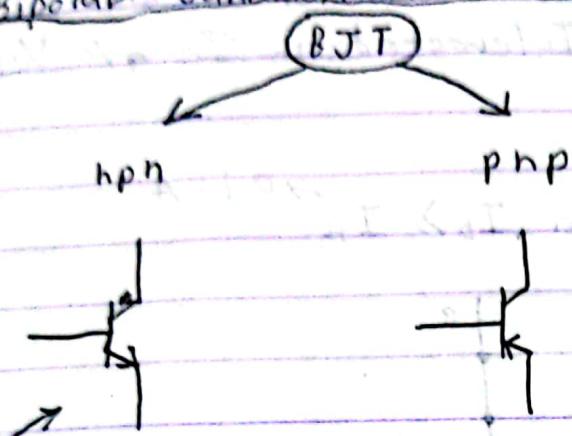


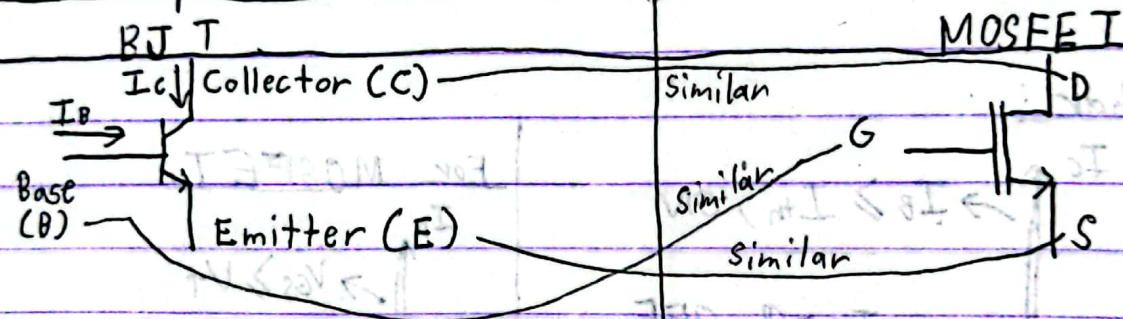
## # BJT Transistor:

### \* Bipolar Junction Transistors

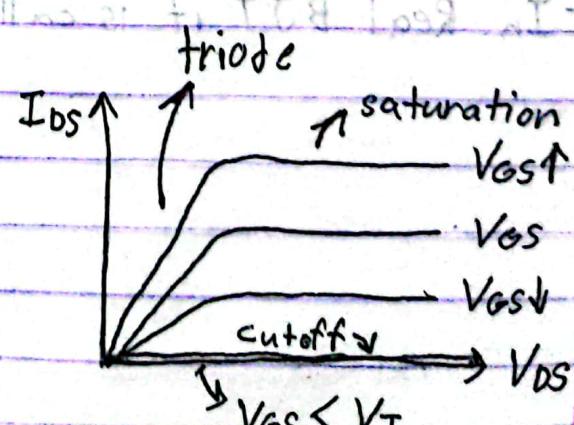
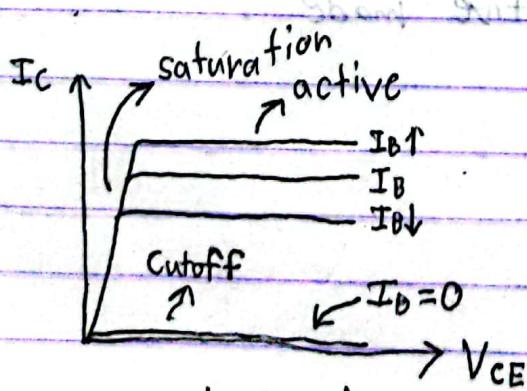


This will be studied most.

## # Relationship between BJT and MOSFET:



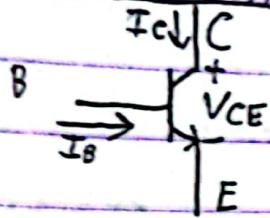
- $I_B \neq 0$  and  $I_C \neq I_E$ ,  $I_E = I_B + I_C$  •  $I_G = 0$  and  $I_D = I_S$
- $I_B$  controls I-V characteristics between C-E, so it is called a current controlled device. • I-V Characteristics of D-S is controlled by  $V_{GS}$  so it is a voltage controlled device.



- The slope is constant and doesn't depend on  $I_B$

- Slope is lower and depends on  $V_{GS}$

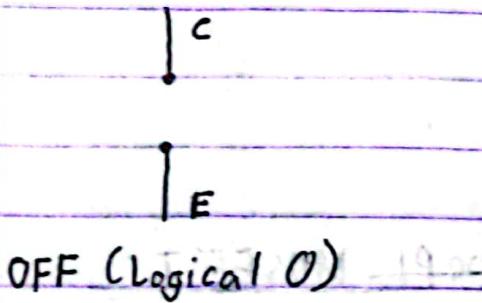
## # Switch (S) - model of BJT:



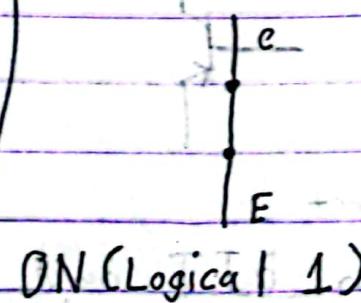
\* Current Controlled ( $I_B$ )

\* Interested in  $I_C$  vs  $V_{CE}$ ,

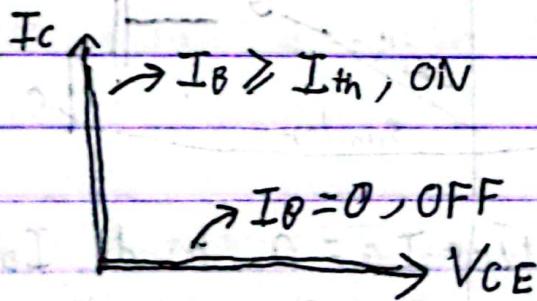
\* When  $I_B = 0$ ,



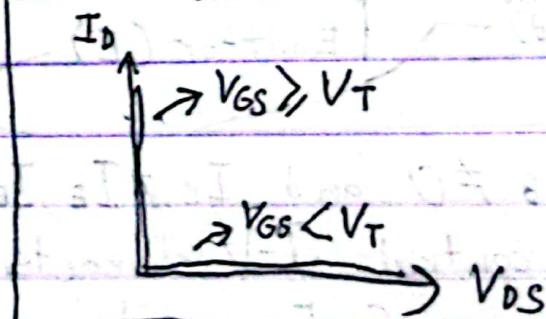
• When  $I_B > I_{th} \rightarrow 0.1mA$



## \* IV Char:



For MOSFET,

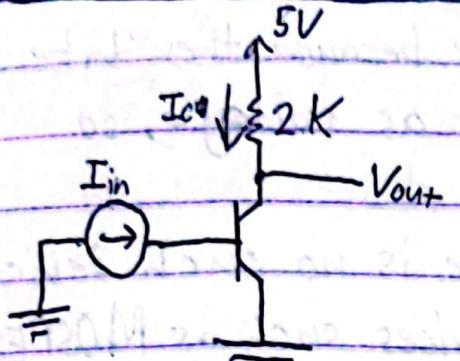


- If  $0 < I_B < I_{th}$

- Invalid in S-model

- In Real BJT it is called 'active mode'.

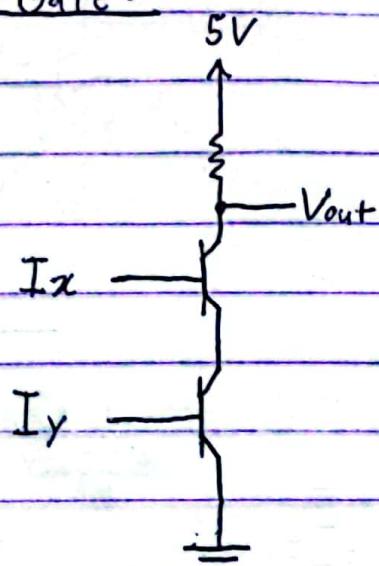
### \* NOT Gate / Inverter :



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

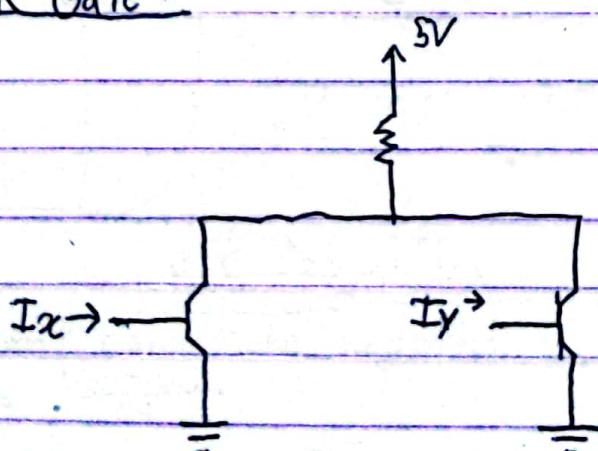
$$Out = \overline{I_h}$$

### \* NAND Gate :



$$OUT = \overline{XY}$$

### \* NOR Gate :



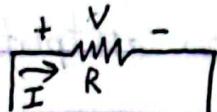
DATA

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

## # 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  $I_{\infty} = 0$  exactly

## # Voltage Controlled logic gates:

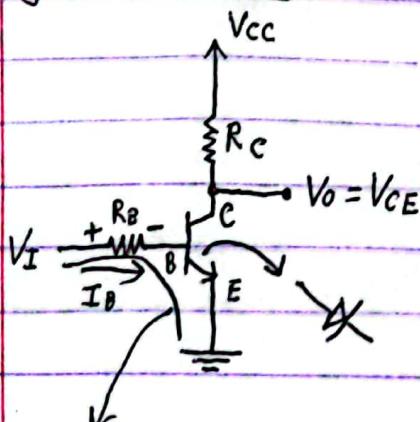


$$I = \frac{V}{R} \Rightarrow V = RI$$

or vice versa

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

### \* Eg: Inverter



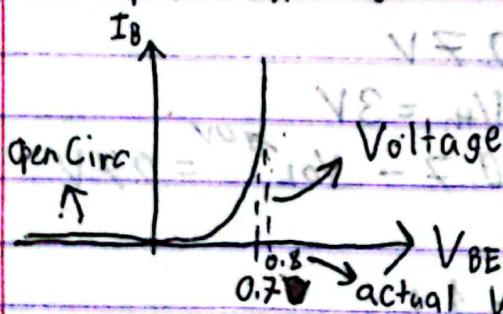
$I_B$	$V_I$
$I_B = 0$	$V_I < 0.7$
$I_B > I_{th}$	$V_I > V_{th}$

### \* 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

$$\bullet I_B = \frac{V_I - 0.7}{R_B}$$

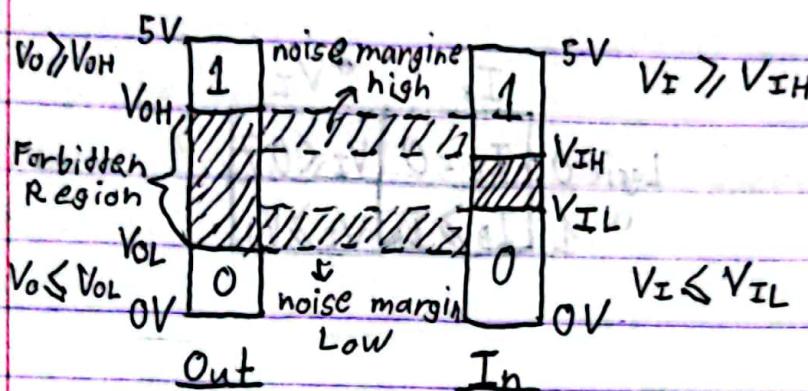
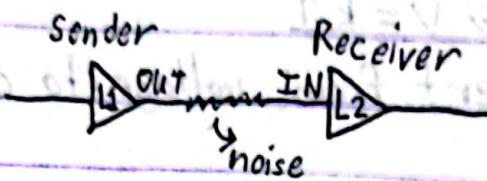
$$V_I \leq 0.7V \Rightarrow I_B = 0 \Rightarrow \text{Logical } 0$$

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

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

## # Improving Noise Margin:

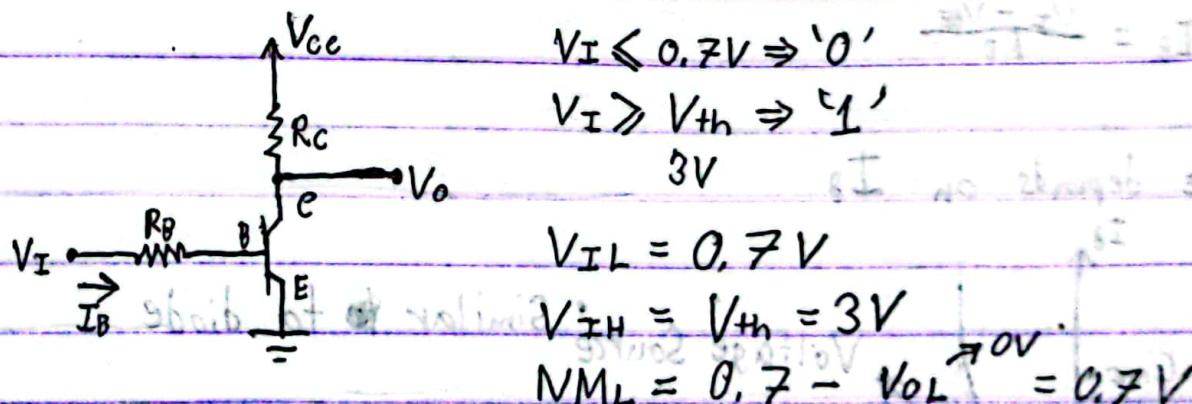
\* Static discipline  $\Rightarrow$  tighter restriction on output (sender).



$$* V_{OH} > V_{IH} \Rightarrow NM_H = V_{OH} - V_{IH}$$

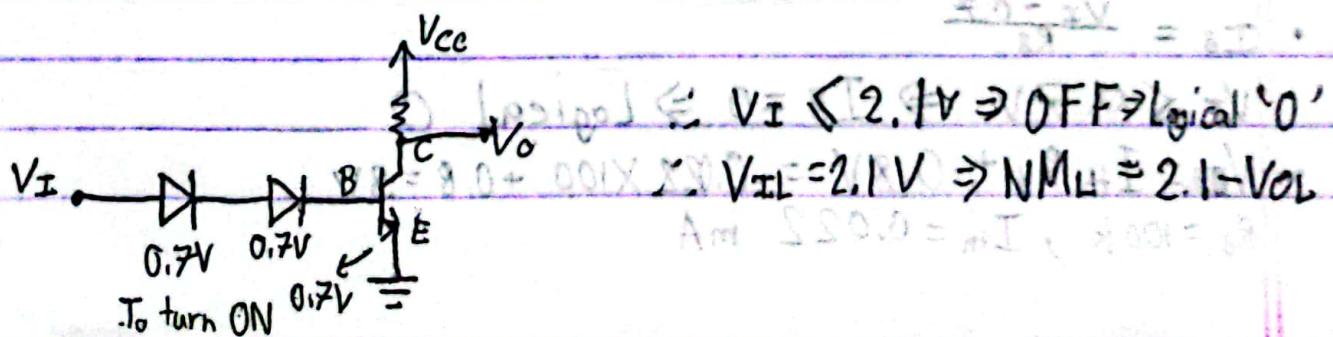
$$* V_{OL} < V_{IL} \Rightarrow NM_L = V_{IL} - V_{OL}$$

\*



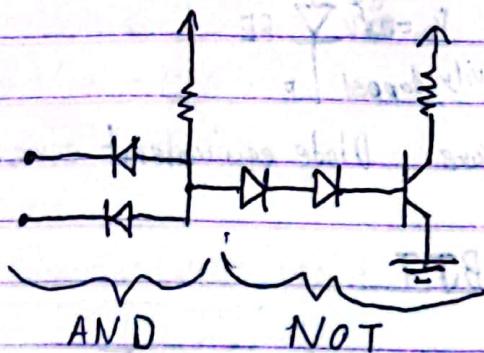
## \* Improve ~~NM~~ Noise Margin - 1:

\* Add 1 or more diodes in the Base,

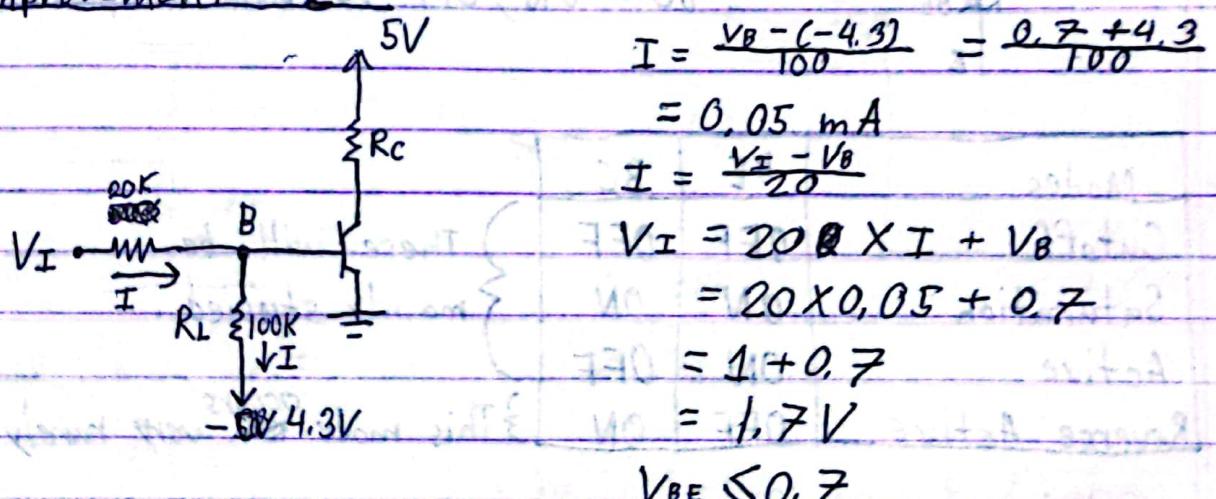


- These types of circuits are called DTL (Diode Transistor Logic Gate).

\* DTL (NAND Gate):



\* Improvement - 2:



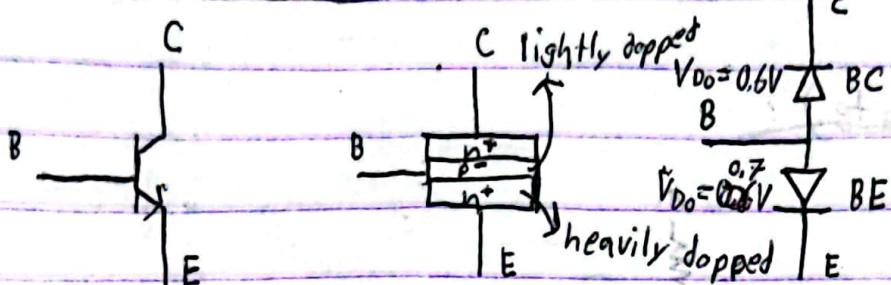
$V_I \leq 1.7 \text{ V} \Rightarrow \text{Logic '0'}$

$$V_{IL} = 1.7$$

$$NM_L = 1.7 - V_{OL} \rightarrow 0^{\text{v}} = 1.7 \text{ V}$$

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

## # BJT Structure

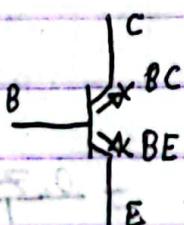


Circuit Symbol

Physical Structure

Diode equivalent circuit

### \* (Over) Simplified Operation of BJT:



$BE \rightarrow ON, OFF \} 4$  combinations

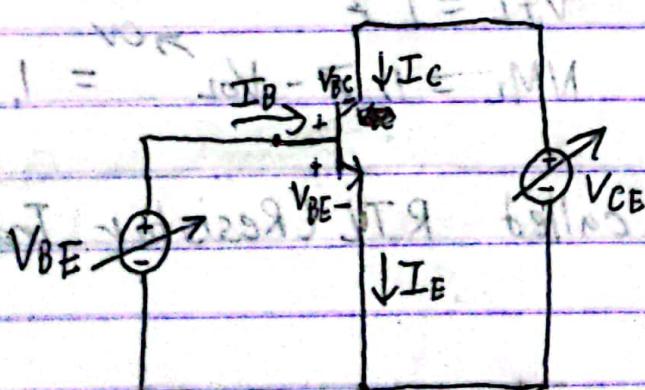
$BC \rightarrow ON, OFF \} 4$  modes of operation

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

} These will be mainly studied.

} This mode occurs very rarely.

### \* Circuit Analysis



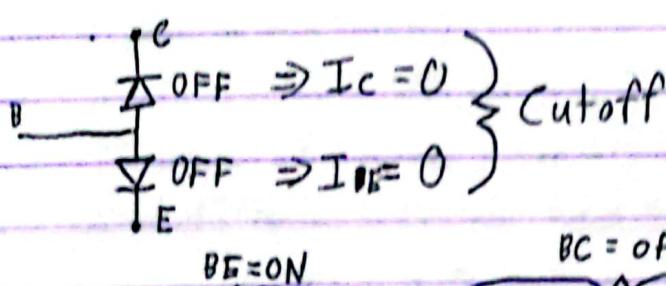
$$V_{BC} = V_{BE} - V_{CE}$$

$$I_E = I_B + I_C$$

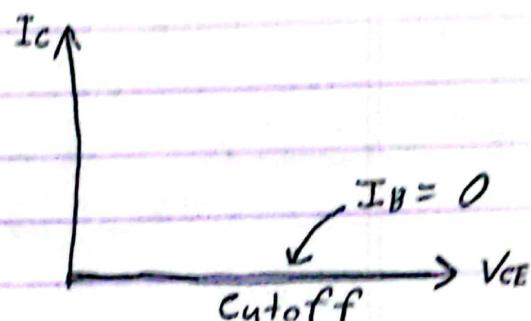
- $V_{BC} = V_B - V_C = (V_B - V_E) + (V_C - V_E) = V_{BE} - V_{CE}$
- $BC \rightarrow OFF$ ,  
 $\Rightarrow V_{BC} \leq 0.6V$   
 $\Rightarrow V_{BE} - V_{CE} \leq 0.6V$   
 $\Rightarrow V_{CE} \geq V_{BE} - 0.6V$
- $V_{BE} \leq 0.7V \Rightarrow OFF$

## # IV Characteristics:

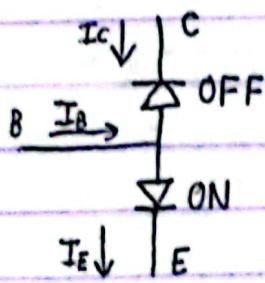
- \* Case - 1:  $V_{BE} \leq 0.7$  and  $V_{CE} \geq V_{BE} - 0.6$   
 $\Rightarrow I_B = 0$



$BC \rightarrow OFF$



- \* Case - 2:  $I_B > 0$  and  $V_{CE} \geq V_{BE} - 0.6$



$$I_c = \beta I_B$$

$$V_{BE} = 0.7V$$

Huge amount of current flows from the collector to the emitter  
 $\beta = [50, 200] = 100$  (Mostly)

Active Mode

$$I_E = I_c + I_B$$

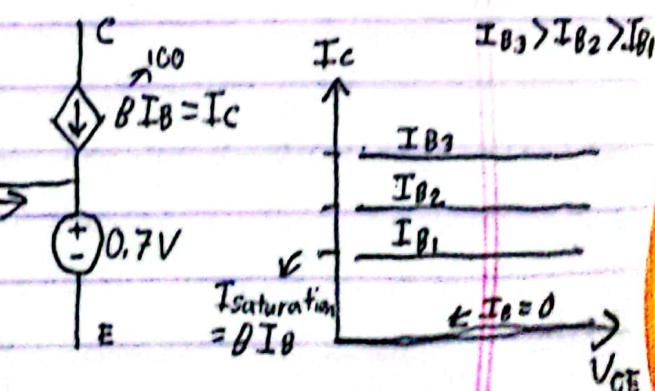
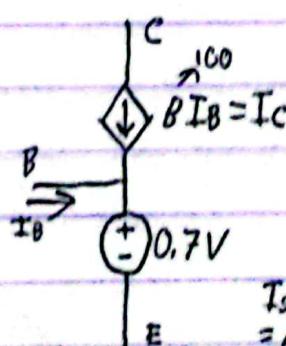
$$= I_c + \frac{1}{\beta} I_c$$

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

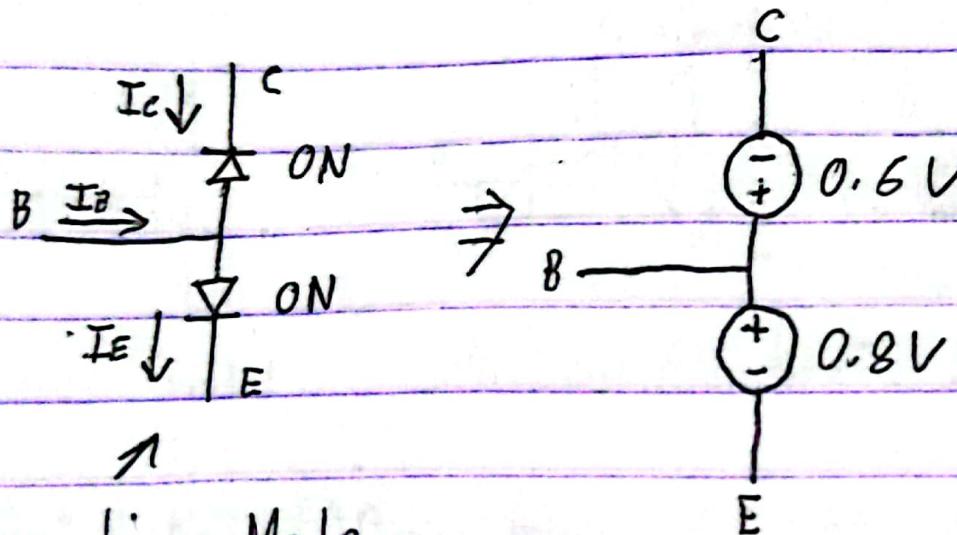
$$I_E = \frac{\beta + 1}{\beta} I_c \approx I_c$$

$$\alpha = \frac{\beta}{\beta + 1} \quad I_c = \frac{\beta}{\beta + 1} I_E$$

$$I_c = \alpha I_E$$



\* Case-3:  $I_B > 0$  and  $V_{CE} < V_{BE} - 0.6$



Saturation Mode

$\uparrow I_B$  increases

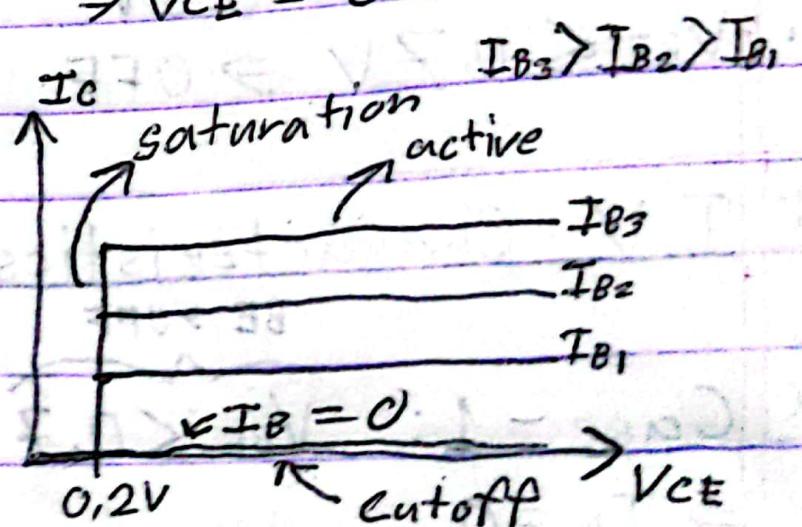
$\downarrow I_C$  decreases

$$\Rightarrow \frac{I_C}{I_B} < B$$

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

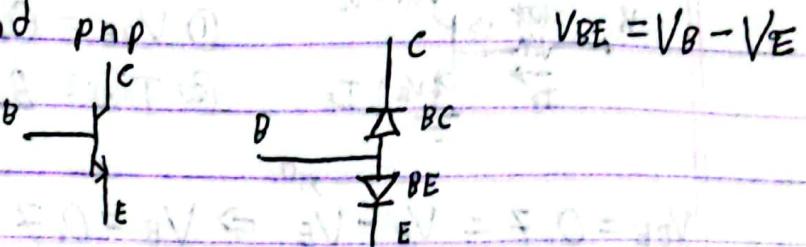
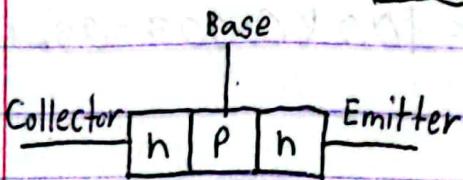
$$\Rightarrow V_{CE} = 0.8 - 0.6$$

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



## # Bipolar Junction Transistors (BJT):

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



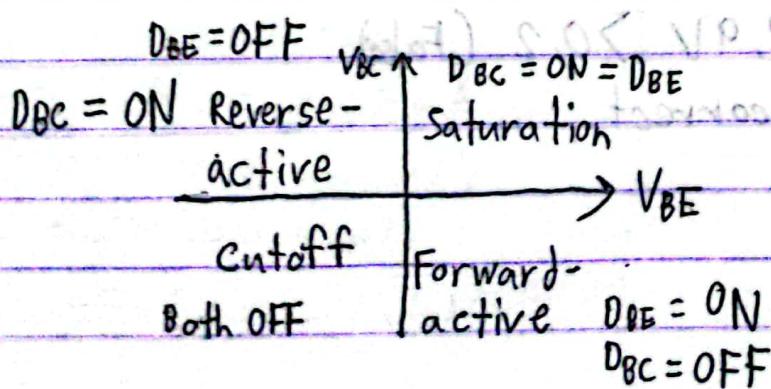
- \* If 2 diodes are connected back to back it won't work like a BJT.

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

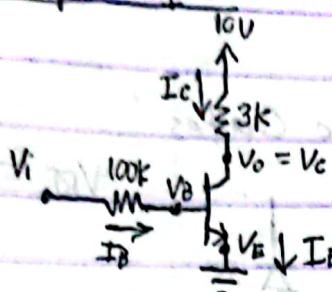
## # Method of Assumed State:

- 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]

- ①
  - ACTIVE  $[V_{CE} > 0.2V]$
  - SATURATION  $[I_C/I_B < \beta]$  so important
  - CUTOFF  $[V_{BE} < 0.7V \text{ and } V_{BC} < 0.5V]$



### \* Example - 1 :



• Find  $V_o$  for  $V_i = 1V$ .

• Assume BJT is in Active Mode.

$$\textcircled{1} \quad V_{BE} = 0.7V$$

$$\textcircled{2} \quad I_c = \beta I_B = 100 \times 0.003 = 0.3mA$$

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

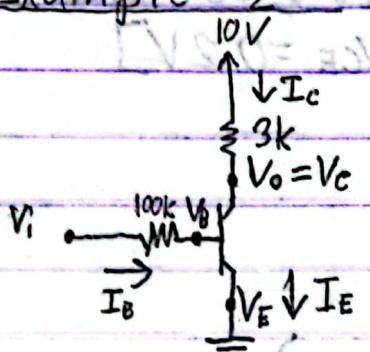
$$I_B = \frac{V_i - V_B}{R_B} = \frac{1 - 0.7}{100} = 0.003mA$$

$$I_c = \frac{10 - V_c}{3} = V_c = 10 - I_c \times 3 = 9.1V$$

• Verify:

$$V_{CE} = V_c - V_E = 9.1V > 0.2 \therefore \text{Assumption is Correct.}$$

### \* Example - 2 :



• Find  $V_o$  for  $V_i = 5V$ .

• Assume BJT in Active mode.

$$\textcircled{1} \quad V_{BE} = 0.7V = V_B - V_E \Rightarrow V_B = 0.7V$$

$$\textcircled{2} \quad I_c = \beta I_B = 100 \times 0.043 = 4.3mA$$

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

$$I_c = \frac{10 - V_c}{3} \Rightarrow V_c = 10 - I_c \times 3 = -2.9V$$

• Verify:

$$V_{CE} = V_c - V_B = -2.9V < 0.2 \text{ (False)}$$

∴ Assumption is not correct.

• New Assumption Saturation Mode.

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

$$V_{BE} = 0.8 = V_B - V_E^{\text{ov}} \Rightarrow V_B = 0.8V$$

$$\therefore I_B = \frac{5-0.8}{10k} = 0.042 \text{ mA}$$

$$V_{CE} = 0.2V = V_C - V_E^{\text{ov}} \Rightarrow V_C = 0.2V$$

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

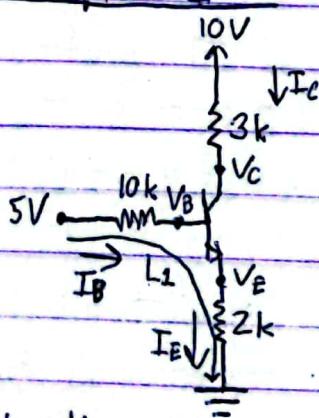
• Verify:

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

∴ 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.

$$\textcircled{1} V_{BE} = 0.7V$$

$$\textcircled{2} I_C = \beta I_B$$

$$\textcircled{3} I_E = \alpha I_E$$

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

Line-1:

$$5 = 10I_B + 0.7 + 2I_E$$

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

$$\Rightarrow I_B = 0.02 \text{ mA}$$

$$I_C = 100 \times 0.02 = 2 \text{ mA}$$

$$I_E = I_C + I_B = 2.02 \text{ mA}$$

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

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

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

• Verify:

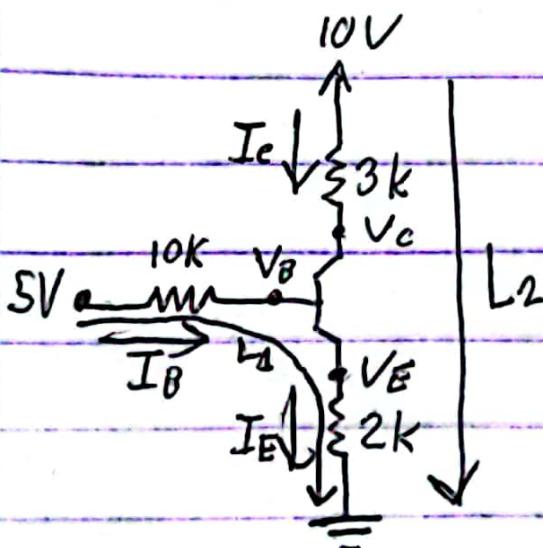
$$V_{CE} = -0.04 \text{ V} > 0.2 \text{ V (False)}$$

∴ Assumption is not correct.

- Assume BJT is Saturation Mode.

$$\textcircled{1} V_{BE} = 0.8V$$

$$\textcircled{2} V_{CE} = 0.2V$$



$$I_E = I_C + I_B \quad \text{--- } \textcircled{1}$$

$$L_1: 5 = 10I_B + 0.8 + 2I_E \quad \text{--- } \textcircled{11}$$

$$L_2: 10 = 3I_C + 0.2 + 2I_E \quad \text{--- } \textcircled{10}$$

$$I_B = 0.03 \text{ mA}$$

$$I_C = 1.95 \text{ mA}$$

$$I_E = 1.98 \text{ mA}$$

- Verify:

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

$\therefore$  Assumption is correct.