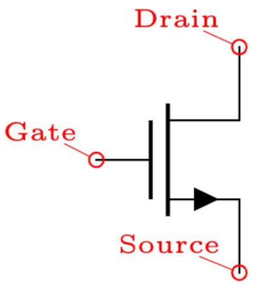
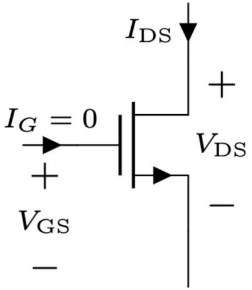
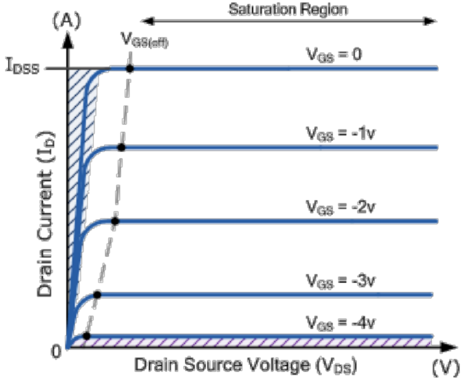
Lecture-8:
BJT

Transistors as Digital Switch

- Transistors are 3 terminal non-linear devices, can be used as switch
- 2 types – **Voltage Controlled**, **Current Controlled**
- **M**etal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistor (**MOSFET**) are voltage controlled
- Control, $\boldsymbol{C} = \boldsymbol{V_{GS}}$. The IV characteristics ($\boldsymbol{I_{DS}}$ vs $\boldsymbol{V_{DS}}$) depends on $\boldsymbol{V_{GS}}$
- Actual dependency is complex.
- Will start with a simple (but approximate) one – **S-Model** (Switch Model)

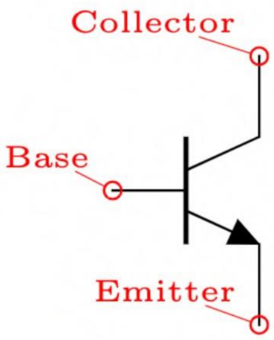


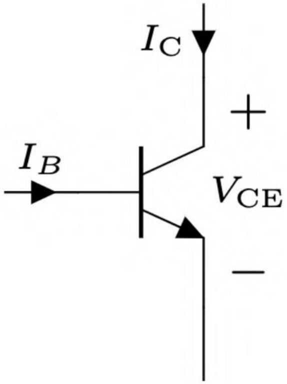


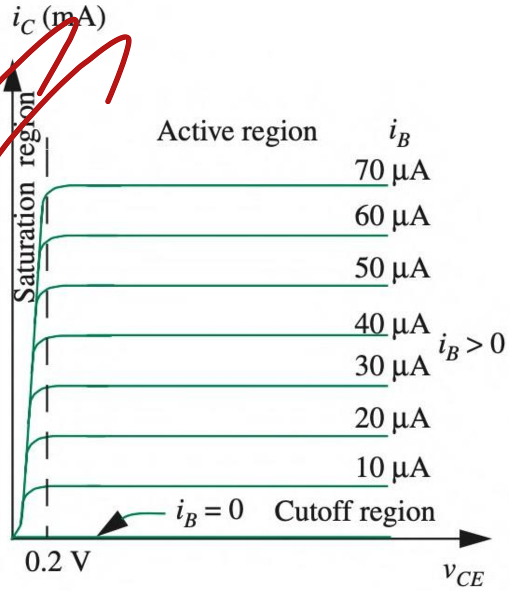


Bipolar Junction Transistor

- **Current-controlled** transistor, 3 terminals – Base, Emitter, Collector
- IV between C and E (I_C vs V_{CE}) is controlled by base current, $\boldsymbol{I_B}$
- IV is quite like MOSFET, but there are some differences
- We can use a S-model here too, but controlled by $\boldsymbol{I_B}$ (instead of $\boldsymbol{V_{GS}}$)

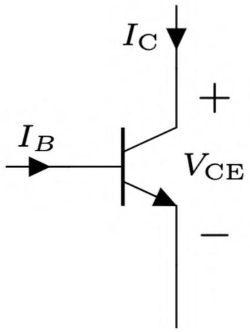






BJT vs MOSFET - Differences

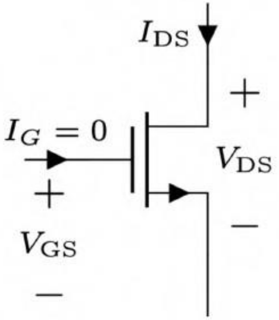
BJT



Current controlled, $\boldsymbol{I_B}$ controls ($\boldsymbol{I_C}$ vs $\boldsymbol{V_{CE}}$)

Base current, $\boldsymbol{I_B}$, is the control. Hence $I_E \neq I_C$, rather $\boldsymbol{I_E = I_C + I_B}$

MOSFET

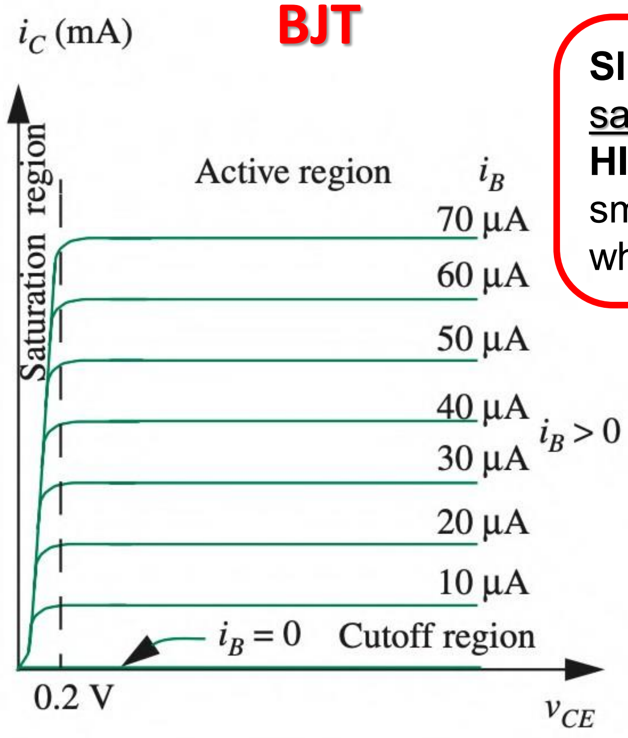


Voltage controlled, $\boldsymbol{V_{GS}}$ controls ($\boldsymbol{I_{DS}}$ vs $\boldsymbol{V_{DS}}$)

Gate current, $\boldsymbol{I_G}$, is always $\mathbf{0}$. Hence $I_S = I_D = I_{DS}$.

BJT vs MOSFET - Differences

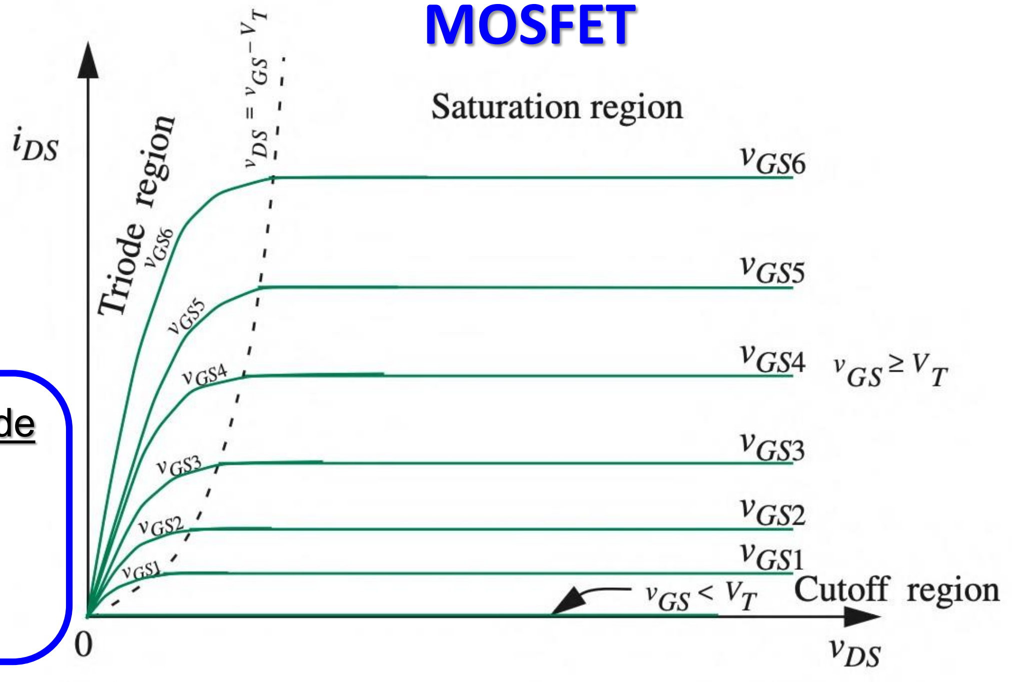
BJT



Slope in the saturation region is **HIGH**, hence very small resistance when "**ON**"

Slope in the Triode region is **LOW**, hence significant resistance when "**ON**"

MOSFET



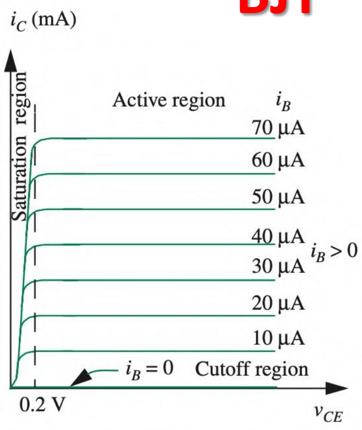
Current in **active** region changes linearly with control I_B.
Hence, $I_C \propto I_B$

Current in **Saturation** region changes quadratically with control V_{GS}.
Hence, $I_{DS} \propto V_{GS}^2$

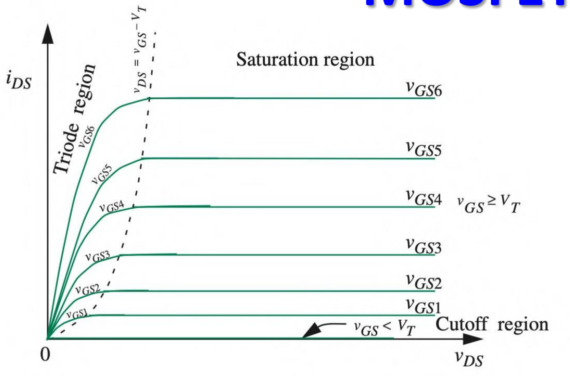
BJT vs MOSFET - Similarities

VBE < 0.7

BJT



MOSFET

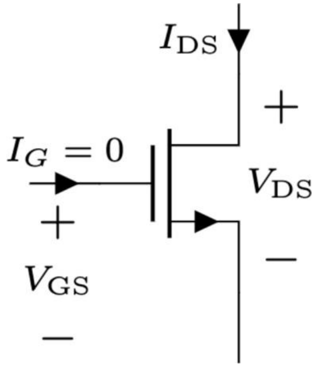


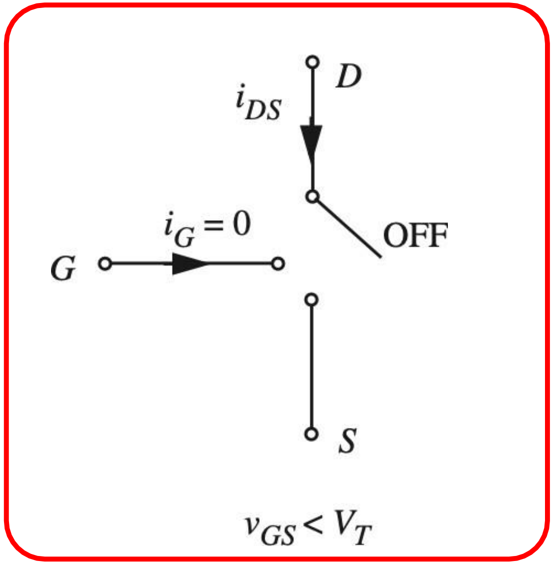
- **Saturation** mode for small V_{CE}($<$ 0.2 V)
- Approximately Short circuit in **Saturation** mode (I_B **HIGH**)
- Open circuit in **Cutoff** mode ($I_B = 0$)
- Can use as a switch ⇒ S-Model!

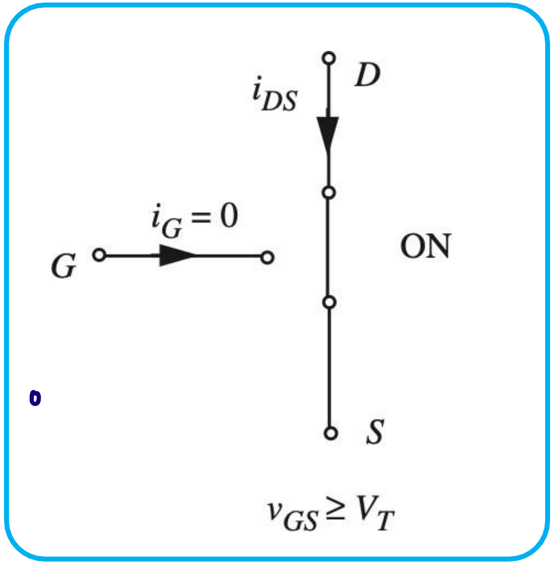
- **Triode** mode for small $V_{DS}(< V_{OV})$
- Approximately Short circuit in **Triode** mode (V_{GS} **HIGH**)
- Open circuit in **Cutoff** mode $\boldsymbol{(V_{GS} < V_T = 0)}$
- Can use as a switch ⇒ S-Model!

MOSFET S-Model

- The MOSFET (approximately) behaves like a switch
- C = V_{GS}. Here, C = "0" $\Rightarrow$ $\boldsymbol{V_{GS} < V_T}$, and C = "1" $\Rightarrow$ $\boldsymbol{V_{GS} \geq V_T}$



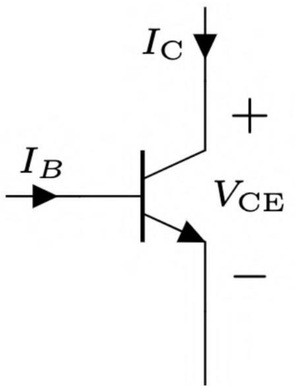


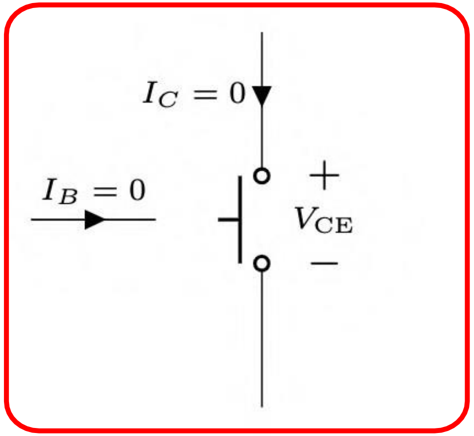


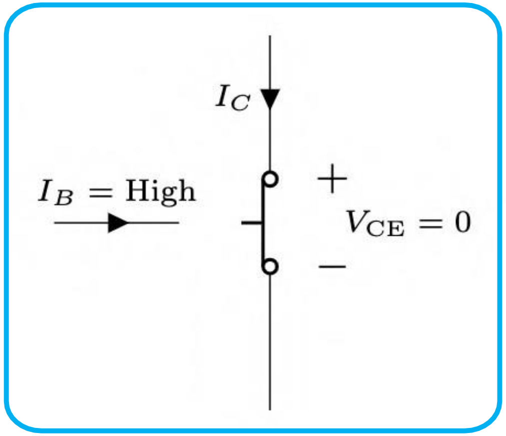
BJT S-Model

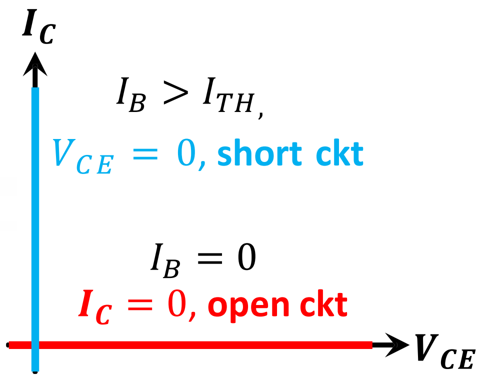
	Representation
Logic 0	$\boldsymbol{I_B = 0}$
Logic 1	$\boldsymbol{I_B > I_{TH}, I_B = HIGH}$

- The BJT (approximately) behaves like a switch
- $C = I_B$. Here, $C = \text{“0”} \Rightarrow \boldsymbol{I_B = 0}$, and $C = \text{“1”} \Rightarrow \boldsymbol{I_B > I_{TH}}$



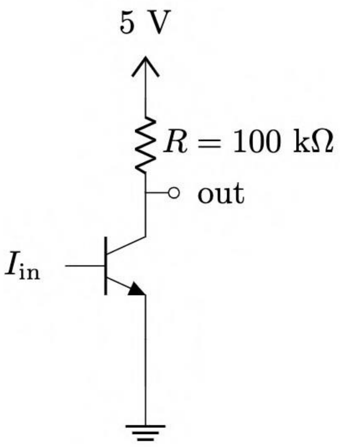




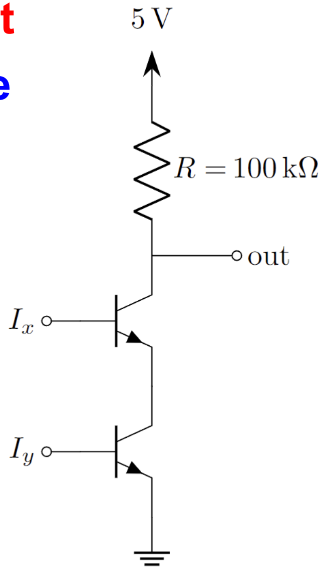


Current-Controlled Logic Gates using BJT

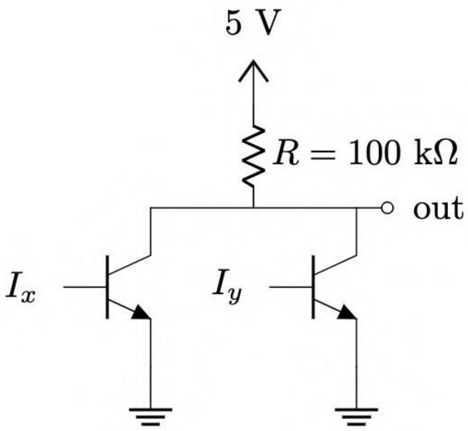
- Just replace switches with BJTs!
- Major problem: Cannot cascade! (Why?)
  - Input Logic Variable: **Current**
  - Output Logic Variable: **Voltage**



BJT Inverter (NOT Gate)



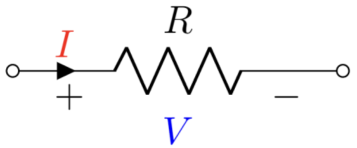
BJT NAND Gate



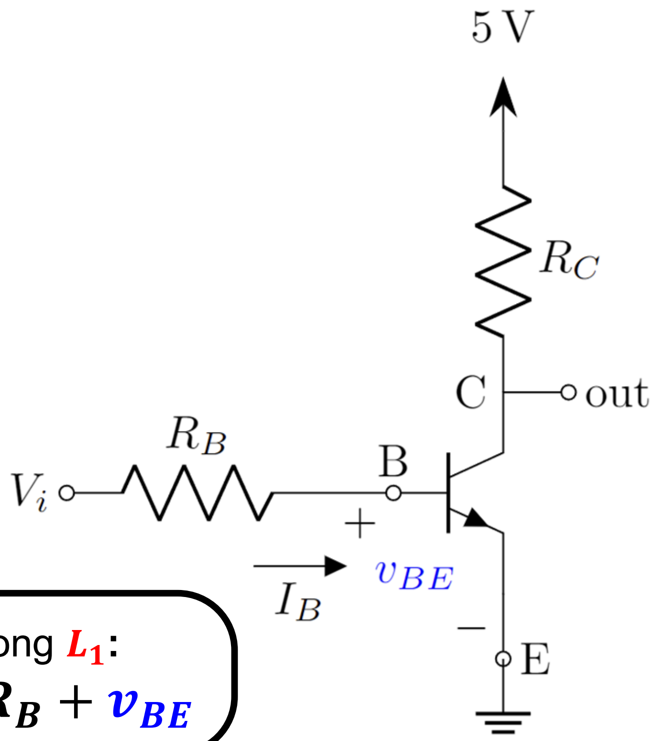
BJT NOR Gate

From Current Controlled to Voltage Controlled

How to convert current $\boldsymbol{I}$ into voltage $\boldsymbol{V}$?



$$\boxed{\boldsymbol{V} = \boldsymbol{I}\boldsymbol{R}}$$



$$\boldsymbol{V_i = I_B R_B + v_{BE}}$$

$$\boldsymbol{I_B = \frac{V_i - v_{BE}}{R_B}}$$

$\boldsymbol{v_{BE}}$ depends on I_B.

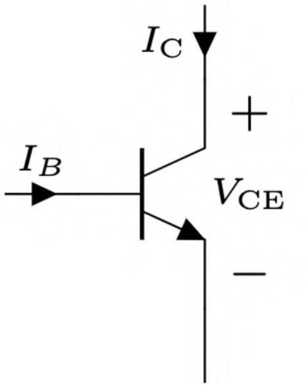
How?

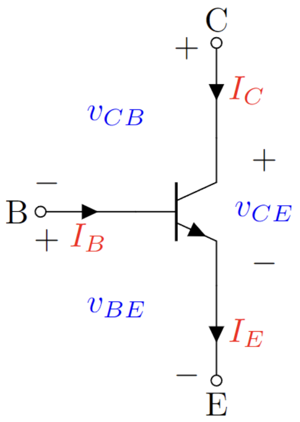
KVL along $\boldsymbol{L_1}$:

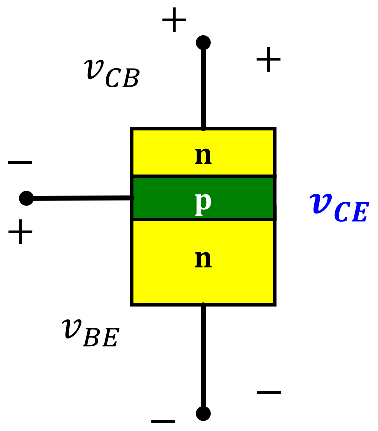
$$\boldsymbol{V_i = I_B R_B + v_{BE}}$$

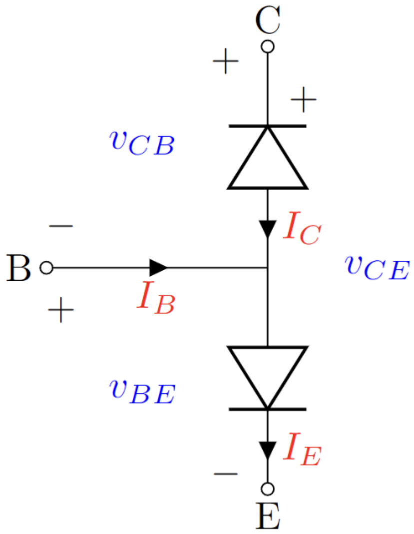
Parameters of BJT

A BJT can be thought of as two **"pn"** junctions placed back-to-back.



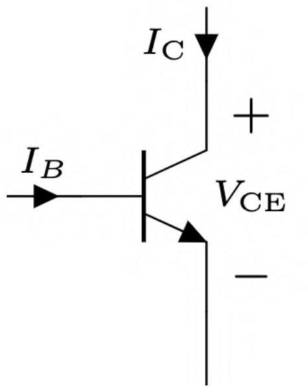


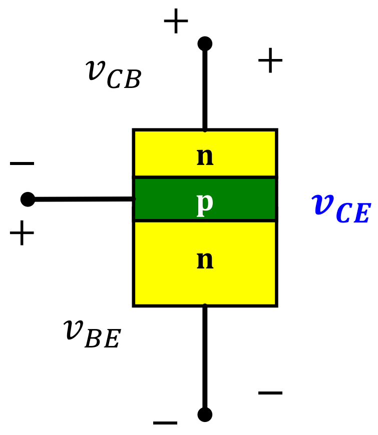


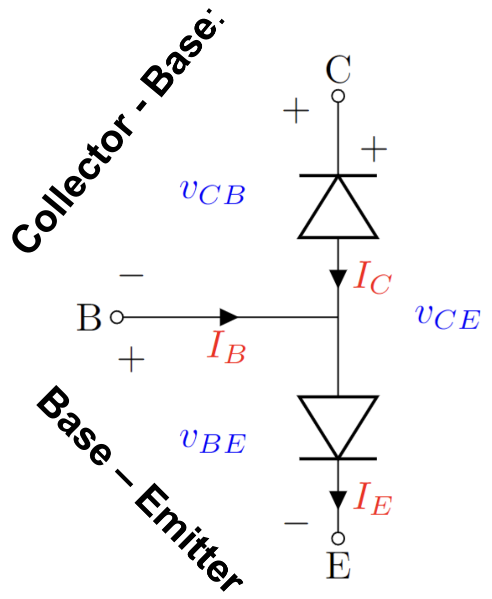


1st pn junction: Across **Base – Emitter**: Voltage v_{BE}
2nd pn junction: Across **Collector - Base**: Voltage v_{CB}

Parameters of BJT





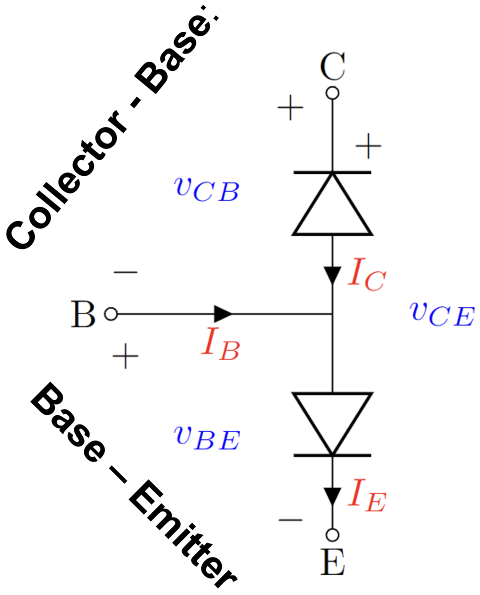


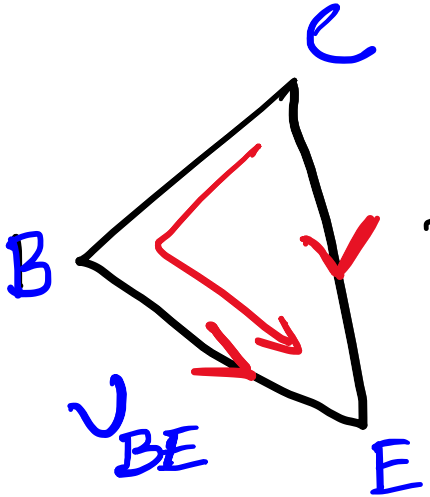
Base – Emitter: Emitter is highly-doped. So, **BE** junction has higher *cut in voltage* ($V_{BE} = 0.7\ \mathbf{V}$ usually)

Base – Collector: Collector is less-doped (compared to Emitter).
So, **BC** junction has **lower** *cut in voltage* ($V_{BC} = 0.5\ \mathbf{V}$ usually)

Parameters of BJT

A BJT can be thought of as two **"pn"** junctions placed back-to-back.

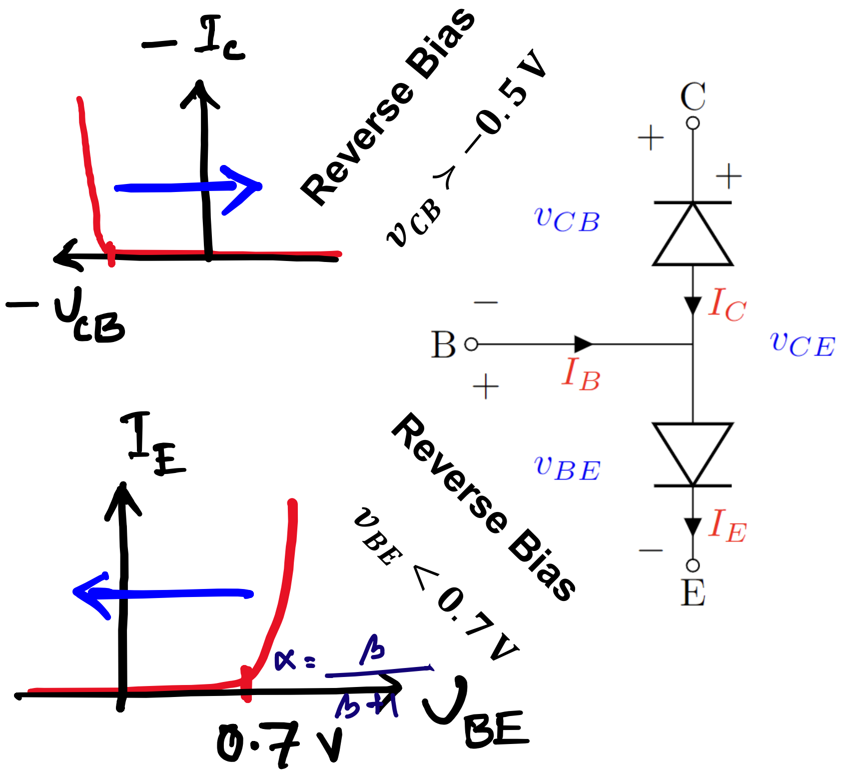


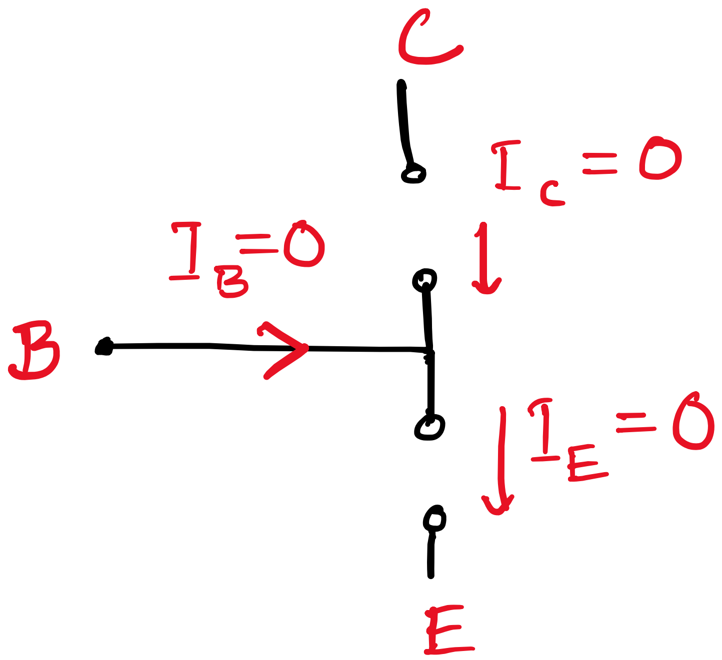


$v_{CE} = v_{CB} - v_{EB}$

Modes of operation of BJT

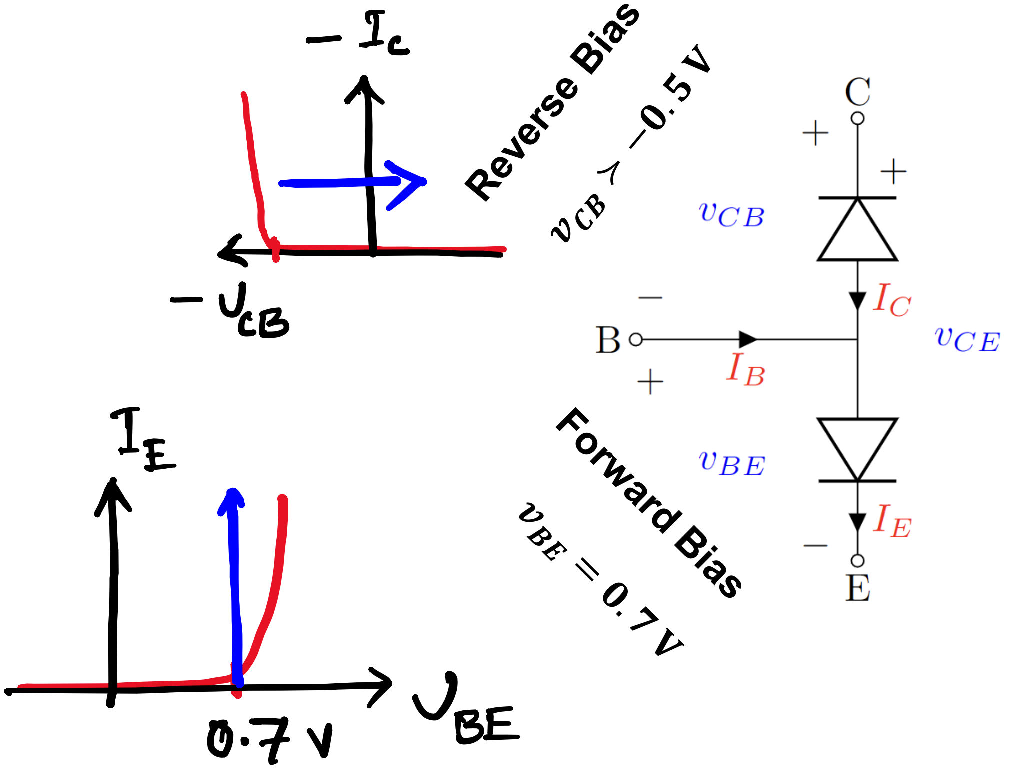
1. Cut off



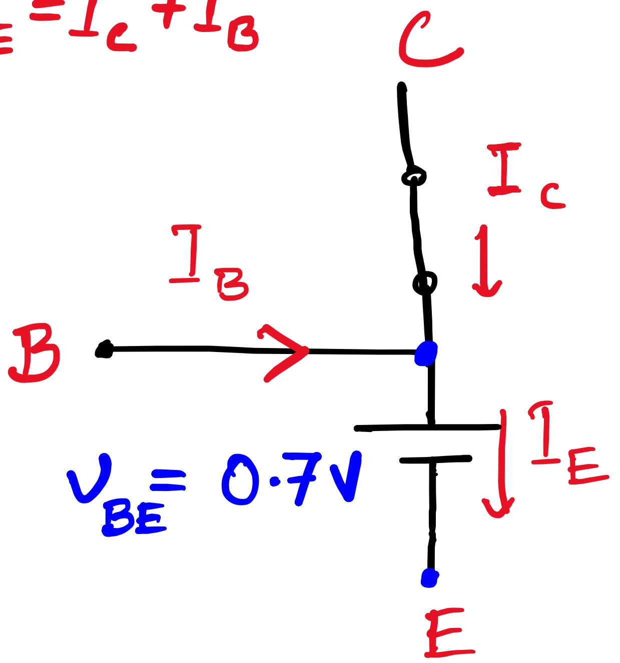


Modes of operation of BJT

2. Active Mode

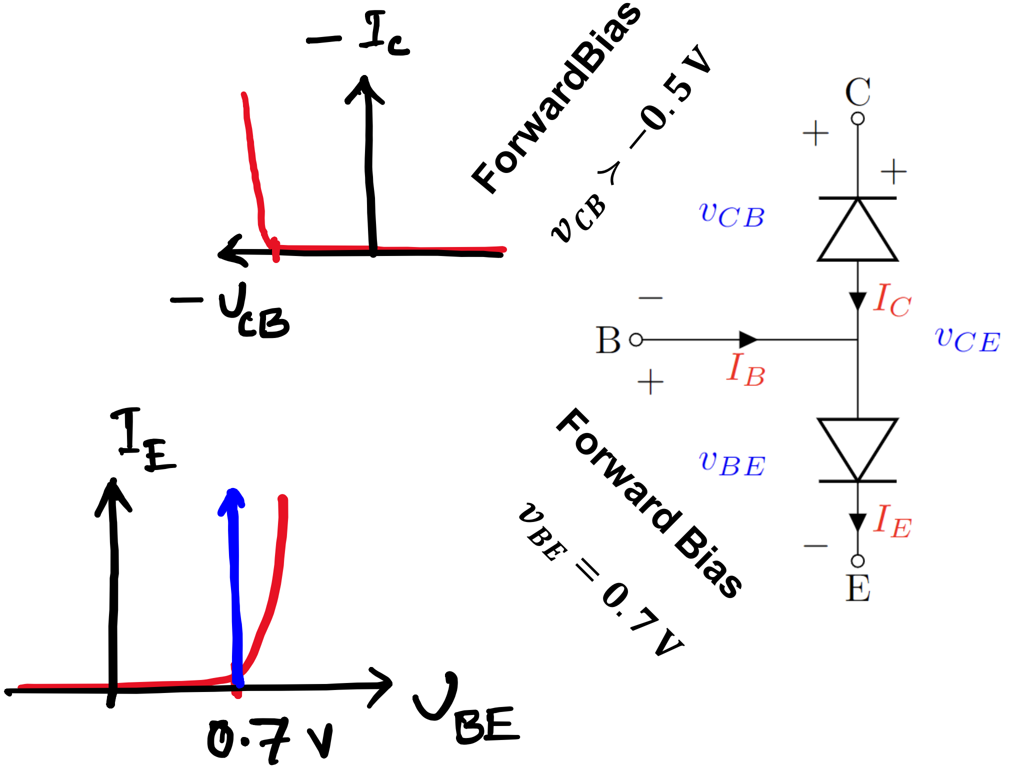


$I_E = I_c + I_B$

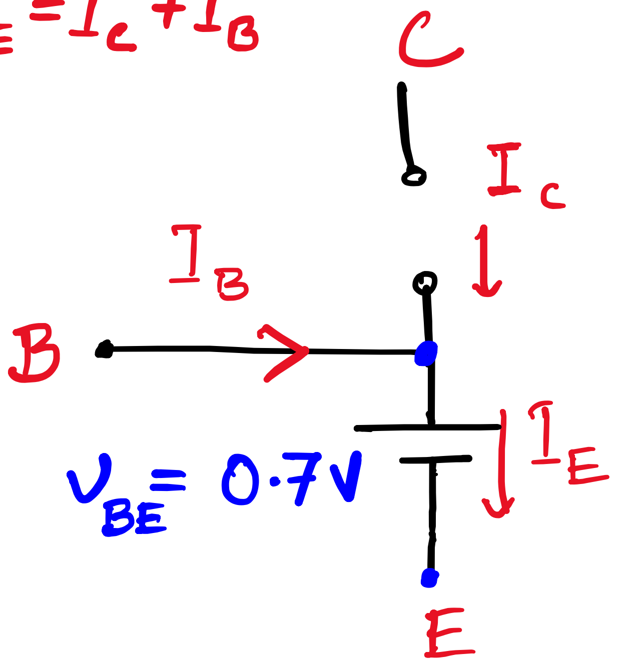


Modes of operation of BJT

2. Saturation Mode

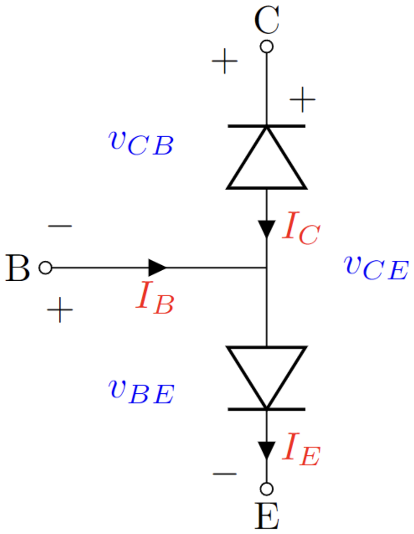


$I_E = I_c + I_B$



Parameters of BJT

A BJT can be thought of as two **"pn"** junctions placed back-to-back.



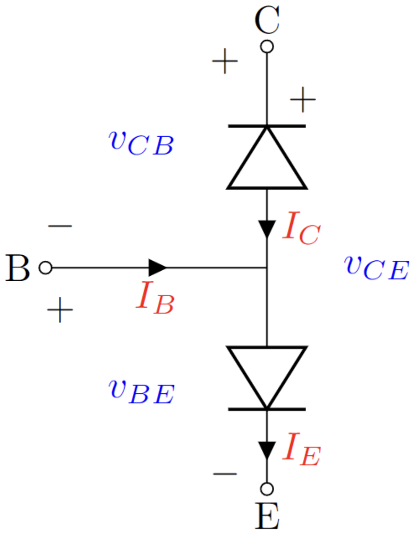
Modes	BE Junction	v_{BE}	CB Junction	v_{CB}	v_{CE}
Cut-off	Reverse Bias	$v_{BE} < 0.7\text{ V}$	Reverse Bias	$v_{CB} > -0.4\text{ V}$	
Active	Forward Bias	$v_{BE} = 0.7\text{ V}$	Reverse Bias	$v_{CB} > -0.4\text{V}$	$v_{CE} > 0.3\text{ V}$
Saturation	Forward Bias	$v_{BE} = 0.7\text{ V}$	Forward Bias	$v_{CB} = -0.5\text{ V}$	$v_{CE} = 0.2\text{ V}$
Reverse Active	Reverse Bias	$v_{BE} < 0.6\text{ V}$	Forward Bias	$v_{CB} = -0.5\text{ V}$	$v_{CE} < 0.1\text{ V}$

1st pn junction: Across **Base – Emitter**: Voltage v_{BE}
2nd pn junction: Across **Collector - Base**: Voltage v_{CB}

$$\boxed{v_{CE} = v_{CB} + v_{BE}}$$

Parameters of BJT

Current relationships between the three currents in an npn BJT.



$$I_B + I_C = I_E$$

β: Common Emitter Current Gain
α: Common Base Current Gain

$$\boxed{\begin{aligned} I_C &= \beta I_B \\ I_C &= \alpha I_E \end{aligned}}$$

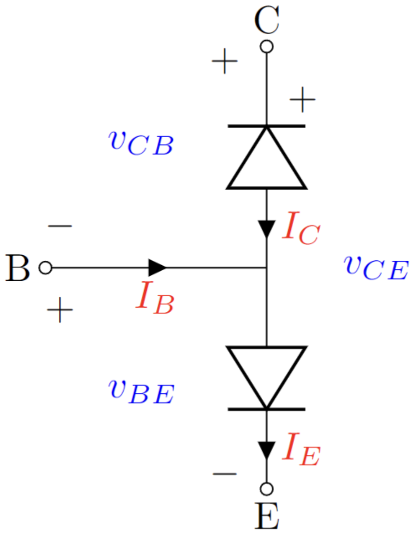
Only valid for active mode

1st pn junction: Across **Base – Emitter**: Voltage $\boldsymbol{v_{BE}}$
2nd pn junction: Across **Collector - Base**: Voltage $\boldsymbol{v_{CB}}$

$$v_{CE} = v_{CB} + v_{BE}$$

Parameters of BJT

A BJT can be thought of as two **“pn”** junctions placed back-to-back.



Modes	**Conditions!**
Cut-off	$v_{BE} < 0.7\ V$ and $v_{CB} > -0.4\ V$
Active	$v_{BE} = 0.7\ V$ and $v_{CE} > 0.3\ V$
Saturation	$v_{BE} = 0.7\ V$ and $v_{CE} = 0.2\ V$ and $\frac{I_C}{I_B} < \beta$
Reverse Active	$v_{BC} = 0.7\ V$ and $v_{EC} > 0.1\ V$

1st pn junction: Across **Base – Emitter**: Voltage v_{BE}
2nd pn junction: Across **Collector - Base**: Voltage v_{CB}

$$\boxed{v_{CE} = v_{CB} + v_{BE}}$$

Solving Circuits with ~~MOSFET~~ **BJT**

- Use **Method of Assumed State**!
- Three steps:
  - **Assume**: One of the modes
    (Cutoff, ~~Triode~~ Saturation, ~~Saturation~~ Active)
  - **Solve**: Use corresponding equation and KCL + KVL with currents
  - **Verify**: Check if the conditions of $\cancel{V_{GS}}$ $\boldsymbol{v_{BE}}$ and $\cancel{V_{DS}}$ $\boldsymbol{v_{CE}}$ are satisfied. If not, repeat.
- Might need to solve quadratic equation ($ax^2 + bx + c = 0$).
- If we get two roots, choose the one that's ***favorable*** to your assumption

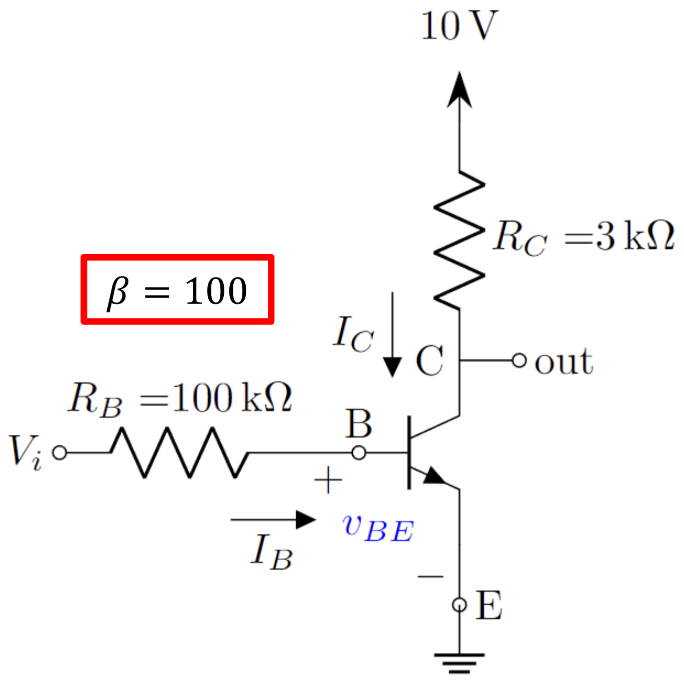
Important!

	D_1	D_2	State	V_{CB}	V_{BE}	I_C	$V_{CE} = V_{CB} + V_{BE}$
★★	on	on	Satn	$V_{CB} = -0.5$	$V_{BE} = 0.7$		$V_{CE} = 0.2$, $\boxed{\frac{I_C}{I_B} < \beta}$
X	on	off	reverse active	$V_{CB} = -0.5$	$V_{BE} < 0.6$		$V_{CE} < 0.1$
★★	off	on	active	$V_{CB} > -0.4$	$V_{BE} = 0.7$	$I_C = \beta I_B$ $= \alpha I_E$	$V_{CE} > 0.3$
★	off	off	cutoff	$V_{CB} > -0.4$	$V_{BE} < 0.6$	0	X (floating)

BJT Problem 1

Analyze the circuit to find I_C and v_{out} using the Method of Assumed State. Here, the input of the BJT is $V_i = 1\ V$. You must validate your assumptions.

$\boxed{\beta = 100}$



BJT Problem 1

Analyze the circuit to find $\boldsymbol{I_C}$ and $\boldsymbol{v_{out}}$ using the Method of Assumed State. Here, the input of the BJT is $\boldsymbol{V_i = 1\ V}$. You must validate your assumptions.

Assume:

Let the BJT be in **ACTIVE** mode

So, $v_{BE} = 0.7\ V$

$v_{CE} > 0.3\ \mathrm{V}$

Solve:

Equations: $\boldsymbol{I_B} = \frac{V_i - v_{BE}}{R_B} = \frac{1-0.7}{100}\ \mathrm{mA} = \mathbf{3\ \mu A}$

$\boldsymbol{I_C} = \beta I_B = 100 \times 3 \times 10^{-3}\ \mathrm{mA} = \mathbf{0.3\ mA}$

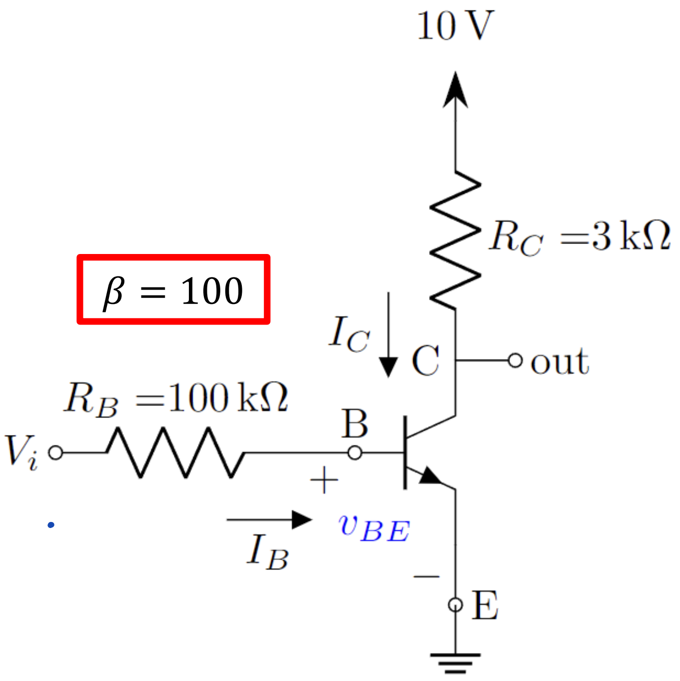
$\boldsymbol{v_{out}} = 10 - I_C R_C = (10 - 0.3 \times 3\,)\ \mathrm{V} = \mathbf{9.1\ V}$

Verify: For **ACTIVE** condition → $\boldsymbol{v_{CE} > 0.3\ V}$

Here, $v_{CE} = v_{out} = 9.1\ \mathrm{V} > 0.3\ \mathrm{V}$

Assumption is Correct!

$\boxed{\beta = 100}$



BJT Problem 1

Analyze the circuit to find I_C and v_{out} using the Method of Assumed State. Here, the input of the BJT is $V_i = 5\ V$. You must validate your assumptions.

Assume:

Let the BJT be in **ACTIVE** mode

So, $v_{BE} = 0.7\ V$

$v_{CE} > 0.2$ V

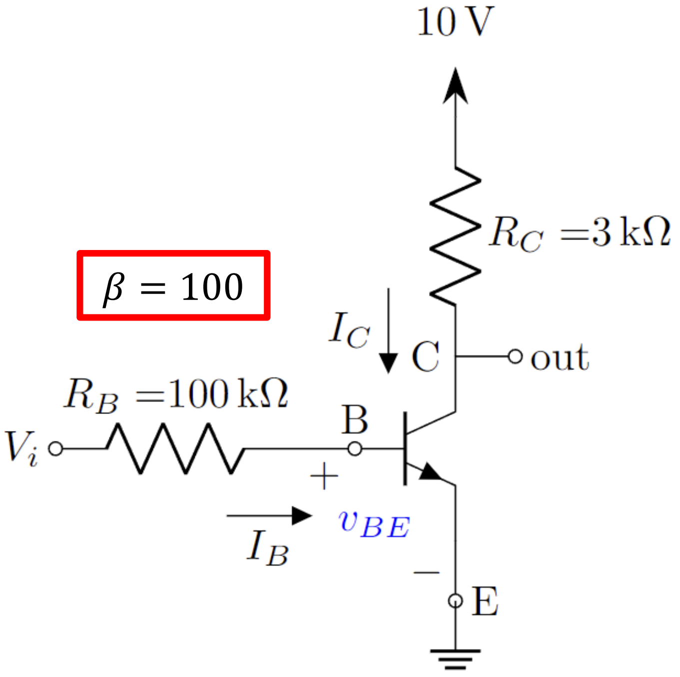
Solve:

Equations: $I_B = \frac{V_i - v_{BE}}{R_B} = \frac{5-0.7}{100}$ mA $= \mathbf{43\ \mu A}$

$I_C = \beta I_B = 100 \times 43 \times 10^{-3}$ mA $= \mathbf{4.3\ mA}$

$v_{out} = 10 - I_C R_C = (10 - 4.3 \times 3)$ V $= \mathbf{-2.9\ V}$

$\boxed{\beta = 100}$



Verify: For **ACTIVE** condition → $v_{CE} > \mathbf{0.2\ V}$

Here, $v_{CE} = v_{out} = \mathbf{-2.9}$ V $\ngtr 0.2$ V

Assumption is Wrong!

BJT Problem 1

Analyze the circuit to find I_C and v_{out} using the Method of Assumed State. Here, the input of the BJT is $V_i = 5\ V$. You must validate your assumptions. $V_{BE,sat} = 0.8$

$V_{BE} = V_B - \cancel{V_E}^{\,0} = 0.7$

$V_B = 0.7$

Assume:

Let the BJT be in **Saturation** mode

So, $\boxed{v_{BE} = 0.7\ V}$ and $\frac{I_C}{I_B} < \beta$

$\boxed{v_{CE} = 0.2\ \text{V}}$

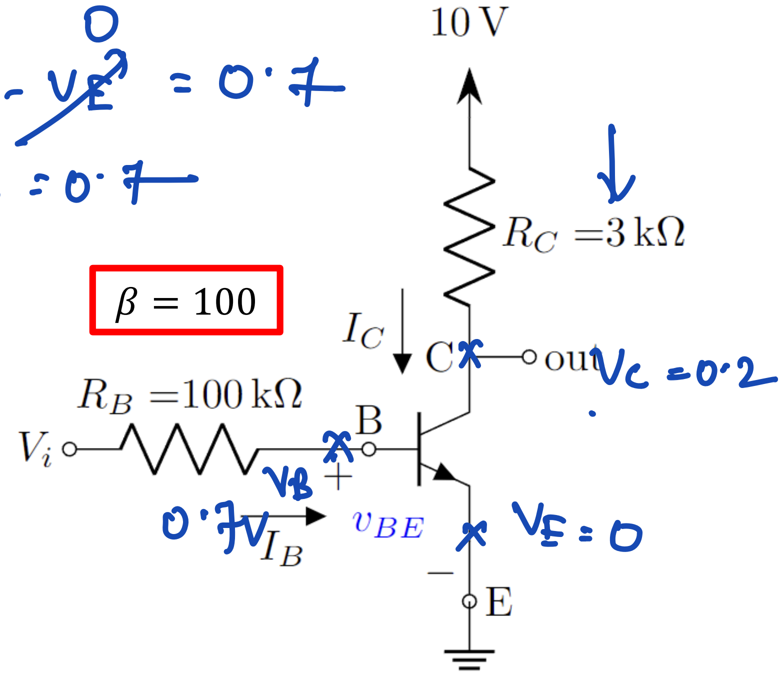
Solve:

Equations: $I_B = \frac{V_i - v_{BE}}{R_B} = \frac{5-0.7}{100}\ \text{mA} = \mathbf{43\ \mu A}$

$\frac{I_C}{I_B} < \beta$ $\quad I_C = \beta \cancel{I_B}\ \frac{10 - v_{CE}}{R_C} = \frac{10-0.2}{3}\text{mA} = \mathbf{3.27\ mA}$

$v_{out} = v_{CE} = \mathbf{0.2\ V}$

$\beta = 100$



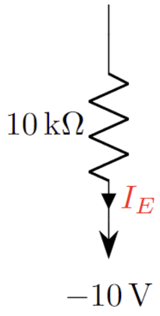
Verify: For **Saturation** condition → $\frac{I_C}{I_B} < \beta$

Here, $\beta = 100$ $\quad \frac{I_C}{I_B} = \frac{3.27}{0.043} = \mathbf{76 < 100}$

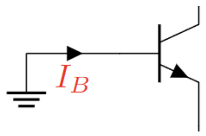
Assumption is Correct!

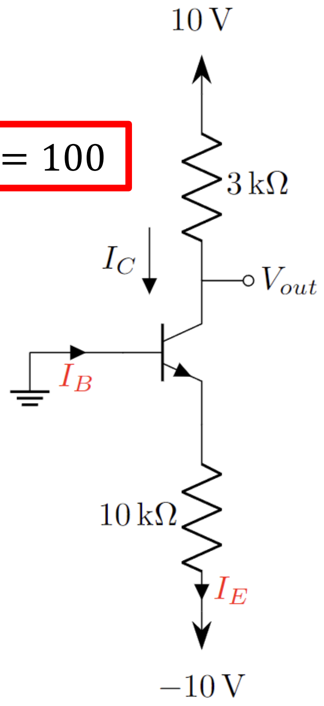
BJT Problem 2

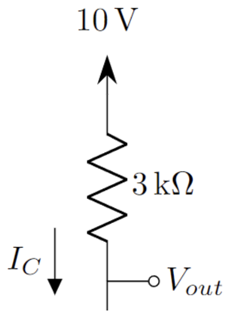
Analyze the circuit to find $\boldsymbol{I_B, I_C, I_E}$ and $\boldsymbol{v_{out}}$ using the Method of Assumed State. You must validate your assumptions.



$\boxed{\beta = 100}$







BJT Problem 2

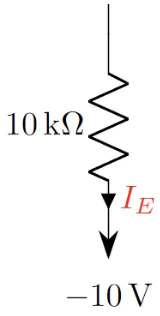
Analyze the circuit to find $\boldsymbol{I_B}, \boldsymbol{I_C}, \boldsymbol{I_E}$ and $\boldsymbol{v_{out}}$ using the Method of Assumed State. You must validate your assumptions.

Assume:

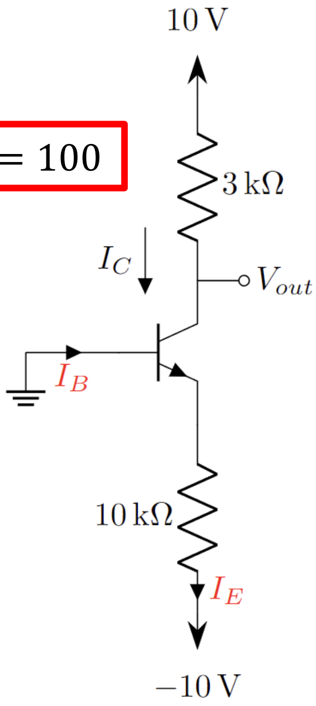
Let the BJT be in **Active** mode

So, $v_{BE} = 0.7\ V$

$v_{CE} > 0.2$ V



$\beta = 100$

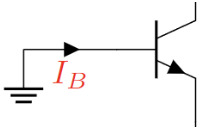


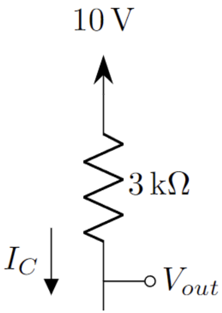
Solve:

Equations:

$$\boldsymbol{I_E} = \frac{v_E-(-10)}{10} = \frac{-0.7+10}{10}\,\text{mA} = \mathbf{0.93\ mA}$$

$$\boldsymbol{I_B} = \frac{\mathbf{1}}{\boldsymbol{\beta}}\boldsymbol{I_C} = \frac{1}{\beta}\cdot \alpha \boldsymbol{I_E} = \frac{1}{\beta}\cdot\frac{\beta}{\beta+1}\boldsymbol{I_E} = \frac{1}{\beta+1}\boldsymbol{I_E} = \mathbf{9.21\ \mu A}$$





$$\boldsymbol{v_{out}} = \boldsymbol{v_C} = \mathbf{10} - \mathbf{3}\boldsymbol{I_C} = \mathbf{10} - \mathbf{3}\boldsymbol{\beta I_B}$$

$$= (\mathbf{10} - \mathbf{3}\cdot\mathbf{100}\cdot\mathbf{9.207}\times\mathbf{10^{-3}})\mathbf{V}$$

$$= \mathbf{7.237\ V}$$

BJT Problem 2

Analyze the circuit to find I_B, I_C, I_E and v_{out} using the Method of Assumed State. You must validate your assumptions.

Assume:

Let the BJT be in **Active** mode

So, $v_{BE} = 0.7\ V$

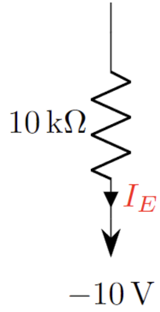
$v_{CE} > 0.2$ V

Solve:

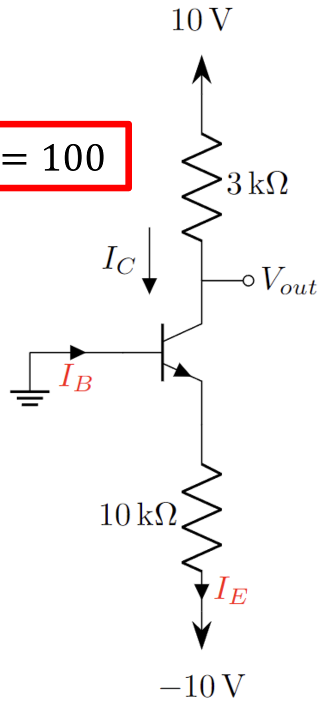
Equations: $\mathbf{I_E = 0.93\ mA}$

$\mathbf{I_B = 9.21\ \mu A}$

$\mathbf{v_{out} = v_C = 7.237\ V}$ $\quad \mathbf{v_B = 0\ V}$ $\quad \mathbf{v_E = -0.7\ V}$



$\boxed{\beta = 100}$

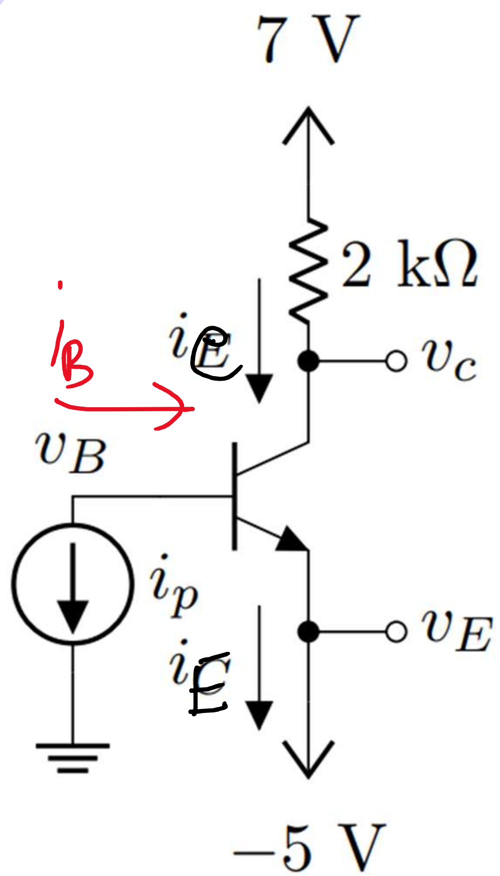


Verify: For **ACTIVE** condition → $\mathbf{v_{CE} > 0.2\ V}$

Here, $v_{CE} = (7.237 + 0.7)\ \mathbf{V} = \mathbf{7.937\ V} > 0.2\ \mathrm{V}$

Assumption is Correct!

Example 2



Analyze the circuit above to find i_B, i_C, i_E and v_{CE}. Assume, the BJT is in **Saturation**. Here, use the Method of Assumed State. You must validate your assumptions. Assume, i_p= -1mA ; $\beta = 100$

Sol^n:

$i_B = -i_P = -(-1) = 1$ mA

$V_E = -5$V

In saturation mode

So, $V_BE = 0.8$ V &

$V_{CE} = 0.2$ V

$\Rightarrow V_C - V_E = 0.2V \Rightarrow V_C = 0.2 + V_E = 0.2 + (-5)$

$\therefore V_C = -4.8$ V

$i_c = (7 - V_C)/2 = (7+4.8)/2 = 5.9$ mA

$i_E = i_c + i_B = 6.9$ mA

<u>Verify:</u>

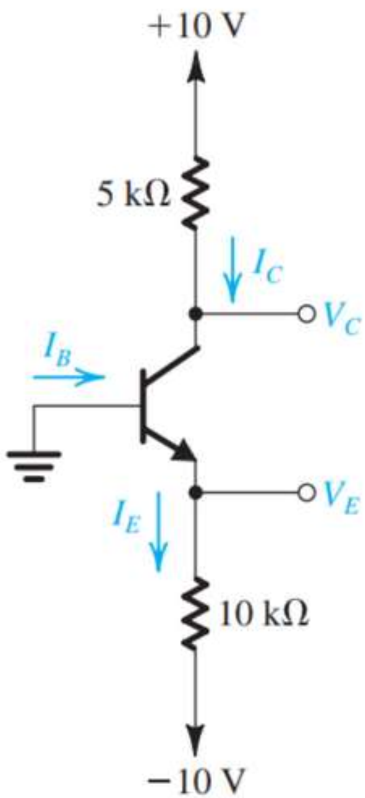
$\beta = 100$

$i_c / i_B = 5.9/1 = 5.9 < \beta$

$\therefore$ Assumption Correct

Example 7

In the circuit shown in Fig. the voltage at the emitter was measured and found to be –0.7 V. If $\beta = 50$, find I_E, I_B, I_C, and V_C.



Sol^{n}:

$$I_E = \frac{V_E - (-10)}{10\ k\Omega} = \frac{-0.7 + 10}{10} = 0.93\ mA$$

$$\alpha = \frac{\beta}{\beta + 1} = \frac{50}{51}$$

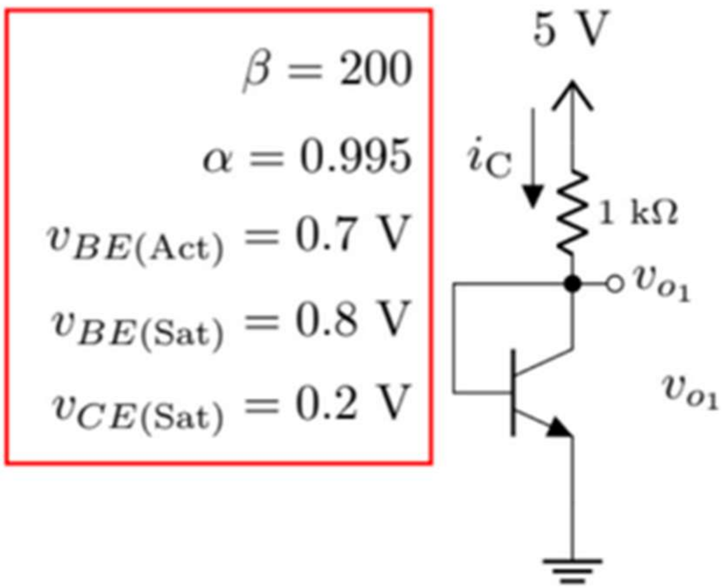
Assuming forward active mode,

$I_C = \alpha I_E = 0.9118$ mA
$V_C = 10 - 5I_C = 5.44$ V

So, $V_{CE} = V_C - V_E = 6.141$ V > 0.2 V so, forward active mode
Assumption correct!

$I_B = I_E - I_C = 18.2$ uA

Example 8



Analyze the circuit above to find i_C, i_E, i_B, and v_{01}. Here, use the Method of Assumed State.

Sol^{n}:

Assuming forward active mode,
V_{BE}=0.7 V → V_B-V_E= 0.7 V ∴ V_B= 0.7 V= V_C
So, V_{CE}= V_C-V_E= 0.7 V > 0.2 V so, forward active mode
Assumption correct!

$$i_C = \frac{5 - V_C}{1\ k\Omega} = \frac{5 - 0.7}{1} = 4.3\ mA$$

$I_C = \alpha I_E$
∴ I_E= 4.3/0.995= 4.3216 mA
I_B=I_E-I_C= 21.6 uA

Analyze the Ckt - 2 to find i_C and v_{O_1} using the Method of Assumed State. **Validate** your assumptions.

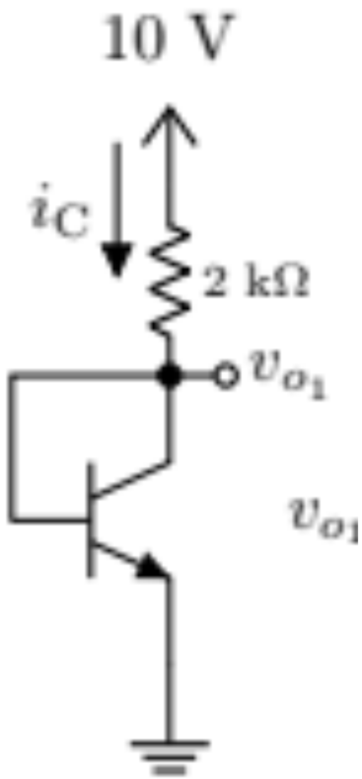
$$\beta = 100$$

$$\alpha = 0.99$$

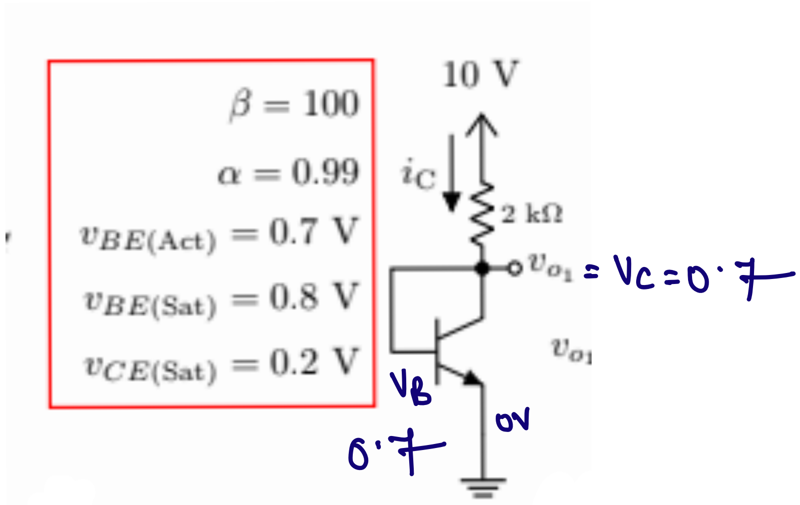
$$v_{BE(\text{Act})} = 0.7\text{ V}$$

$$v_{BE(\text{Sat})} = 0.8\text{ V}$$

$$v_{CE(\text{Sat})} = 0.2\text{ V}$$



Ckt - 2



$V_E = 0V$

$V_B = V_C$

Assuming active,

$V_{BE} = 0.7$

$V_B - V_E = 0.7$

$\Rightarrow V_B = 0.7$

$V_C = 0.7$

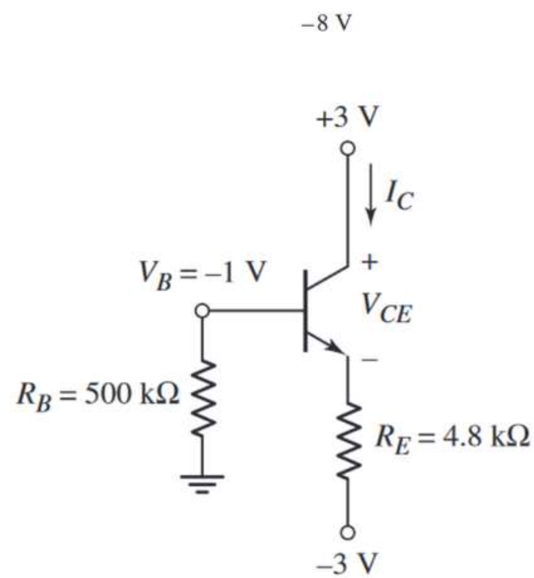
$$i_C = \frac{10 - 0.7}{2} = 4.65\,mA$$

$V_{CE} = V_C - V_E = 0.7 - 0$

$= 0.7 > 0.3V$ ✓ Active

Example 9

In the circuit shown in adjacent figure, the values of measured parameters are shown. Determine $\boldsymbol{\beta}, \boldsymbol{\alpha}$, and the other labeled currents and voltages.



Sol^n:

Assuming Active mode,

V_{BE}=0.7 V → V_B-V_E= 0.7 V ∴ V_E= (-1)-0.7 V= -1.7 V

$$I_B = \frac{0 - V_B}{R_B} = \frac{0-(-1)}{500\ k\Omega} = 2\ uA$$

$$I_E = \frac{V_E - (-3)}{R_E} = \frac{-1.7+3}{4.8\ k\Omega} = 0.271\ mA$$

I_C=I_E-I_B=0.269 mA

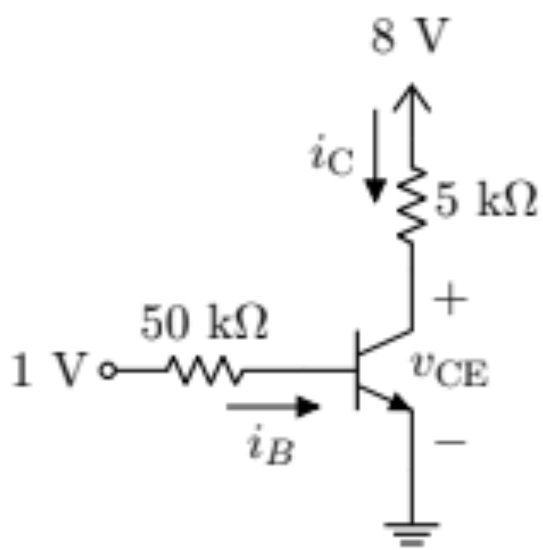
$$\beta = \frac{I_C}{I_B} = 134.5$$

$$\alpha = \frac{I_C}{I_E} = 0.9926$$

V_{CE}= V_C-V_E= 3-(-1.7)= 4.7 V > 0.2 V so, forward active mode

Assumption correct!

Analyze the circuit below to find i_C and v_{CE}. Here, **use** the Method of Assumed State. You must **validate** your assumptions.



$\beta = 100$

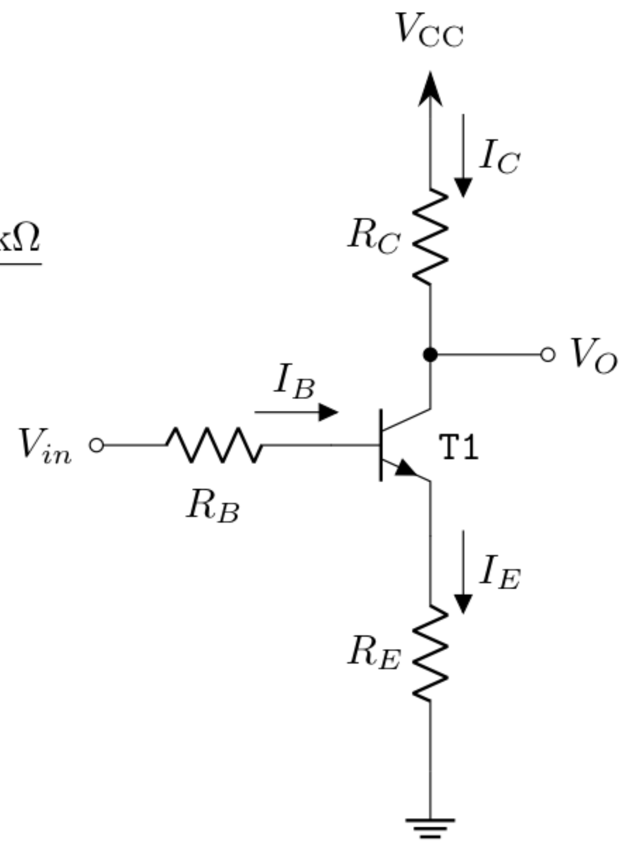
$\alpha = 0.99$

$v_{BE(\text{Active})} = 0.7$ V

$v_{BE(\text{Saturation})} = 0.8$ V

$v_{CE(\text{Saturation})} = 0.2$ V

Andrew and Nicole found the adjacent circuit built in a trainer board. From the transistor model, they knew it had a gain of ~~[Set-A] $\beta = 80$. They also saw $V_{CC} = 5\,\text{V}$, $R_B = 2\,\text{k}\Omega$, and $R_C = 3\,\text{k}\Omega$~~ or [**Set-B**] $\beta = 60$. They also saw $V_{CC} = 6\,\text{V}$, $R_B = 3\,\text{k}\Omega$, and $R_C = 4\,\text{k}\Omega$ However, the R_C resistor was an unknown one. So, they provided an input of $V_{in} = 2\,\text{V}$ and measured the output to be $V_0 = 2.2\,\text{V}$. Nicole said, "In this condition, the transistor is in **active** mode". But, Andrew disagreed.



(a) **[CO1] Illustrate** the Voltage Transfer Characteristic curve of a BJT driven inverter with proper labeling. [1.5]

(b) **[CO3] Design** the circuit, i.e., determine the value of R_E, using what Nicole said about the mode of the transistor. [4]

(c) **[CO2]** Use the calculations in (c), and **determine** who is right between Andrew and Nicole.

(d) **[CO2]** Using the value of R_E obtained from (b), **determine** who will be right if $V_{in} = 4\,\text{V}$.

Solution: For **active** mode of operation:

$$
\begin{aligned}
V_{in} &= R_B I_B + 0.7 + R_E I_E \\
2 &= 2I_B + 0.7 + R_E(\beta + 1)I_B \\
I_B &= \frac{2 - 0.7}{2 + (1 + \beta)R_E} \\
I_B &= \frac{1.3}{3 + 61R_E}
\end{aligned} \tag{3}
$$

We can also write the equation of I_C from our knowledge of V_O.

$$
\begin{aligned}
I_C &= \frac{V_{CC} - V_O}{R_C} = \beta I_B \\
I_C &= 0.95 = 60I_B \\
0.95 &= \frac{1.3 \times 60}{3 + 61R_E} \\
R_E &= 1.298\,\mathrm{k\Omega}
\end{aligned} \tag{4}
$$

Solution: ANDREW WILL BE RIGHT THEN. Assuming **saturation** mode of operation and taking KVL along base-emitter we get:

$$
\begin{aligned}
V_{in} - R_B I_B - 0.7 - R_E I_E &= 0 \\
R_B I_B + R_E(I_C + I_B) &= V_{in} - 0.7 \\
(R_B + R_E)I_B + R_E I_C &= V_{in} - 0.7 \\
4.298 I_B + 1.298 I_C &= 3.3
\end{aligned}
$$

Taking KVL along collector-emitter junction, we get:

$$
\begin{aligned}
V_{CC} - R_C I_C - 0.2 - R_E I_E &= 0 \\
R_C I_C + R_E(I_C + I_B) &= V_{CC} - 0.2 \\
R_E I_B + (R_E + R_C)I_C &= V_{CC} - 0.2 \\
1.298 I_B + 5.298 I_C &= \cancel{4.8}\ 5.8
\end{aligned}
$$

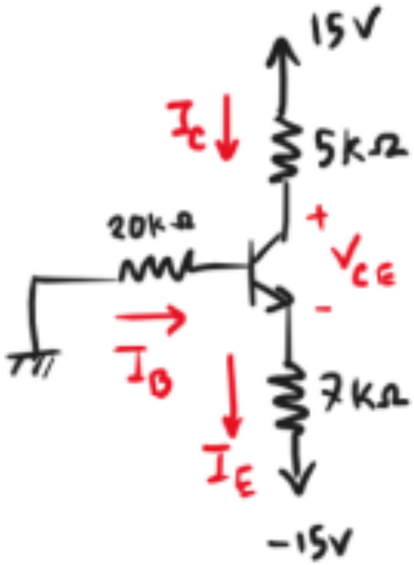
If $v_{BE(sat)} = 0.7\,\mathrm{V}$, solving Eqn. 7 and 8 we get:

$$
\begin{aligned}
I_B &= 0.534\,\mathrm{mA} \\
I_C &= 0.775\,\mathrm{mA}
\end{aligned}
$$

If $v_{BE(sat)} = 0.8\,\mathrm{V}$, solving above two equations, we get:

$$
\begin{aligned}
I_B &= 0.509\,\mathrm{mA} \\
I_C &= 0.781\,\mathrm{mA}
\end{aligned}
$$

Analyze the following circuit to find the values of I_D and V_{DS}. Here, **use** the Method of Assumed State. You must **validate** your assumptions.



$V_{BE(ACTIVE)} = 0.7\text{V}$

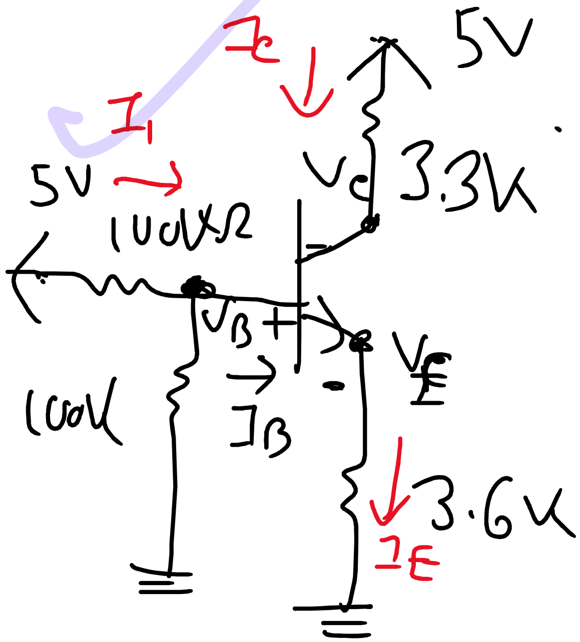
$V_{BE(SAT)} = 0.8\text{V}$

$V_{CE(SAT)} = 0.2\text{V}$

$\beta = 100$

$\alpha = 0.99$

Example 3



Analyze the circuit above to find i_B, i_C, i_E and v_{CE}. Here, use the Method of Assumed State. You must validate your assumptions. **β= 100, α= (β)/(β+1)= 0.99**

Sol^n:

Assume, Active mode

So, V_{BE}= 0.7 V & $I_C = \beta I_B = \alpha I_E$

Nodal analysis (at base terminal):

$$\frac{V_B - 5}{100\ k\Omega} + \frac{V_B}{100\ k\Omega} + I_B = 0 ----(1)$$

KVL:

$$5 - 0 = 100 I_1 + V_{BE} + 3.6 I_E$$

$$5 = 100\frac{5 - V_B}{100\ k\Omega} + 0.7 + 3.6\frac{\beta}{\alpha} I_B ---(2)$$

Solving, eq^n 1 & 2, V_B= 2.28 V , I_B= 4.35 uA

$I_C = \beta I_B$= 0.435 mA, $I_E = I_c + I_B$=0.43935 mA

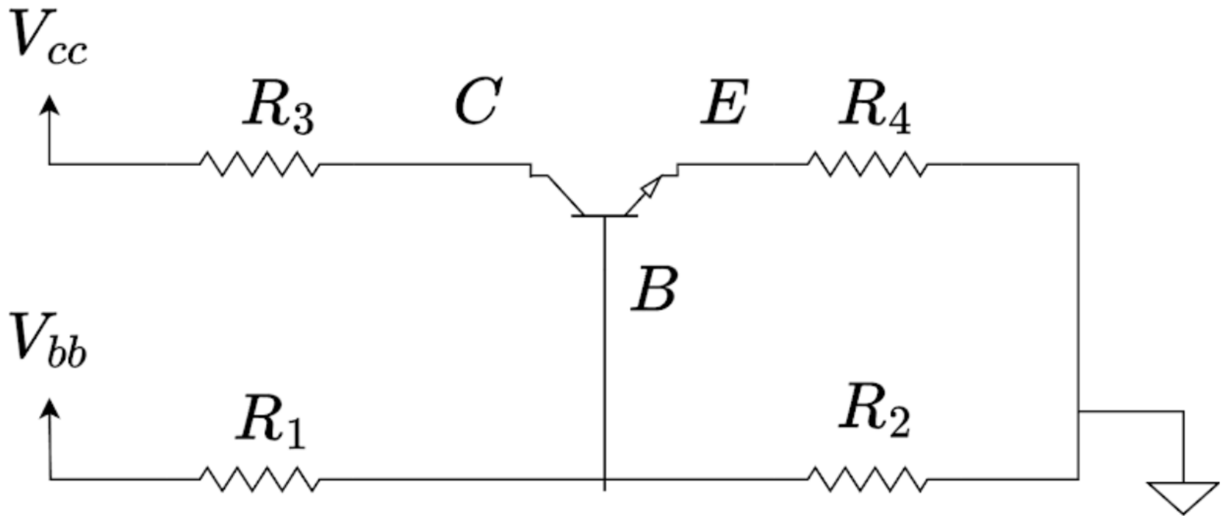
V_C= 5-3.3I_C= 3.5645 V

V_E= 3.6I_E= 1.582 V

$V_{CE} = V_C - V_E$= 1.983 V

So, V_{CE}> 0.2 V

$\therefore$ Assumption Correct!



In the above circuit, V_{bb} = 5V, V_{cc} = 15V, R_1 = 20kΩ(40kΩ), R_2 = 80kΩ(60kΩ), R_3 = 2kΩ and R_4 = 1kΩ. Also, assume current gain, Ic/Ib = 100.

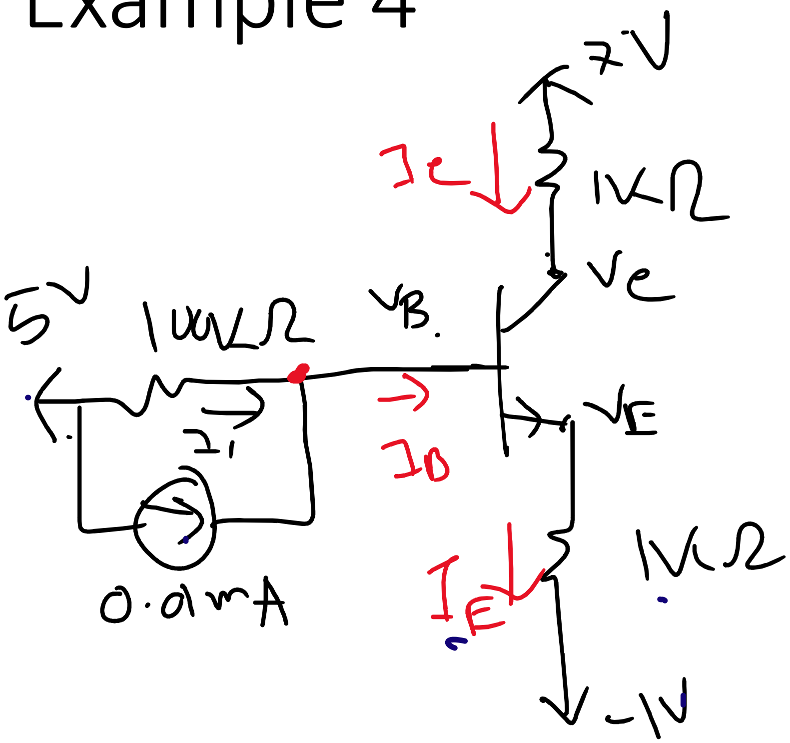
a) Draw the equivalent circuit of BJT during saturation and active modes. [2]

b) Solve the above circuit and calculate I_B, I_C, I_E, V_{CE} and V_C using the method of assumed states. [Hint: try to find the Thevenin equivalent of the left hand side circuit from the B terminal and ground] [3]

c) If V_{bb} is changed from 5V to 5.1V, what happens to the outputs of the circuits? Calculate I_B, I_C, I_E, V_{CE} and V_C again. Now for a 0.1V increase in input V_{bb}, what is the change of I_c? Use $\Delta I_C = I_{C,new} - I_{C,old}$. [3+1]

d) Explain any use case of the differences in voltage increase between input and output. What could the use case be to such a phenomenon? [1]

Example 4



Analyze the circuit above to find v_{CE}. Here, use the Method of Assumed State. You must validate your assumptions. β= 100, α= (β)/(β+1)= 0.99

Sol^n:

Assume, Active mode

So, V_{BE}= 0.7 V & I_C= βI_B= αI_E

KCL (at base terminal):

$$I_1 + 0.01 = I_B$$
$$\therefore I_1 = I_B - 0.01$$

KVL:

$$5 - (-1) = 100 I_1 + V_{BE} + 1 I_E$$
$$6 = 100(I_B - 0.01) + 0.7 + \frac{\beta}{\alpha} I_B \text{ --- (2)}$$
$$\therefore I_B = 0.0313 \text{ mA}$$

I_C= βI_B= 3.13 mA, I_E= I_c+ I_B=3.1613 mA

V_C= 7-1I_C= 3.87 V

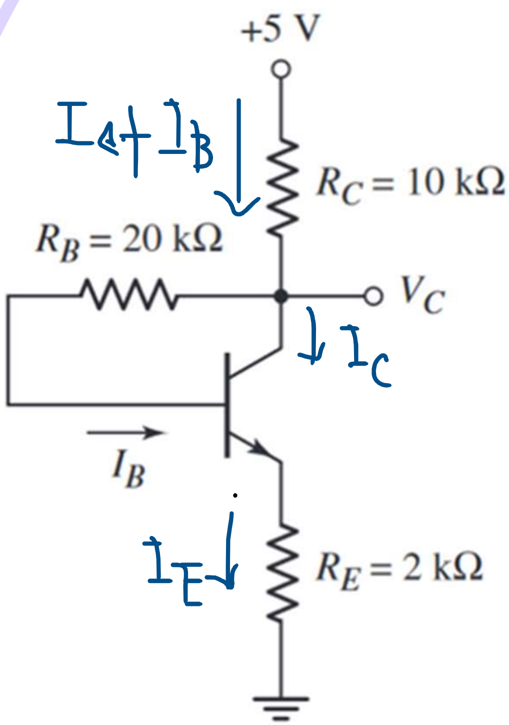
V_E= 1I_E-1= 2.16 V

V_{CE}= V_C-V_E= 1.709 V

So, V_{CE}> 0.2 V

$\therefore$ Assumption Correct!

Example 10



$\beta = 75$. Find the labelled voltages and currents.

Sol^n:

Assuming Active mode,

$V_{BE}=0.7$ V

$$5 - 0 = R_C(I_C + I_B) + R_B I_B + V_{BE} + R_E I_E$$

$$5 = 10(\beta I_B + I_B) + 20 I_B + 0.7 + 2\frac{\beta}{\alpha} I_B$$

$\therefore I_B = 4.604$ uA

$I_C = \beta I_B = 0.345$ mA

$V_C = 5\text{-}10(I_C+I_B) = 1.5$ V

$I_E = I_c + I_B = 0.3496$ mA

$V_E = 2I_E = 0.7$ V

$V_{CE} = V_C\text{-}V_E = 1.5\text{-}0.7 = 0.8\ V > 0.2$ V so, forward active mode

Assumption correct!