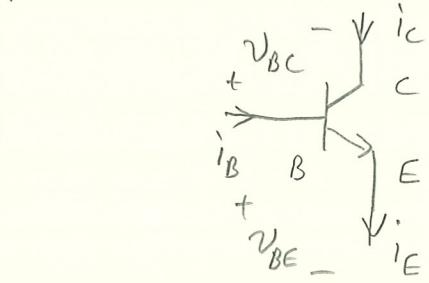
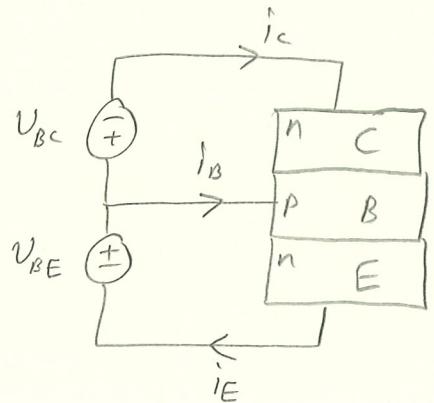


1. NPN BJT

 i_C = collector current i_B = base current i_E = emitter current V_{Bc} = base-collector voltage V_{Be} = base-emitter voltage

$\leftarrow V_{Bc}$ and V_{Be} defined such that
they forward bias their respective
pn junctions

a. Forward characteristics - NPN BJT

→ let $V_{Bc} = 0V$ and apply some $V_{Be} > 0$

definition: i_F = current entering C and flowing through E

→ model i_F with the ideal diode equation

$$\therefore i_F = I_s [e^{\frac{V_{BE}}{V_T}} - 1] = i_C$$

where I_s = transistor saturation current

V_T = thermal voltage: $V_T = \frac{kT}{q}$

$V_T \approx 0.025V$ at room temperature

typically: $10^{-18}A \leq I_s \leq 10^{-9}A$

→ $i_B = \frac{i_F}{\beta_F} = \frac{i_C}{\beta_F}$, β_F = forward common-emitter current gain

typically: $10 \leq \beta_F \leq 500$

$$\rightarrow i_E = i_C + i_B \Rightarrow i_E > i_C$$

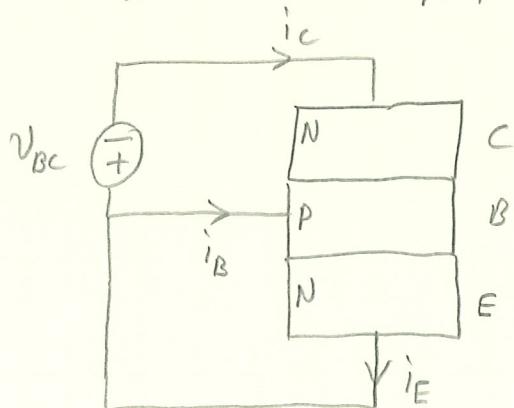
definition : $\alpha_F = \frac{\beta_F}{1 + \beta_F} \equiv$ common-base current gain

$$\text{typically : } 0.95 \leq \alpha_F \leq 1.0 \quad \text{also : } \beta_F = \frac{\alpha_F}{1 - \alpha_F}$$

$$\text{Observe : } i_C = \beta_F i_B = \alpha_F i_E$$

b. Reverse Characteristics - NPN BJT

Let $V_{BE} = 0V$ and apply some $V_{BC} > 0$



Observe: in this configuration: $i_B > 0A$ but $i_C < 0A$ and $i_E < 0A$

Note: unlike the MOSFET, the BJT is not a symmetrical device, due to different doping levels in the emitter and collector regions

definition: $i_R \equiv$ current entering E and flowing through C

$$i_R = I_S [e^{V_{BC}/V_T} - 1] = -i_E$$

$$i_B = \frac{i_R}{\beta_R} = -\frac{i_E}{\beta_R}$$

$\beta_R \equiv$ reverse common-emitter current gain

typically: $0 < \beta_R \leq 10 \rightarrow$ compare to $10 \leq \beta_F \leq 500$!

$$i_C = -\frac{i_R}{\alpha_R} = \frac{i_E}{\alpha_R}$$

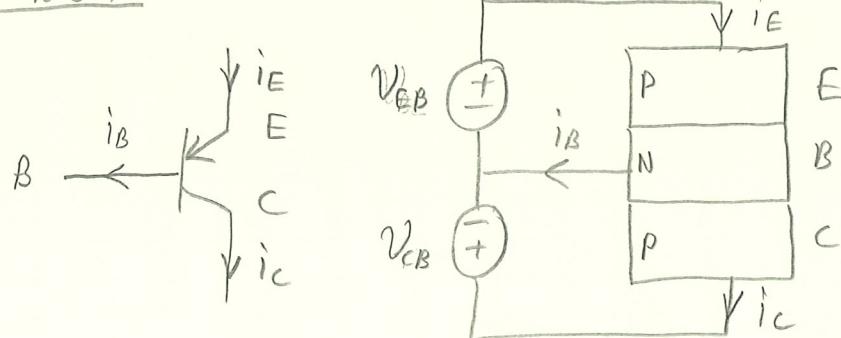
$$\alpha_R = \frac{\beta_R}{\beta_R + 1} \rightarrow \beta_R = \frac{\alpha_R}{1 - \alpha_R}$$

typically: $0 < \alpha_R \leq 0.95$

ii. $i_E = \alpha_R i_C = -\beta_R i_B \rightarrow$ Reverse Characteristics

$$|i_{CE}| = |i_E| + |i_B| : |i_{CE}| > |i_E|$$

2 PNP BJT



$\rightarrow V_{EB} + V_{CB}$ defined to forward bias the pn junctions

a. Forward Characteristics - PNP BJT

$\rightarrow V_{CB} = 0$ and $V_{EB} > 0$

$i_F \rightarrow$ current entering E and flowing through C

$$i_F = I_s [e^{\frac{V_{EB}}{kT}} - 1] = i_C$$

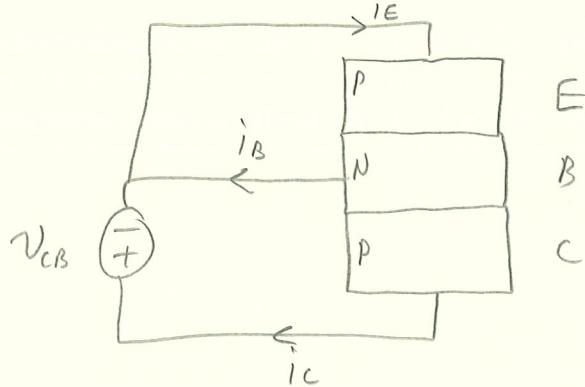
$$i_B = \frac{i_C}{\beta_F}$$

$$i_E = i_C + i_B$$

$$i_C = \beta_F i_B = \alpha_F i_E$$

b. Reverse characteristics - PNP BJT

$V_{EB} = 0$ and $V_{CB} > 0$



Observe: $i_B > 0A$, but $i_C < 0A$ and $i_E < 0A$

$$\therefore i_R = I_s [e^{V_{CB}/V_T} - 1] = -i_E$$

$$i_B = \frac{i_R}{B_R} = -\frac{i_E}{B_R}$$

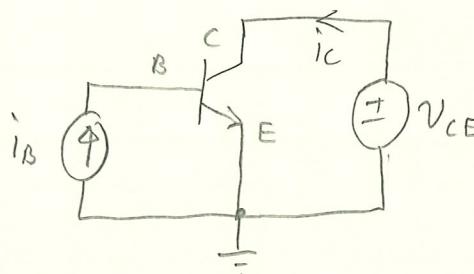
$$|i_E| = |i_C| - i_B$$

1. BJT output characteristics

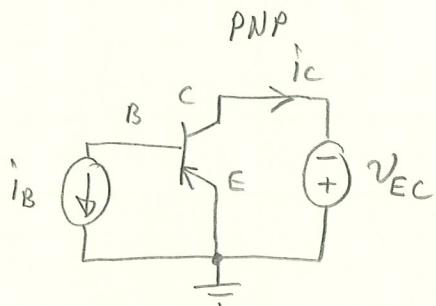
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11

NPN



or



plot i_C vs $i_B + V_{CE}$

plot i_C vs $i_B + V_{EC}$