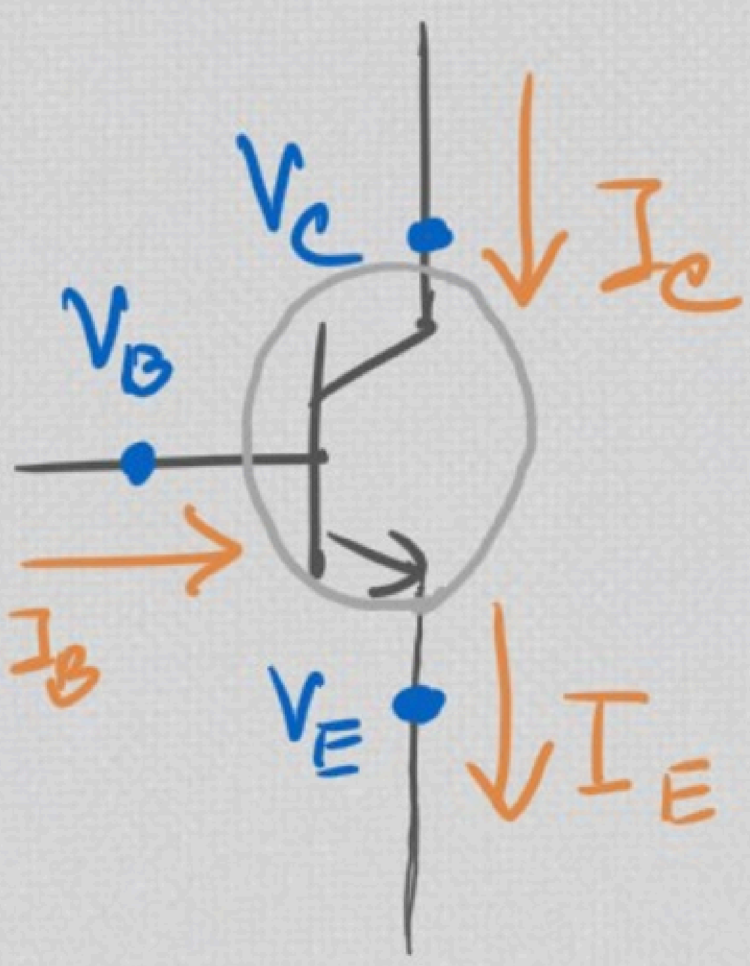
# BJT in DC




KCL at supernode BCE $\Rightarrow$

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

$\hookrightarrow$ True for any mode.

In ACTIVE, $\boxed{I_C = \beta I_B}$ $\rightarrow$ ONLY in ACTIVE

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

$$\therefore \boxed{I_C = \frac{\beta}{1+\beta} I_E} \rightarrow \text{ONLY in ACTIVE}$$

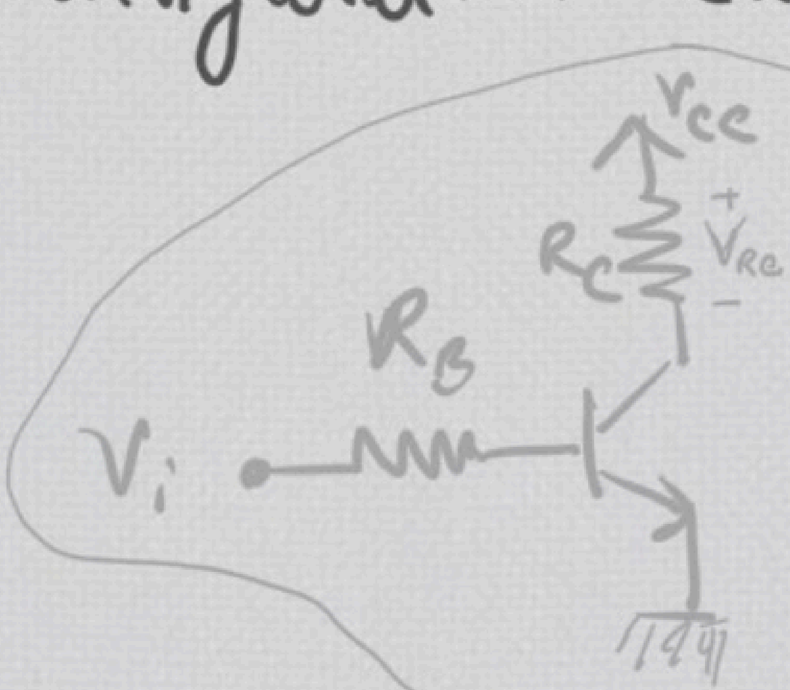
We define $\frac{\beta}{1+\beta}$ as $\alpha$

So, $\boxed{I_C = \alpha I_E}$

The typical value for $\beta = 100$. So, $\alpha \simeq 0.99$. So, we can say, during ACTIVE region, $I_C \approx I_E$.

In SATURATION, $V_{CE} = V_{CE(sat)} = 0.2V$. This is the lowest possible value of $V_{CE}$. This implies that the voltage $V_{RC}$ in the CE configuration can be, at max, $V_{CC} - 0.2V$.

$\hookrightarrow$ That is, 0.2V less than supply




Common Emitter (CE) configuration.

# How to solve circuits with BJT?

$\Rightarrow$ Our old friend, Method of assumed state!

**3 steps**

① **Assume** a state. there are 3 possible states: ACTIVE, SATURATION, CUTOFF

② **Solve** the ckt and find $I_C$, $I_B$, $V_{CE}$, $V_{BE}$

③ **Verify** your assumption. If wrong, repeat ①, ②, ③

For BJT

① If assume in ACTIVE mode

$\boxed{V_{BE} = 0.7,\ I_C = \beta I_B}$ $\Rightarrow$ Eqn true for ACTIVE

You must show $V_{CE} > 0.2$

② If assume in SATURATION

$\boxed{V_{BE} = 0.8,\ V_{CE} = 0.2}$ $\Rightarrow$ Eqn true for SAT.

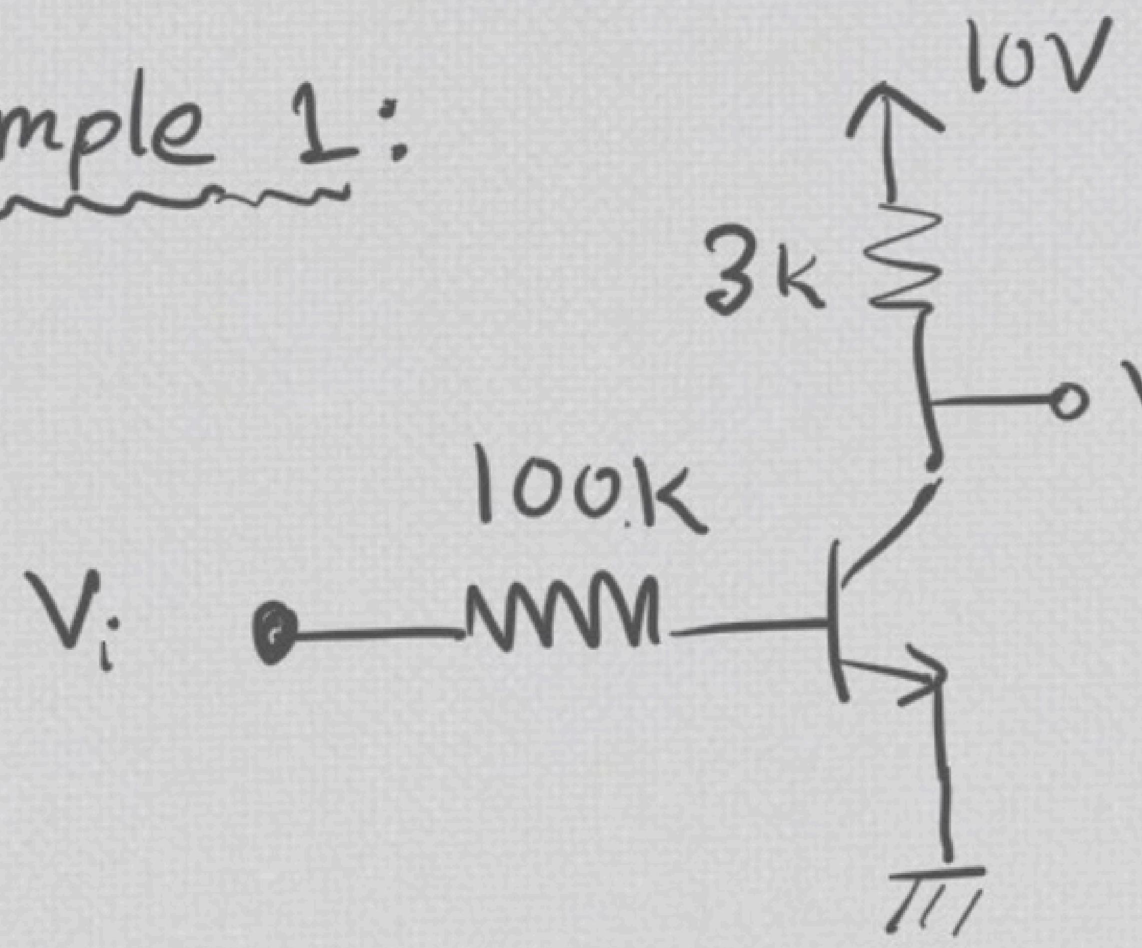
You must show $I_C < \beta I_B$, that is $\frac{I_C}{I_B} < \beta$

③ If assume in CUTOFF, $\boxed{I_C = I_B = I_E = 0.}$ $\Rightarrow$ Eqn true for CUTOFF

You must show $V_{BE} \leq 0.7V$ and $V_{CE} > 0.2$

*must show $\Rightarrow$ condition

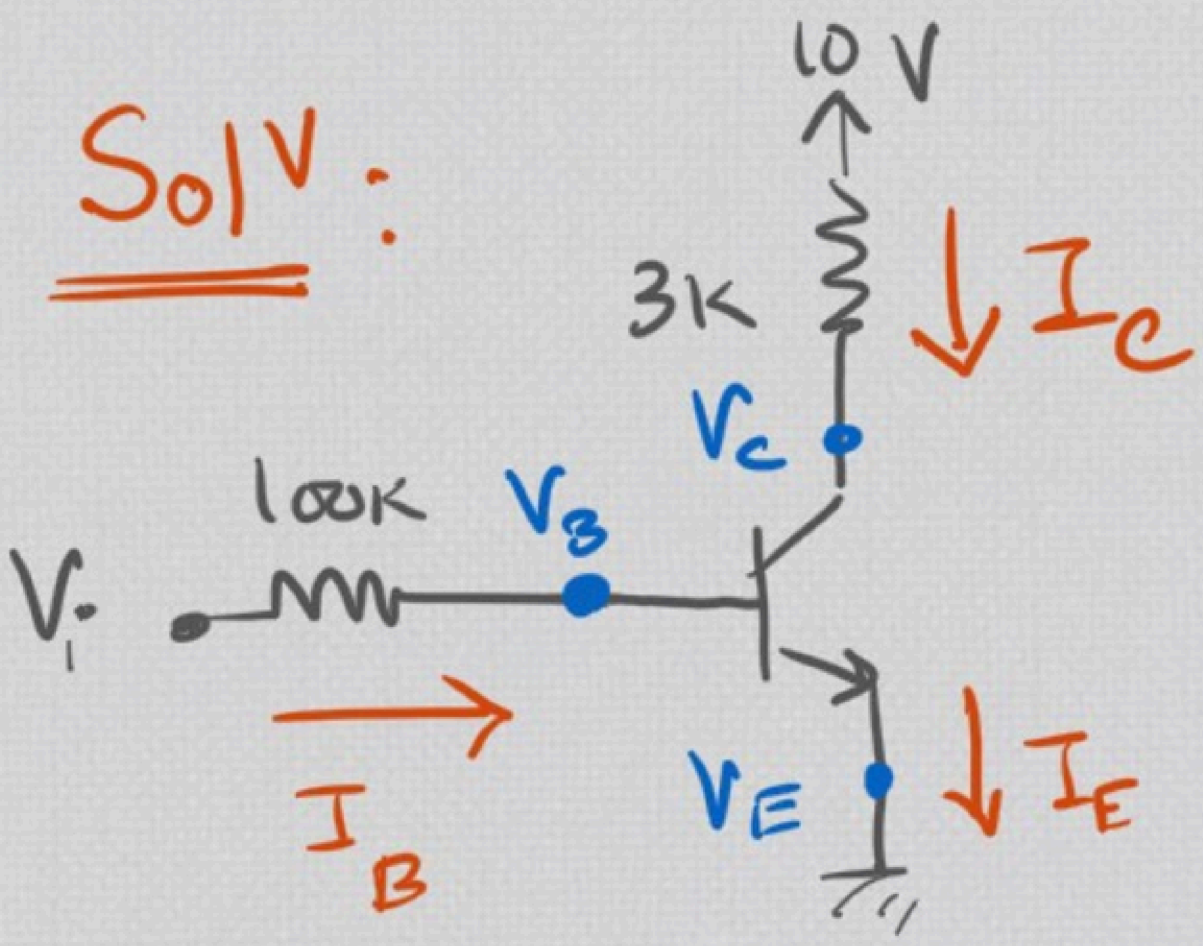
Example 1:




$\underline{\beta = 100}$

Find $V_o$ for (i) $V_i = 1V$ (ii) $V_i = 5V$

**Solⁿ:**




$$\boxed{V_o = V_C}$$

Since $V_i > 0.7V$ in both (a) and (b), it will be either in ACTIVE or SATURATION

BE = ON $\Rightarrow V_{BE} = 0.7V$

since $V_E = 0V \Rightarrow \therefore V_B - V_E = 0.7 =$

$\Rightarrow V_B = 0.7V$

(a) Assume BJT in ACTIVE

$$\therefore I_B = \frac{V_i - V_B}{R_B} = \frac{1-0.7}{100} = 0.003\,mA$$
$$= 3\,\mu A$$

Since active, $I_C = \beta I_B = 100 \times 0.003 = 0.3\,mA$

from the circuit,

$$I_C = \frac{10 - V_C}{R_C}$$

$$\Rightarrow V_C = 10 - R_C I_C = 10 - 3 \times 0.3$$

$$\Rightarrow \boxed{V_o = V_C = 9.1V}$$

VERIFICATION: Since we assumed ACTIVE, we need to check if $V_{CE} > 0.2V$

Since $V_E = 0 \Rightarrow V_{CE} = V_C - V_E = 9.1V. \Rightarrow$ Assumption Correct

(yay!)

(b) Assume BJT in ACTIVE

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

$$\Rightarrow I_C = \beta I_B = 4.3mA$$

$$\Rightarrow V_o = V_C = 10 - I_C R_C = 10 - 3 \times 4.3 = -2.9V$$

VERIFICATION: $V_{CE} = -2.9V \therefore V_{CE} < 0.2V$

$\Rightarrow$ Assumption WRONG! :(

Now assume in SATURATION

$\therefore V_{CE} = 0.2V$

since $V_E = 0V$ and $V_{CE} = V_C - V_E$

$\therefore V_C = V_o = 0.2V.$

Because SAT $\Rightarrow V_{BE} = 0.8V$

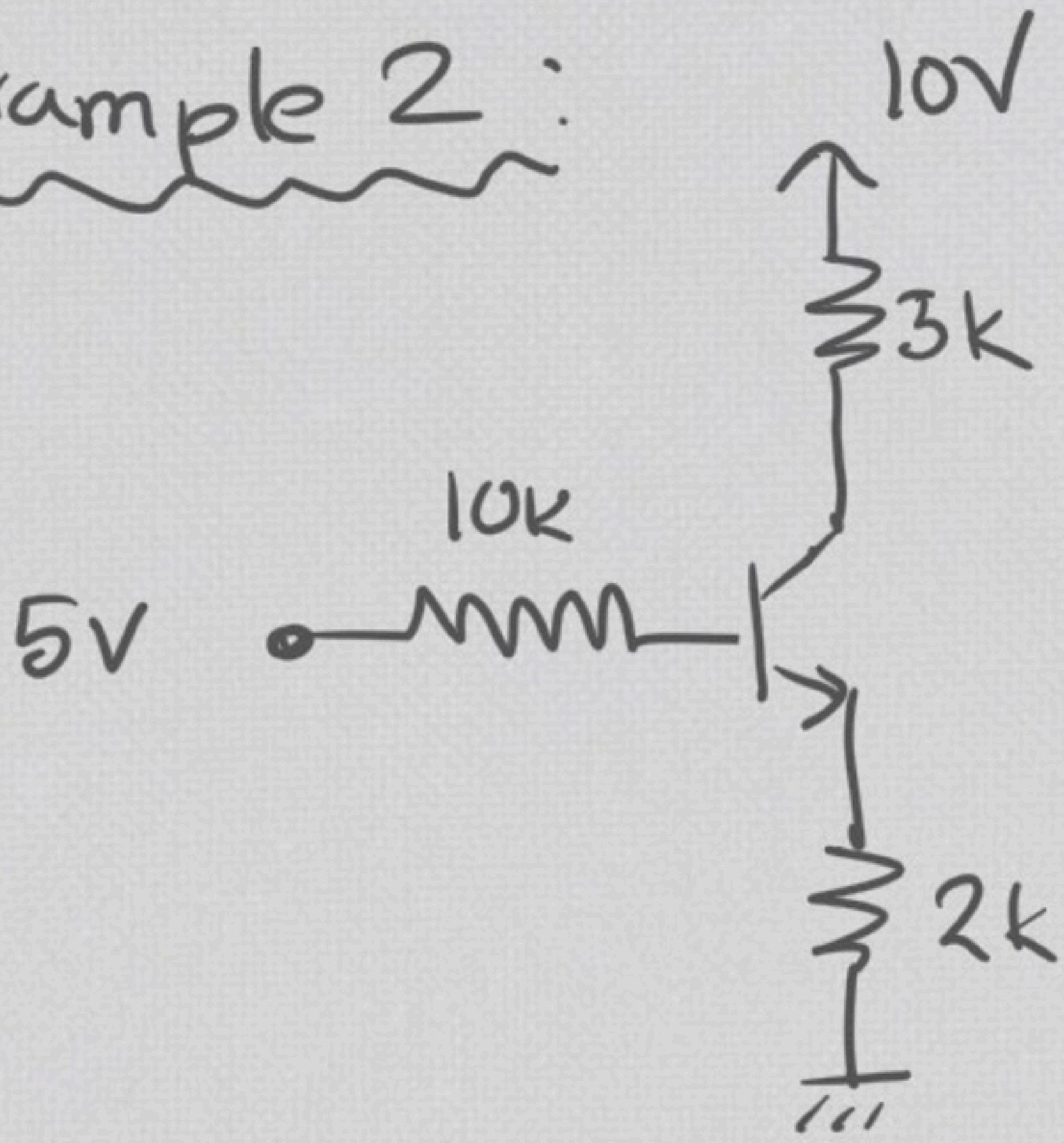
$$I_B = \frac{V_i - V_B}{R_B} = \frac{5-0.8}{100} = 0.043mA$$

$$I_C = \frac{10 - V_C}{R_C} = \frac{10-0.2}{3} = 3.27mA$$

VERIFICATION: Since we've assumed saturation, we need to show $\frac{I_C}{I_B} < \beta$. Now, $\frac{I_C}{I_B} = \frac{3.27}{0.043} = 76$

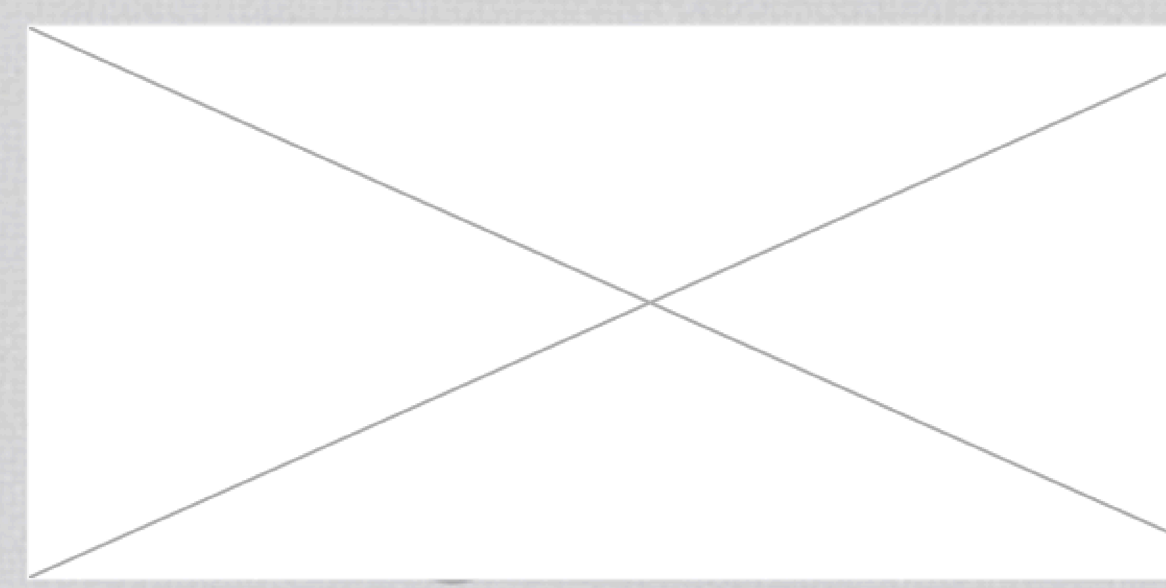
$\therefore \frac{I_C}{I_B} < 100 \Rightarrow$ Assumption correct. :D

## Example 2:




$\beta = 100$

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



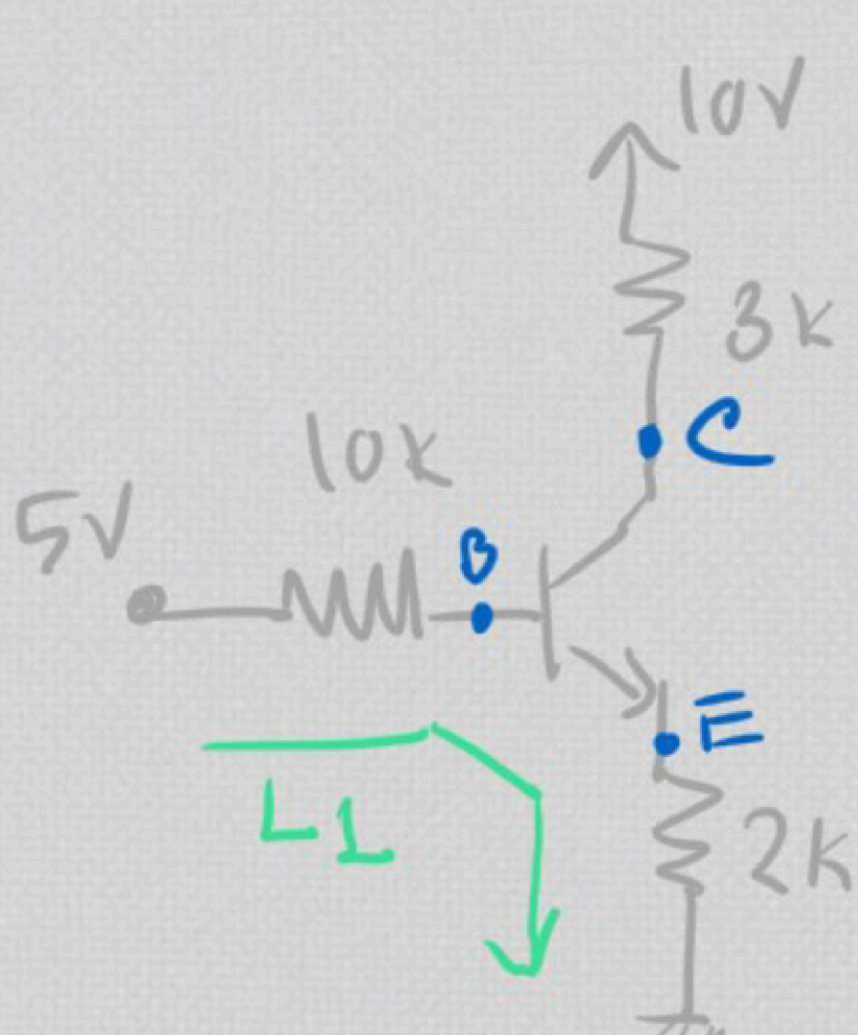
Soln: Assume in ACTIVE

$$\Rightarrow I_C = \alpha I_E \quad \text{— (i)}$$

$$I_C = \beta I_B \quad \text{— (ii)}$$

from (i) and (ii), $\beta I_B = \alpha I_E$

$$\Rightarrow I_E = \frac{\beta}{\alpha} I_B \quad \text{— (iii)}$$




Writing KVL along $L_1$ $\Rightarrow$

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

from (iii)

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

Since assumed ACTIVE, $V_{BE} = 0.7$

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

$\therefore I_C = \beta I_B = 100 \times 0.02 = 2\,mA$

$\therefore \boxed{I_C = 2\,mA}$

$\therefore I_E = I_C + I_B \Rightarrow \boxed{I_E = 2.02\,mA}$

From the ckt, $V_E - 0 = I_E \times 2$

$\Rightarrow V_E = 4.04\,V$

Again, from the ckt, $10 - V_C = I_C \times 3$

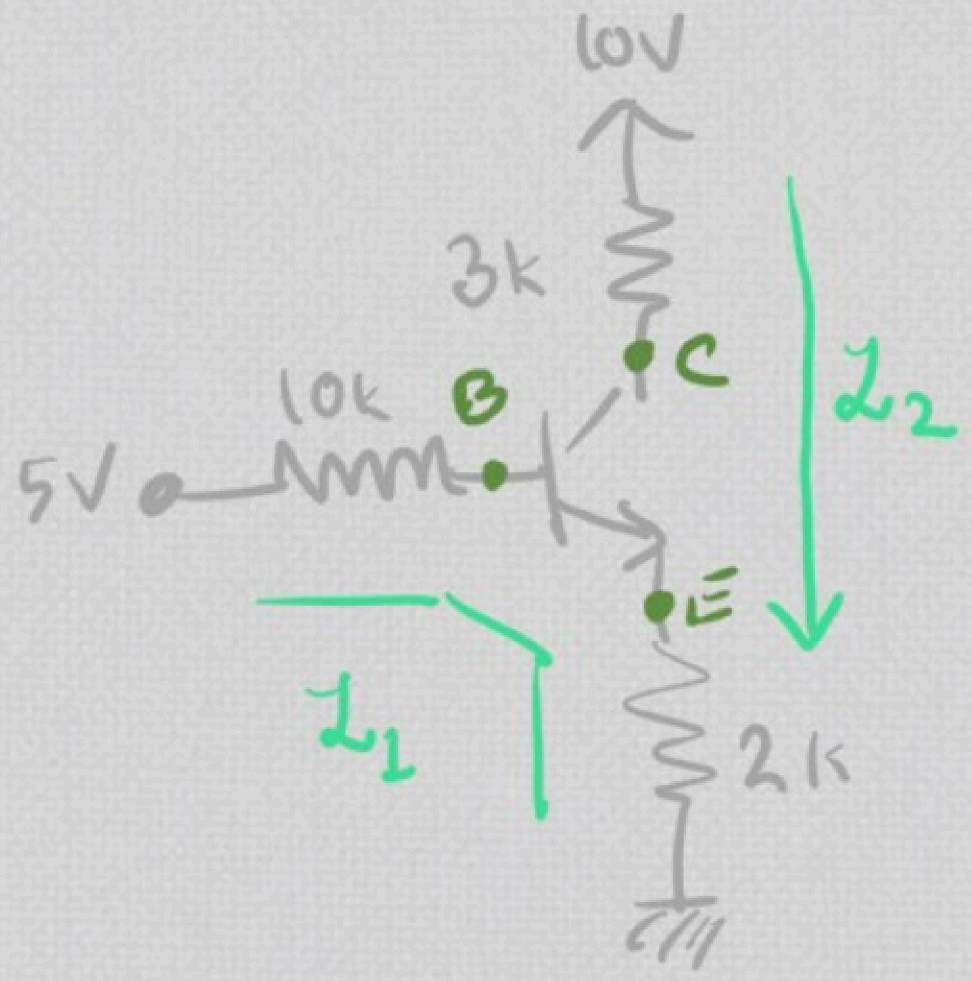
$\Rightarrow V_C = 4\,V$

$\therefore V_{CE} = V_C - V_E$

$\Rightarrow \boxed{V_{CE} = 0.04\,V}$

Assumed ACTIVE, found $V_{CE} < 0.2\,V$. So assumption WRONG!! (-_-)

Assume in SATURATION $\Rightarrow \boxed{\therefore V_{CE} = 0.2\,V}$




KVL along $L_1$

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

$\Rightarrow 5 = 10 I_B + 0.8 + 2 I_E$ —— (i)

KVL along $L_2$

$10 = 3 I_C + V_{CE} + 2 I_E$

$\Rightarrow 10 = 3 I_C + 0.2 + 2 I_E$ —— (ii)

PTO

From KCL $\Rightarrow$

$$I_E = I_C + I_B \quad \text{—— (iii)}$$

Solving (i), (ii) and (iii)

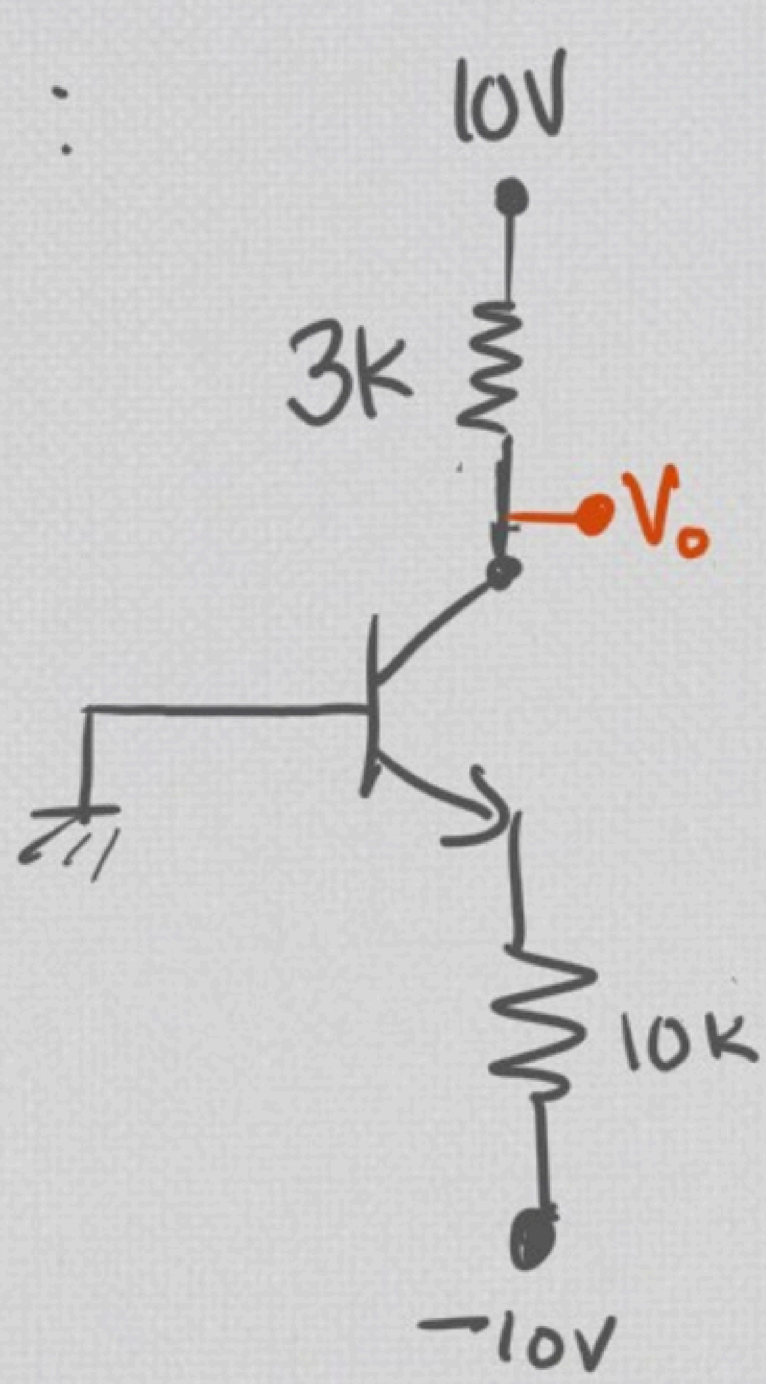
$$I_B = 0.03\ mA$$

$$I_C = 1.95\ mA$$

$$I_E = 1.98\ mA$$

Since $\frac{I_C}{I_B} = \frac{1.95}{0.03} < \beta$, so assumption CORRECT!

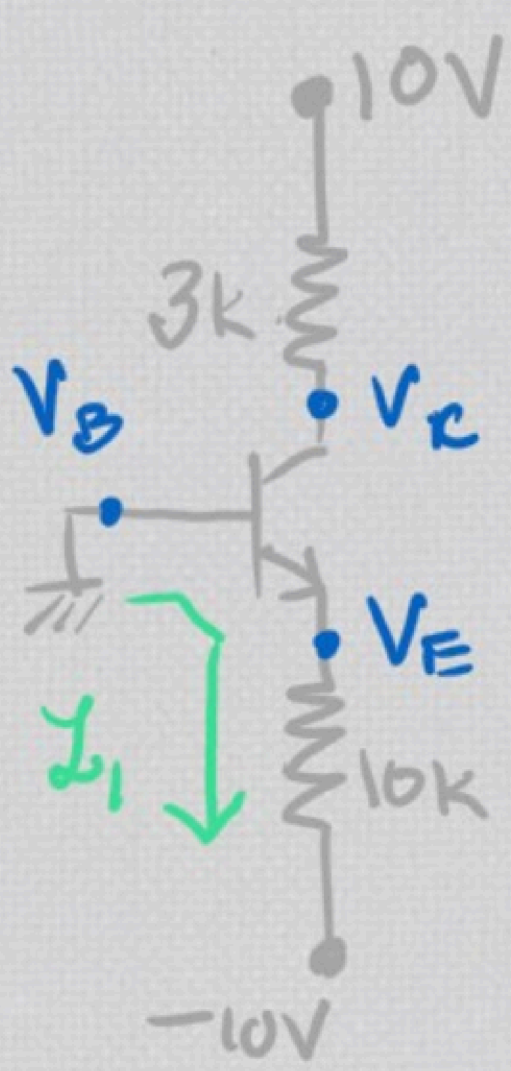
## Example 3:




$\beta = 100$

Find $I_B$, $I_C$, $I_E$ and $V_o$

**Soln:**




Base connected to GND

$\therefore V_B = 0\,V$

Assume BJT ACTIVE

$\therefore V_{BE} = 0.7\,V$

$\Rightarrow V_B - V_E = 0.7\,V$

$\Rightarrow V_E = -0.7\,V$

$\beta = 100$

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

$= 0.99$

KVL along $I_2$: $0 = V_{BE} + 10 I_E + (-10)$

$\Rightarrow 0 = 0.7 + 10 I_E - 10$

$\Rightarrow \underline{I_E = 0.93\,mA}$

$\therefore I_C = \alpha I_E = 0.99 \times 0.93 \Rightarrow \underline{I_C = 0.92\,mA}$

$\therefore I_B = I_E - I_C \Rightarrow \underline{I_B = 0.01\,mA}$

From ckT, $10 - V_C = 3I_C$

$$\Rightarrow \underline{\underline{V_C = 7.24\,V}}$$

Check: $V_{CE} = V_C - V_E = 7.24 - (-0.7)$

$$\Rightarrow V_{CE} = 7.94\,V$$

$\therefore V_{CE} > 0.2 \Rightarrow$ Assumption correct!