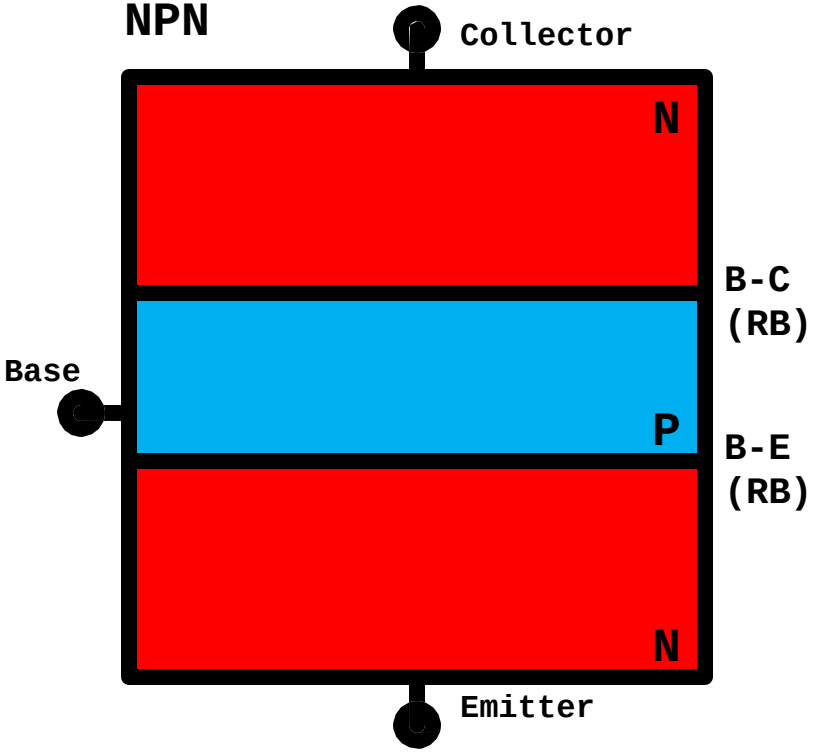
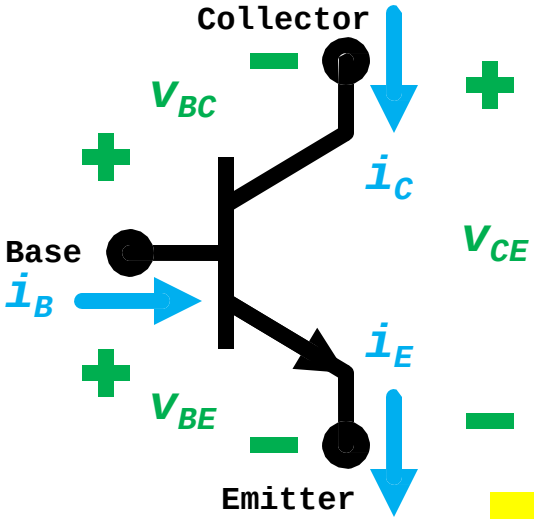
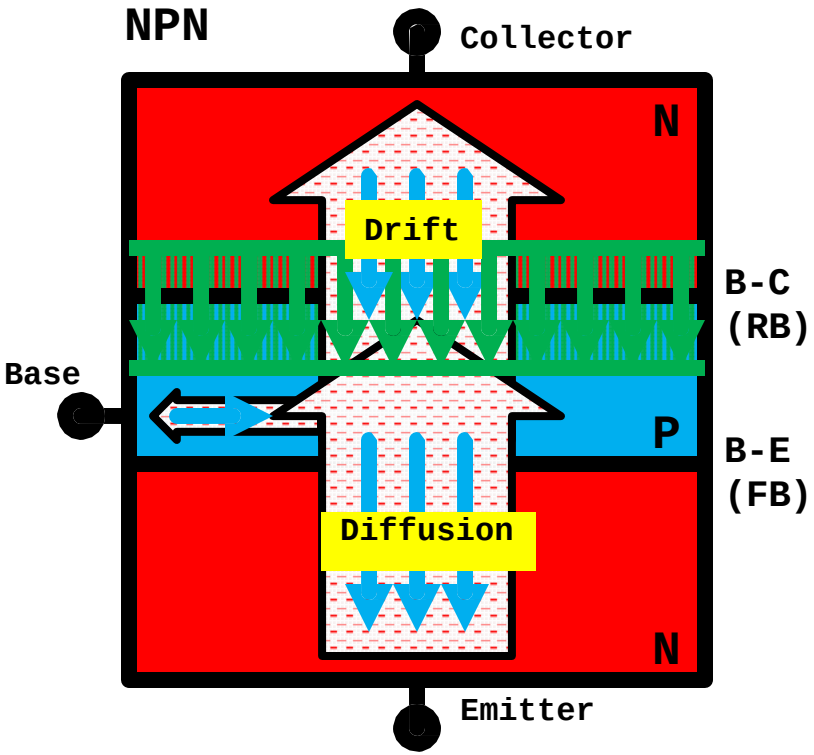
$i_C = i_B = i_E = 0$

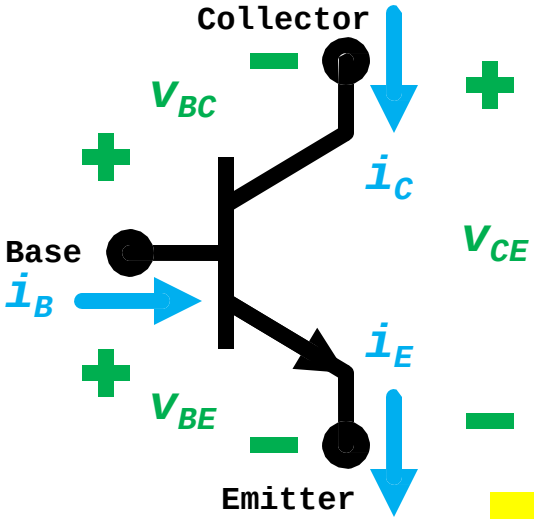




CUTOFF MODE

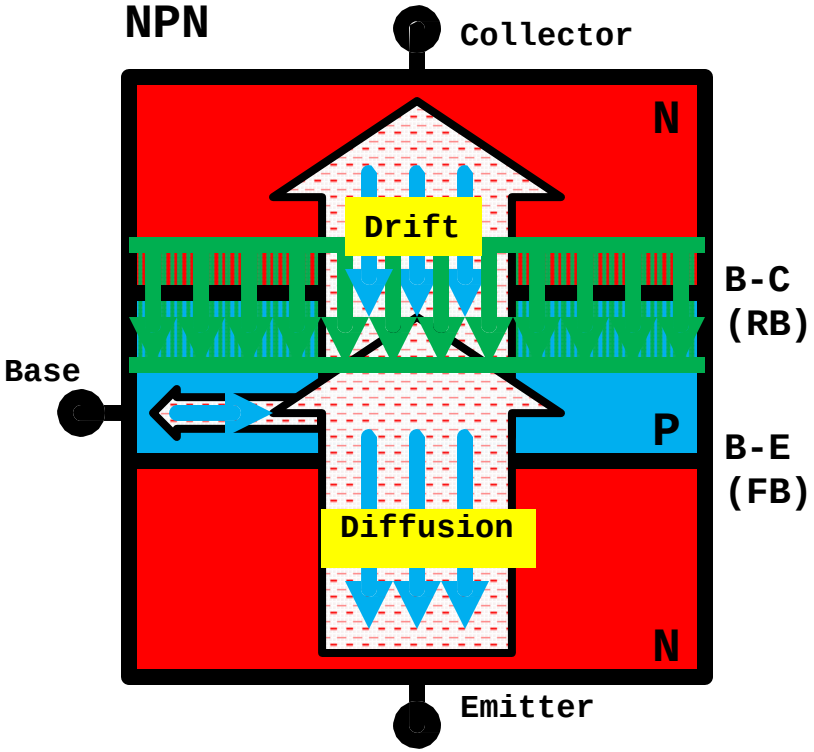
$i_C = I_S \exp(v_{BE}/V_T)$

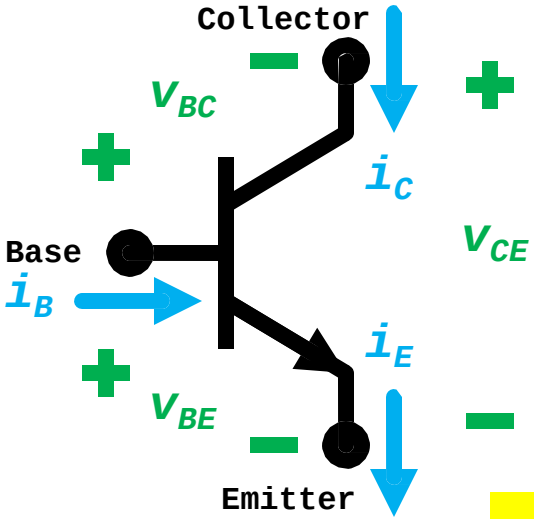




ACTIVE MODE

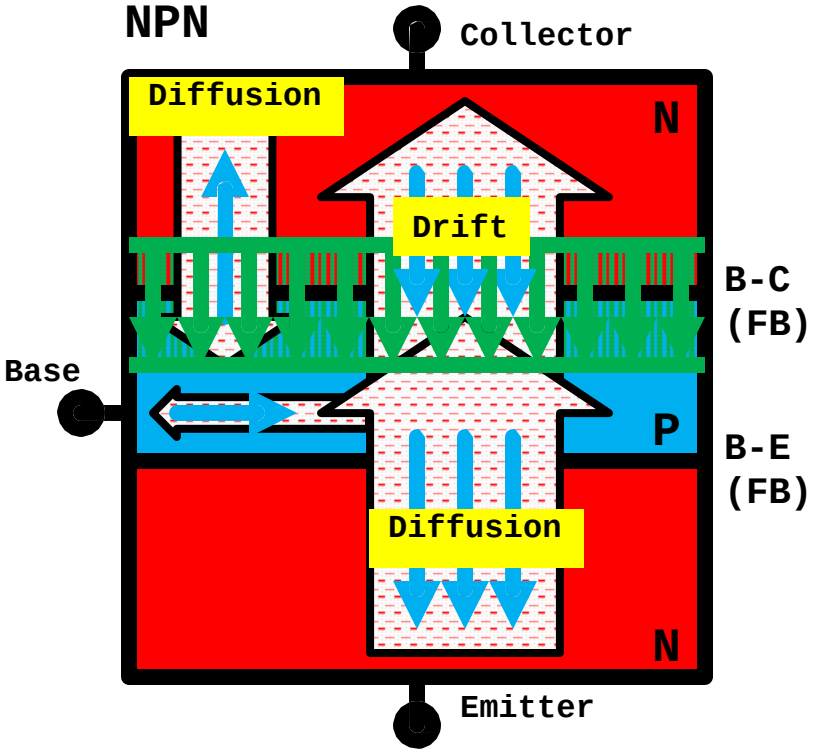
$i_C = I_S \exp(v_{BE}/V_T)(1+\lambda v_{CE})$

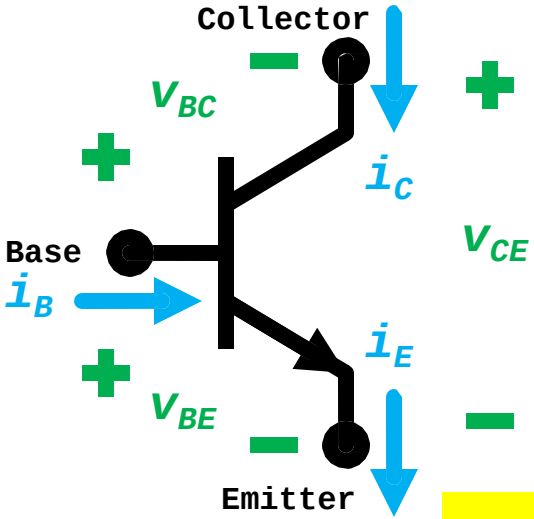




ACTIVE MODE

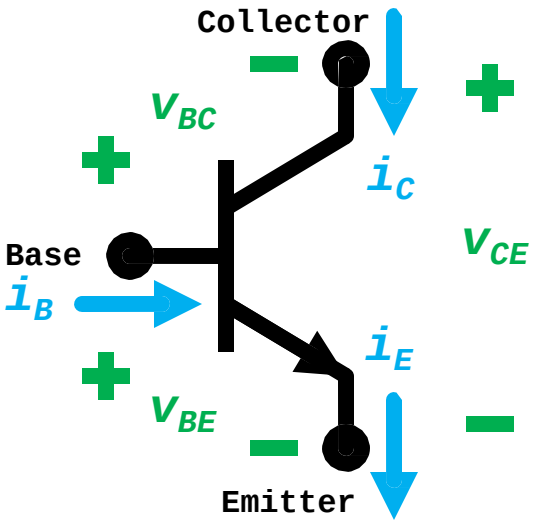
$$i_C = I_S \exp(v_{BE}/V_T) - I_{SC} \exp(V_{BC}/V_T)$$





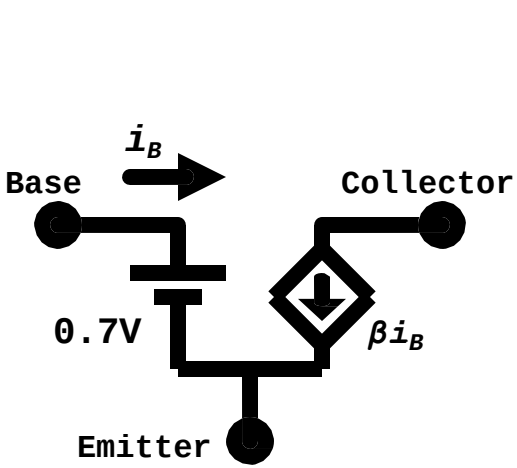
SATURATION MODE

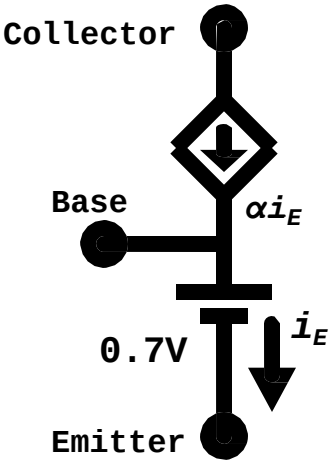
NPN Mode	PN Junction B-E Bias	PN Junction B-C Bias	i-v Characteristic
Cutoff	Reverse	Reverse	$i_C=i_B=i_E=0$
Active	Forward	Reverse	$i_C=I_S\exp(v_{BE}/V_T)(1+\lambda V_{CE})$ $i_B=i_C/\beta,\ i_E=i_C/\alpha$
Saturation	Forward	Forward	$i_C=I_S\exp(V_{BE}/V_T)-I_{SC}\exp(V_{BC}/V_T)$ $i_B=(I_S/\beta)\exp(V_{BE}/V_T)+I_{SC}\exp(V_{BC}/V_T)$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



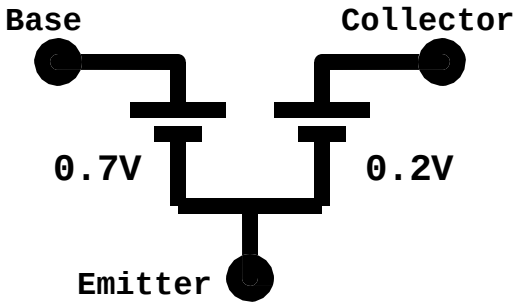
NPN Mode	PN Junction B-E Bias	PN Junction B-C Bias	i-v Characteristic
Cutoff	Reverse v_{BE}<0.7V	Reverse v_{BC}<0.5V	$i_C=i_B=i_E=0$
Active	Forward v_{BE}=0.7V i_C>0	Reverse v_{BC}<0.5V v_{CE}>0.2V	$i_B=i_C/\beta$, $i_E=i_C/\alpha$, $\alpha=\beta/(\beta+1)$
Saturation	Forward v_{BE}=0.7V i_C>0	Forward v_{BC}=0.5V v_{CE}=0.2V	$i_B>i_C/\beta$, $i_C/i_B=\beta_{forced}<\beta$

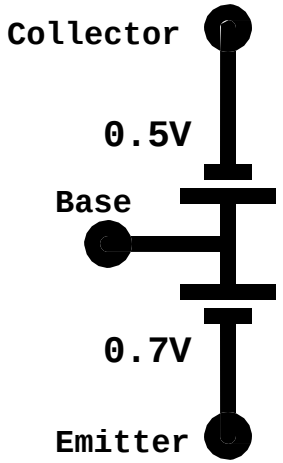
ACTIVE MODE

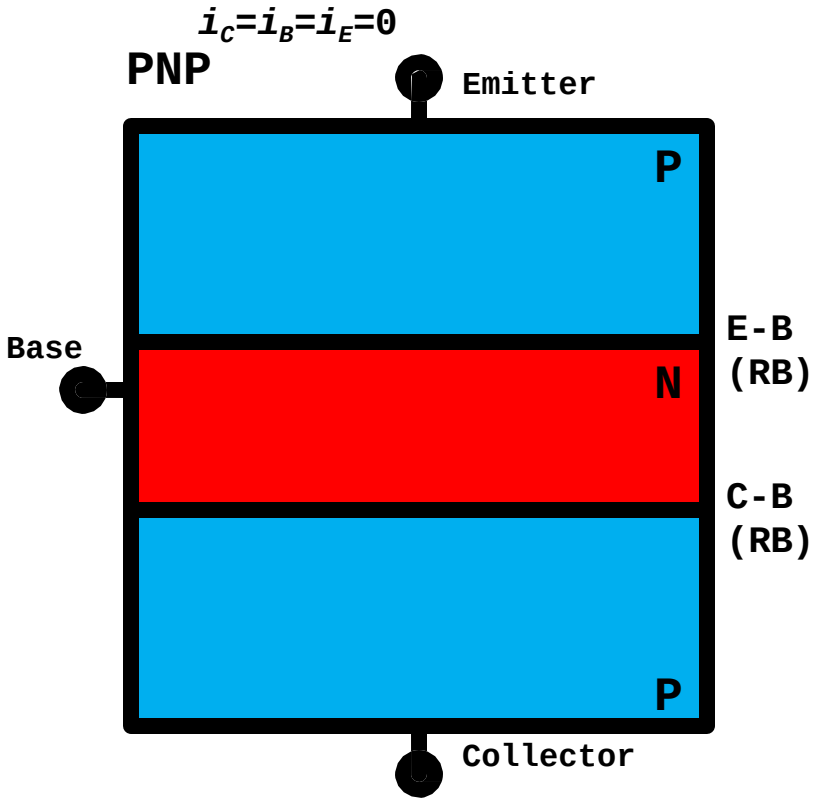


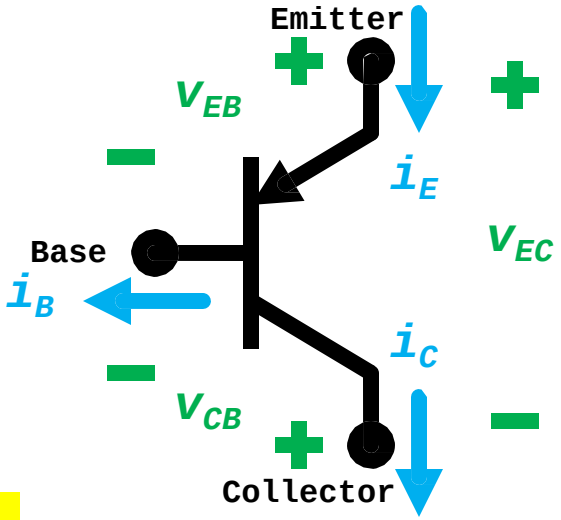


SATURATION MODE



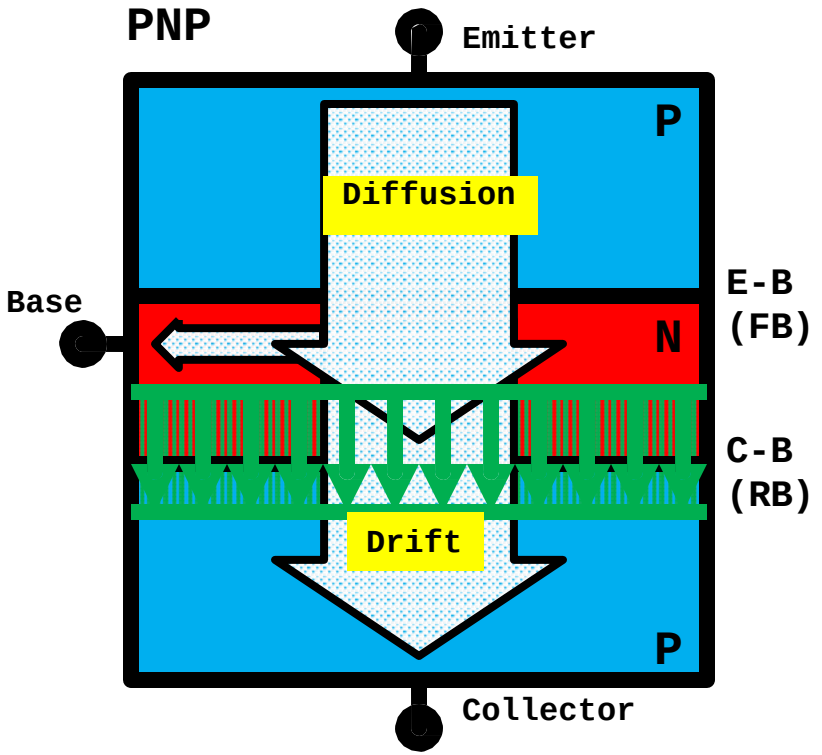


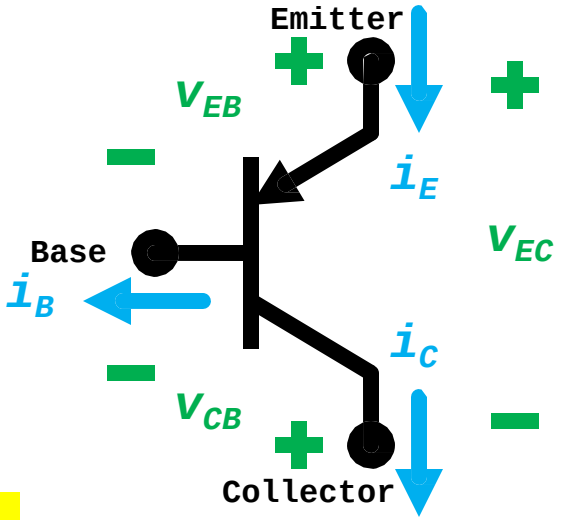

$i_C=i_B=i_E=0$
PNP
Emitter
P
Base
N
E-B
(RB)
C-B
(RB)
P
Collector


Emitter
V_{EB}
i_E
V_{EC}
Base
i_B
i_C
V_{CB}
Collector

CUTOFF MODE

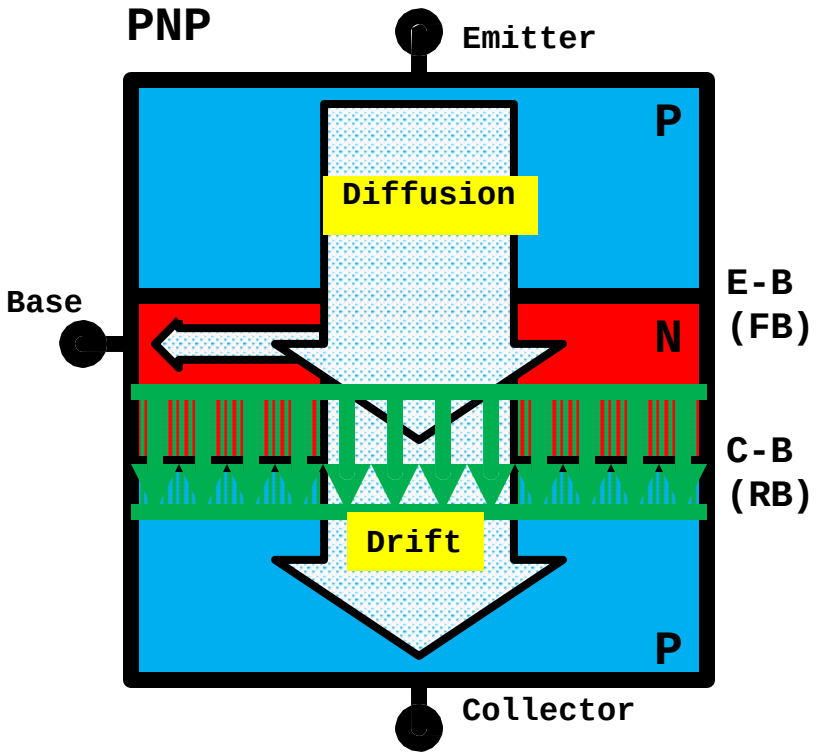
$i_C = I_S \exp(v_{EB}/V_T)$

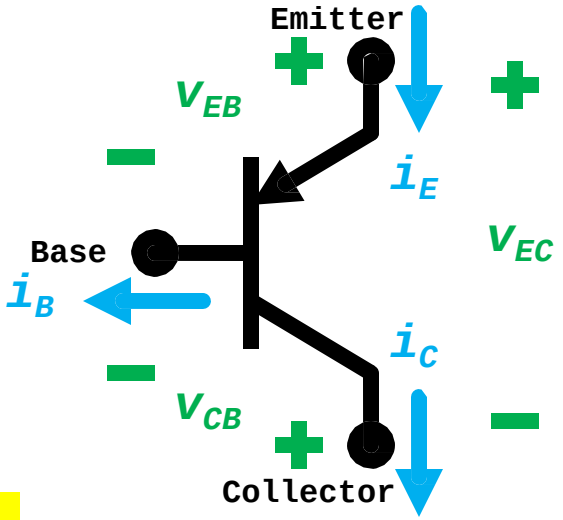




ACTIVE MODE

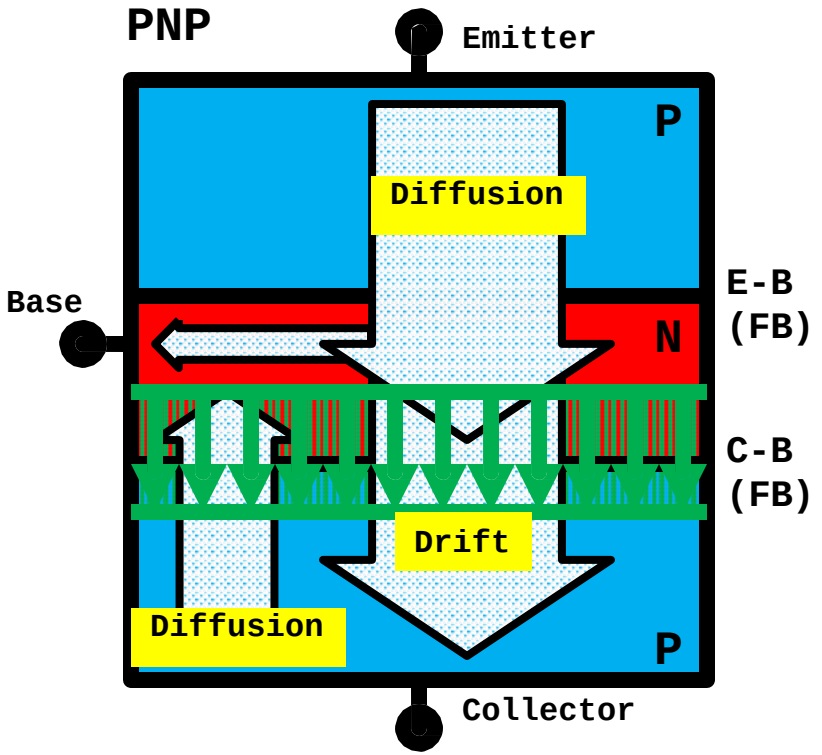
$i_C = I_S \exp(v_{EB}/V_T)(1+|\lambda| v_{EC})$

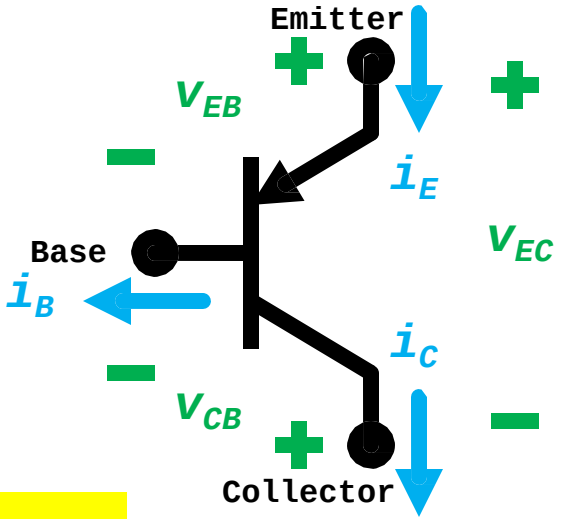




ACTIVE MODE

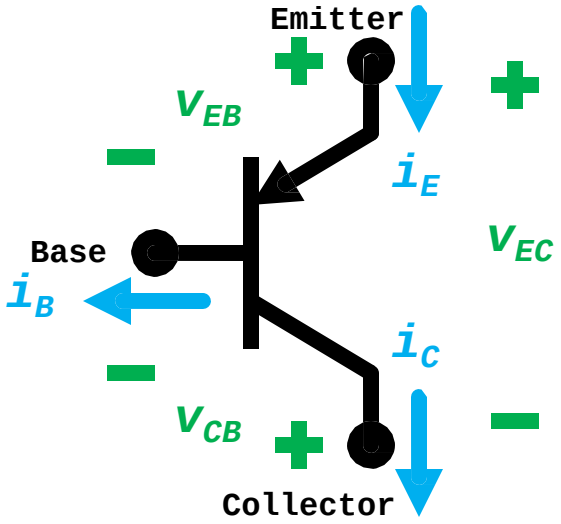
$i_C = I_S \exp(v_{EB}/V_T) - I_{SC} \exp(V_{CB}/V_T)$





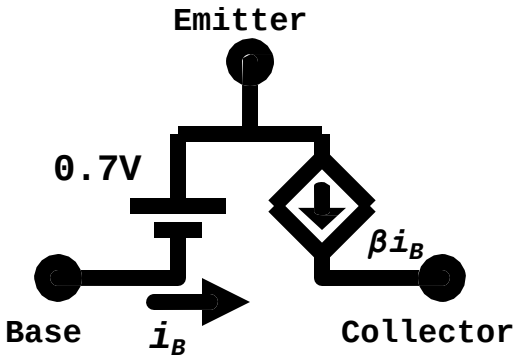
SATURATION MODE

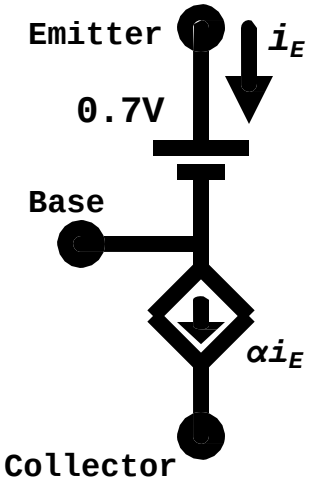
PNP Mode	PN Junction E-B Bias	PN Junction C-B Bias	i-v Characteristic
Cutoff	Reverse	Reverse	$i_C=i_B=i_E=0$
Active	Forward	Reverse	$i_C=I_S\exp(v_{EB}/V_T)(1+\lvert\lambda\rvert v_{EC})$ $i_B=i_C/\beta,\ i_E=i_C/\alpha$
Saturation	Forward	Forward	$i_C=I_S\exp(V_{EB}/V_T)-I_{SC}\exp(V_{CB}/V_T)$ $i_B=(I_S/\beta)\exp(V_{EB}/V_T)+I_{SC}\exp(V_{CB}/V_T)$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



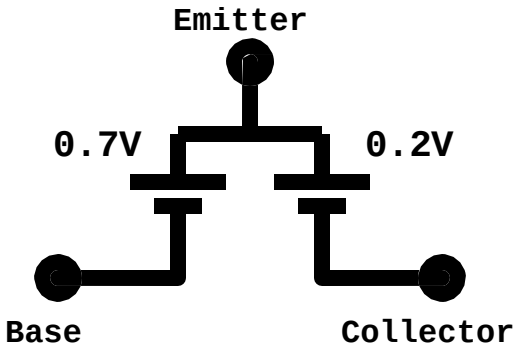
PNP Mode	PN Junction E-B Bias	PN Junction C-B Bias	i-v Characteristic
Cutoff	Reverse	Reverse	$i_C=i_B=i_E=0$
	$v_{EB}<0.7V$	$v_{CB}<0.5V$	
	$i_C=0$		
Active	Forward	Reverse	$i_B=i_C/\beta,\ i_E=i_C/\alpha,\ \alpha=\beta/(\beta+1)$
	$v_{EB}=0.7V$	$v_{CB}<0.5V$	
	$i_C>0$	$v_{EC}>0.2V$	
Saturation	Forward	Forward	$i_B>i_C/\beta,\ i_C/i_B=\beta_{forced}<\beta$
	$v_{EB}=0.7V$	$v_{CB}=0.5V$	
	$i_C>0$	$v_{EC}=0.2V$	

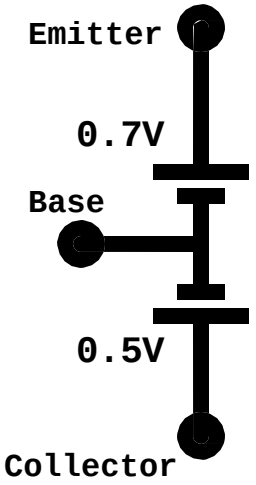
ACTIVE MODE





SATURATION MODE





NPN Mode	PN Junction B-E Bias	PN Junction B-C Bias	i-v Characteristic
Active	Forward	Reverse	$i_C = I_S \exp(v_{BE}/V_T)(1+\lambda V_{CE})$
			$i_B = i_C/\beta,\ i_E = i_C/\alpha$

Small Signal

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

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

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

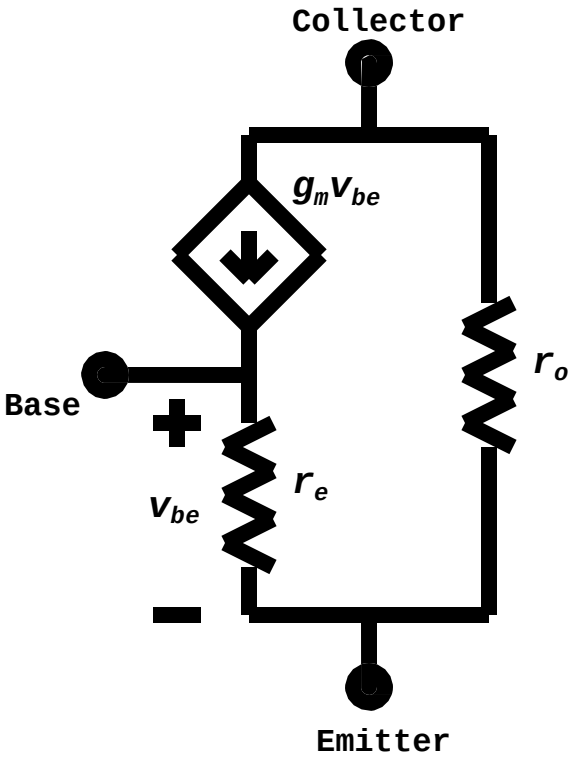
$r_\pi = \beta/g_m$

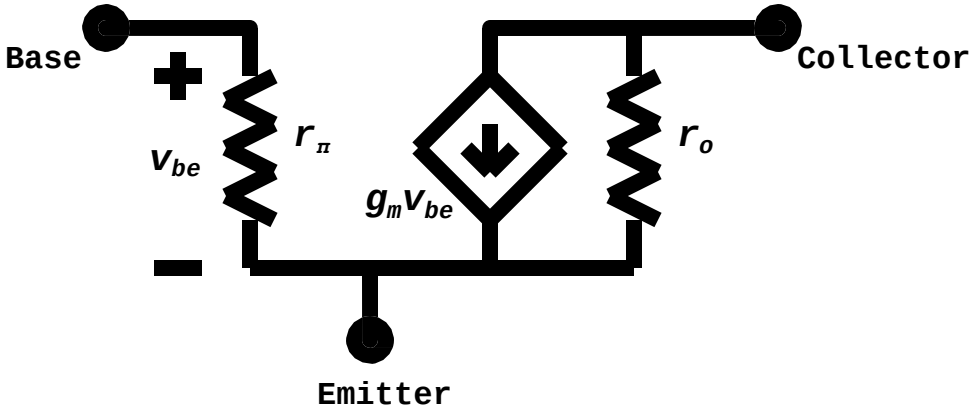
$i_e = i_c/\alpha = g_m v_{be}/\alpha = v_{be}/r_e$

$r_e = \alpha/g_m$

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

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





PNP Mode	PN Junction E-B Bias	PN Junction C-B Bias	i-v Characteristic
Active	Forward	Reverse	$i_C = I_S \exp(v_{EB}/V_T)(1+\lvert\lambda\rvert v_{EC})$
			$i_B = i_C/\beta,\ i_E = i_C/\alpha$

Small Signal

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

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

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

$r_\pi = \beta/g_m$

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

$r_e = \alpha/g_m$

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

$r_o = \lvert V_A\rvert/I_C = 1/(\lvert\lambda\rvert I_C)$