CSE 251
Electronic Devices and Circuits

Lecture 10

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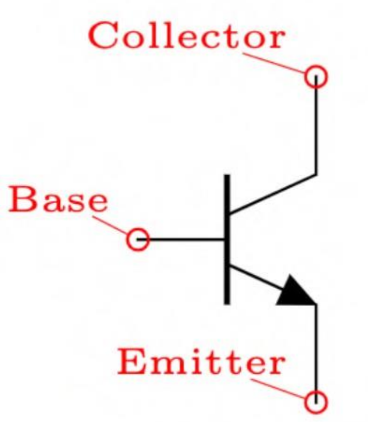
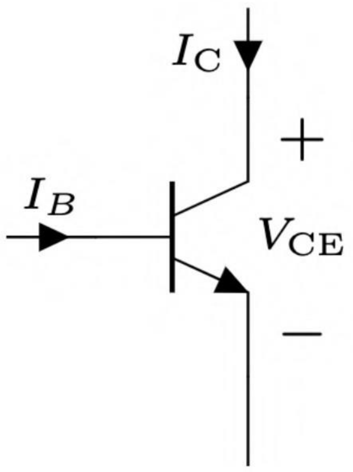
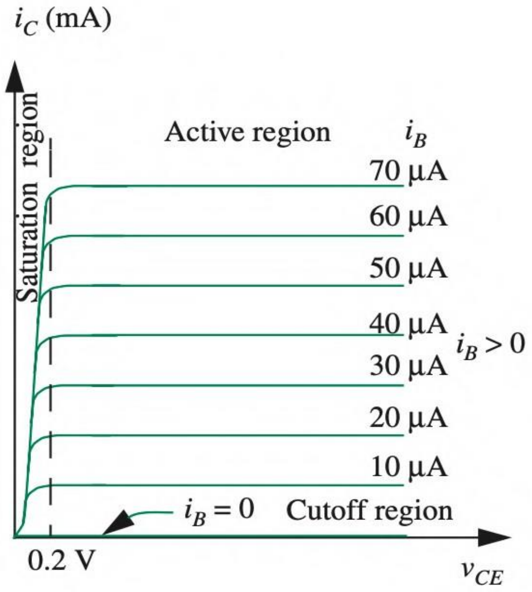
Transistors as Digital Switch

- Transistors are 3 terminal non-linear devices, can be used as switch
- 2 types – **Voltage Controlled**, **Current Controlled**
- **Current-controlled** transistor, 3 terminals – Base, Emitter, Collector
- IV between C and E $(I_C\ vs\ V_{CE})$ is controlled by base current, $\boldsymbol{I_B}$
- Will start with a simple (but approximate) one – **S-Model** (Switch Model)



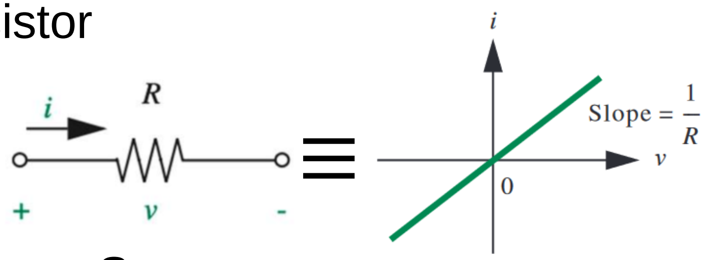




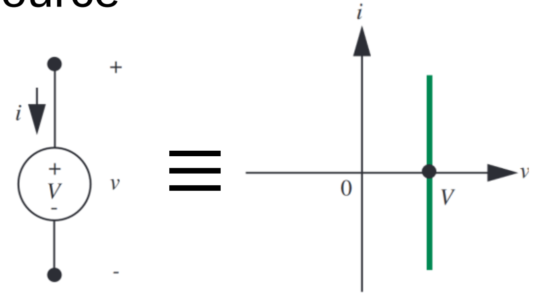
Two terminal Devices

Linear Devices

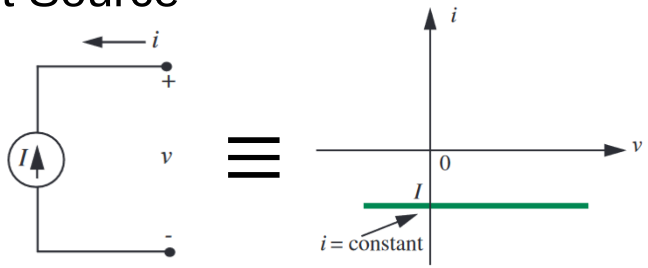
Resistor



Voltage Source



Current Source

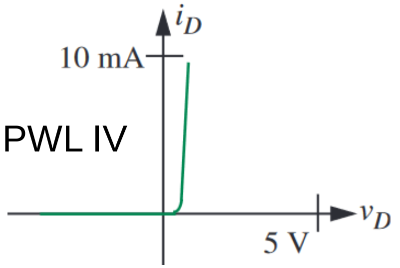


IV characteristics of two terminal devices are fixed.

Non-linear Devices

Diode

PWL: Piecewise Linear



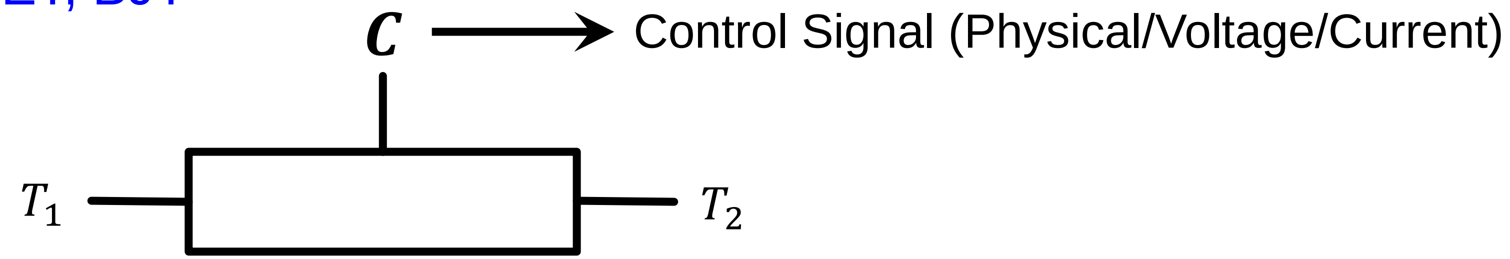
IV characteristics of **three terminal devices** can be changed

Three terminal Devices

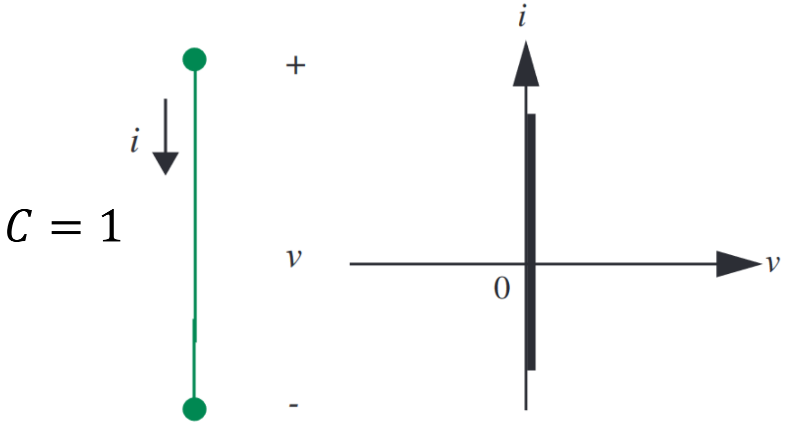
IV of two terminal can be controlled using a third terminal.

Example: Switch, MOSFET, BJT

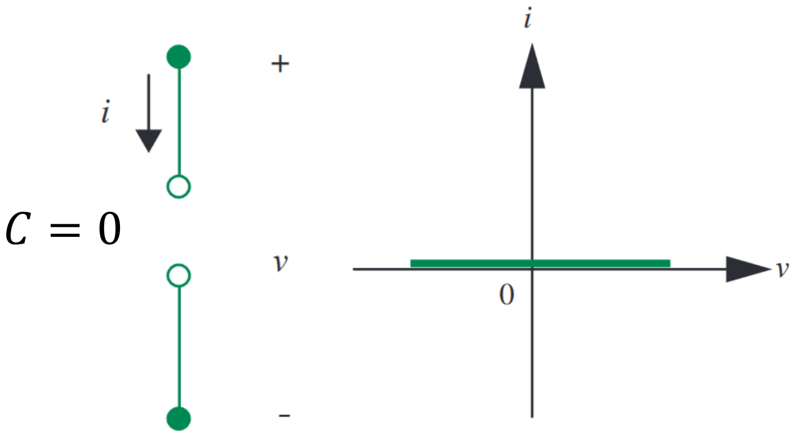
Switch



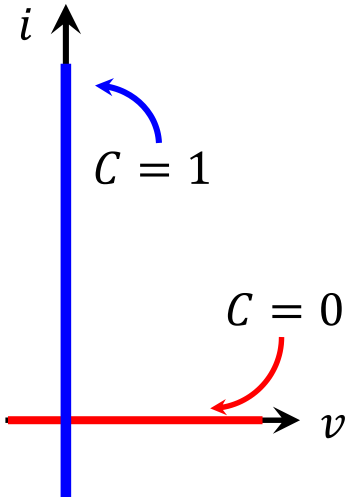
IV characteristics between T_1 and T_2 can be controlled by C



Switch **ON**

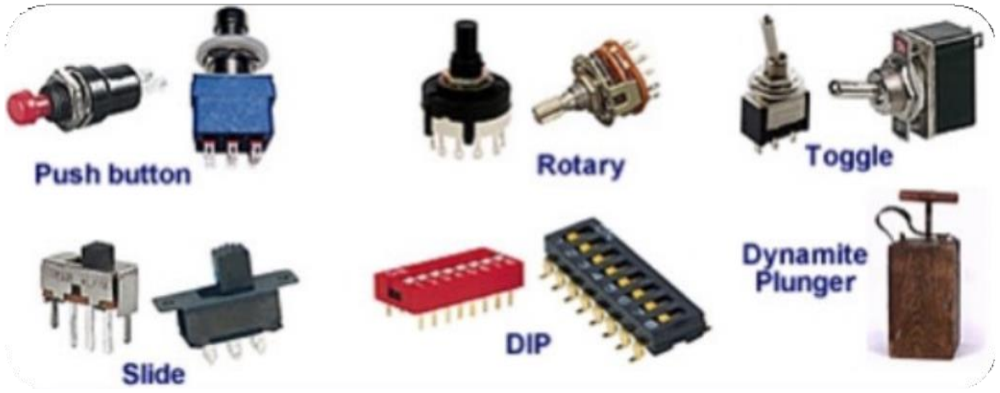


Switch **OFF**

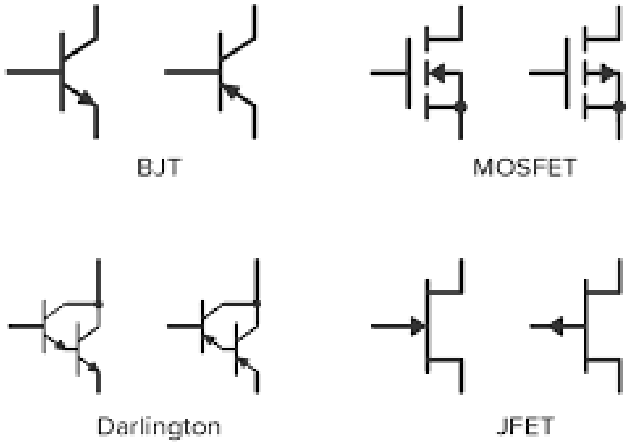


Switch – Types

- Depending on the control, the switch can be
  - **Analog**: Controlled using physical toggle/button
  - **Digital**: Controlled using voltage or current. Example – MOSFET (voltage controlled), BJT (current controlled)



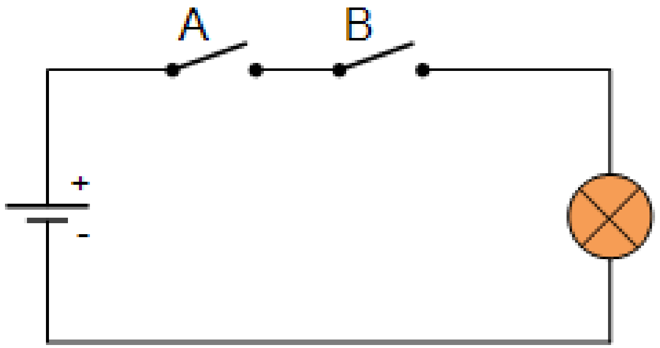
Analog switches



Digital switches (Transistors)

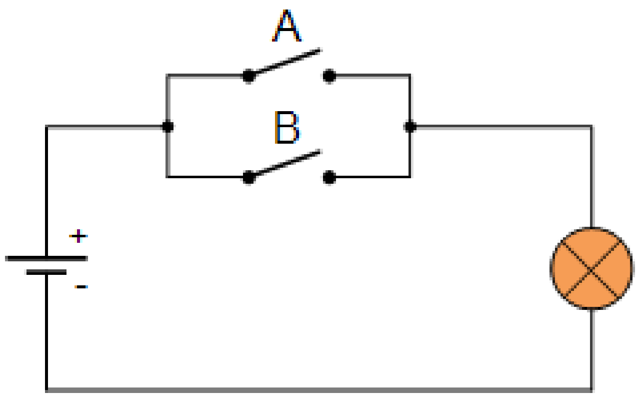
Switch Application – Logic Gates

- We can use switches to build logic gates



A	B	Bulb
0	0	OFF
0	1	OFF
1	0	OFF
1	1	ON

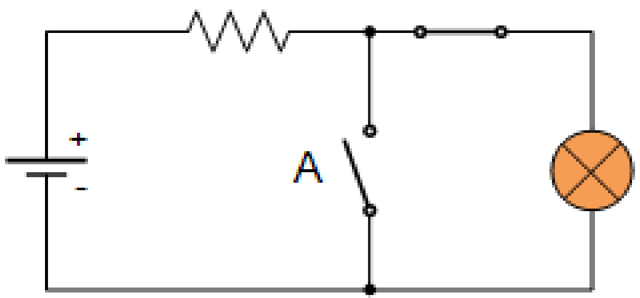
AND operation

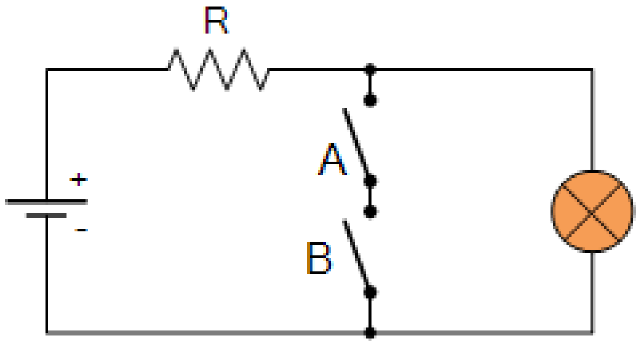


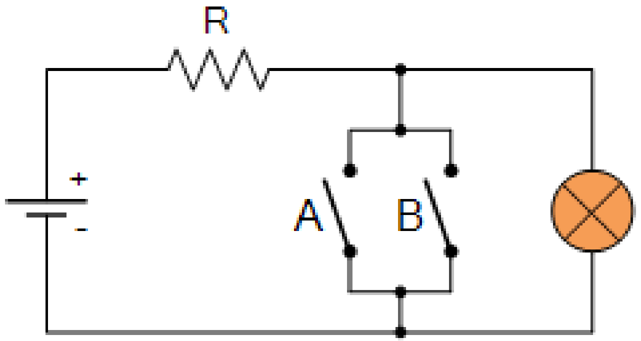
A	B	Bulb
0	0	OFF
0	1	ON
1	0	ON
1	1	ON

OR operation

Switch Application – Logic Gates







A	Bulb
0	ON
1	OFF

A	B	Bulb
0	0	ON
0	1	ON
1	0	ON
1	1	OFF

NAND operation

A	B	Bulb
0	0	ON
0	1	OFF
1	0	OFF
1	1	OFF

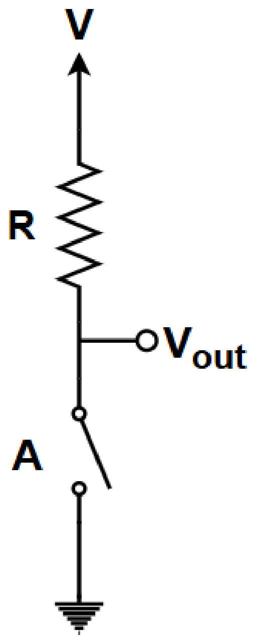
NOR operation

These circuits are “preferred” – because they can be cascaded to build combinational logic circuits

-> if we remove the bulb and use the voltage across instead to cascade and drive the next gate

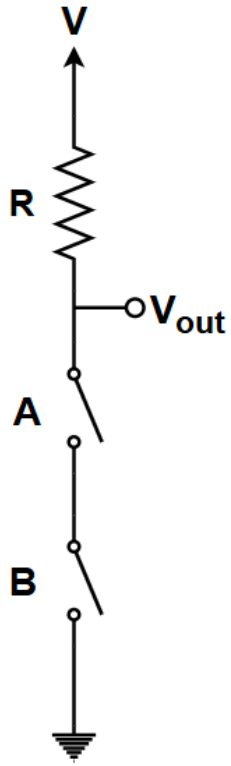
Switch Application – Logic Gates

Alternative representations:



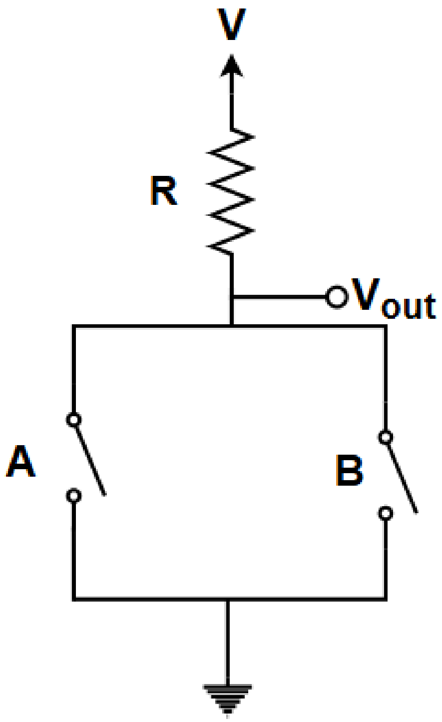
$$V_{out} = \overline{A}$$

NOT



$$V_{out} = \overline{AB}$$

NAND

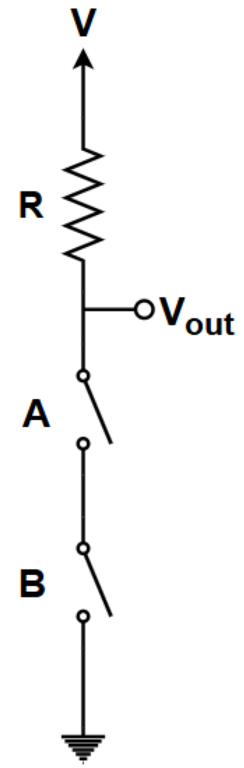


$$V_{out} = \overline{A + B}$$

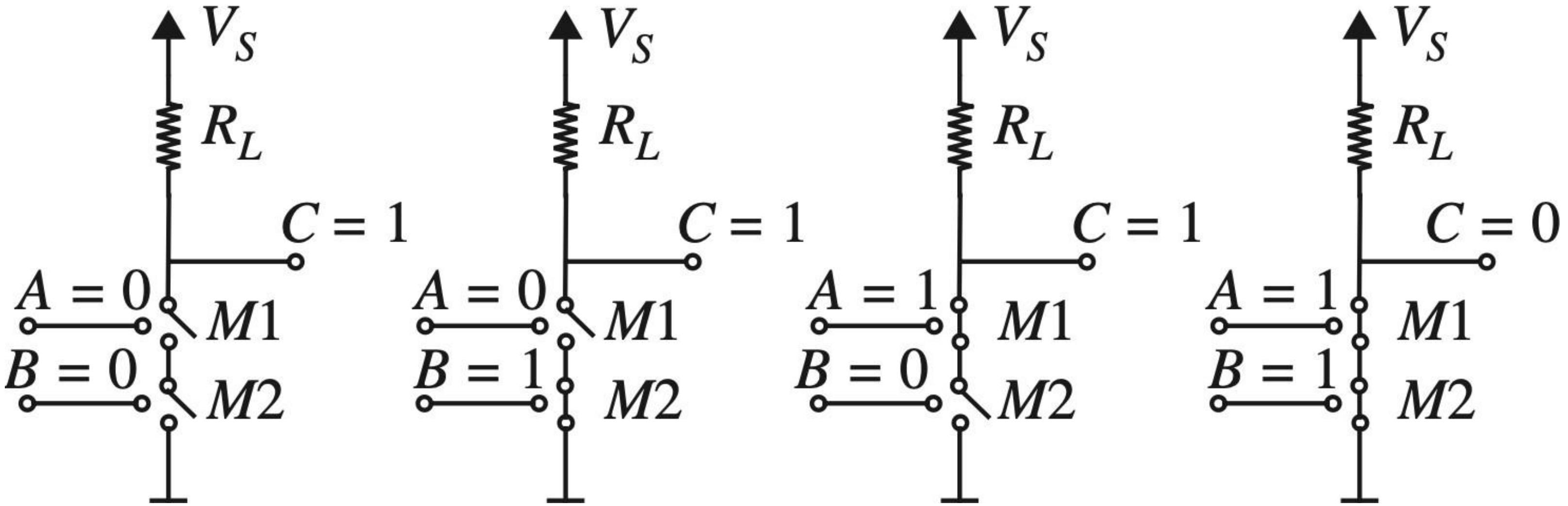
NOR

Switch Application – Logic Gates

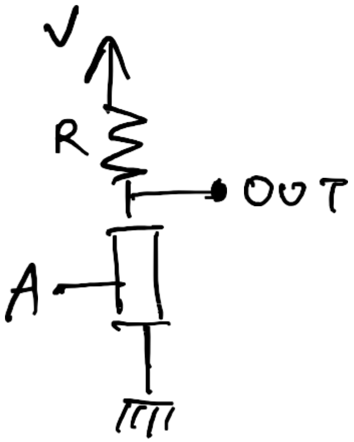
Alternative representations:



$$V_{out} = \overline{AB}$$

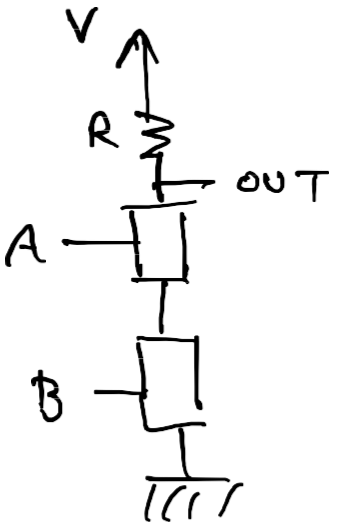


Switch Application – Logic Gates



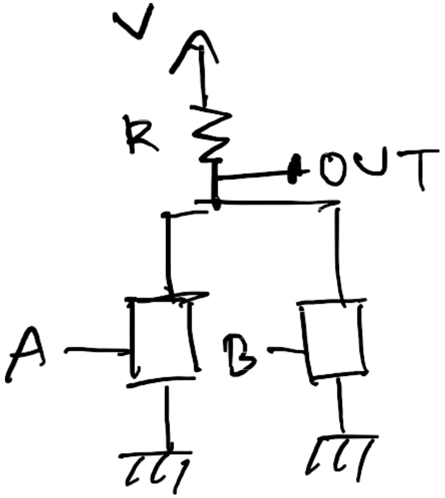
$OUT = \overline{A}$

A	V_{OUT}
0	5V
1	0V



$OUT = \overline{AB}$

A	B	V_{OUT}
0	0	5V
0	1	5V
1	0	5V
1	1	0V

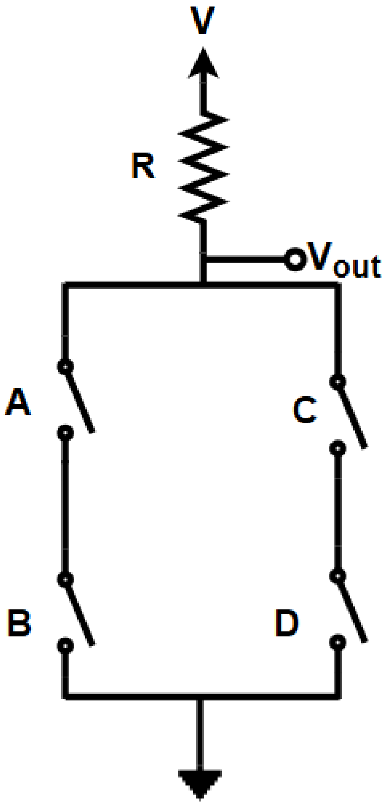


$OUT = \overline{A+B}$

A	B	V_{OUT}
0	0	5V
0	1	0V
1	0	0V
1	1	0V

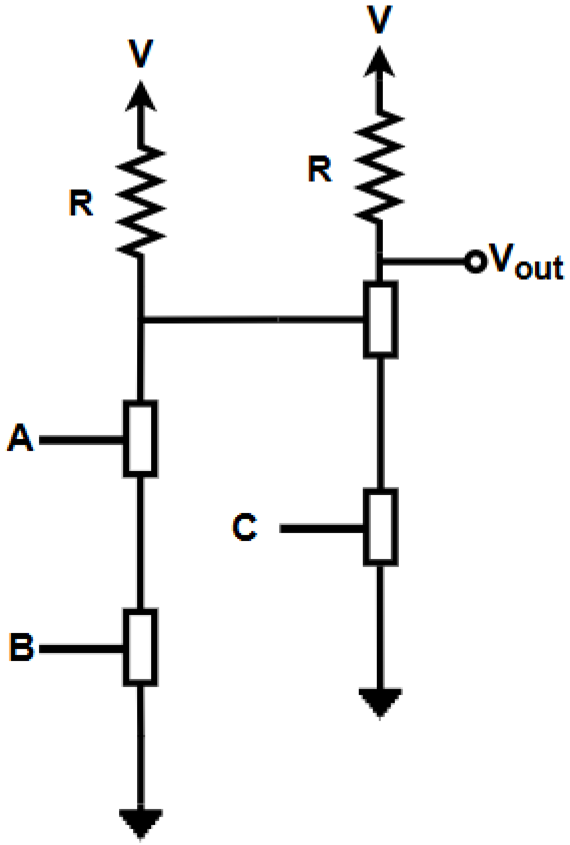
Examples

1.



$$\mathbf{Vout} = \overline{\mathbf{AB + CD}}$$

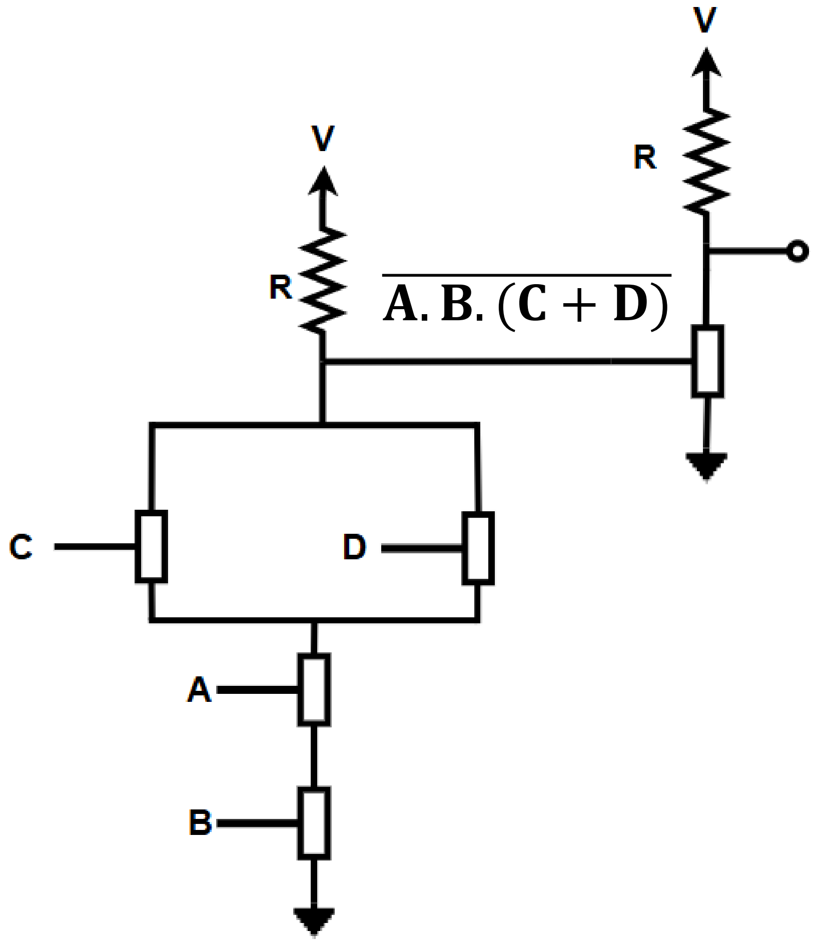
2.



$$\mathbf{Vout} = \overline{\overline{\boldsymbol{AB}}.\boldsymbol{C}}$$

Example

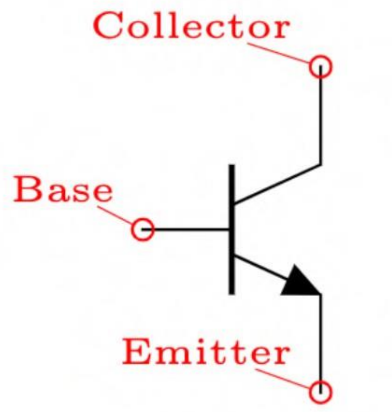
Implement using switches: f = A.B.(C+D)

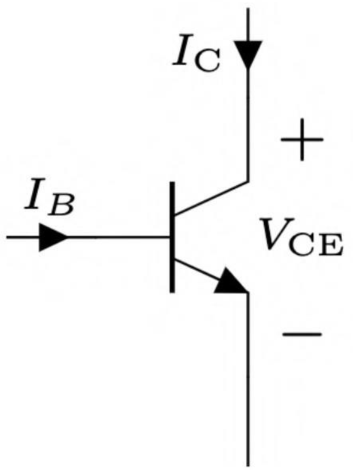


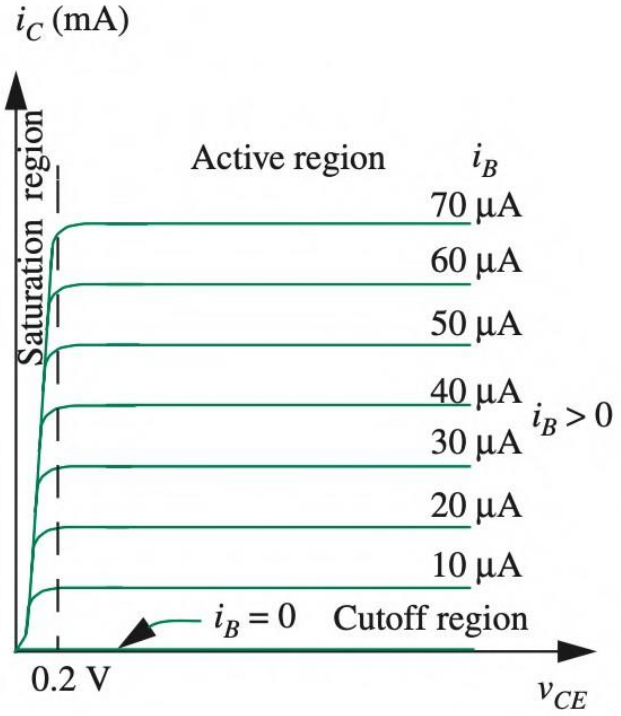
$$\mathbf{V_{out}} = \overline{\overline{\mathbf{A.B.(C+D)}}} \\ = \mathbf{A.B.(C+D)}$$

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 $\boldsymbol{V_{GS}}$)

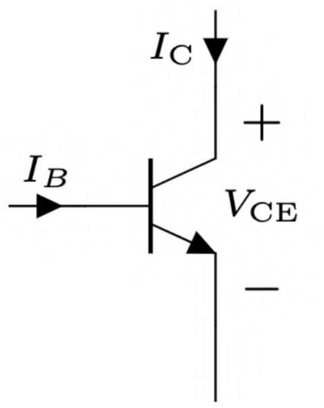






BJT vs MOSFET - Differences

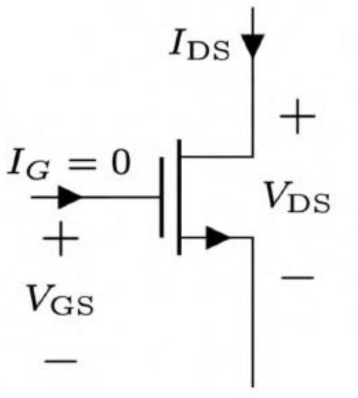
BJT



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

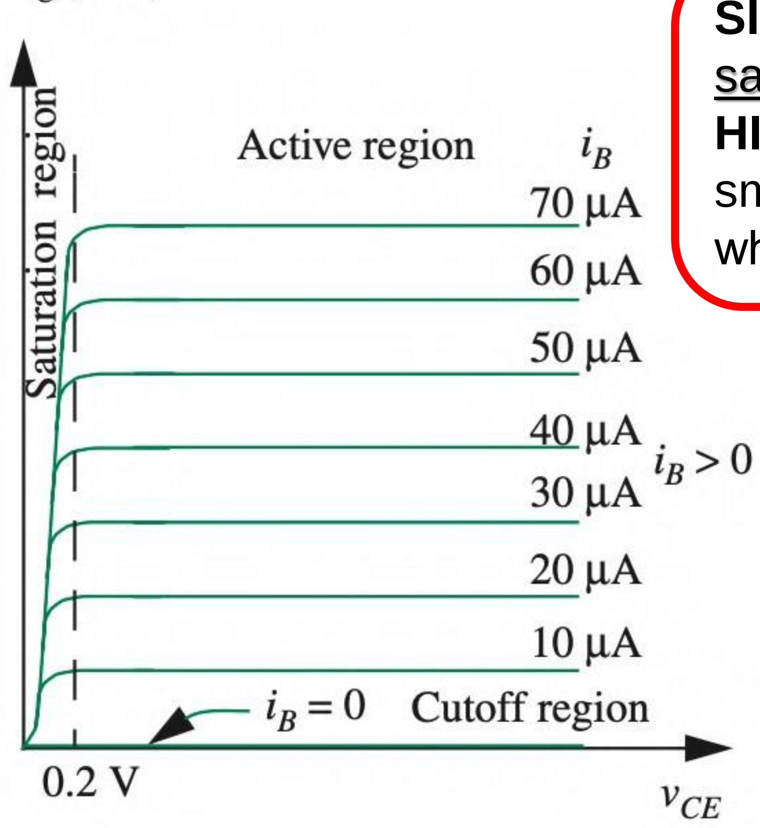


Voltage controlled, $\boldsymbol{V_{GS}}$ controls ($\boldsymbol{I_{DS}}$ vs $\boldsymbol{V_{DS}}$)

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

BJT vs MOSFET - Differences

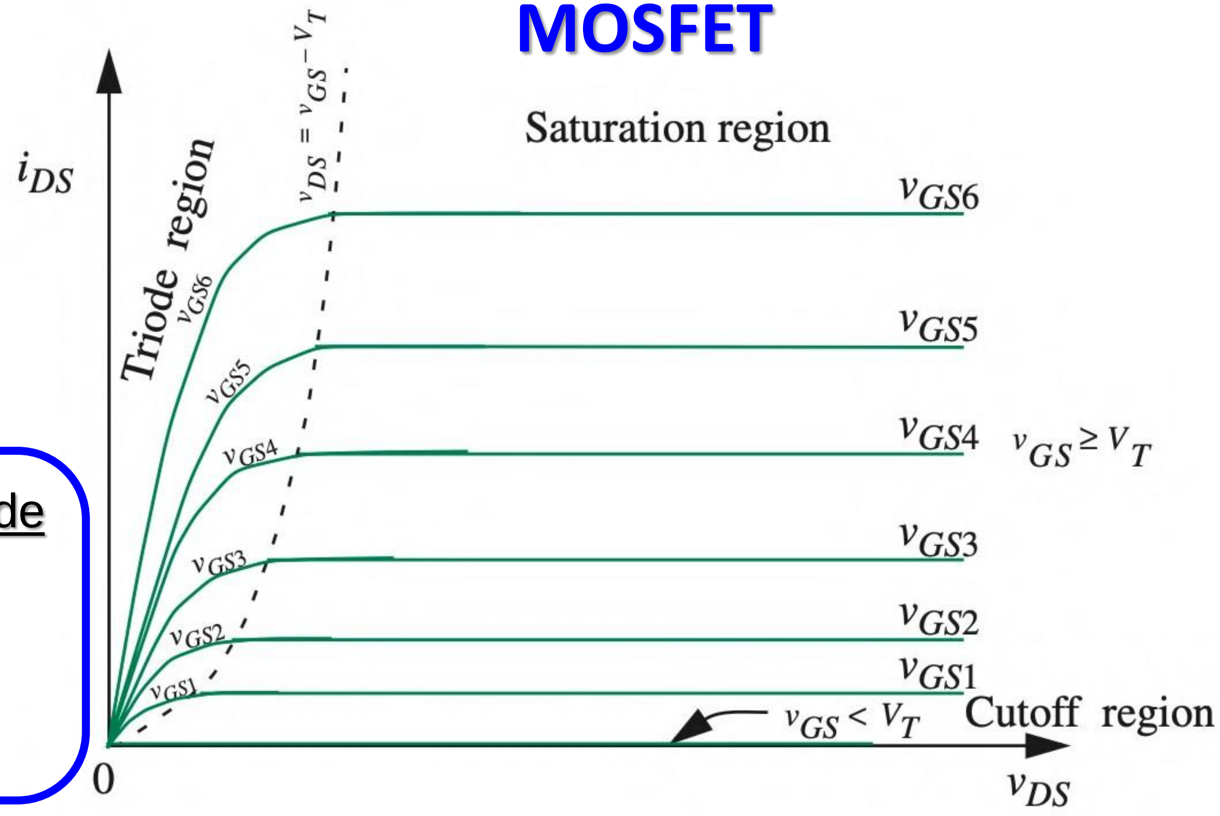
BJT



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

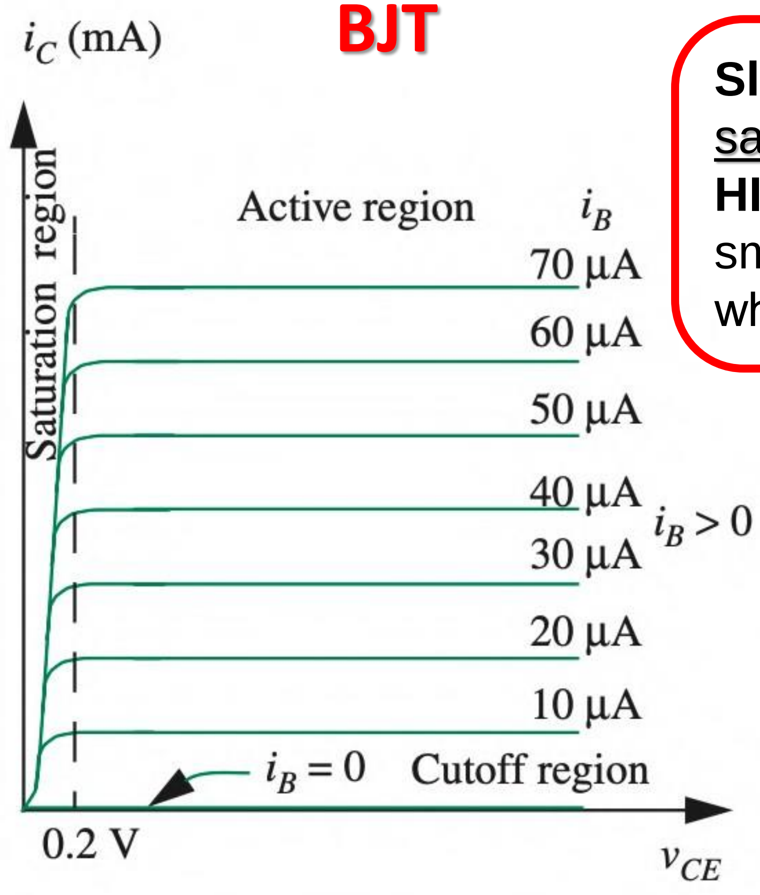


Current in **active** region changes linearly with control $\boldsymbol{I_B}$.
Hence, $\boldsymbol{I_C \propto I_B}$

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

BJT vs MOSFET - Differences

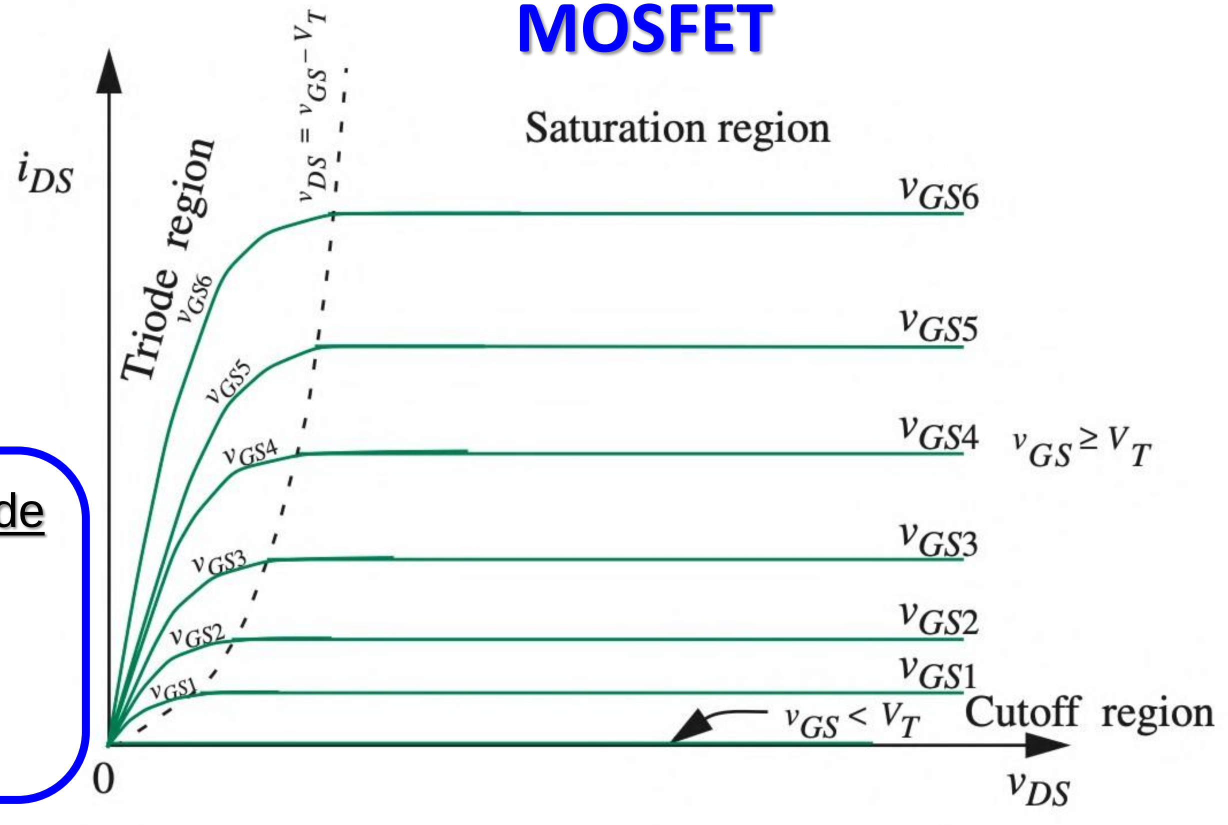
BJT



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

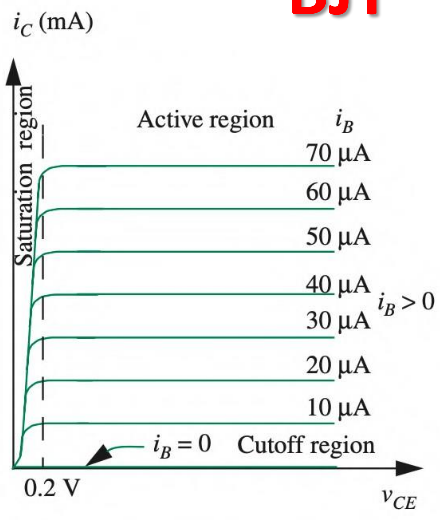


Current in **active** region changes linearly with control I_B.
Hence, $I_C \propto I_B$

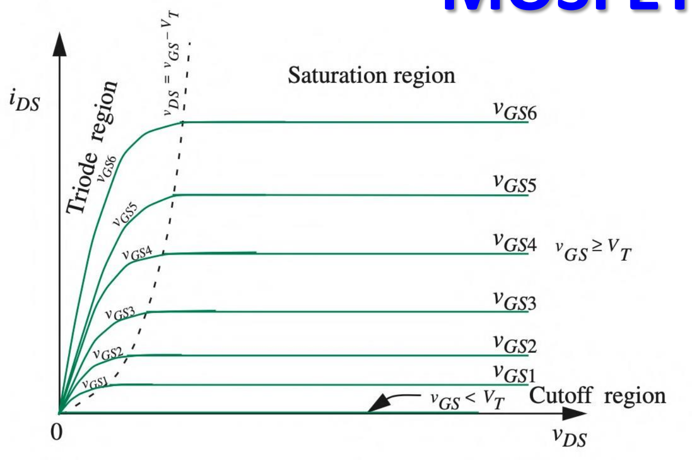
Current in **Saturation** region changes quadratically with control V_{GS}.
Hence, $I_{DS} \propto V_{GS}^2$

BJT vs MOSFET - Similarities

BJT



MOSFET



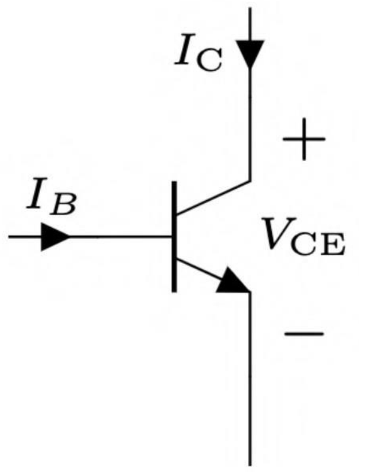
- **Saturation** mode for small $V_{CE}(< 0.2\ \mathrm{V})$
- Approximately Short circuit in **Saturation** mode (I_B **HIGH**)
- Open circuit in **Cutoff** mode ($I_B = 0$)
- Can use as a switch ⇒ S-Model!

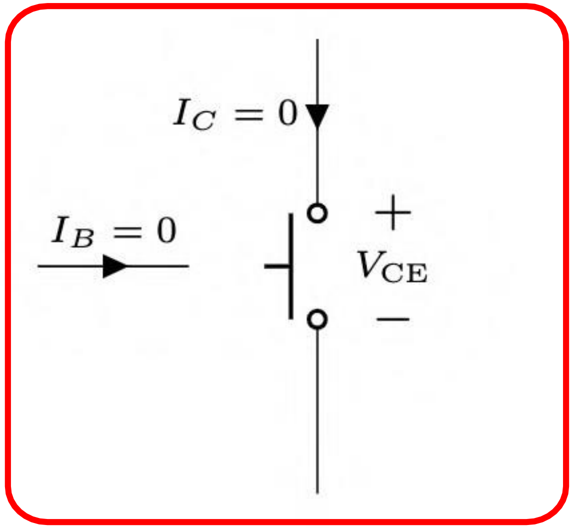
- **Triode** mode for small $V_{DS}(< V_{OV})$
- Approximately Short circuit in **Triode** mode (V_{GS} **HIGH**)
- Open circuit in **Cutoff** mode **($\boldsymbol{V_{GS} < V_T = 0}$)**
- Can use as a switch ⇒ S-Model!

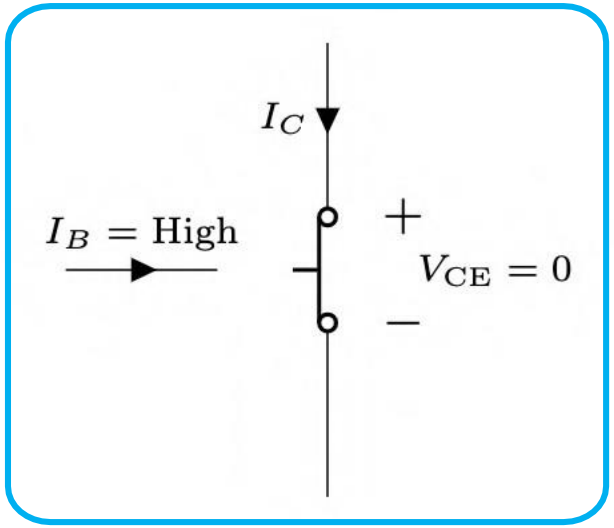
BJT S-Model

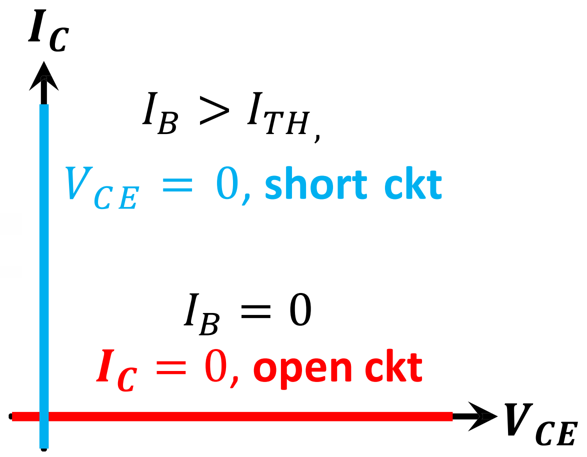
	Representation
Logic 0	$\boldsymbol{I_B = 0}$
Logic 1	$\boldsymbol{I_B > I_{TH}, I_B = HIGH}$

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



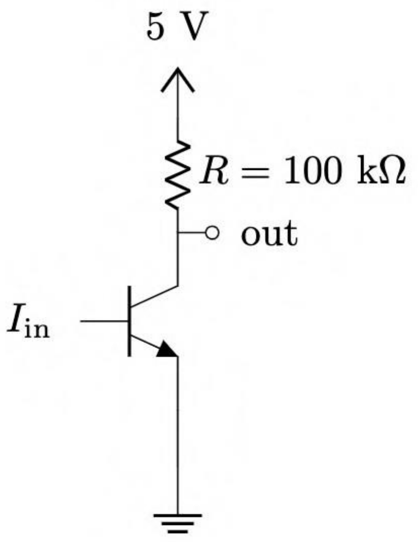




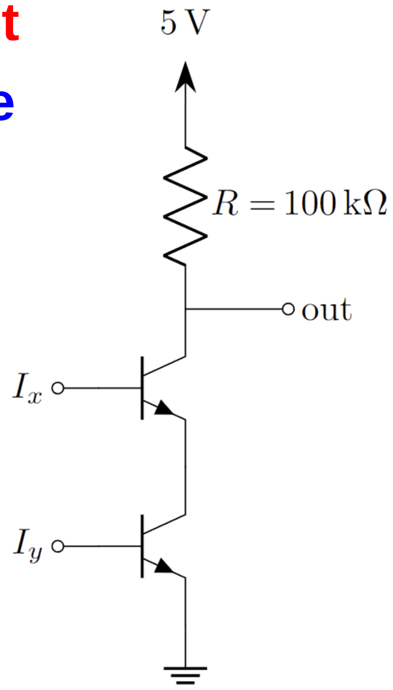


Current-Controlled Logic Gates using BJT

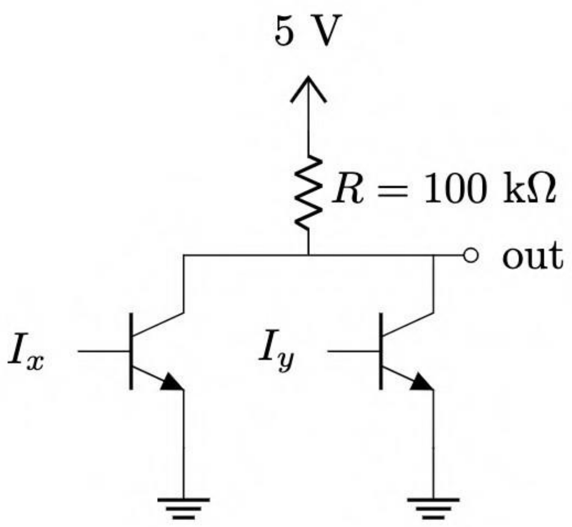
- Just replace switches with BJTs!
- Major problem: Cannot cascade! (Why?)
  - Input Logic Variable: **Current**
  - Output Logic Variable: **Voltage**



BJT Inverter (NOT Gate)



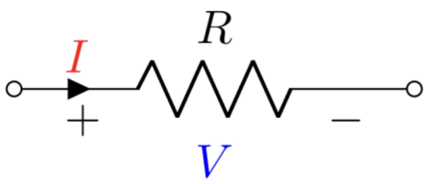
BJT NAND Gate



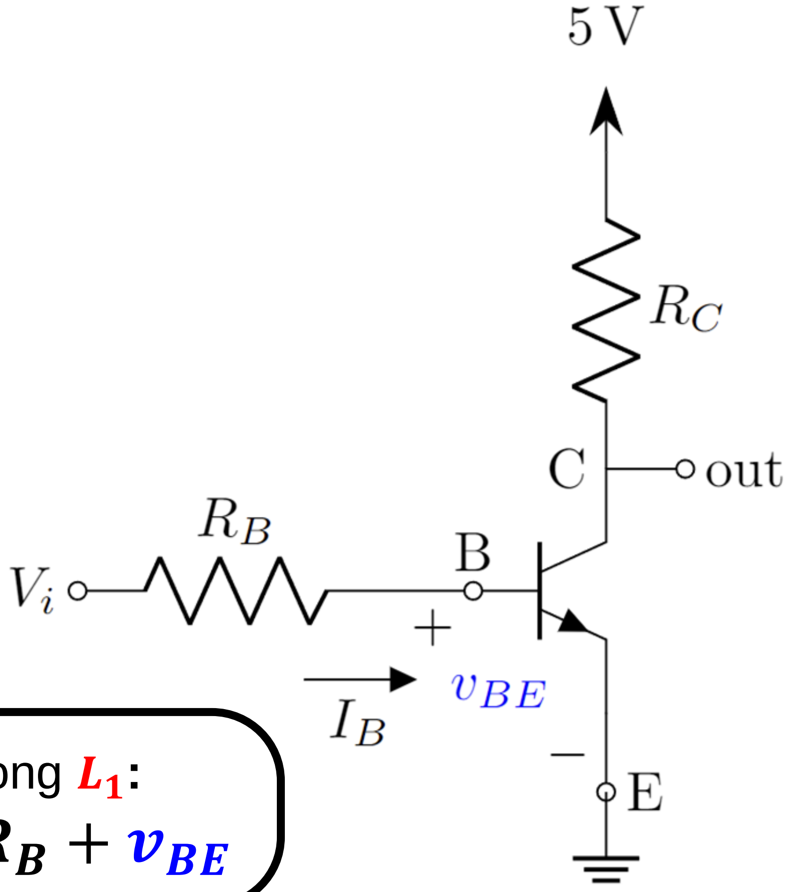
BJT NOR Gate

From Current Controlled to Voltage Controlled

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



$$\boxed{\boldsymbol{V} = \boldsymbol{IR}}$$



KVL along $\boldsymbol{L_1}$:

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

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

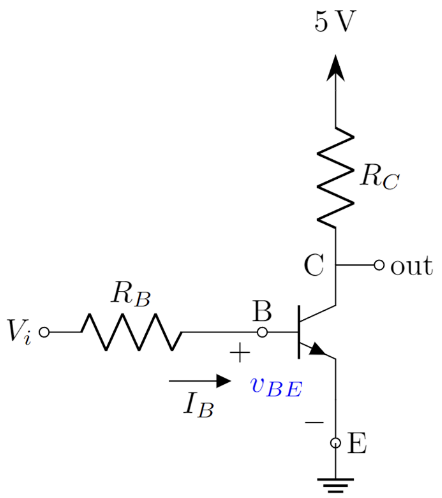
$$\boldsymbol{I_B = \frac{V_i - v_{BE}}{R_B}}$$

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

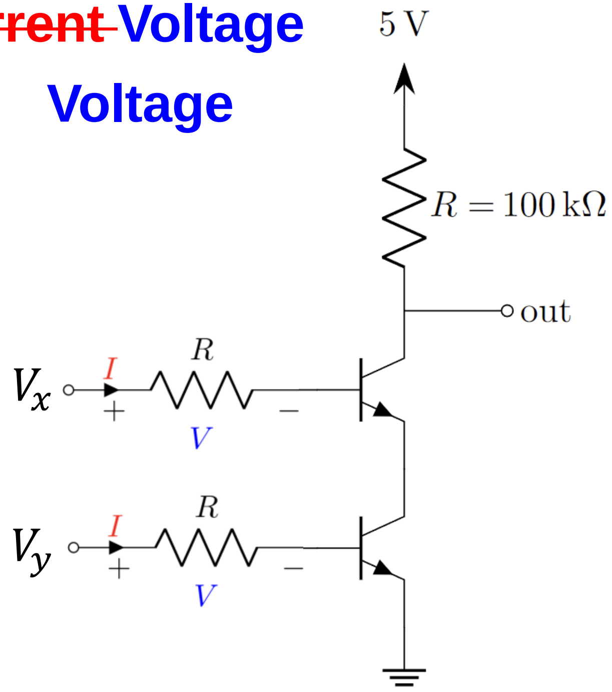
How?

Logic Gates using BJT

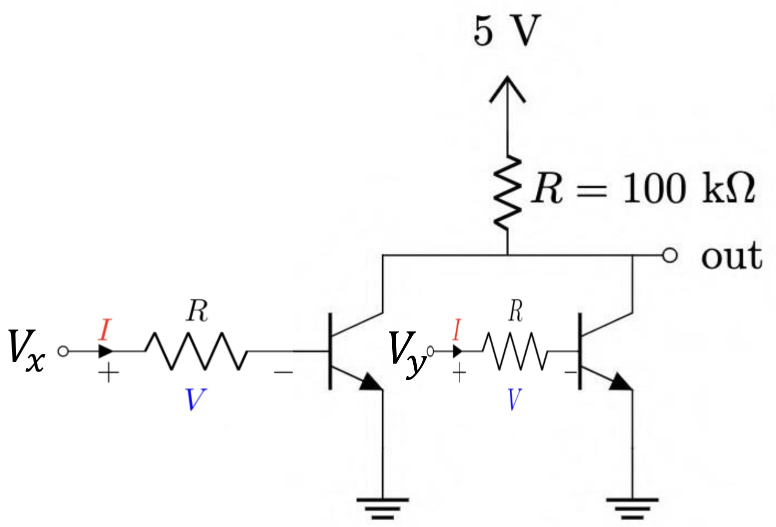
- Just replace switches with BJTs! **– and add a Resistor to the Base terminal**
- ~~Major problem: Cannot cascade! (Why?)~~ Can be cascaded.
  - Input Logic Variable: ~~**Current**~~ **Voltage**
  - Output Logic Variable: **Voltage**



BJT Inverter (NOT Gate)



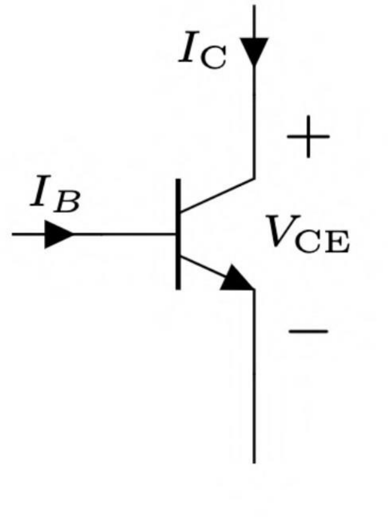
BJT NAND Gate

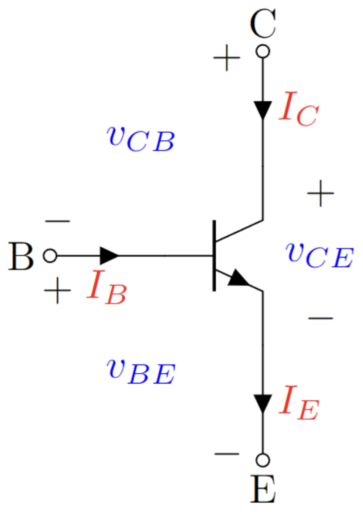


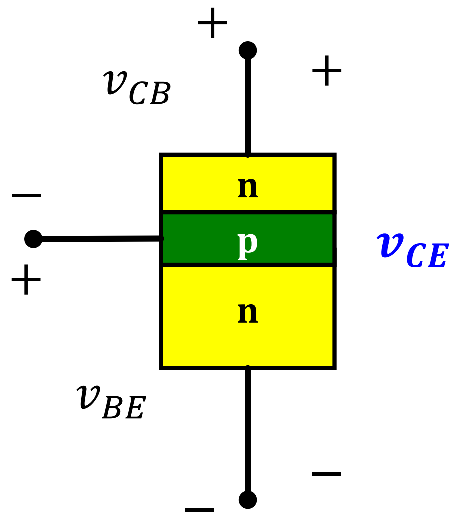
BJT NOR Gate

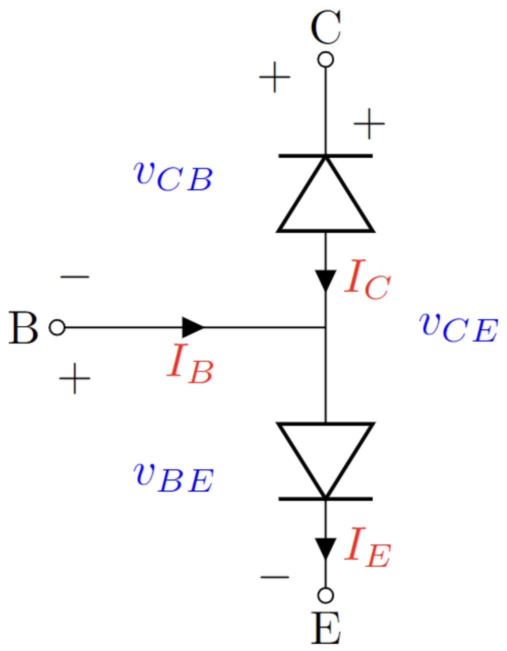
Parameters of BJT

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





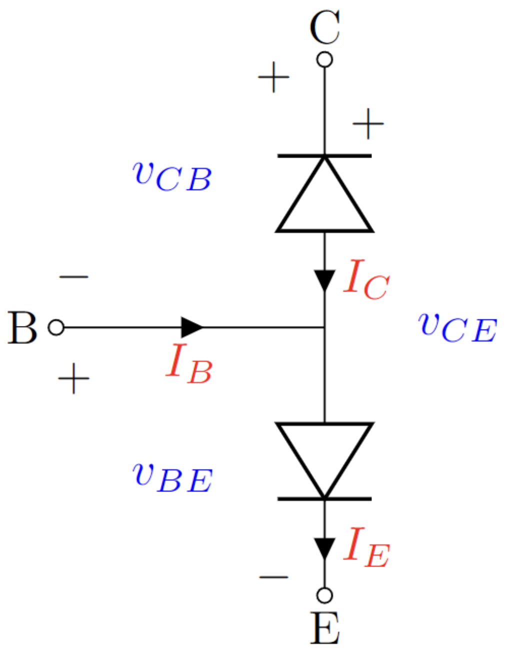




1st pn junction: Across **Base – Emitter**: Voltage $\boldsymbol{v_{BE}}$
2nd pn junction: Across **Base - Collector**: Voltage $\boldsymbol{v_{BC}}$

Parameters of BJT

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



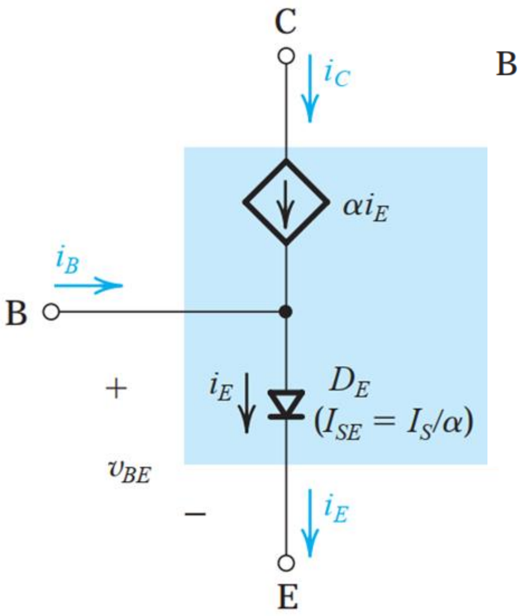
Modes	BE Junction	v_{BE}	CB Junction	v_{CB}	v_{CE}
Cut-off	Reverse Bias	$v_{BE} < 0.7$ V	Reverse Bias	$v_{BC} < 0.6$ V	
Active	Forward Bias	$v_{BE} = 0.7$ V	Reverse Bias	$v_{BC} < 0.6$V	$v_{CE} > 0.2$ V
Saturation	Forward Bias	$v_{BE} = 0.8$ V	Forward Bias	$v_{BC} = 0.6$ V	$v_{CE} = 0.2$ V
Reverse Active	Reverse Bias	$v_{BE} < 0.7$ V	Forward Bias	$v_{BC} = 0.6$ V	$v_{CE} < 0.2$ V

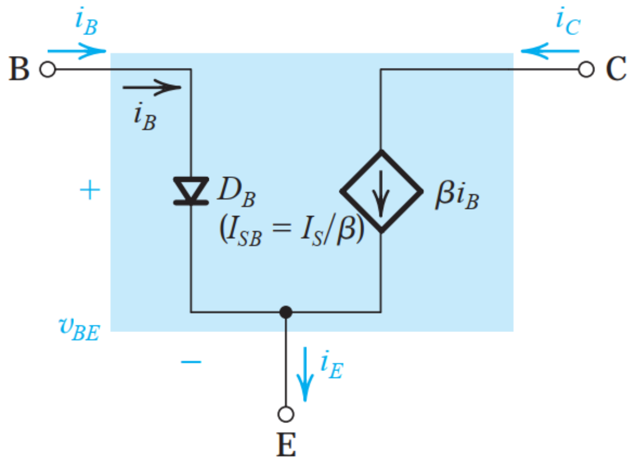
1st pn junction: Across **Base – Emitter**: Voltage $\boldsymbol{v_{BE}}$
2nd pn junction: Across **Collector - Base**: Voltage $\boldsymbol{v_{CB}}$

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

Parameters of BJT: **Active Mode**

Equivalent circuit of an npn-BJT in **Active Mode**





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

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

Only valid for active mode

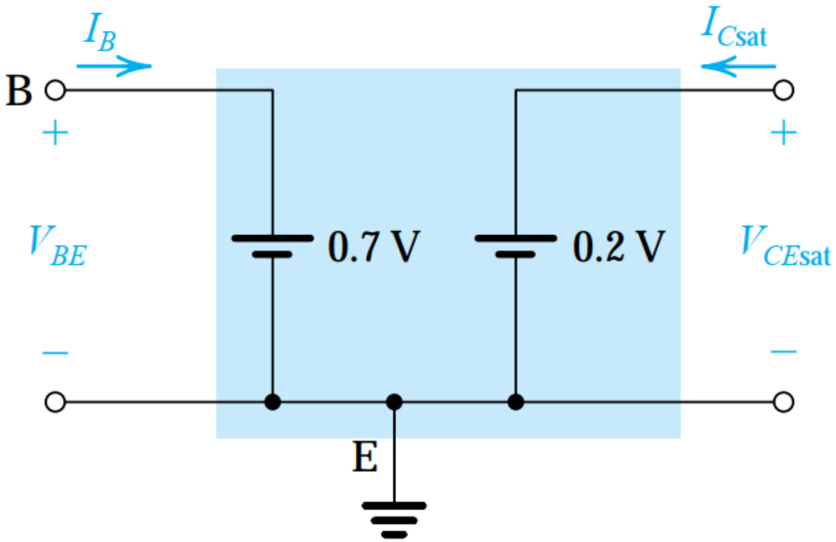
$$\alpha = \frac{\beta}{1+\beta}$$

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

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

Parameters of BJT: **Saturation Mode**

Equivalent circuit of an npn-BJT in **Saturation Mode**



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

$$I_{C(sat)} < \beta I_B$$

$$I_C \neq \alpha I_E$$

Only valid for **Saturation** mode

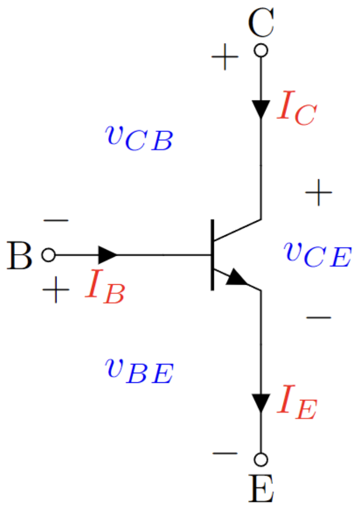
Figure 6.20 A simplified equivalent-circuit model of the saturated transistor.

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

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

Parameters of BJT

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

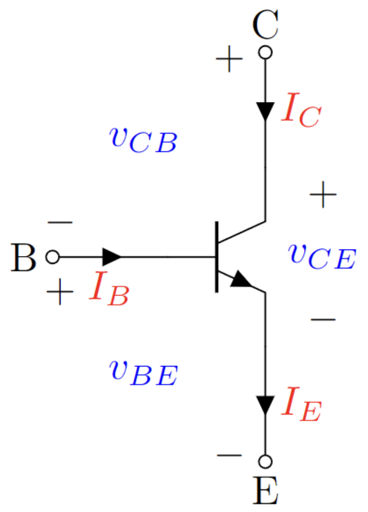


Modes	**Conditions!**
Cut-off	$v_{BE} < 0.7\ V$ and $v_{BC} < 0.6\ V$
Active	$v_{BE} = 0.7\ V$ and $v_{CE} > 0.2\ V$
Saturation	$v_{BE} = 0.8\ V$ and $v_{CE} = 0.2\ V$ and $\frac{I_C}{I_B} < \beta$
Reverse Active	$v_{BC} = 0.6\ V$ and $v_{EC} > 0.2\ V$

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

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

Parameters of BJT



Modes	Conditions	Equations
Cut-off	$V_{BE} < 0.7$ V , $V_{BC} < 0.6$ V	$I_C = I_B = I_E = 0$
Active	$V_{CE} > 0.2$ V	$V_{BE} = 0.7$ V $I_C = \beta I_B$ $I_E = (1+\beta) I_B$ $I_C = \alpha I_E$
Saturation	$\frac{I_C}{I_B} < \beta$	$V_{BE} = 0.8$ V $V_{CE} = 0.2$V

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

Solving Circuits with **BJT**

- Use **Method of Assumed State**!
- Three steps:
  - **Assume**: One of the modes

    (Cutoff, Saturation, Active)
  - **Solve**: Use corresponding equation and KCL + KVL with currents
  - **Verify**: Check if the conditions of $\boldsymbol{v_{BE}}$ and $\boldsymbol{v_{CE}}$ 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

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.

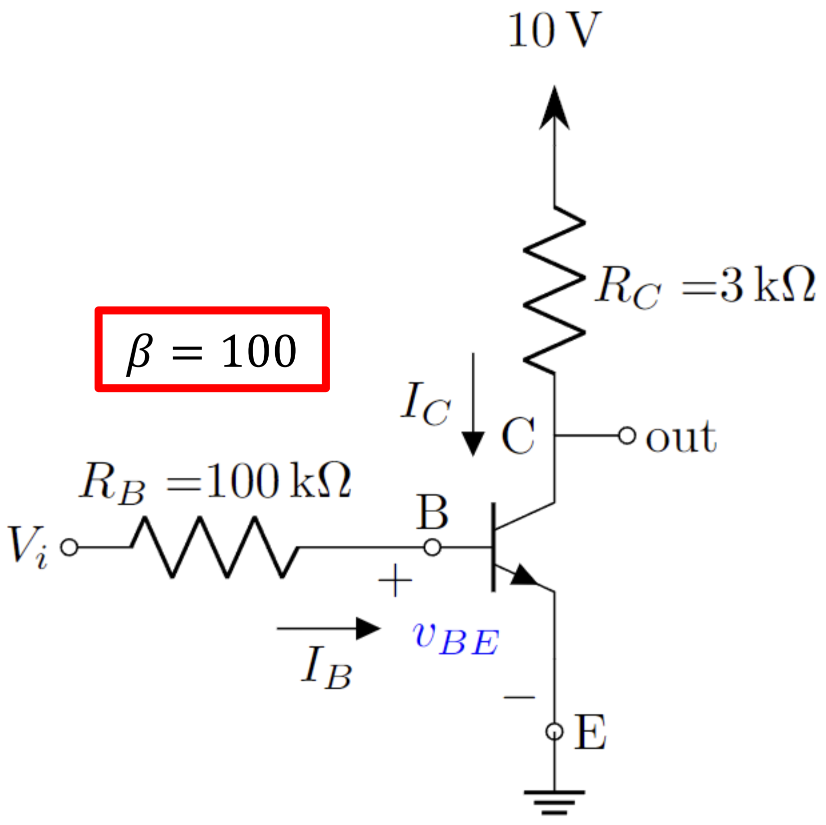
Assume:

Let the BJT be in **ACTIVE** mode

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

$v_{CE} > 0.2$ V

$\boxed{\beta = 100}$



Solve:

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

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

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

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

Here, $v_{CE} = v_{out} = 9.1$ V > 0.2 V

Assumption is Correct!

BJT Problem 2

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

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

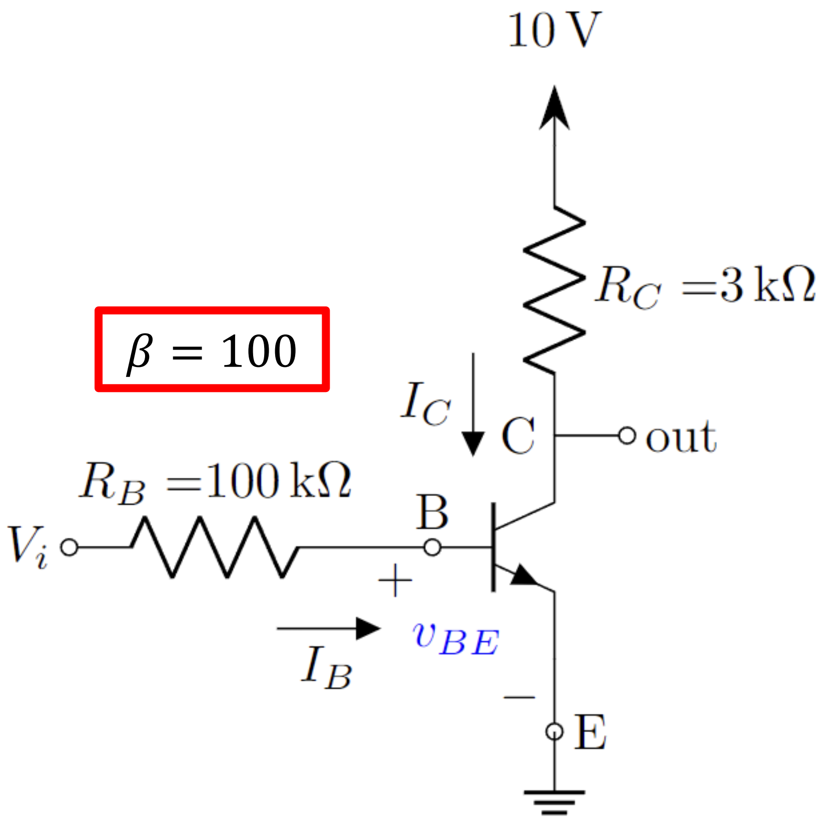
$\boldsymbol{v_{out}} = 10 - I_C R_C = (10 - 4.3 \times 3\,)$ V $= \mathbf{-2.9\ V}$

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

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

Assumption is Wrong!

$\boxed{\beta = 100}$



BJT Problem 2

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 $\boldsymbol{V_i = 5\ V}$. You must validate your assumptions.

Assume:

Let the BJT be in **Saturation** mode

So, $v_{BE} = 0.8\ V$ and $\boldsymbol{\frac{I_C}{I_B} < \beta}$

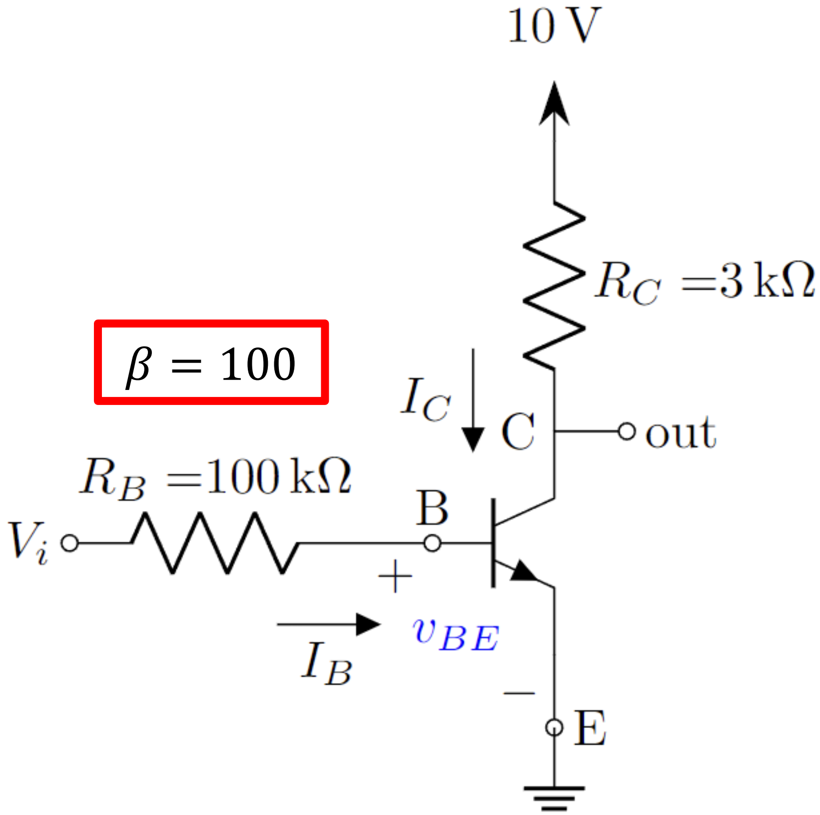
$v_{CE} = 0.2$ V

Solve:

Equations: $\boldsymbol{I_B} = \frac{V_i - v_{BE}}{R_B} = \frac{5-0.8}{100}$ mA $= \mathbf{43\ \mu A}$

$$\boldsymbol{I_C} = \cancel{\beta I_B}\ \frac{10-v_C}{R_C} = \frac{10-0.2}{3}\text{mA} = \mathbf{3.27\ mA}$$

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



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

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

Assumption is Correct!

BJT Problem 3

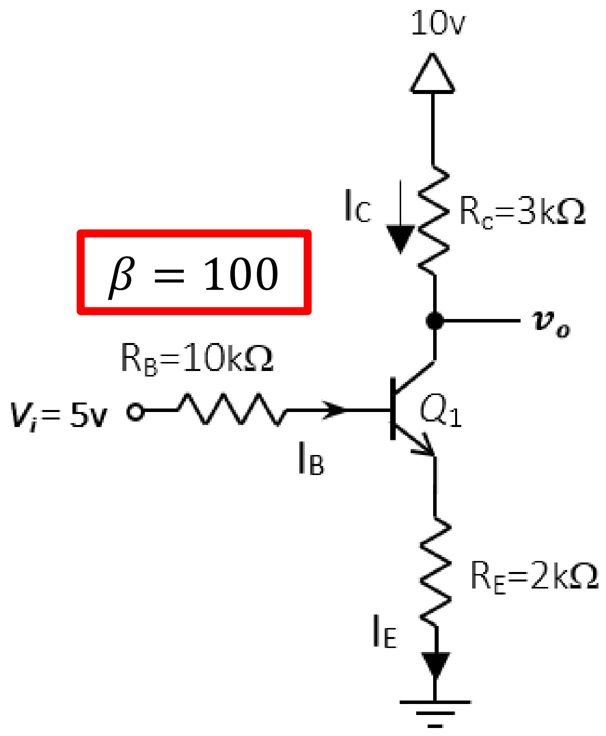
Analyze the circuit to find $\boldsymbol{I_B}, \boldsymbol{I_C}, \boldsymbol{I_E}$ and $\boldsymbol{v_o}$ using the Method of Assumed State. You must validate your assumptions.

Assume:

Let the BJT be in **ACTIVE** mode

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

$v_{CE} > 0.2\ \mathrm{V}$



Solve:

Equations: $V_i = I_B R_B + V_{BE} + I_E R_E = I_B R_B + V_{BE} + (1+\beta) I_B R_E$

$$I_B = \frac{V_i - V_{BE}}{R_B + (1+\beta) R_E} = \frac{5-0.7}{10+(1+100)2} = 0.0203\ mA$$

$$I_C = \beta I_B = 2.03\ \mathrm{mA}$$

$$I_E = I_B + I_C = 2.05\ \mathrm{mA}$$

$$\mathbf{10} = I_c R_c + V_{CE} + I_E R_E$$

$$V_{CE} = \textit{-1.9}$$

Verify: For **ACTIVE** condition → $\boldsymbol{V_{CE} > 0.2\ \mathrm{V}}$

Here V_{CE} < 0.2 V **Assumption is Wrong!**

BJT Problem 3

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

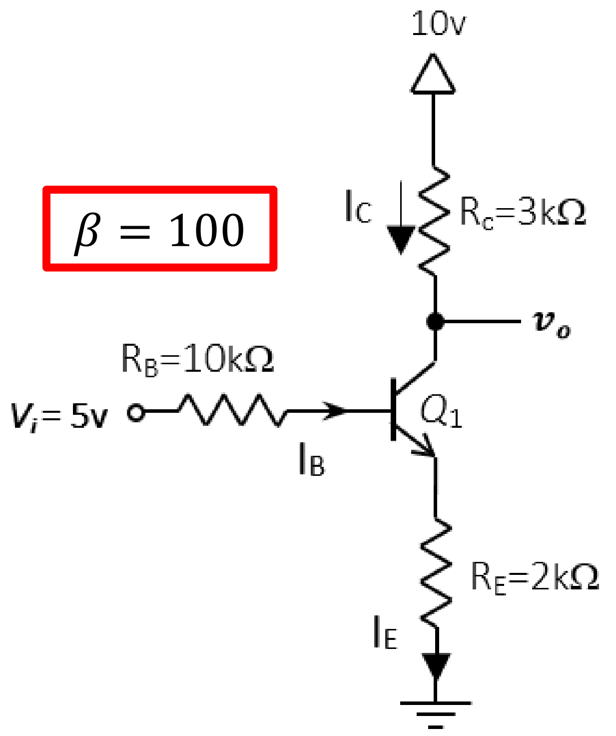
Assume:

Let the BJT be in **Saturation** mode

So, $v_{BE} = 0.8\,V$ and $\frac{\boldsymbol{I_C}}{\boldsymbol{I_B}} < \boldsymbol{\beta}$

$v_{CE} = 0.2$ V

$\beta = 100$



Solve:

Equations:

$5 = 10I_B + 0.8 + 2I_E$

$\boldsymbol{10I_B + 0.I_C + 2I_E = 4.2} \quad \ldots\ldots\ldots\ldots (\boldsymbol{a})$

$10 = 3I_C + 0.2 + 2I_E$

$\boldsymbol{0.I_B + 3I_C + 2I_E = 9.8} \quad \ldots\ldots\ldots\ldots (\boldsymbol{b})$

$\boldsymbol{I_B + I_C - I_E = 0} \quad \ldots\ldots\ldots\ldots (\boldsymbol{c})$

Solving (a),(b) & (c) $\boldsymbol{I_B}$ **= 0.025mA** $\boldsymbol{I_C}$**= 1.95mA** $\boldsymbol{I_E}$**= 1.975mA**

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

$$\frac{\boldsymbol{I_C}}{\boldsymbol{I_B}} = \frac{\mathbf{1.95}}{\mathbf{0.025}} = \mathbf{78 < 100}$$

$v_O = 10 - I_c R_c$ **= 4.15V**

Assumption is Correct!

BJT Problem 4

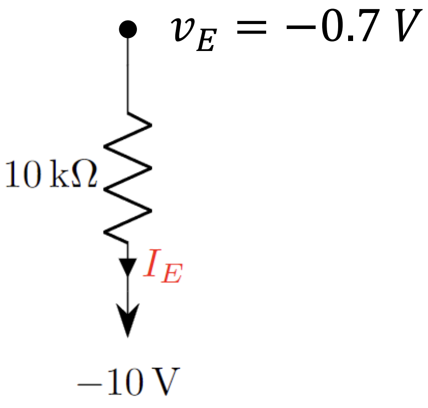
Analyze the circuit to find $\boldsymbol{I_B, I_C, I_E}$ and $\boldsymbol{v_{out}}$ using the Method of Assumed State. You must validate your assumptions.

Assume:

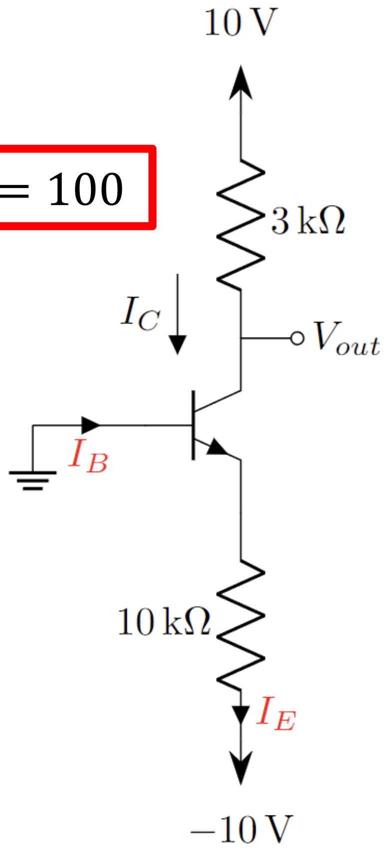
Let the BJT be in **Active** mode

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

$v_{CE} > 0.2\ \mathrm{V}$



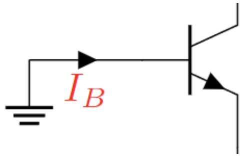
$\boxed{\beta = 100}$

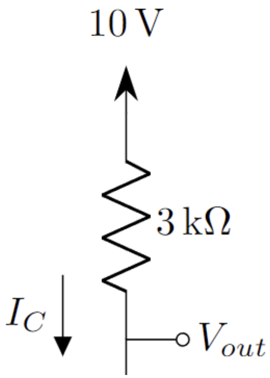


Solve:

Equations:

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





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

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

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

$$\boldsymbol{= 7.237\ V}$$

BJT Problem 4

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.

Assume:

Let the BJT be in **Active** mode

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

$v_{CE} > 0.2$ V

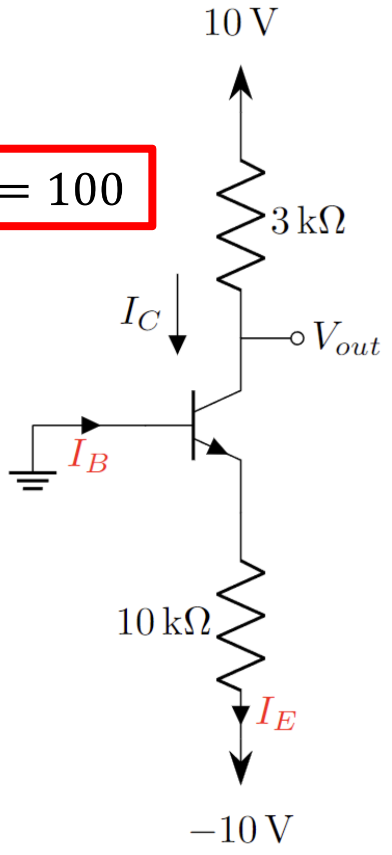
Solve:

Equations: $\boldsymbol{I_E = 0.93\ \text{mA}}$

$\boldsymbol{I_B = 9.21\ \mu\text{A}}$

$\boldsymbol{v_{out} = v_C = 7.237\ \text{V}}$ $\boldsymbol{v_B = 0\ \text{V}}$ $\boldsymbol{v_E = -0.7\ \text{V}}$

$\boxed{\beta = 100}$



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

Here, $v_{CE} = (7.237 + 0.7)\ \textbf{V} = \boldsymbol{7.937\ \text{V}} > 0.2$ V

Assumption is Correct!

BJT Problem 5

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

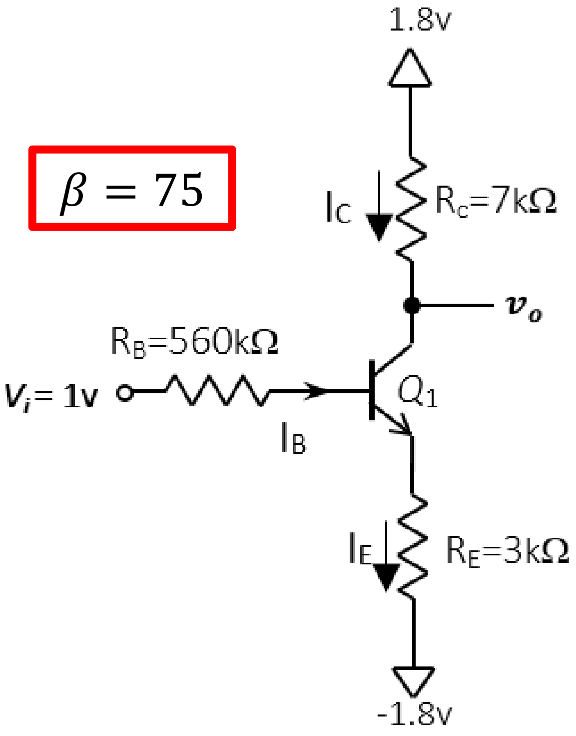
Assume:

Let the BJT be in **Active** mode

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

$v_{CE} > 0.2\ \mathrm{V}$

$\boxed{\beta = 75}$



Solve:

Equations:

$$V_i = I_B R_B + V_{BE} + I_E R_E - 1.8 = I_B R_B + V_{BE} + (1+\beta) I_B R_E - 1.8$$

$$I_B = \frac{V_i - V_{BE} + 1.8}{R_B + (1+\beta)R_E} = \frac{1-0.7+1.8}{560+(1+75)3} = 2.66\mu A$$

$$I_C = \beta I_B = 0.2\ \mathrm{mA}$$

$$I_E = I_B + I_C = 0.203\ \mathrm{mA}$$

$$\mathbf{1.8} = I_c R_c + V_{CE} + I_E R_E - 1.8$$

$$V_{CE} = \boldsymbol{1.59}$$

Verify: For **ACTIVE** condition → $\boldsymbol{V_{CE} > 0.2}$ **V**

Here V_{CE} **> 0.2 V**

Assumption is Correct!

BJT Problem 6

Analyze the circuit to determine the voltages at all nodes and current through all branches. Assume $\beta = 100$

Assume:

Let the BJT be in **Active** mode

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

$v_{CE} > 0.2\ \mathrm{V}$

Solve:

Equations:

$15 = 100I + 0.7 + 3I_E$

$15 = 100I + 50I_1$

$I = \boldsymbol{I_B} + I_1$

$I_E = (1 + \beta)I_B$

$\mathbf{100}\boldsymbol{I_1} + \mathbf{403}\boldsymbol{I_B} = \mathbf{14.3} \ldots\ldots\ldots\ldots\ldots (\boldsymbol{a})$

$\mathbf{150}\boldsymbol{I_1} + \mathbf{100}\boldsymbol{I_B} = \mathbf{15} \ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{b})$

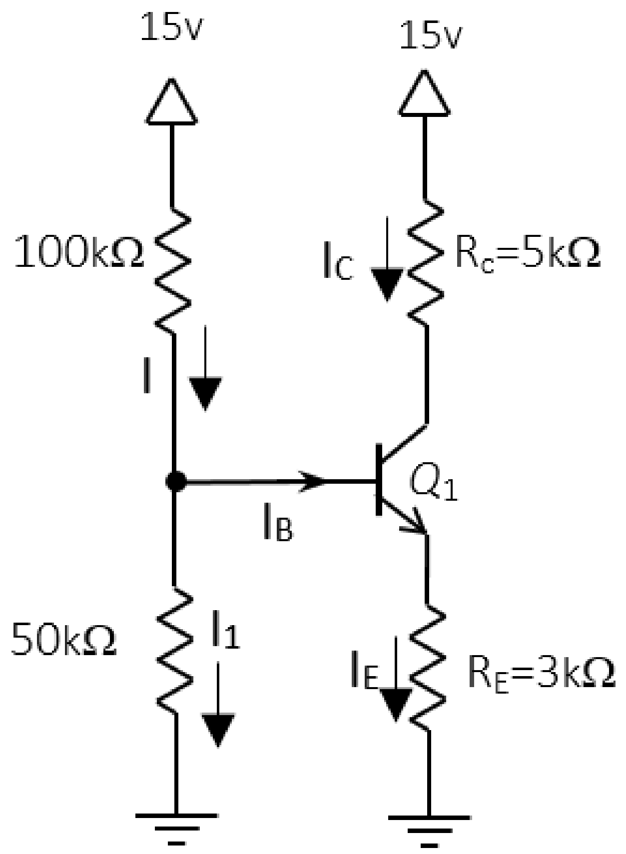
Solving (a) and (b)

$\boldsymbol{I_B} = \mathbf{0.013}\ \boldsymbol{mA}$

$\boldsymbol{I_c} = \boldsymbol{\beta I_B} = \mathbf{1.3}\ \boldsymbol{mA}\ , \boldsymbol{I_E} = \mathbf{1.313}\boldsymbol{mA}$

$\mathbf{15} = I_c R_c + V_{CE} + I_E R_E$

$V_{CE} = \boldsymbol{4.561}$



BJT Problem 6

Analyze the circuit to determine the voltages at all nodes and current through all branches. Assume $\beta = 100$

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

Here, $v_{CE} = \mathbf{4.561}\ \mathrm{V} > 0.2\ \mathrm{V}$

Assumption is Correct!

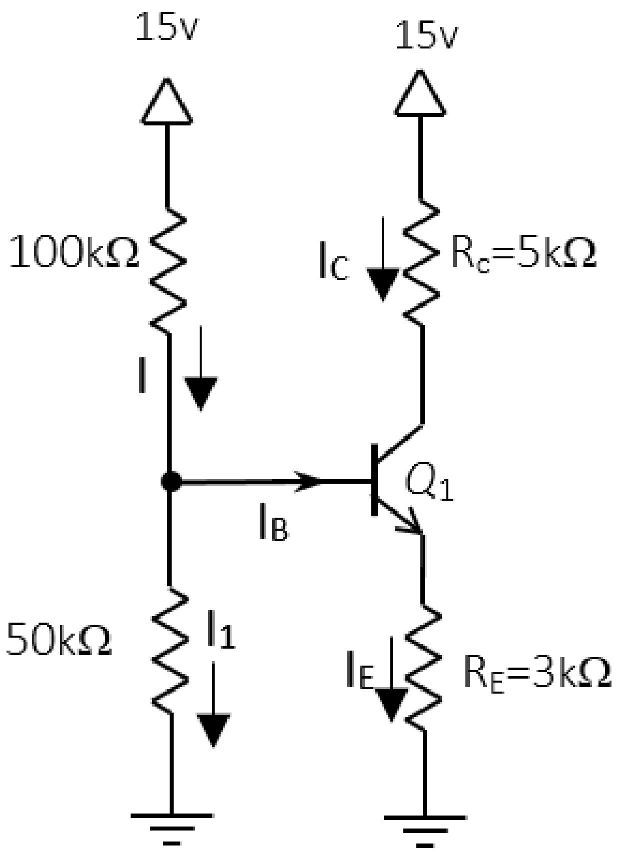
$\boldsymbol{v_B} = 0.7 + 3I_E$ **= 4.639v**

$$I_C = \frac{15 - \boldsymbol{v_c}}{5}$$

$\boldsymbol{v_c}$**= 8.5v**

$$I_E = \frac{\boldsymbol{v_E - 0}}{3}$$

$\boldsymbol{v_E}$**= 3.94v**

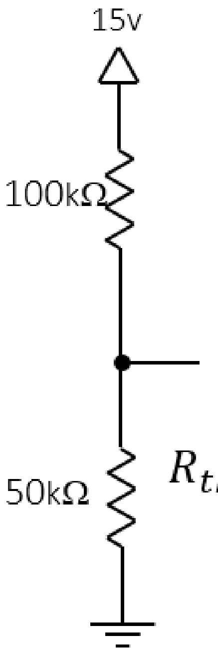


BJT Problem 6

Analyze the circuit to determine the voltages at all nodes and current through all branches. Assume $\beta = 100$

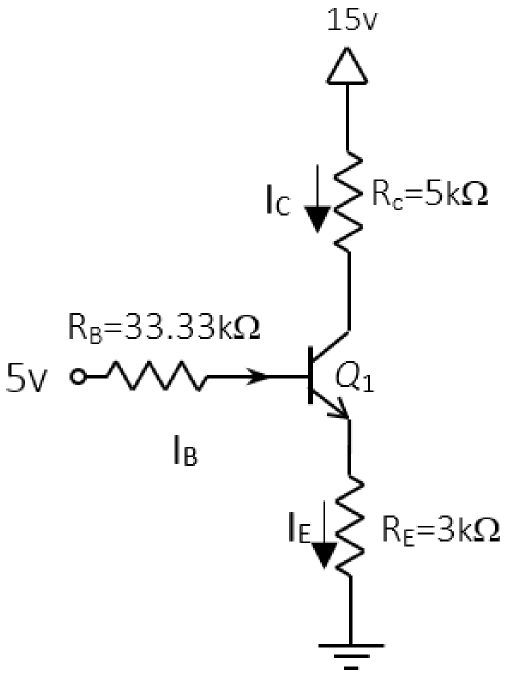
Alternative Method

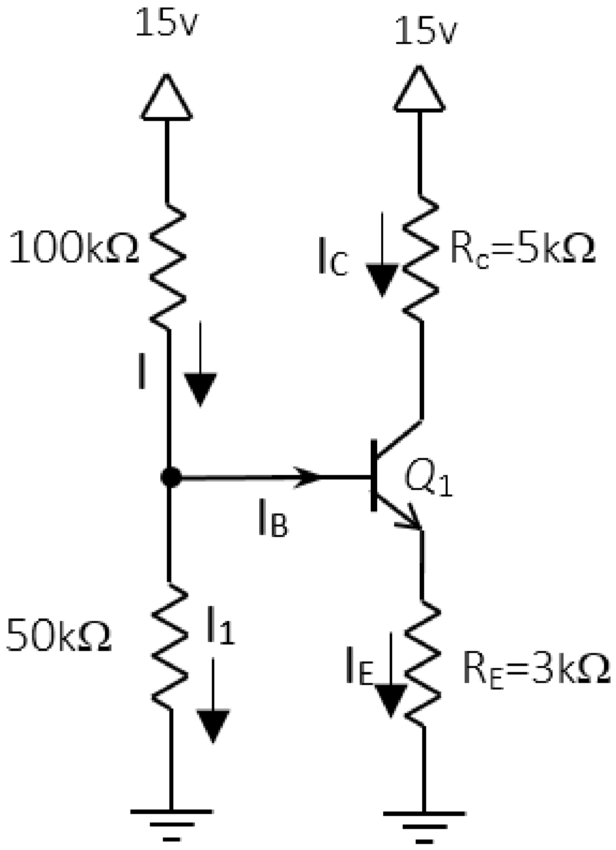
Simplifying the base circuit using **Thevenin's Theorem**



$$V_{th} = 5v$$

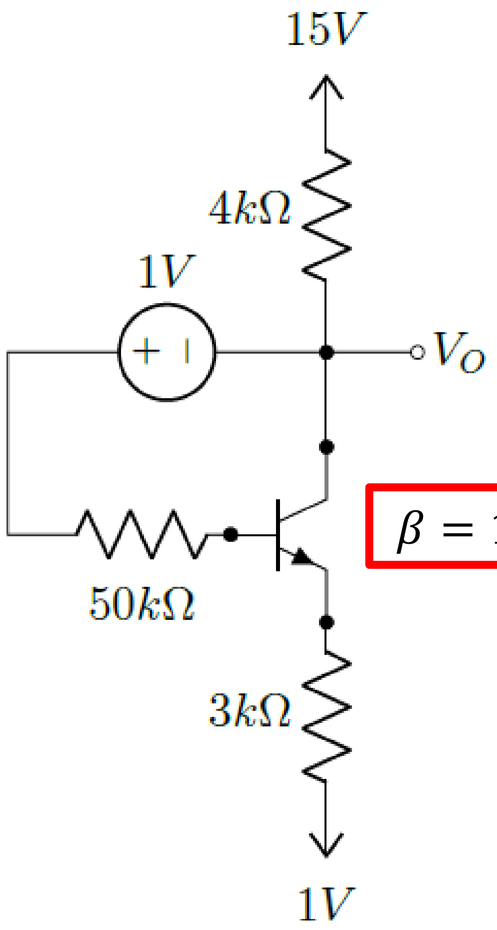
$$R_{th} = 100||50 = 33.33\text{k}$$





BJT Problem 7

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



$\beta = 100$