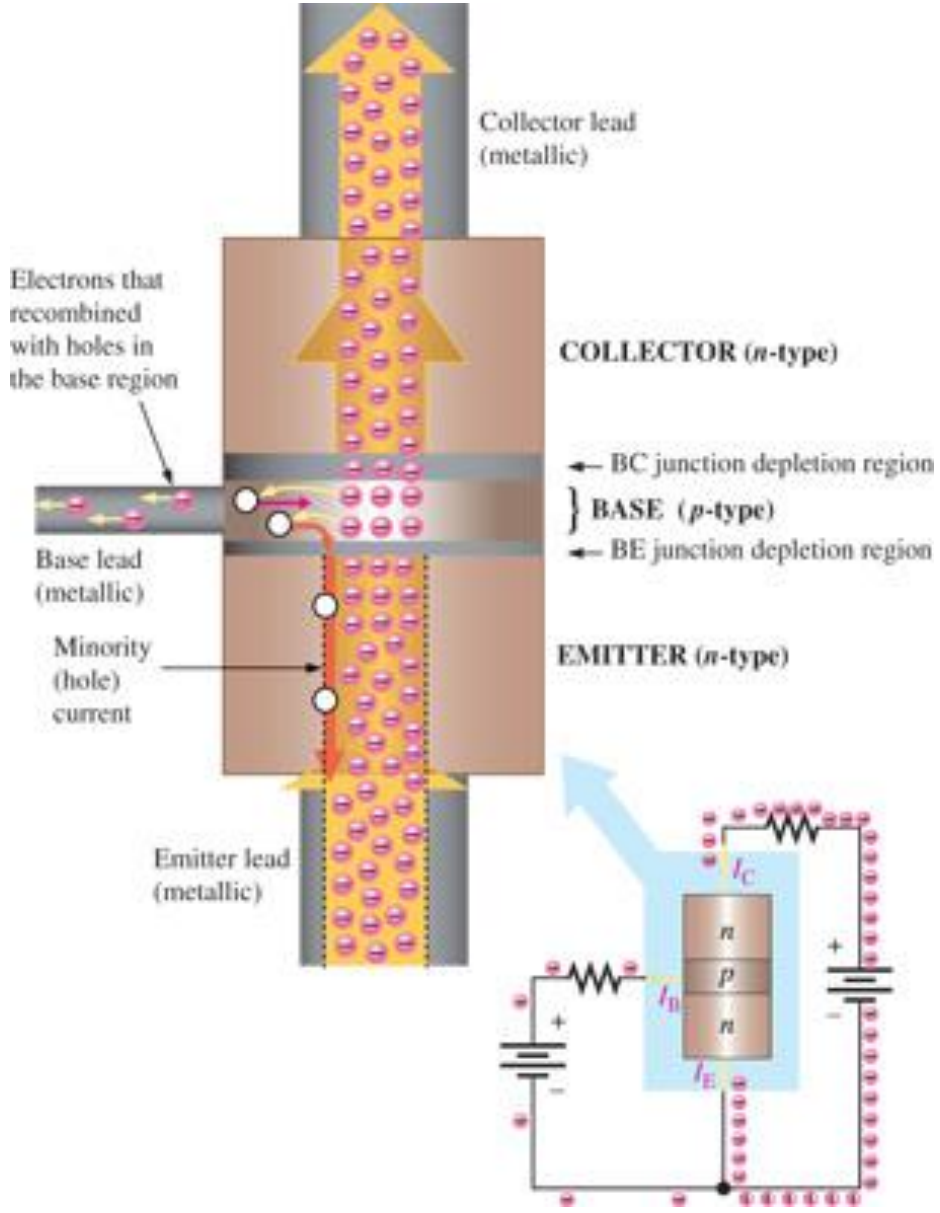
used for switching!

1) **Cut-Off**
2) **Saturation**
3) **Active**



used for amplification!





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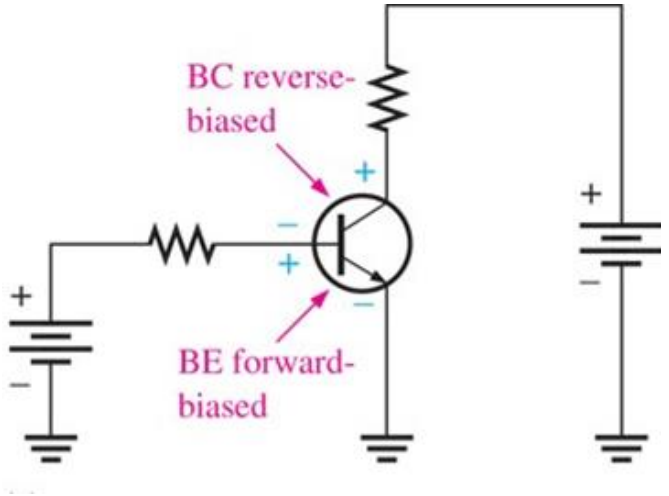
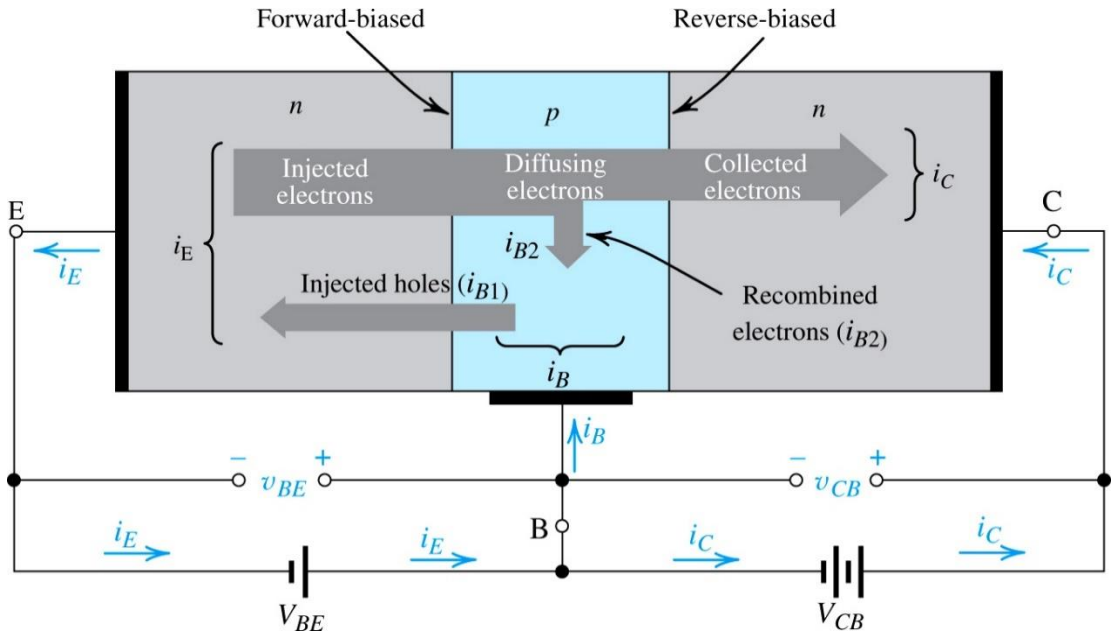
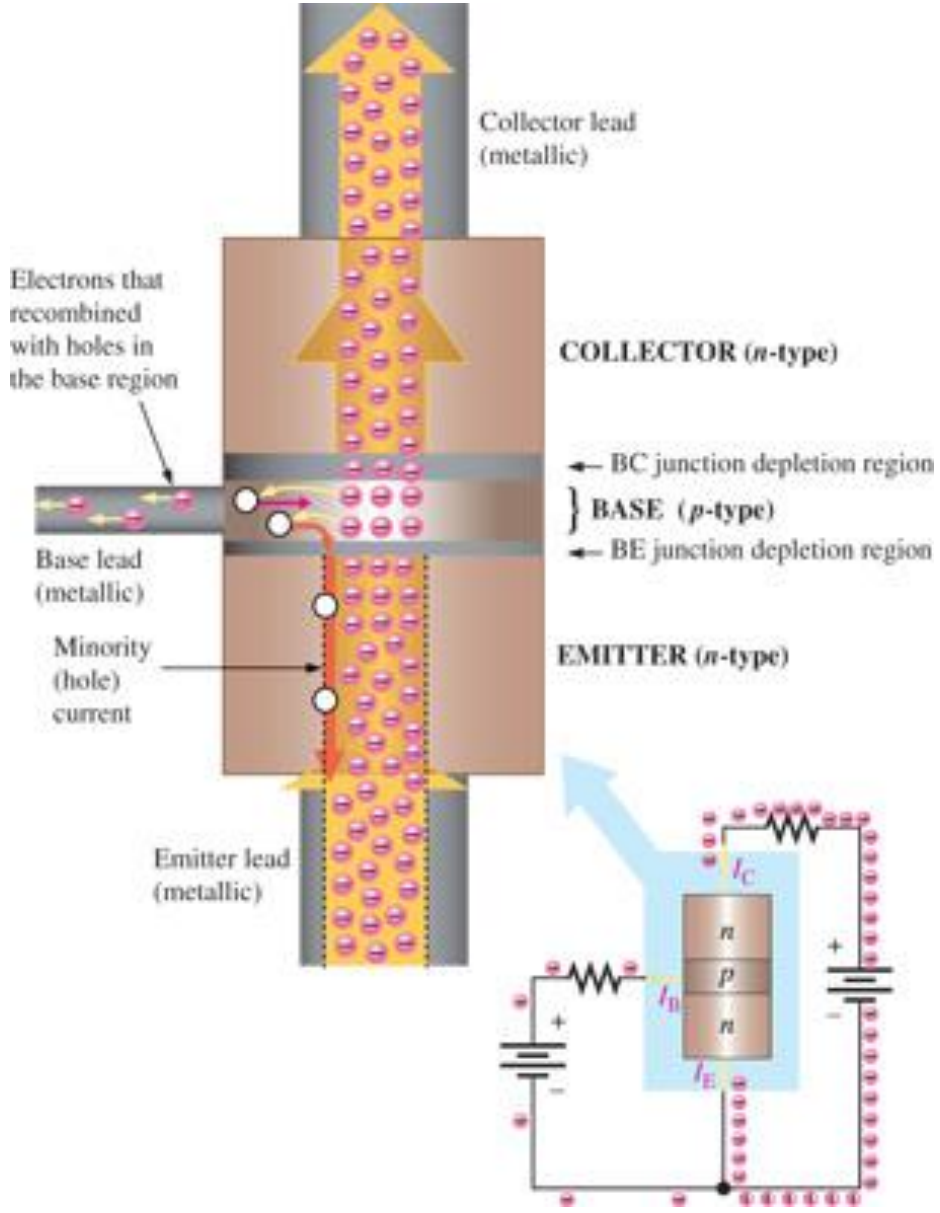
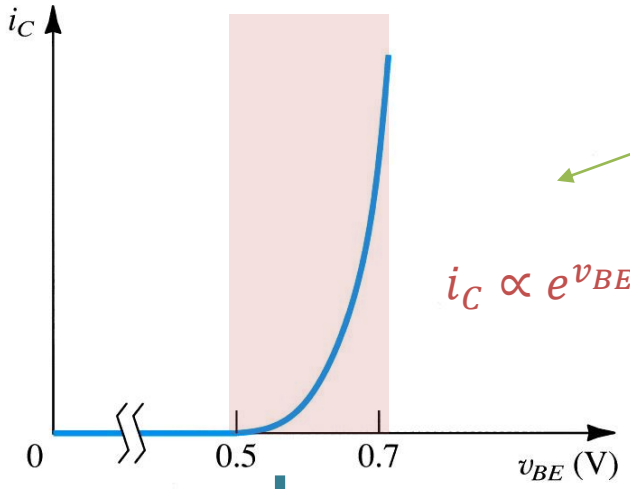




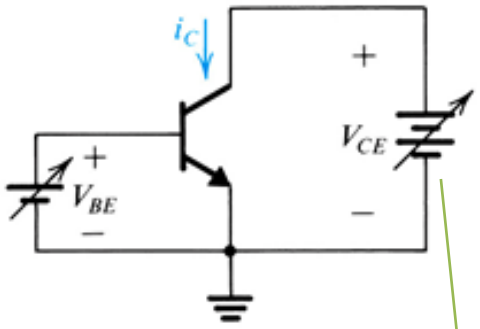


BJT Mathematical Model → Active

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

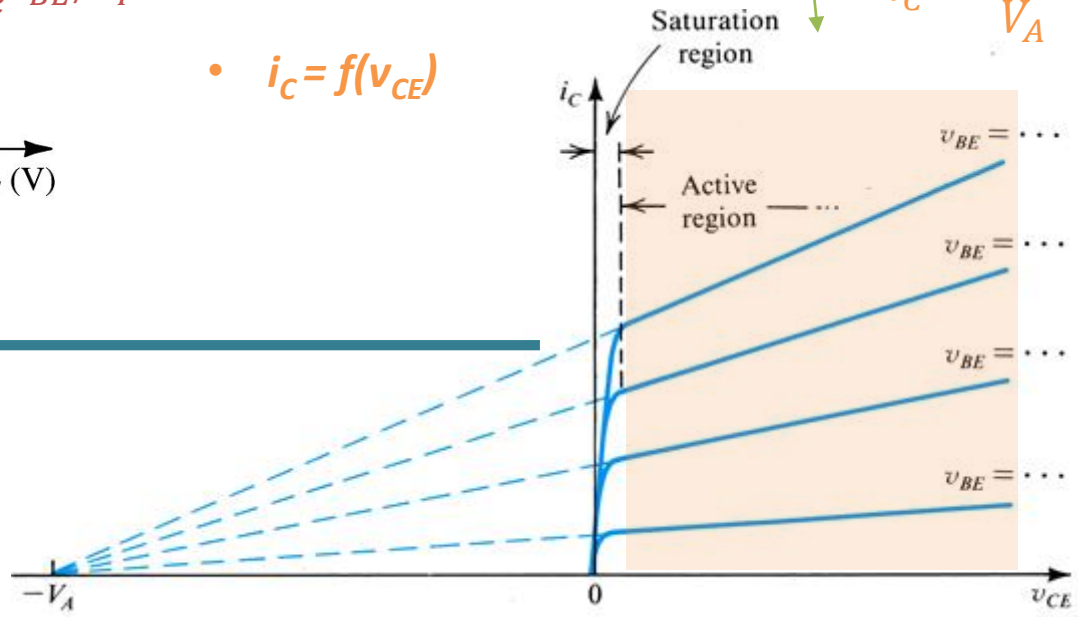


$$i_C \propto e^{v_{BE}/V_T}$$



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

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



Collector Current

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

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

Base / Emitter Currents

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

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

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

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

β - Current Gain [50 - 200] A/A

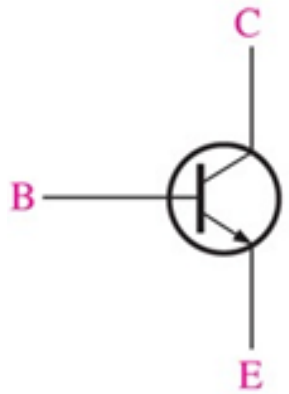
$$\beta_{forced} = \frac{i_C}{i_B}|_{sat} \leq \beta$$

$\propto$ - Constant

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

V_A - Early Voltage [10 - 100] V

Large Signal Model → npn

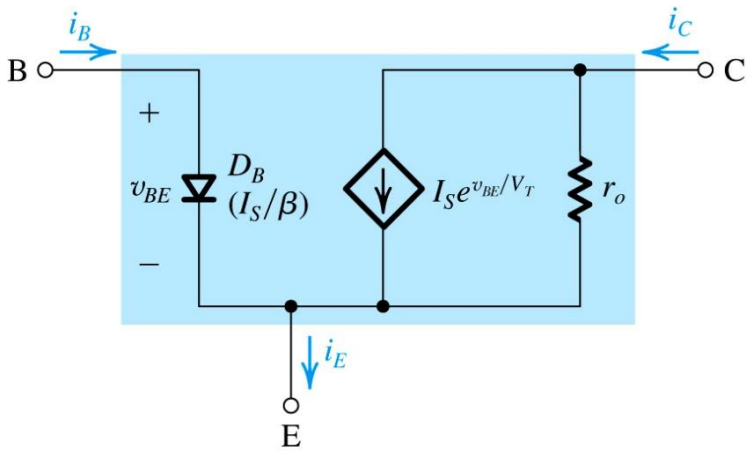


Active Mode

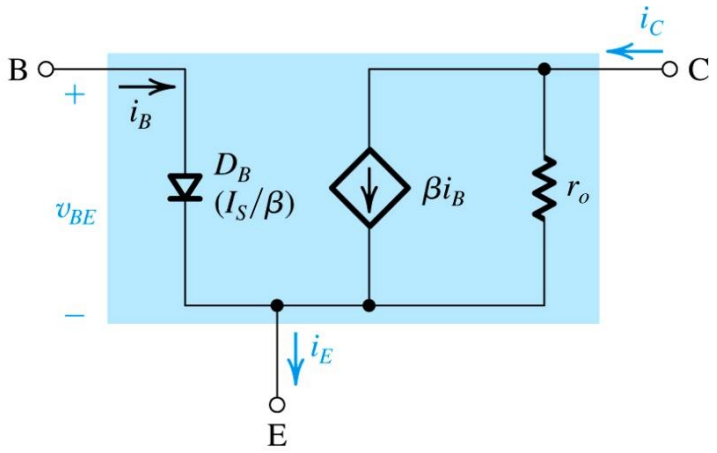
- v_{BE} → forward bias
- v_{BC} → reverse bias
- $v_{CE} > 0.3V$
- $i_C = f(v_{BE})$

Saturation Mode

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

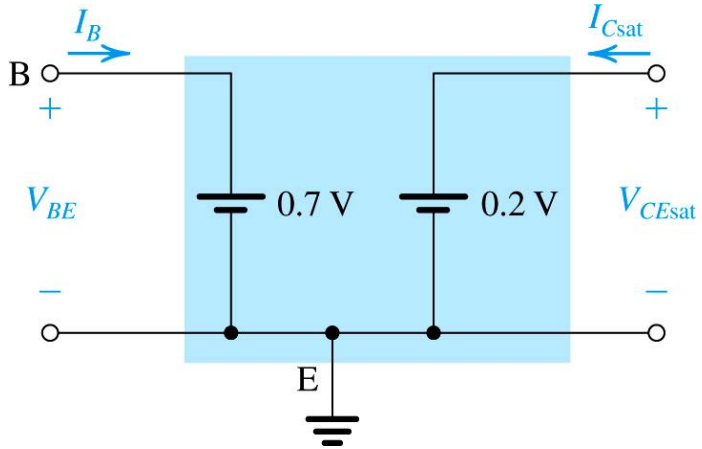


(a)



(b)

npn circuit model



npn circuit model

Example 6.1

An npn transistor having $I_s = 10^{-15}$A, $\beta = 100$, and $V_A = \infty$ is connected as follows: the emitter is grounded, the base is fed with a constant-current source supplying a dc current of 10μA, and the collector is connected to a 5-V dc supply via a resistance R_C of 3kΩ. Assuming that the transistor is operating in the active mode, find V_{BE} and V_{CE}. Use these values to verify active-mode operation. Replace the current source with a resistance connected from the base to the 5-V dc supply. What resistance value is needed to result in the same operating conditions?