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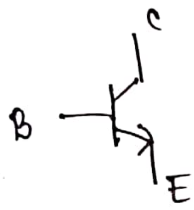
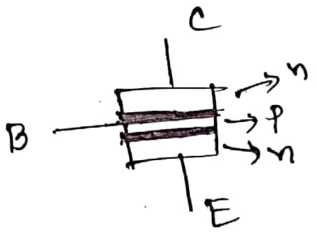
physical structure of BJT

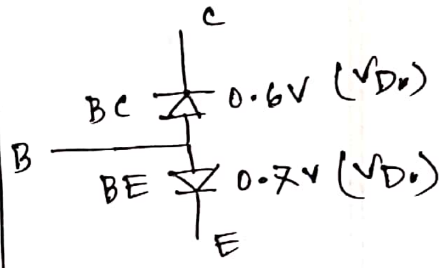


circuit symbol



physical structure

Here,
Base is very thin. Emitter is heavily dopped base is lightly dopped.



Diode equivalent circuit.

Now will it work like BJT if we put two simple diode like the ~~2~~ diode equivalent ckt. configuration?

⇒ No. Because for BJT base is lighter than Emitter and collector and emitter is heavily dopped and base is lightly dopped.

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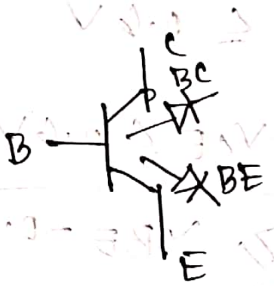
(Overview) Simplified operation of BJT



BE → ON, OFF
BC → ON, OFF

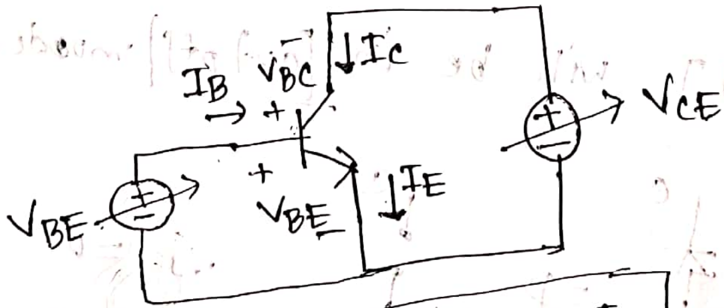
} 4 combinations so BJT has 4 modes of operation

BE	BC	operation mode / region of BJT
OFF	OFF	cut off
ON	ON	Saturation
ON	OFF	Active
OFF	ON	Reverse Active

→ This 3 modes we will mainly study.

Reverse Active ↪ very rear in practical application.

For study of BJT we will use this circuit. that is want see how I_B controls IV of I_C vs V_{CE}



$\boxed{I_E = I_B + I_C}$

$\boxed{V_{BC} = V_{BE} - V_{CE}}$

↪ $V_{BC} = V_B - V_C$

$= (V_B - V_E) - (V_C - V_E)$

$= V_{BE} - V_{CE}$

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condition for BC ⇒ OFF

$V_{BC} \le 0.6V$

$\therefore V_{BE} - V_{CE} \le 0.6V$

$\boxed{V_{CE} \ge V_{BE} - 0.6V}$

∴ the Base-collector will be off for this condition.

BE ~~will~~ ~~be~~ ⇒ OFF

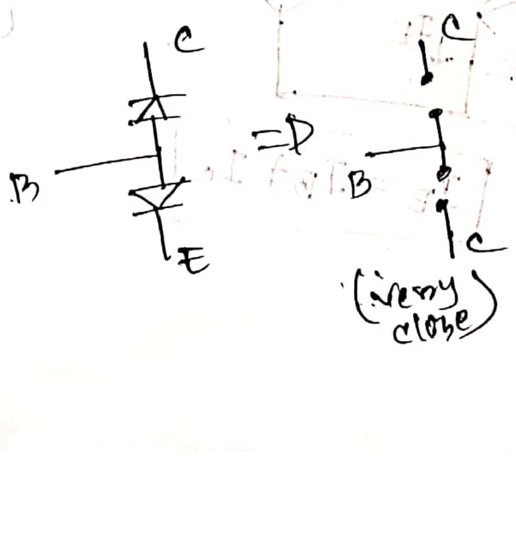
$V_{BE} \le 0.7V$

Case 1: $V_{BE} \le 0.7$ and $V_{CE} \ge V_{BE} - 0.6$

$\Downarrow$ $\Downarrow$

BE → OFF (diode)   BC → OFF (diode)

∴ ~~A~~ BJT will be in $\boxed{\text{cutoff}}$ mode.



∴ $I_C = 0$

$I_E = 0$

∴ $\boxed{I_B = 0}$] equation

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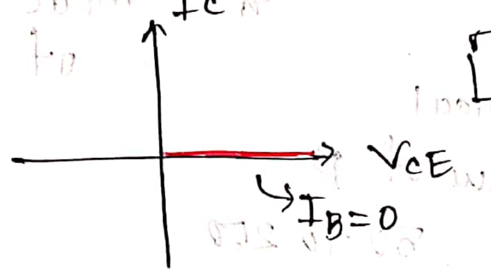
∴ I V will be like this for cutoff :

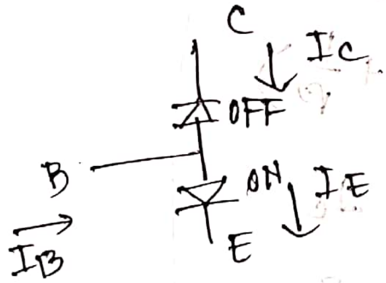


Case2 : $I_B > 0$ and $V_{CE} \geq V_{BE} - 0.6$

∴ BE ⇒ ON (diode)

BC ⇒ OFF (diode)

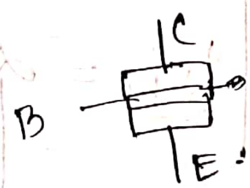
∴ So, Active region.



So will it be $I_C = 0$?

⇒ No Because this is just a ~~circuit~~ diode representation of BJT Not the actual circuit.

~~AA~~ Due to their structure



in this active mode Huge current starts flowing from collector to emitter.

And this current ∝ Base current that is $I_C \propto I_B$

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$$\therefore \boxed{I_C = \beta I_B}$$

Typical value of β is 50 to 200

** [we use this Active mode for creation of amplifier]

$$\therefore \boxed{I_C = \beta I_B}$$

$$\boxed{V_{BE} = 0.7V}$$

equation

$$I_E = I_C + I_B$$

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

$$= I_C \left(1 + \frac{1}{\beta}\right)$$

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

$$\therefore \boxed{I_C = \frac{\beta}{1+\beta} I_E \qquad \therefore I_C = \alpha I_E}$$

alpha, this is also a constant typical value is ≈ 0.99

This represent that in active mode the I_C is almost equal to I_E

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$V_{CE} \geq V_{BE} - 0.6$

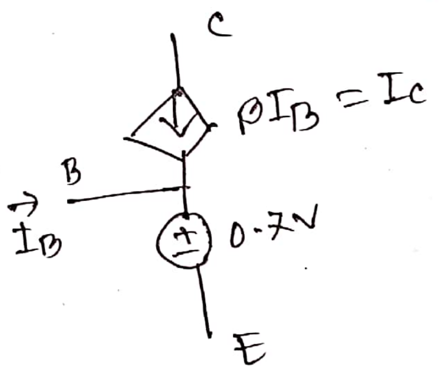
$= 0.7 - 0.6$

$V_{CE} \geq 0.1V$

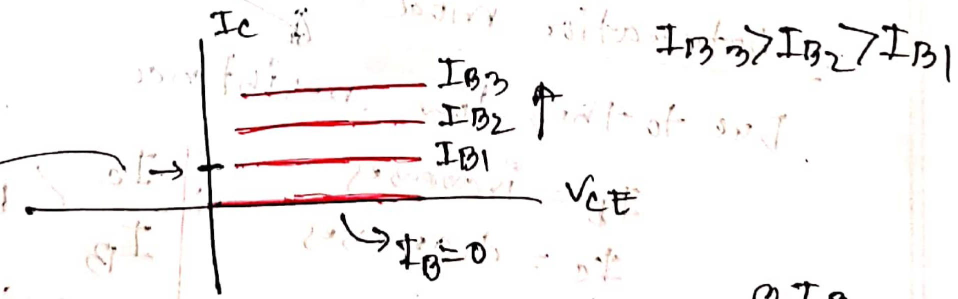
∴ Active Mode $\boxed{I_c = \beta I_B}$

$\boxed{V_{BE} = 0.7V}$

Model the BJT with



∴ IV of I_c vs. V_{CE}



called saturation current $I_{sat} = \beta I_B$

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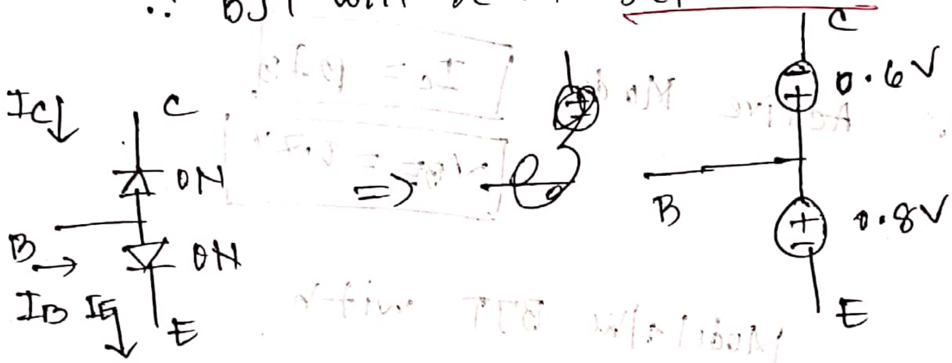
Case 3 : $I_B > 0$ and $V_{CE} < V_{BE} = 0.6$

BE => ON (diode)   BC = ON (diode)

∴ BJT will be in saturation mode.



[using CVD model]

[But in Forward bias mode diode has small resistance]

∴ Here collector and emitter terminal will have small resistance

∴ saturation mode

Due to this low resistance

I_B = increases

I_C = decreases

$\therefore \boxed{\frac{I_C}{I_B} < \beta}$

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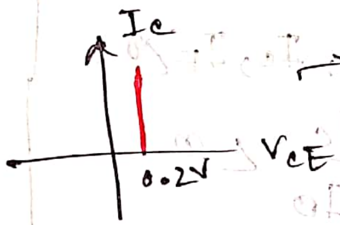
$$V_{CE} = V_{BE} - V_{BC}$$
$$= 0.8 - 0.6$$
$$\boxed{V_{CE} = 0.2V}$$

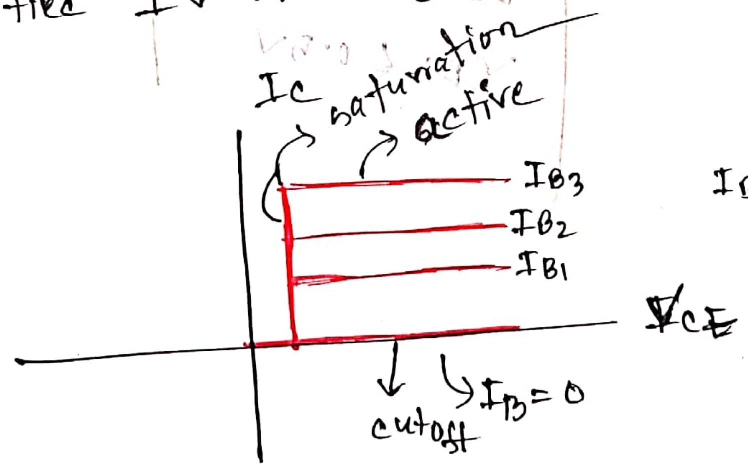
So in saturation region BJT works like voltage source of 0.2 V.

∴ I-V of I_c vs V_{CE} will be like this



→ IV in saturation mode.

(*) simplified IV of BJT will be like this



$I_{B3} > I_{B2} > I_{B1}$

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Summary   condition and Model :

State	condition	Equation
Active	$I_B, I_C, I_E > 0$ $V_{CE} > 0.2V$	$V_{BE} = 0.7V$ $I_C = \beta I_B$ $I_C = \alpha I_E$ | $\alpha = \frac{\beta}{1+\beta}$
Saturation	$I_B, I_C, I_E > 0$ $\frac{I_C}{I_B} < \beta$	$V_{BE} = 0.8V$ $V_{CE(sat)} = 0.2V$
cut off	$V_{BE} \leq 0.7V$ $V_{BC} \leq 0.6V$ $\leq 0.5V$ [some cases]	$I_B = I_C = I_E = 0$

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BJT

[Method of Assumed state]

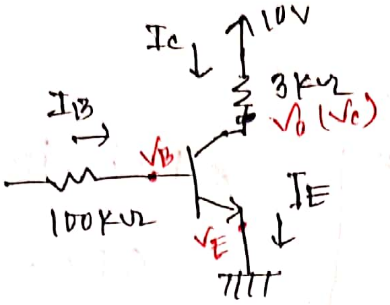
Steps:

1. Assume
   - → Active [$V_{BE} = 0.7\,V$, $I_C = \beta I_B$, $I_C = \alpha I_B$, $\alpha = \frac{\beta}{1+\beta}$]
   - → Saturation [$V_{BE} = 0.8\,V$, $V_{CE} = 0.2\,V$]
   - → cut off [$I_B = I_C = I_E = 0$]

2. solve [KVL, KCL, nodal]

3. Verify
   - → Active [$V_{CE} > 0.2\,V$]
   - → Saturation [$\frac{I_C}{I_B} < \beta$]
   - → cutoff [$V_{BE} \leq 0.7\,V$ and $V_{BC} \leq 0.6\,V$]
     - → $\leq 0.5\,V$ [Some cases]

Ex1 :



* Find V_o for $V_i = 1V$

Given, $\beta = 100$

Assumption 1: Active Mode

$\therefore$ $V_{BE} = 0.7V$ and $I_c = \beta I_B$

$\therefore$ $V_{BE} = V_B - V_E = 0.7$

$\Rightarrow V_B - 0 = 0.7$

$\therefore V_B = 0.7V$

$$I_B = \frac{V_i - V_B}{R_B} = \frac{1 - 0.7}{100} = 0.003 \text{ mA}$$

$\therefore I_c = \beta I_B = 100 * 0.003 = 0.3 \text{ mA}$

now, $10 - V_c = I_c * 3$

$\Rightarrow V_c = 10 - 3I_c = 10 - 3 * 0.3 = 9.1V$

Verification :

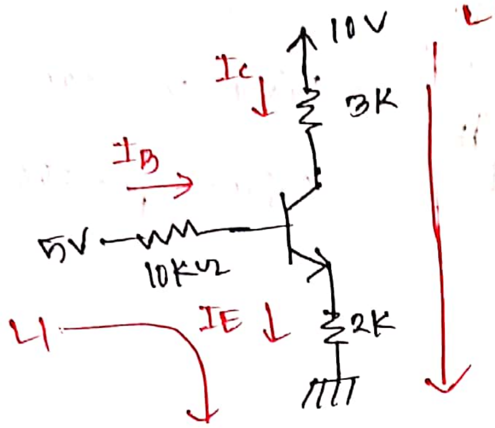
$V_{CE} = V_c - V_E = 9.1 - 0 = 9.1V$

$\therefore$ $V_{CE} > 0.2$

$\therefore$ Assumption 1 is correct.

$\therefore$ $\boxed{V_o = V_c = 9.1V}$ Answer

EX2 :



Find I_B, I_c, I_E, V_{CE}

Given $\beta = 100$

Assumption 1: Active Mode

$\therefore$ $V_{BE} = 0.7V$ and $I_C = \beta I_B$, $I_c = \alpha I_E$ $\Rightarrow$ $I_E = \frac{\beta}{\alpha} I_B$

$\therefore$ ~~$I_E = \frac{\beta}{\alpha} I_B$~~

$I_E = I_B + I_c$

$\alpha = \frac{\beta}{1+\beta} = \frac{100}{100+1} = 0.99$

KVL along L1:

$10 I_B + V_{BE} + 2 I_E = 5 - 0$

$10 I_B + 0.7 + 2 \frac{\beta}{\alpha} I_B$

$\Rightarrow 5V = 10 I_B + 0.7 + 2 \frac{\beta}{\alpha} I_B$

$\Rightarrow I_B = 0.02\ mA$

$\therefore I_c = 100 * I_B = 100 * 0.02 = 2\ mA$

$I_E = I_c + I_B = 2.02\ mA$

~~V_{CE}~~

$$I_E = \frac{V_E - 0}{2}$$

$\Rightarrow V_E = 4.04V$

$$I_c = \frac{10 - V_c}{3}$$

$\Rightarrow V_c = 4V$

$\therefore V_{CE} = V_c - V_E = 4 - 4.04V = -0.04V$

Verification:

$V_{CE} = -0.04V < 0.2V$

$\therefore$ Assumption 1 wrong.

Assumption 2 : Saturation Mode

$\therefore V_{BE} = 0.8V$

$V_{CE} = 0.2V$

KCL: $I_E = I_c + I_B \quad \therefore \quad I_E - I_c - I_B = 0$ — ①

KVL along L1: $10I_B + V_{BE} + 2I_E = 5 - 0$

$\Rightarrow 10I_B + 0.8 + 2I_E - 5 = 0$ — ②

KVL along L2:

$3I_c + V_{CE} + 2I_E = 10 - 0$

$\Rightarrow 3I_c + 0.2 + 2I_E - 10 = 0$ — ③

From ①, ② and ③, $I_E = 1.975$, $I_c = 1.95$, $I_B = 0.025$

Verification:

$$\frac{I_C}{I_B} = \frac{1.05}{0.025} = 78$$

$\therefore$ $\frac{I_C}{I_B} < \beta$

$\therefore$ Assumtion 2 correct.

$\therefore$
$$I_E = 1.075,$$
$$I_C = 1.05$$
$$I_B = 0.025$$
(Answer)