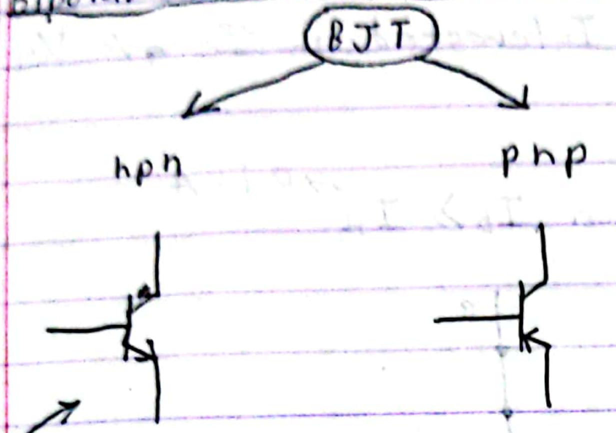
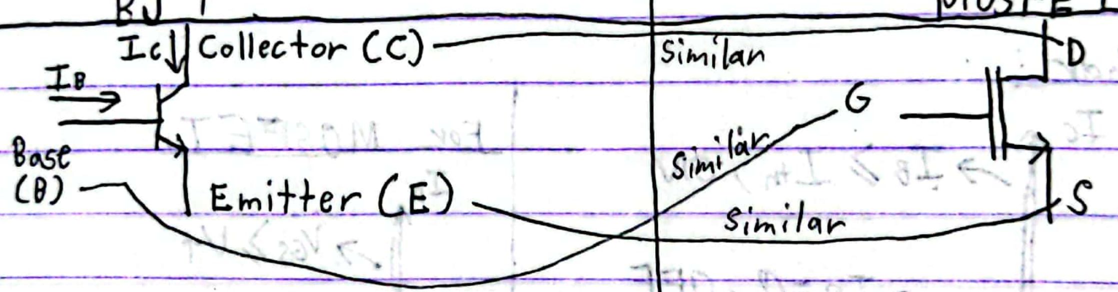
BJT Transistor:

* Bipolar Junction Transistors

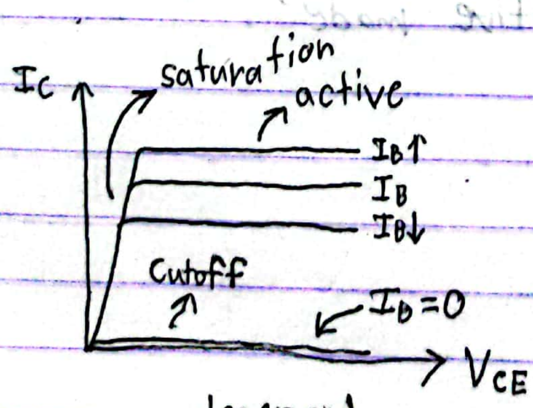


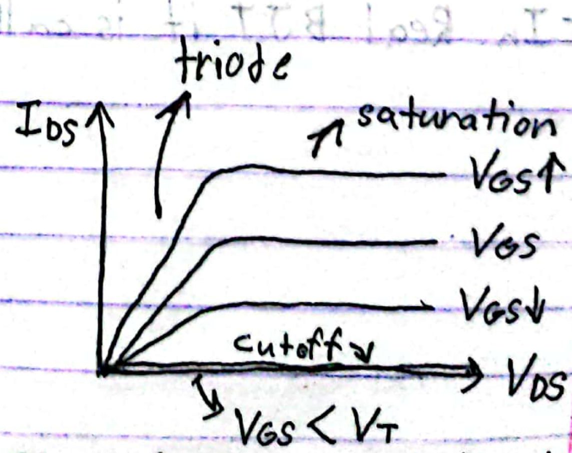
This will be studied most.

Relationship between BJT and ~~MOSFI~~ MOSFET:



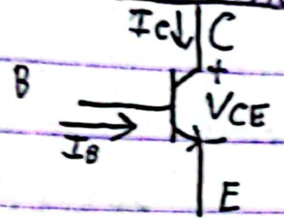
BJT	MOSFET
• $I_B \neq 0$ and $I_C \neq I_E$, $I_E = I_B + I_C$	• $I_G = 0$ and $I_D = I_S$
• I_B controls I-V characteristics between C-E, so it is called a current controlled device.	• I-V Characteristics of D-S is controlled by V_{GS} so it is called Voltage controlled device.





BJT	MOSFET
• The slope is steeper and constant and doesn't depend on I_B	• Slope is lower and depends on V_{GS}

Switch (S) - model of BJT:



* Current Controlled (I_B)
* Interested in I_C vs V_{CE}.

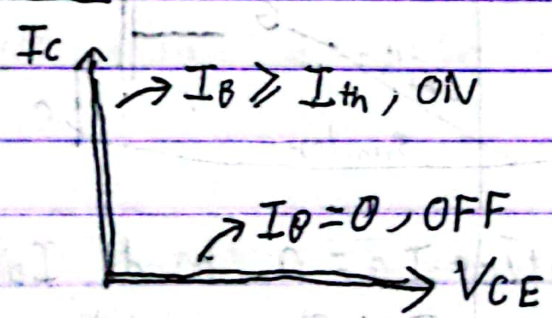
* When $I_B = 0$,

OFF (Logical 0)

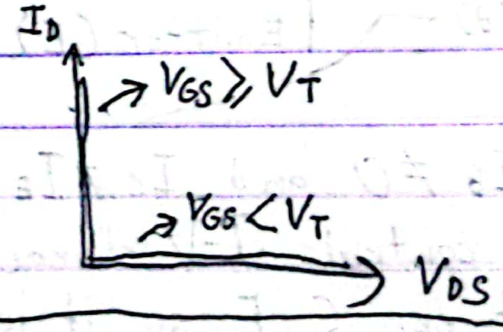
• When $I_B \geq I_{th}$ → 0.1mA

ON (Logical 1)

* IV Char:

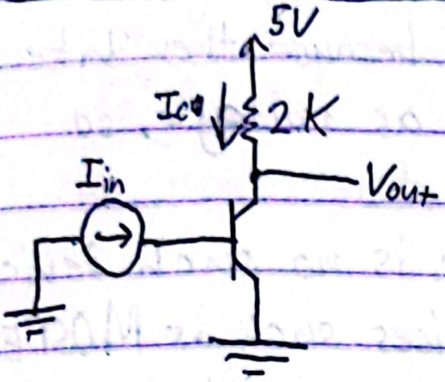


For MOSFET:



• If $0 < I_B < I_{th}$
- Invalid in S-model
- In Real BJT it is called 'active mode'.

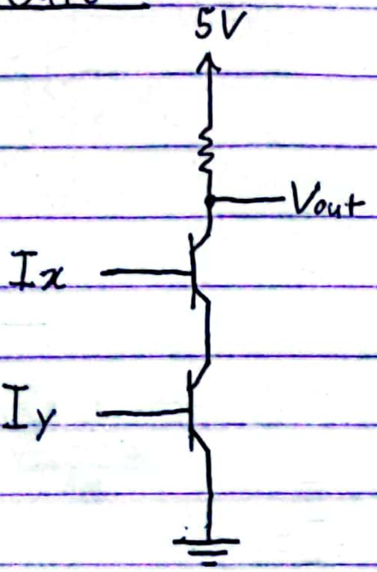
* NOT Gate / Inverter :



I_{in}	IN	V_{out}	OUT
0 mA	0	5 V	1
I_{th}	1	0	0

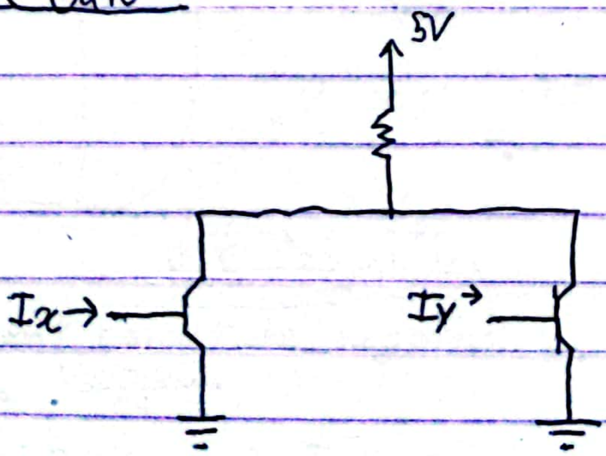
$\boxed{Out = \overline{I_n}}$

* NAND Gate :



$\boxed{OUT = \overline{XY}}$

* NOR Gate :



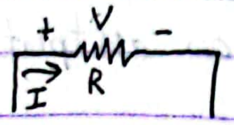
~~OUT~~

$\boxed{OUT = \overline{X+Y}}$

Problem:

* Cannot put 2 logic gate side by side because they take input as current and give output as voltage, so cannot be directly cascaded.
* Need a current source but there is no such device as a current source, so other devices such as MOSFETs can be used as a current source but controlling current with those is very hard.
* Hard to set $I_x = 0$ exactly

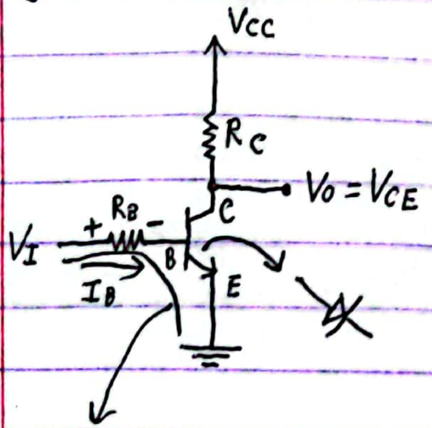
Voltage Controlled logic gates:



$I = \frac{V}{R} \Rightarrow V = RI$ or vice versa

* We can use resistors to convert from voltage to current linearly.

* Eg: Inverter



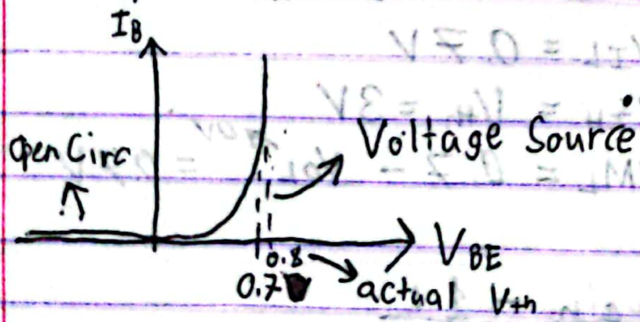
	I_B	V_I
Logic 0	$I_B = 0$	$V_I < 0.7$
" 1	$I_B \geq I_{th}$	$V_I \geq V_{th}$

• K.V.L:

$V_I = I_B R_B + V_{BE} + 0$

$\Rightarrow I_B = \frac{V_I - V_{BE}}{R_B}$

* V_{BE} depends on I_B



• Similar to diode

* Current cannot be negative

• $I_B = \frac{V_I - 0.7}{R_B}$

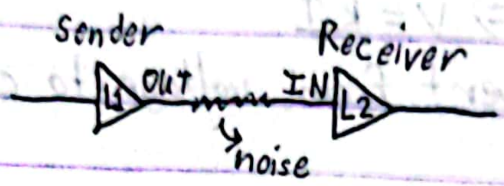
$V_I \leq 0.7V \Rightarrow I_B = 0 \Rightarrow$ Logical 0

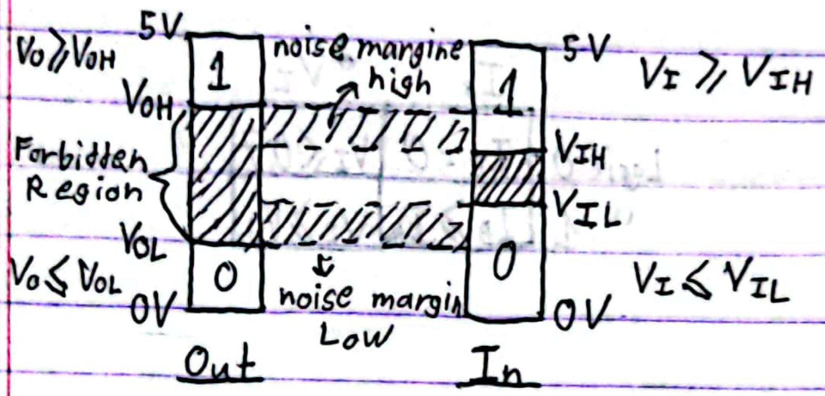
• $V_{th} = I_{th} R_B + 0.8V = 0.022 \times 100 + 0.8 = 3V$

$R_B = 100k$, $I_{th} = 0.022$ mA

Improving Noise Margin:

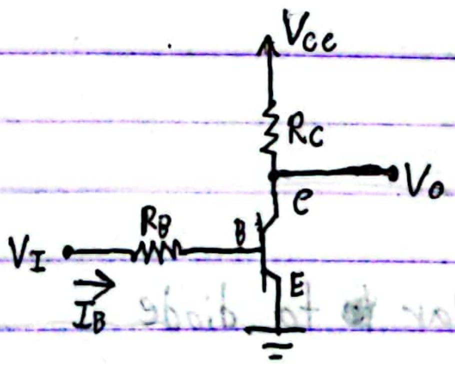
* Static discipline ⇒ tighter restriction on output (sender).





* $V_{OH} > V_{IH} \Rightarrow NM_H = V_{OH} - V_{IH}$
* $V_{OL} < V_{IL} \Rightarrow NM_L = V_{IL} - V_{OL}$

*



$V_I \leq 0.7V \Rightarrow$ '0'

$V_I \geq V_{th} \Rightarrow$ '1'

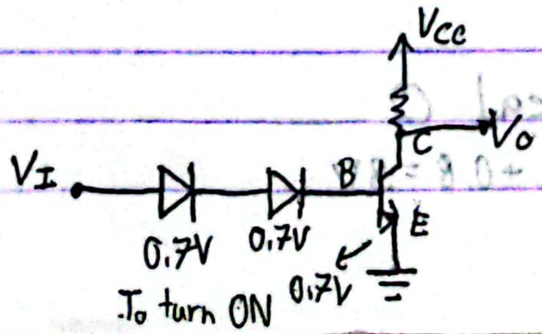
3V

$V_{IL} = 0.7V$

$V_{IH} = V_{th} = 3V$

$NM_L = 0.7 - \overset{0V}{V_{OL}} = 0.7V$

* Improve ~~NM~~ Noise Margin - 1:
* Add 1 or more diodes in the Base,

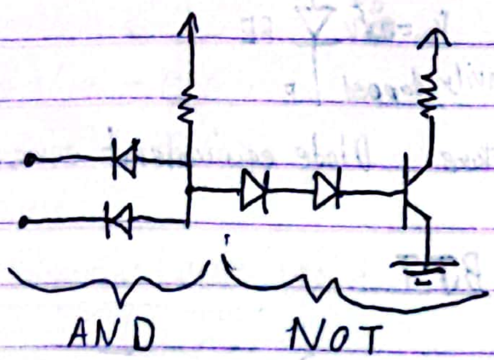


∴ $V_I \leq 2.1V \Rightarrow$ OFF ⇒ logical '0'

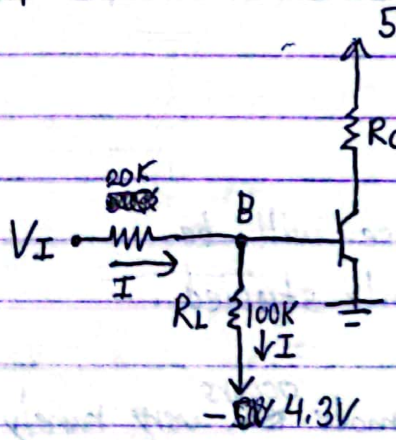
∴ $V_{IL} = 2.1V \Rightarrow NM_L = 2.1 - V_{OL}$

- These types of circuits are called DTL (Diode Transistor Logic Gate).

* DTL (NAND Gate):



* Improvement - 2:



$$I = \frac{V_B - (-4.3)}{100} = \frac{0.7 + 4.3}{100}$$

$$= 0.05 \text{ mA}$$

$$I = \frac{V_I - V_B}{20}$$

$$V_I = 20 \times I + V_B$$

$$= 20 \times 0.05 + 0.7$$

$$= 1 + 0.7$$

$$= 1.7V$$

$$V_{BE} \leq 0.7$$

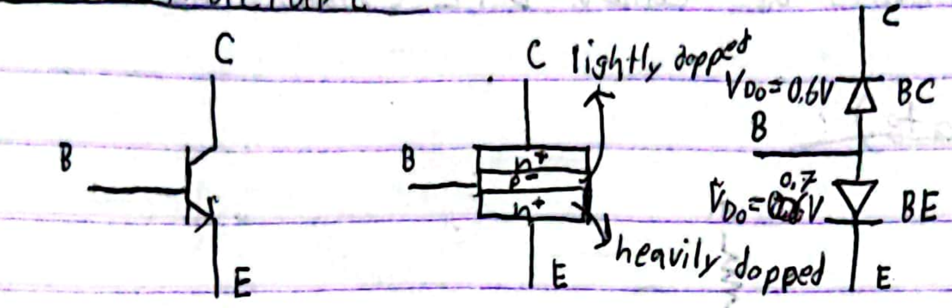
$$V_I \leq 1.7V \Rightarrow \text{Logic '0'}$$

$$V_{IL} = 1.7$$

$$NM_L = 1.7 - \overset{0V}{V_{OL}} = 1.7V$$

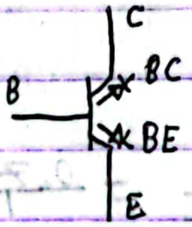
- These types of circuits are called RTL (Resistor Transistor Logic family).

BJT (npn) Structure :



Circuit Symbol　　Physical Structure　　Diode equivalent circuit

* (Over) Simplified Operation of BJT :



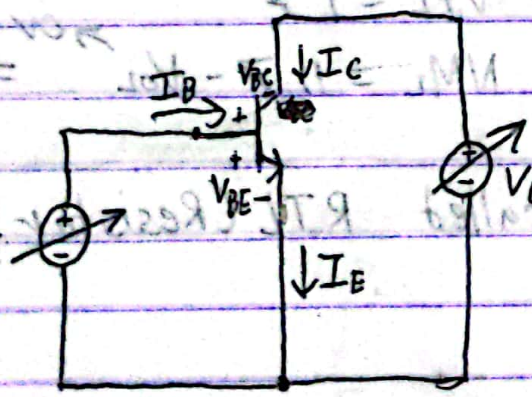
BE → ON, OFF } 4 combinations
BC → ON, OFF } ⇒ 4 modes of operation

Modes	BE	BC
Cutoff	OFF	OFF
Saturation	ON	ON
Active	ON	OFF
Reverse Active	OFF	ON

} These will be mainly studied. (Cutoff, Saturation, Active)

} This mode occurs very rarely. (Reverse Active)

* Circuit:



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

$$\boxed{I_E = I_B + I_C}$$

- $V_{BC} = V_B - V_C = (V_B - V_E) - (V_C - V_E) = V_{BE} - V_{CE}$
- $BC \Rightarrow OFF$,

$\Rightarrow V_{BC} \leq 0.6V$

$\Rightarrow V_{BE} - V_{CE} \leq 0.6V$

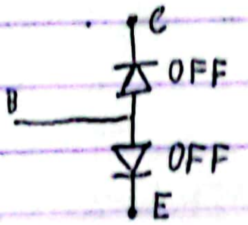
$\Rightarrow V_{CE} \geq V_{BE} - 0.6V$

- $V_{BE} \leq 0.7V \Rightarrow OFF$

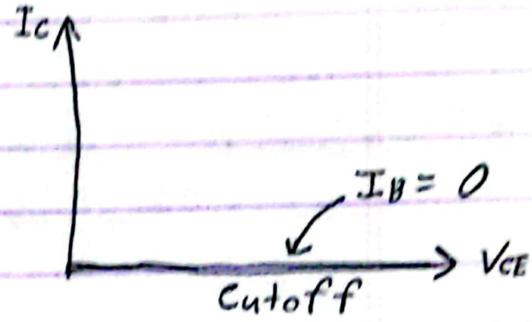
I V Characteristics:

* Case - 1: $\underbrace{V_{BE} \leq 0.7}_{BE \to OFF}$ and $\underbrace{V_{CE} \geq V_{BE} - 0.6}_{BC \to OFF}$

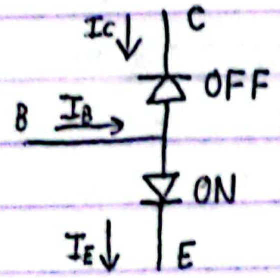
$\Rightarrow I_B = 0$



OFF $\Rightarrow I_C = 0$
OFF $\Rightarrow I_{E} = 0$
} Cutoff



* Case - 2: $\underbrace{I_B > 0}_{BE = ON}$ and $\underbrace{V_{CE} \geq V_{BE} - 0.6}_{BC = OFF}$



$\boxed{I_C = \beta I_B}$

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

- Huge amount of current flows from the collector to the emmitter

$\beta = [50, 200] = 100$ (Mostly)

Active Mode

$I_E = I_C + I_B$

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

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

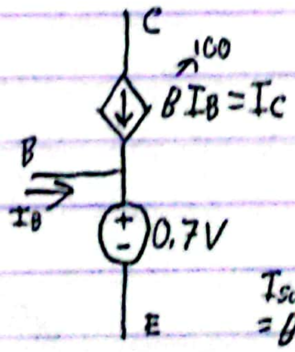
$I_E = \frac{\beta + 1}{\beta} I_C$

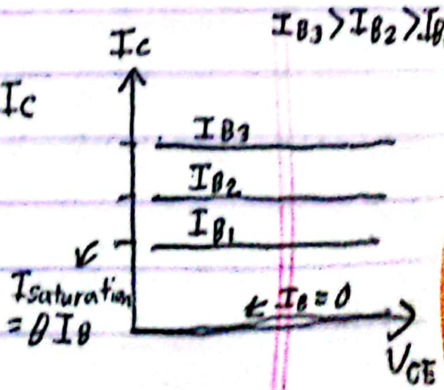
$\Rightarrow I_C = \left(\frac{\beta}{1+\beta}\right) I_E$

$\alpha = \frac{100}{101}$

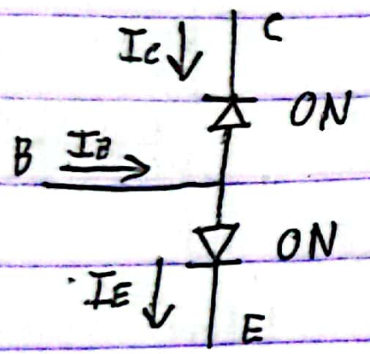
$\boxed{I_C = \alpha I_E}$

$I_C \approx I_E$

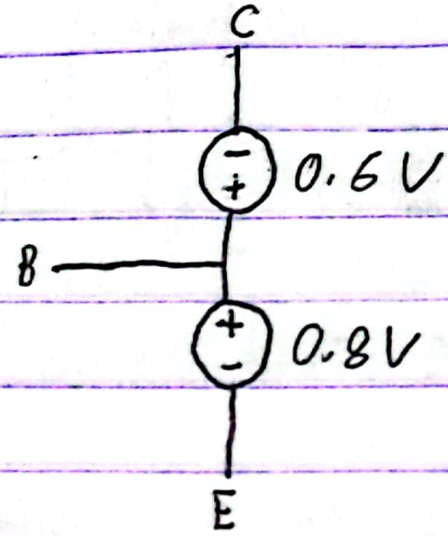




* Case-3: $\overbrace{I_B > 0}^{BE=ON}$ and $\overbrace{V_{CE} < V_{BE} - 0.6}^{BC=ON}$



$\Rightarrow$

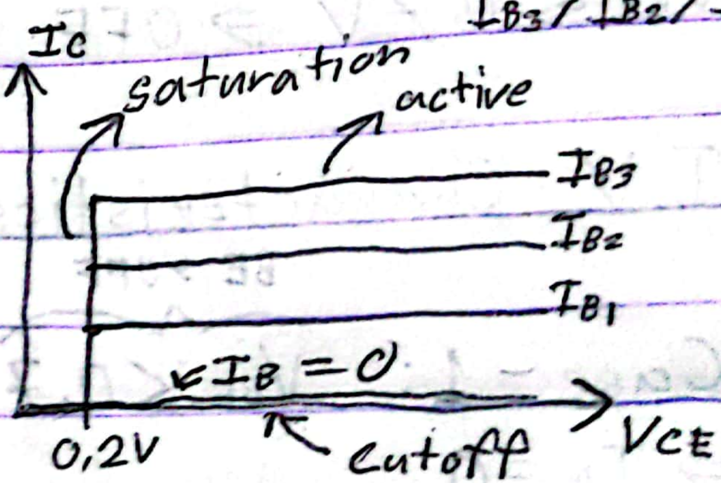


$V_{CE} = V_{BE} - V_{BC}$

$\Rightarrow V_{CE} = 0.8 - 0.6$

$\Rightarrow V_{CE} = 0.2V = V_{saturation}$

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



Saturation Mode

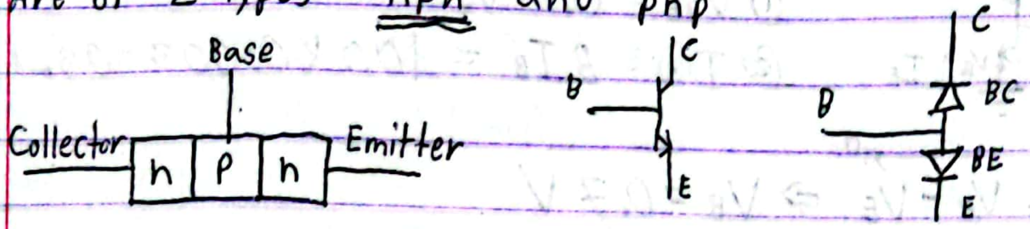
↑ I_B increases

↓ I_C decreases $\Rightarrow$ $\boxed{\dfrac{I_C}{I_B} < \beta}$

Bipolar Junction Transistors (BJT):

* 3 terminal devices
* Used as: ① Amplifiers, ② Switch, ③ Logic Gates
* Are of 2 types: npn and pnp

$V_{BE} = V_B - V_E$



* If 2 diodes are connected back to back it won't work like a BJT.

W-11 (L-18) (V-3)

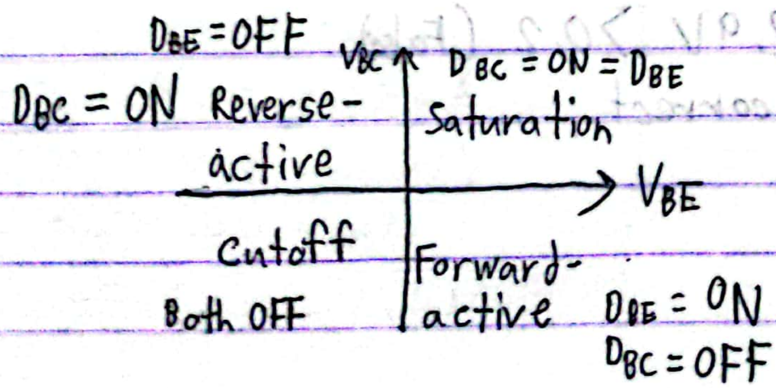
Method of Assumed State:

① Assume —
- ACTIVE [$V_{BE} = 0.7V$, $I_C = \beta I_B$, $I_C = \alpha I_E$] $\alpha = \frac{\beta}{1+\beta}$
- SATURATION [$V_{BE} = 0.8V$, $V_{CE} = 0.2V$]
- CUTOFF [$I_B = I_C = I_E = 0$]

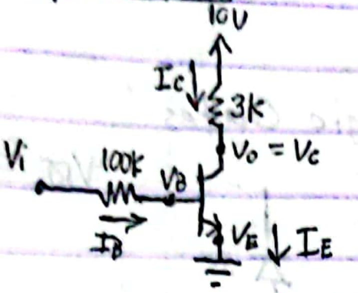
② Solve — [KCL, KVL, Nodal Analysis]

③ Verify —
- ACTIVE [$V_{CE} > 0.2V$]
- SATURATION [$I_C / I_B < \beta$]
- CUTOFF [$V_{BE} \leq 0.7V$ and $V_{BC} \leq 0.5V$]

} $I_B, I_C, I_E > 0$ (Not so important)



* Example-1:



- Find V_o for $V_i = 1V$.
- Assume BJT is in Active Mode.
  1. $V_{BE} = 0.7V$
  2. $I_C = \beta I_B = 100 \times 0.003 = 0.3mA$

$V_{BE} = 0.7 = V_B - \overset{\nearrow 0}{V_E} \Rightarrow V_B = 0.7V$

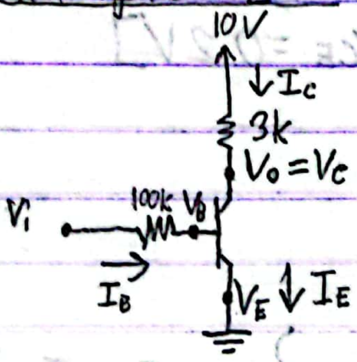
$I_B = \frac{V_i - V_B}{R_B} = \frac{1 - 0.7}{100} = 0.003 \ mA$

$I_C = \frac{10 - V_C}{3} = V_C = 10 - I_C \times 3 = 9.1V$

- ~~Verif~~ Verify:

$V_{CE} = V_C - V_E = 9.1V > 0.2$ ∴ Assumption is Correct.

* Example-2:



- ~~F~~ Find V_o for $V_i = 5V$.
- Assume BJT in Active mode.
  1. $V_{BE} = 0.7V = V_B - \overset{\nearrow 0V}{V_E} \Rightarrow V_B = 0.7V$
  2. $I_C = \beta I_B = 100 \times 0.043 = 4.3 \ mA$

$I_B = \frac{V_i - V_B}{R_B} = \frac{5 - 0.7}{100} = 0.043 \ mA$

$I_C = \frac{10 - V_C}{3} \Rightarrow V_C = 10 - I_C \times 3 = -2.9V$

- Verify:

$V_{CE} = V_C - V_E = -2.9V > 0.2$ (False)

∴ Assumption is not correct.

• New Assumption Saturation Mode.

① $V_{BE} = 0.8V$ and ② $V_{CE} = 0.2V$

$V_{BE} = 0.8 = V_B - V_E^{\nearrow 0V} \Rightarrow V_B = 0.8V$

$\therefore I_B = \frac{5-0.8}{100} = 0.042\ mA$

$V_{CE} = 0.2V = V_C - V_E^{\nearrow 0} \Rightarrow V_C = 0.2V$

$I_C = \frac{10-0.2}{3} \approx 3.29\ mA$

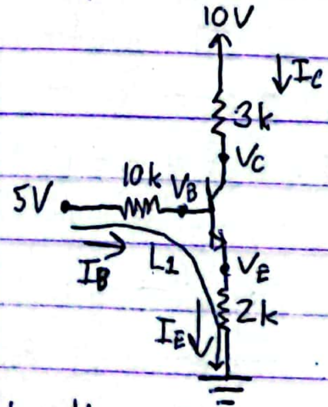
• Verify:

$\frac{I_C}{I_B} = \frac{3.29}{0.042} = 78.33 < \beta$ (True)

$\therefore$ Assumption is correct.

W-11 (L-18) (V-5)

* Example-1:



Find I_B, I_C, I_E, V_{CE}.

• Assume BJT in Active Mode.

① $V_{BE} = 0.7V$

$$\left.\begin{array}{l} ②\ I_C = \beta I_B \\ ③\ I_C = \alpha I_E \end{array}\right\} I_E = \frac{\beta}{\alpha} I_B$$

$\beta = 100,\ \therefore \alpha = \frac{\beta}{1+\beta} = 0.999$

Line-1:

$5 = 10I_B + 0.7 + 2I_E$

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

$\Rightarrow I_B = 0.02\ mA$

$I_C = 100 \times 0.02 = 2mA$

$I_E = I_C + I_B = 2.02\ mA$

$I_E = \frac{V_E - 0}{2} \Rightarrow V_E = 4.04V$

$I_C = \frac{10 - V_C}{3} \Rightarrow V_C = 4V$

$V_{CE} = V_C - V_E = -0.04V$

• Verify:

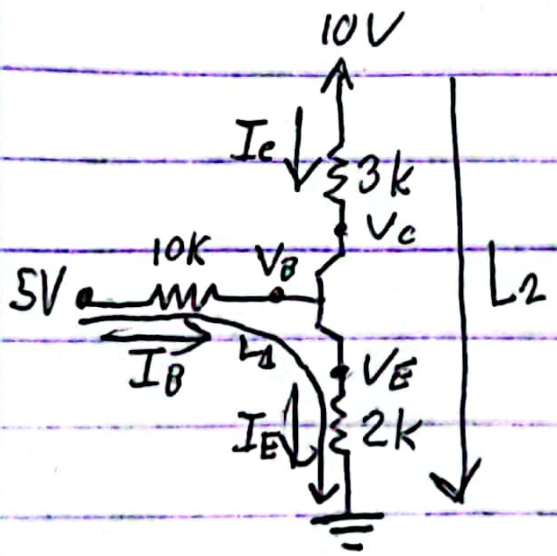
$V_{CE} = -0.04V \ngtr 0.2V$ (False)

$\therefore$ Assumption is not correct.

- Assume BJT is Saturation Mode:

① $V_{BE} = 0.8V$

② $V_{CE} = 0.2V$



$I_E = I_C + I_B$ —— ①

$L_1: 5 = 10 I_B + 0.8 + 2 I_E$ —— ⑪

$L_2: 10 = 3 I_C + 0.2 + 2 I_E$ —— ⑪

$I_B = 0.03\ mA$

$I_C = 1.95\ mA$

$I_E = 1.98\ mA$

- Verify:

$\frac{I_C}{I_B} = \frac{1.95}{0.03} = 65 < 100 = \beta$ (True)

∴ Assumption is correct.