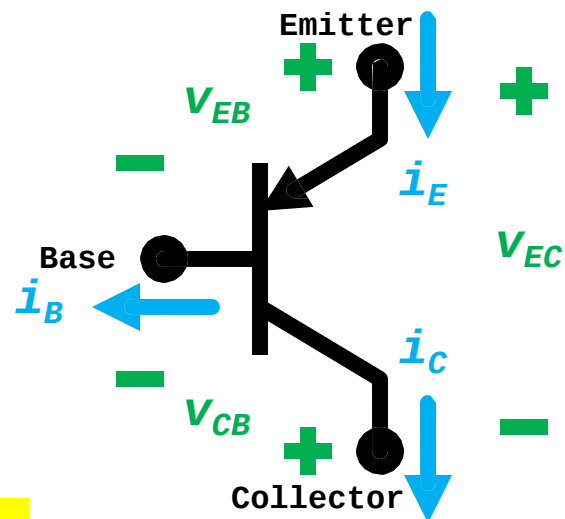
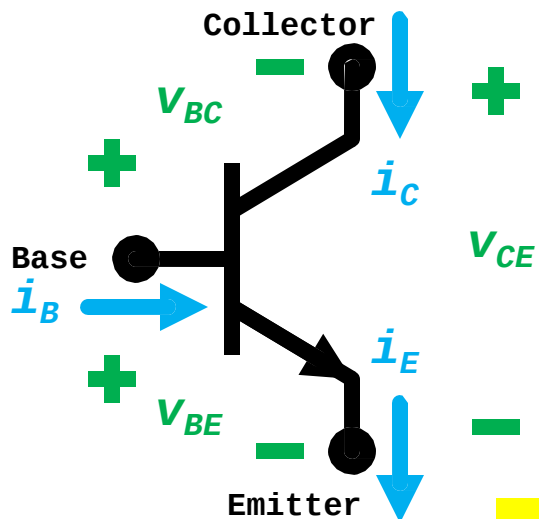
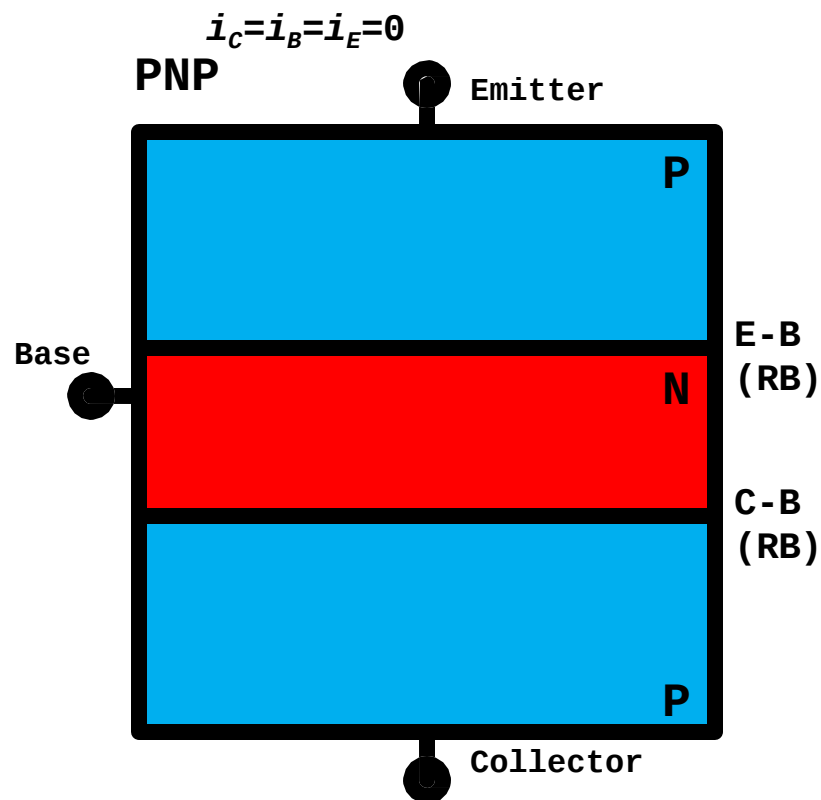
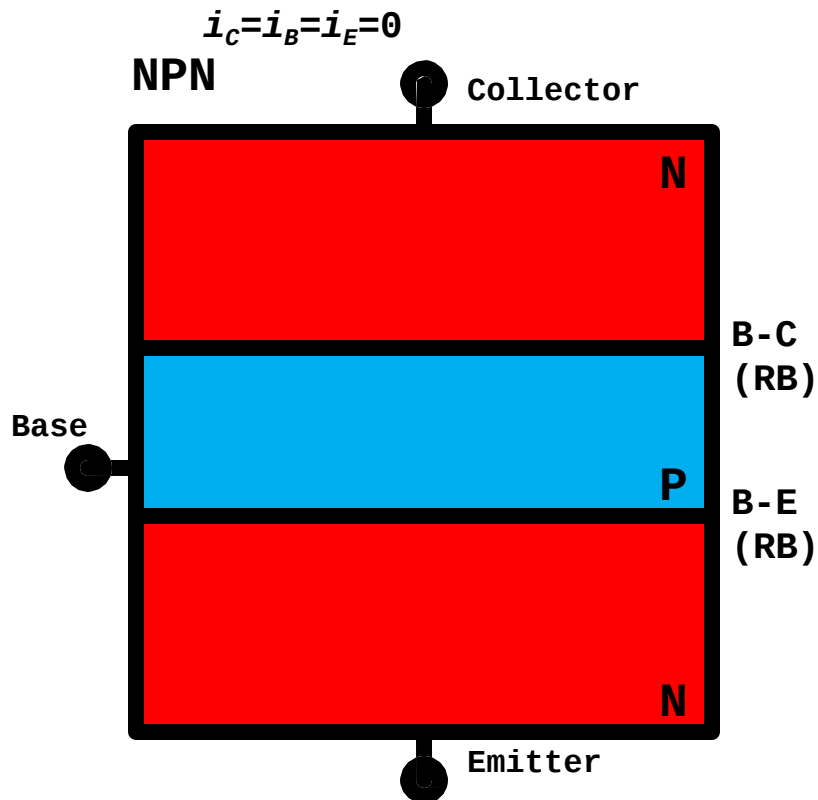
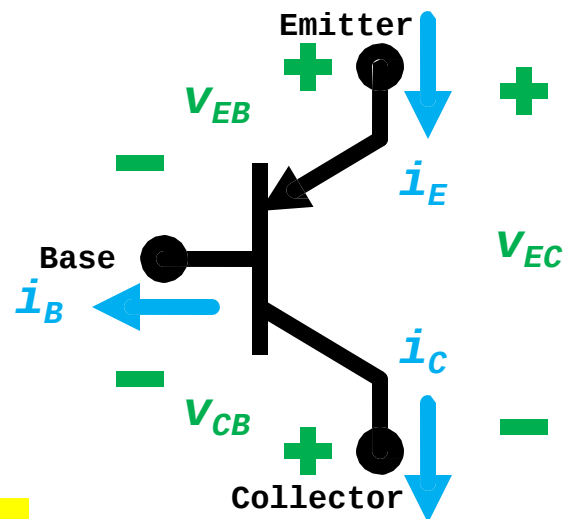
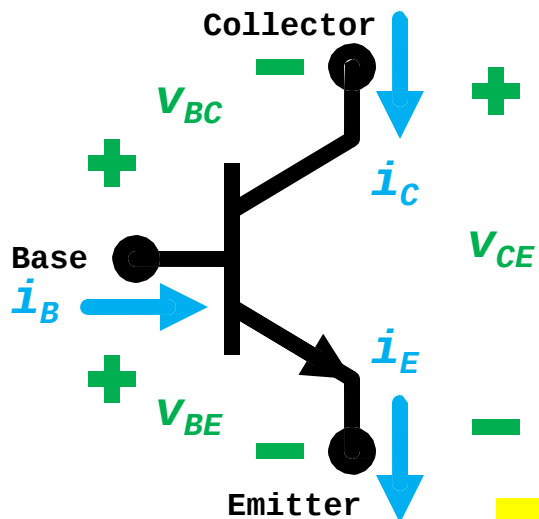
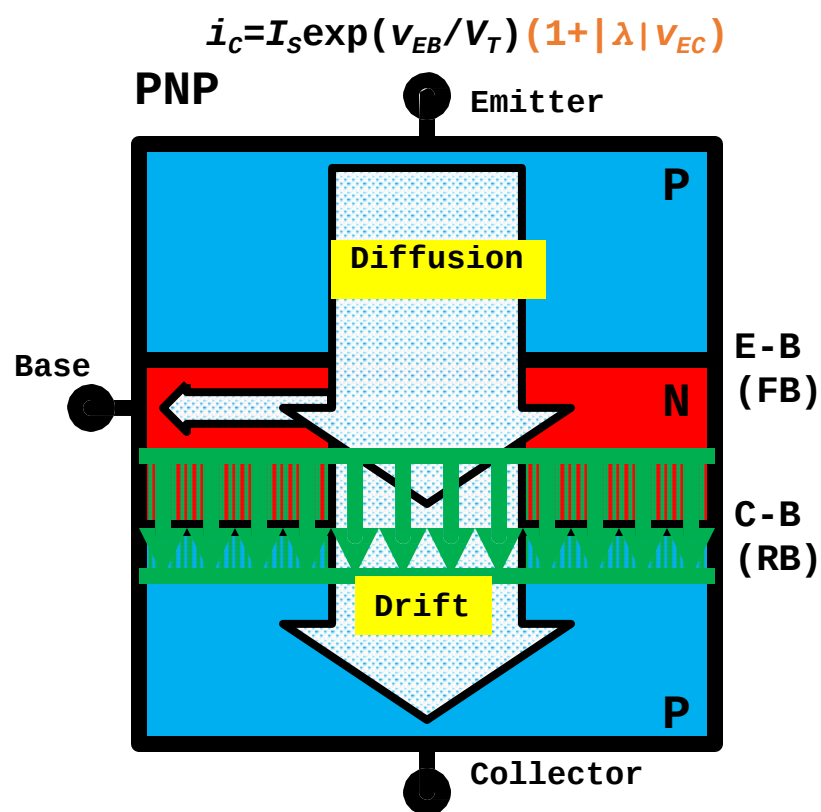
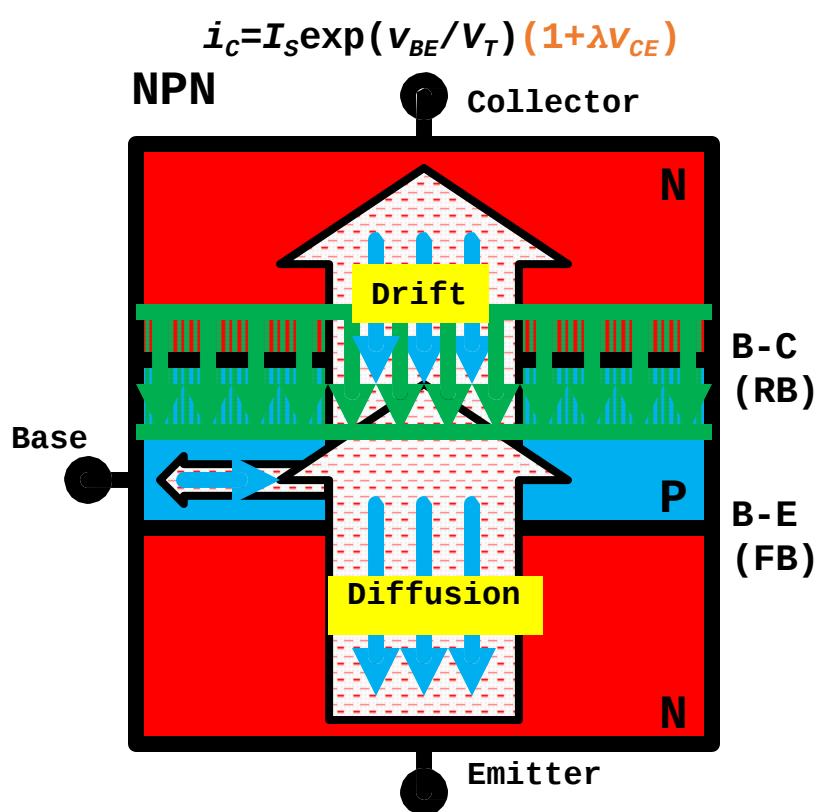




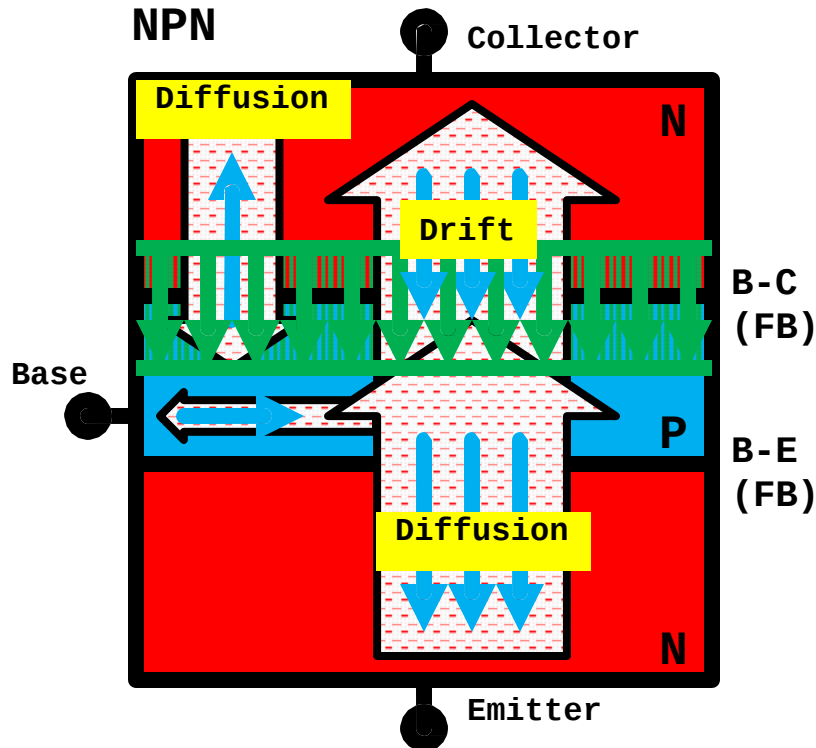
CUTOFF MODE



ACTIVE MODE

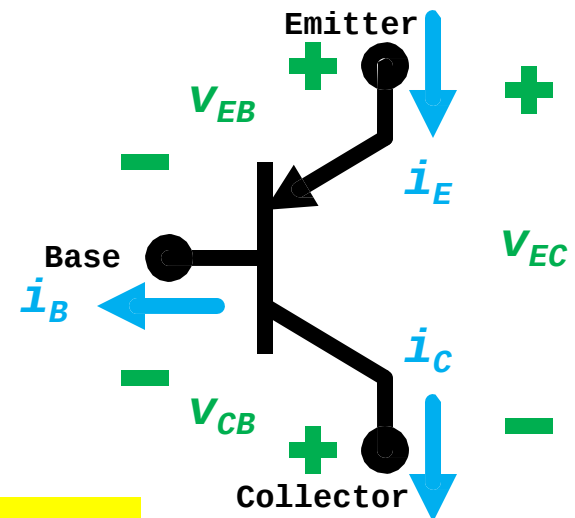
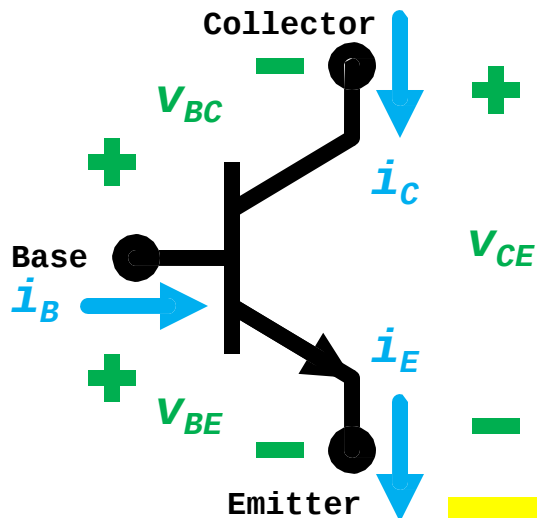
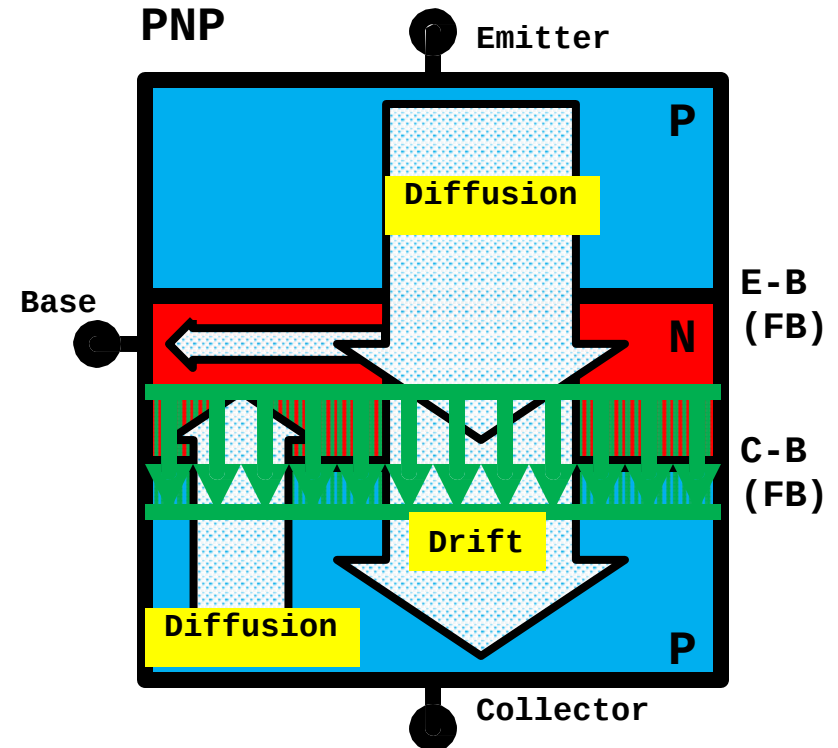
$$i_C = I_S \exp(v_{BE}/V_T) - (I_S/\alpha_R) \exp(v_{BC}/V_T)$$

NPN



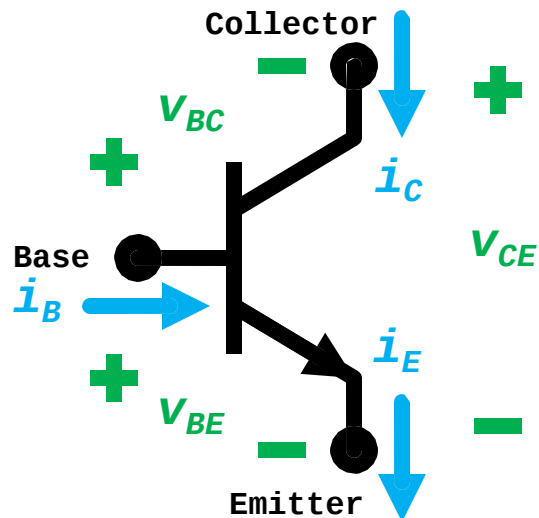
$$i_C = I_S \exp(v_{EB}/V_T) - (I_S/\alpha_R) \exp(v_{CB}/V_T)$$

PNP

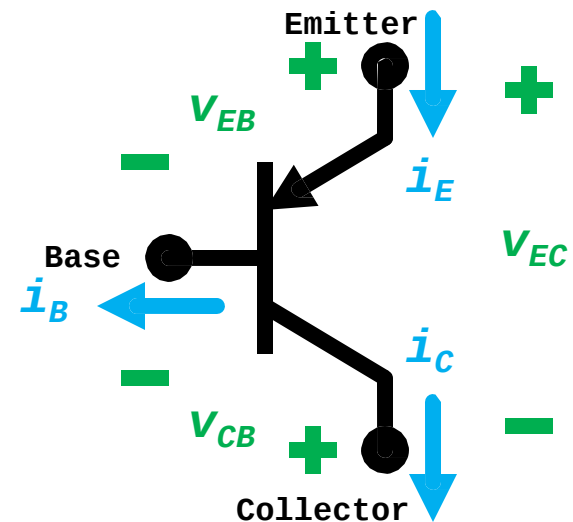


SATURATION MODE

NPN Mode	PN Junction B-E Bias	PN Junction B-C Bias	i-v Characteristic
Cutoff	Reverse	Reverse	$i_C = i_B = i_E = 0$
Active	Forward	Reverse	$i_C = I_S \exp(v_{BE}/V_T) (1 + \lambda v_{CE})$ $i_B = i_C / \beta, \quad i_E = i_C / \alpha$
Saturation	Forward	Forward	$i_C = I_S \exp(v_{BE}/V_T) - (I_S / \alpha_R) \exp(v_{BC}/V_T)$ $i_B = (I_S / \beta) \exp(v_{BE}/V_T) + (I_S / \beta_R) \exp(v_{BC}/V_T)$ $i_B > i_C / \beta, \quad i_C / i_B = \beta_{forced} < \beta$



PNP Mode	PN Junction E-B Bias	PN Junction C-B Bias	i-v Characteristic
Cutoff	Reverse	Reverse	$i_C = i_B = i_E = 0$
Active	Forward	Reverse	$i_C = I_S \exp(v_{EB}/V_T) (1 + \lambda v_{EC})$ $i_B = i_C / \beta, \quad i_E = i_C / \alpha$
Saturation	Forward	Forward	$i_C = I_S \exp(V_{EB}/V_T) - (I_S / \alpha_R) \exp(V_{CB}/V_T)$ $i_B = (I_S / \beta) \exp(V_{EB}/V_T) + (I_S / \beta_R) \exp(V_{CB}/V_T)$ $i_B > i_C / \beta, \quad i_C / i_B = \beta_{forced} < \beta$



NPN
Mode

PN Junction
B-E Bias

PN Junction
B-C Bias

i-v Characteristic

Cutoff

Reverse

$$V_{BE} < 0.7V$$

Reverse

$$V_{BC} < 0.5V$$

$$i_C = i_B = i_E = 0$$

Active

Forward

$$V_{BE} = 0.7V$$

Reverse

$$V_{BC} < 0.5V$$

$$V_{CE} > 0.2V$$

$$i_B = i_C / \beta, \quad i_E = i_C / \alpha, \quad \alpha = \beta / (\beta + 1)$$

Saturation

Forward

$$V_{BE} = 0.7V$$

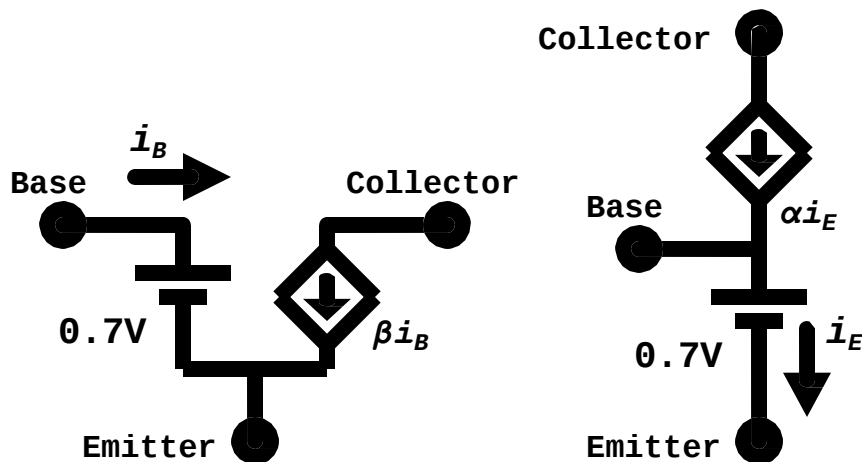
Forward

$$V_{BC} = 0.5V$$

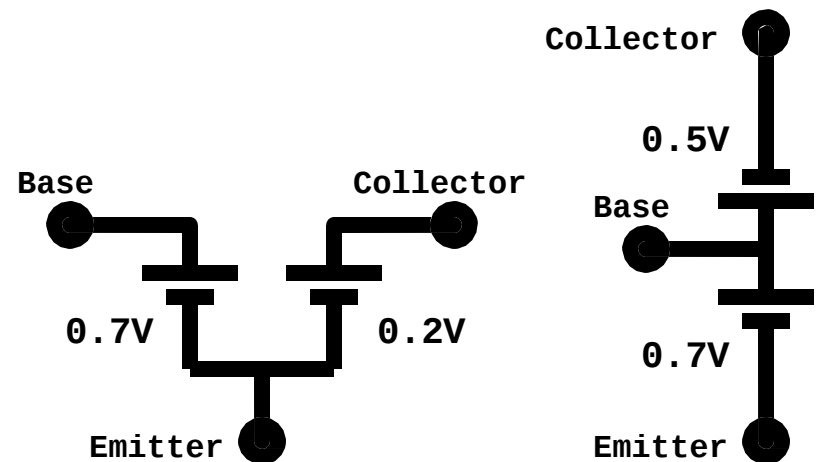
$$V_{CE} = 0.2V$$

$$i_B > i_C / \beta, \quad i_C / i_B = \beta_{forced} < \beta$$

ACTIVE MODE



SATURATION MODE



PNP
Mode

PN Junction
E-B Bias

PN Junction
C-B Bias

i-v Characteristic

Cutoff

Reverse

$$V_{EB} < 0.7V$$

Reverse

$$V_{CB} < 0.5V$$

$$i_C = i_B = i_E = 0$$

Active

Forward

$$V_{EB} = 0.7V$$

Reverse

$$V_{CB} < 0.5V$$

$$V_{EC} > 0.2V$$

$$i_B = i_C / \beta, \quad i_E = i_C / \alpha, \quad \alpha = \beta / (\beta + 1)$$

Saturation

Forward

$$V_{EB} = 0.7V$$

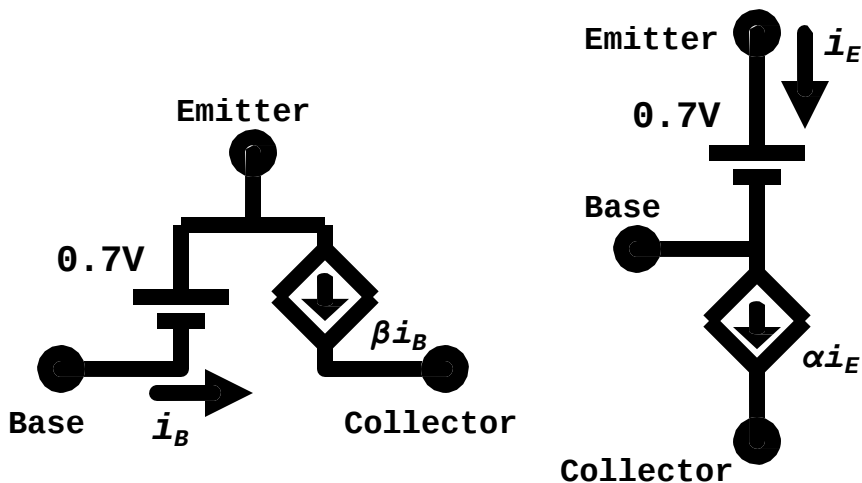
Forward

$$V_{CB} = 0.5V$$

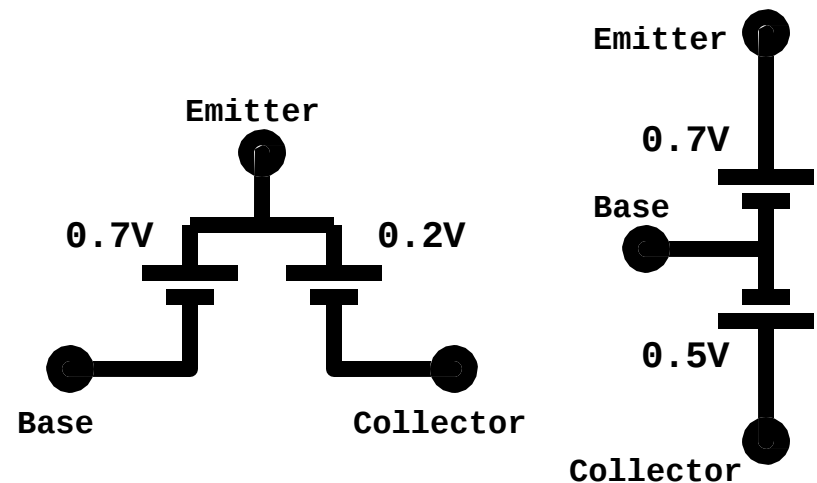
$$V_{EC} = 0.2V$$

$$i_B > i_C / \beta, \quad i_C / i_B = \beta_{forced} < \beta$$

ACTIVE MODE



SATURATION MODE



NPN
Mode

PN Junction
B-E Bias

PN Junction
B-C Bias

i-v Characteristic

Active

Forward

Reverse

$$i_C = I_S \exp(v_{BE}/V_T) (1 + \lambda v_{CE})$$

$$i_B = i_C/\beta, \quad i_E = i_C/\alpha$$

Small Signal

$$g_m = di_C/dv_{BE}@(V_{BE})$$

$$g_m = I_S \exp(V_{BE}/V_T)/V_T = I_C/V_T$$

$$i_b = i_C/\beta = g_m v_{be}/\beta = v_{be}/r_\pi$$

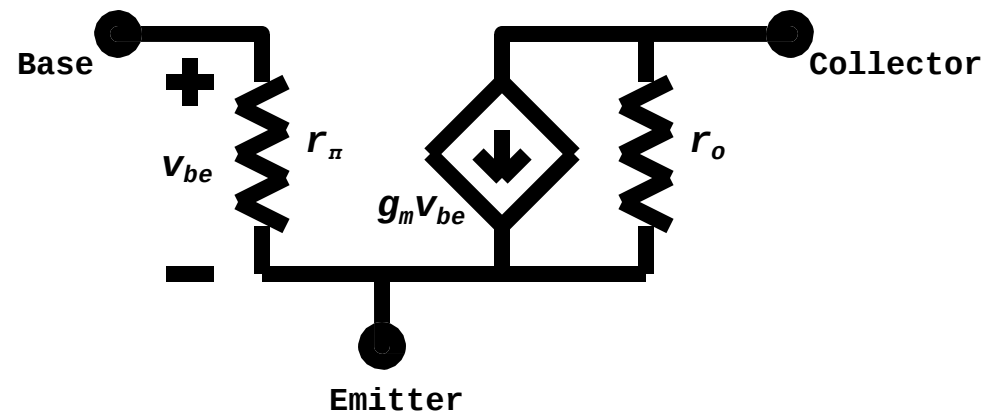
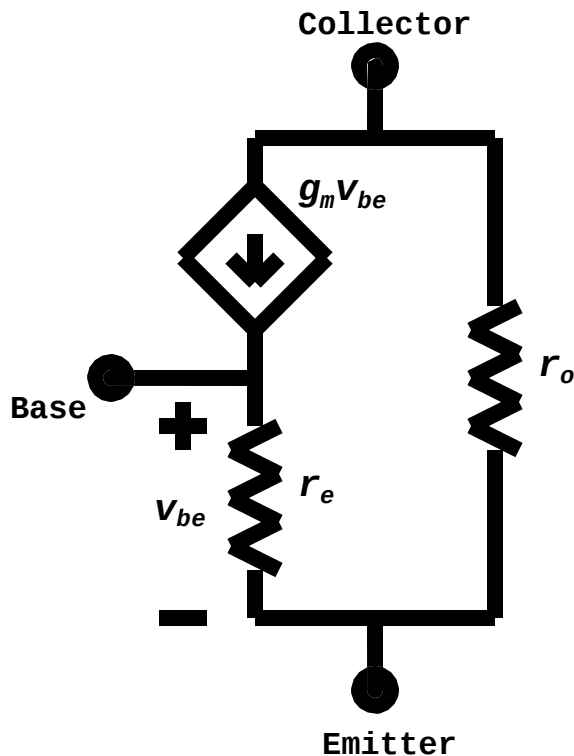
$$r_\pi = \beta/g_m$$

$$i_e = i_C/\alpha = g_m v_{be}/\alpha = v_{be}/r_e$$

$$r_e = \alpha/g_m$$

$$r_o = dv_{CE}/di_C@(I_C)$$

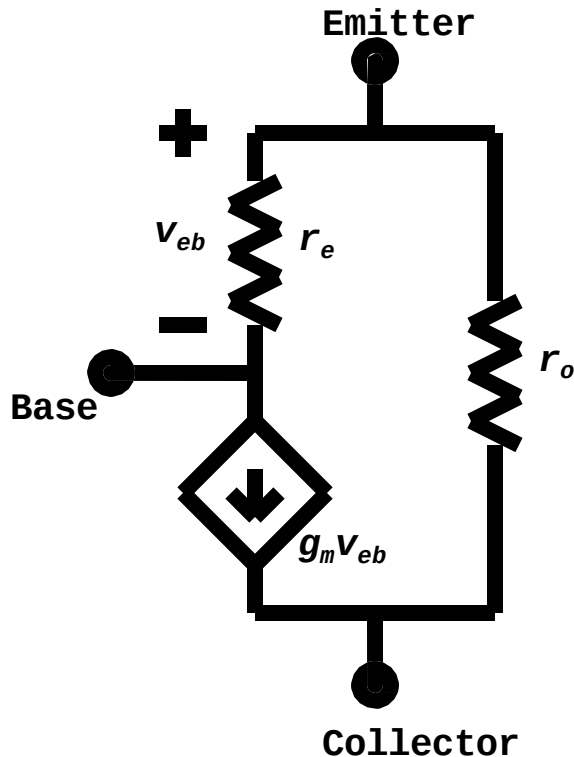
$$r_o = V_A/I_C = 1/\lambda I_C$$



PNP	PN Junction	PN Junction	
Mode	E-B Bias	C-B Bias	i-v Characteristic

Active	Forward	Reverse	$i_c = I_S \exp(v_{EB}/V_T) (1 + \lambda v_{EC})$ $i_B = i_C/\beta, \quad i_E = i_C/\alpha$
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Small Signal



$$g_m = di_c/dv_{EB}@(V_{EB})$$

$$g_m = I_S \exp(V_{EB}/V_T)/V_T = I_C/V_T$$

$$i_b = i_c/\beta = g_m v_{eb}/\beta = v_{eb}/r_\pi$$

$$r_\pi = \beta/g_m$$

$$i_e = i_c/\alpha = g_m v_{eb}/\alpha = v_{eb}/r_e$$

$$r_e = \alpha/g_m$$

$$r_o = dv_{EC}/di_c@(I_C)$$

$$r_o = |V_A|/I_C = 1/(|\lambda| I_C)$$

