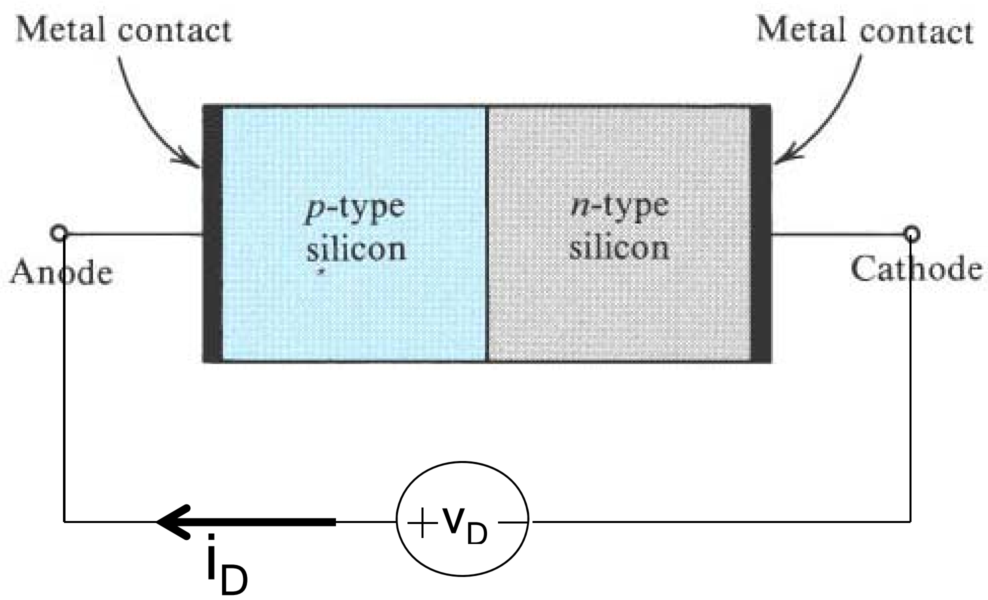
Lect. 10: Bipolar Junction Transistors

(4.1-4.4 in Razavi)

Review of PN Junction



$v_D>0$: $i_{diffusion} > i_{drift}$, ➔ $i_D>0$, very large

$v_D<0$: $i_{diffusion} < i_{drift}$, ➔ $i_D<0$, not much

$$i_D = I_S[\exp(v_D/V_T) - 1]$$

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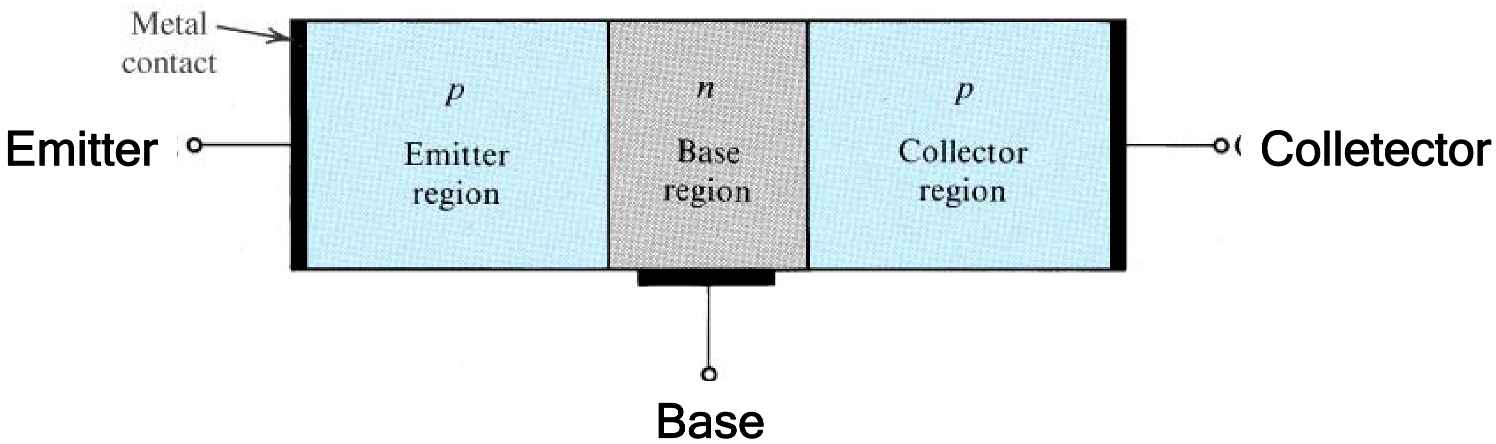
How does BJT work?



- BJT: Two PN junctions connected back-to-back

- Assume EB junction is forward-biased and CB is reverse-biased (active region).

$$i_E = I_S[\exp(v_{EB}/V_T) - 1], \qquad i_B,\ i_C = ?$$

For reverse-biased PN junction,
not much current flows because there are not many carriers (holes).

With BJT, carriers (holes) are supplied from Emitter and they flow to Collector!

i_C is almost equal to i_E: $i_C = \alpha i_E$ ➔ $i_B = i_E - i_C$

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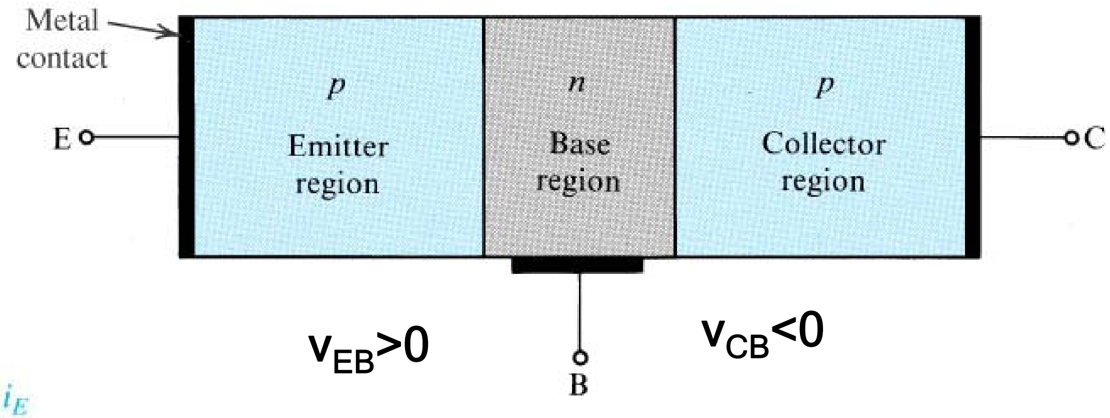
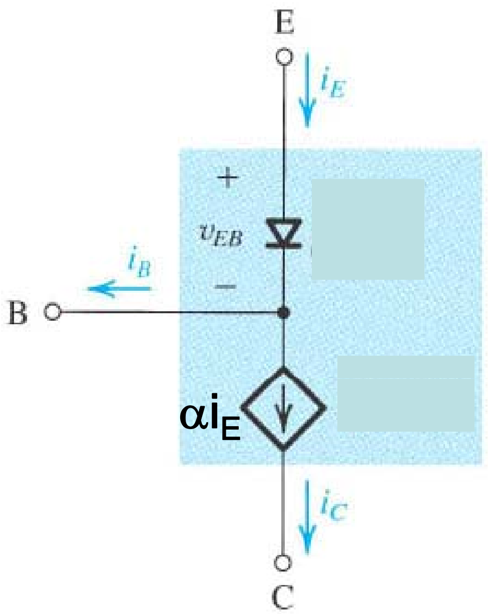


$v_{EB}>0$ $v_{CB}<0$

Circuit model



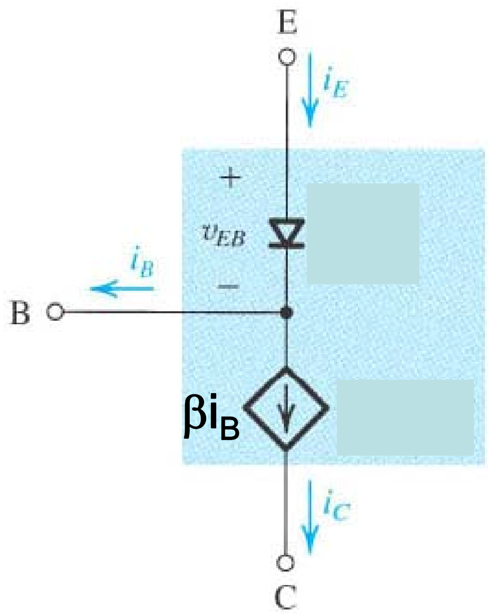
$$i_E = I_S[\exp(v_{EB}/V_T)-1]$$

$$i_C = \alpha i_E$$

$$i_B = i_E - i_C = (1-\alpha)i_E = \frac{1-\alpha}{\alpha} i_C$$

$$= \frac{1}{\beta} i_C$$

$$\therefore\ i_C = \beta i_B$$



voltage-controlled current source

Current-controlled current source

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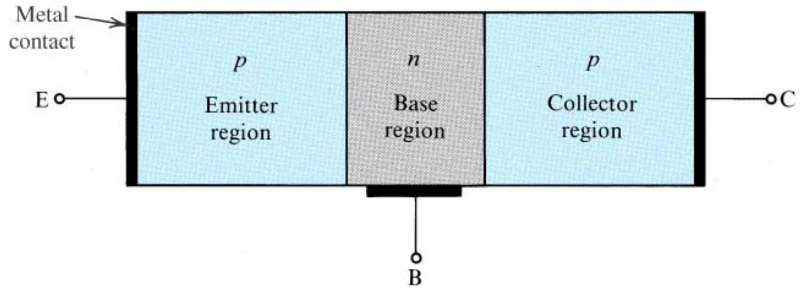
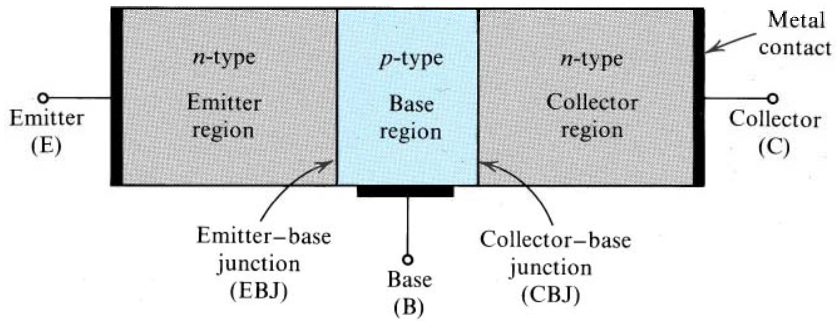
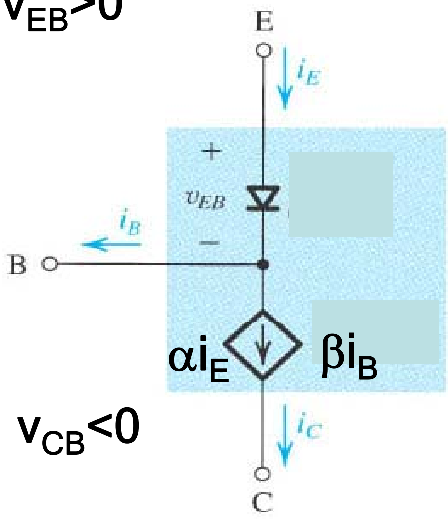
PNP



NPN

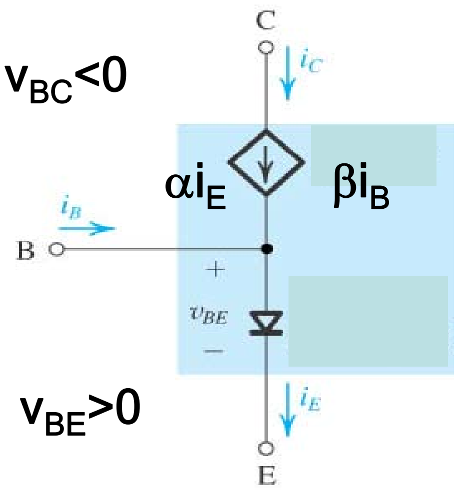


$v_{EB}>0$



$v_{CB}<0$

$v_{BC}<0$



$v_{BE}>0$

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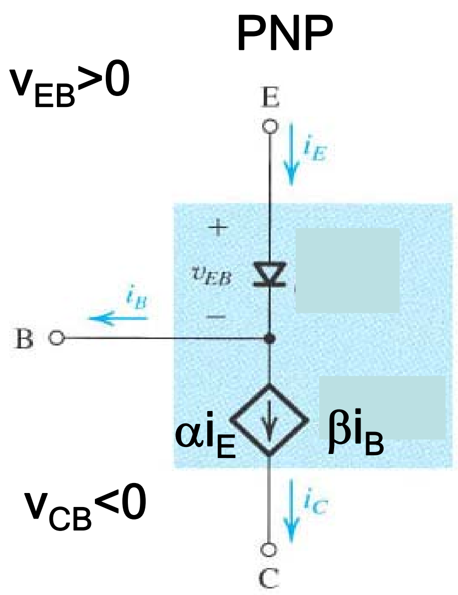
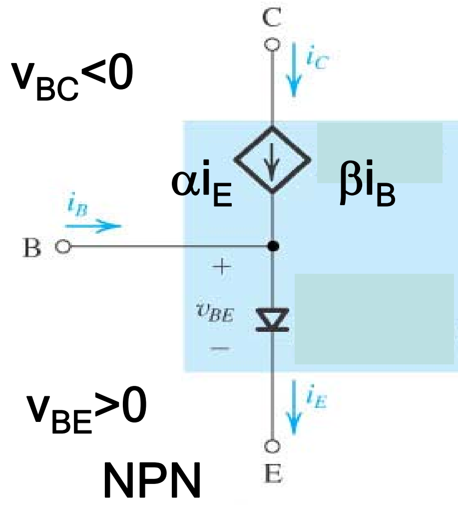
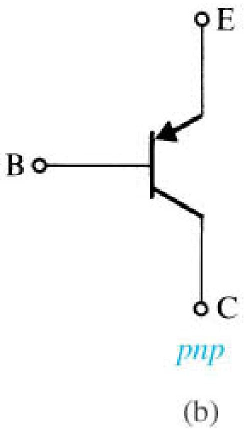
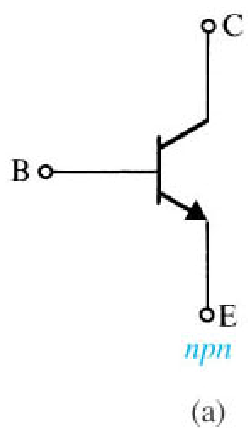






Circuit Symbols



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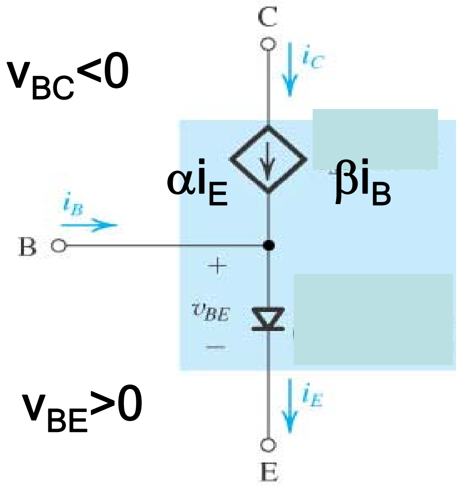
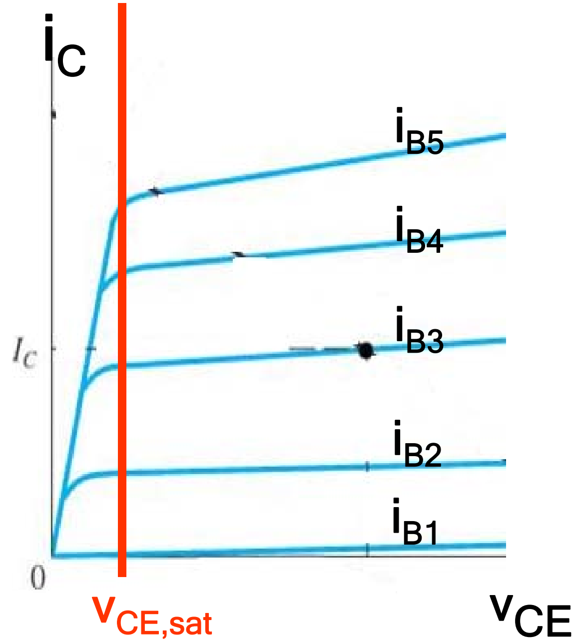
I-V Characteristics (NPN)





1. Model is valid only for $v_{CE}>v_{CE,sat}$ (active region)

2. Even in active region, i_C increases with v_{CE} (Early effect)

➔ Not an ideal current source

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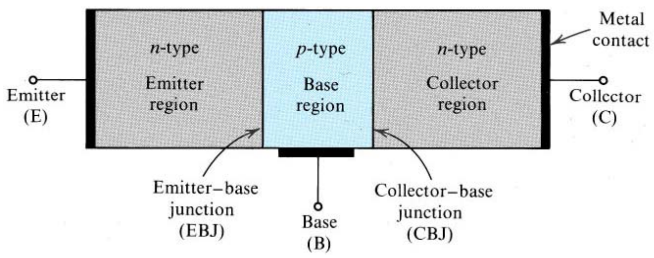
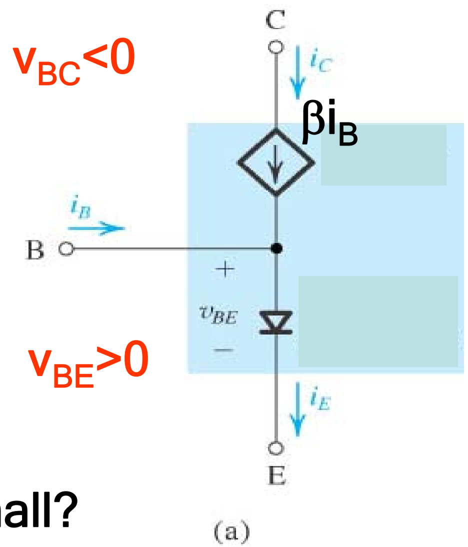
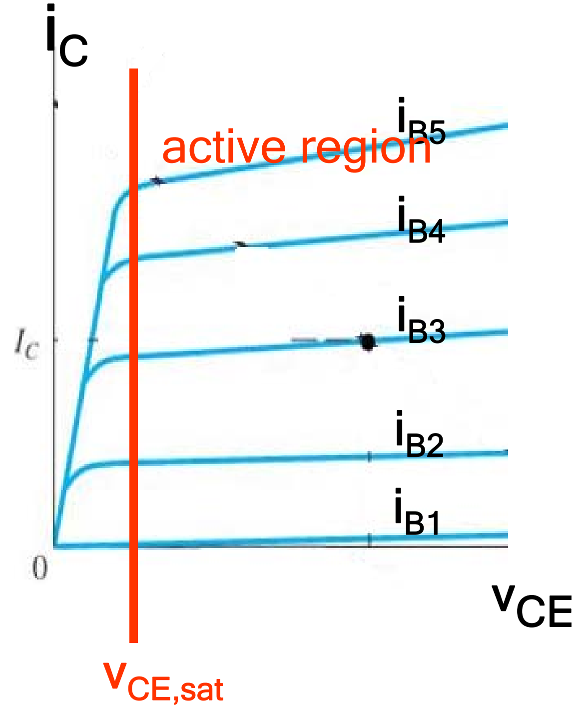
Condition for active region (NPN)?







What happens when v_{CE} is small?

$v_{BE} = v_B - v_E \quad v_{BC} = v_B - v_c \quad \rightarrow v_{CE} = v_{BE} - v_{BC}$

When BC is reverse biased → $v_{CE} >> 0$ → active region

When BC is forward biased → v_{CE} is small → saturation

I-V Characteristics (PNP)