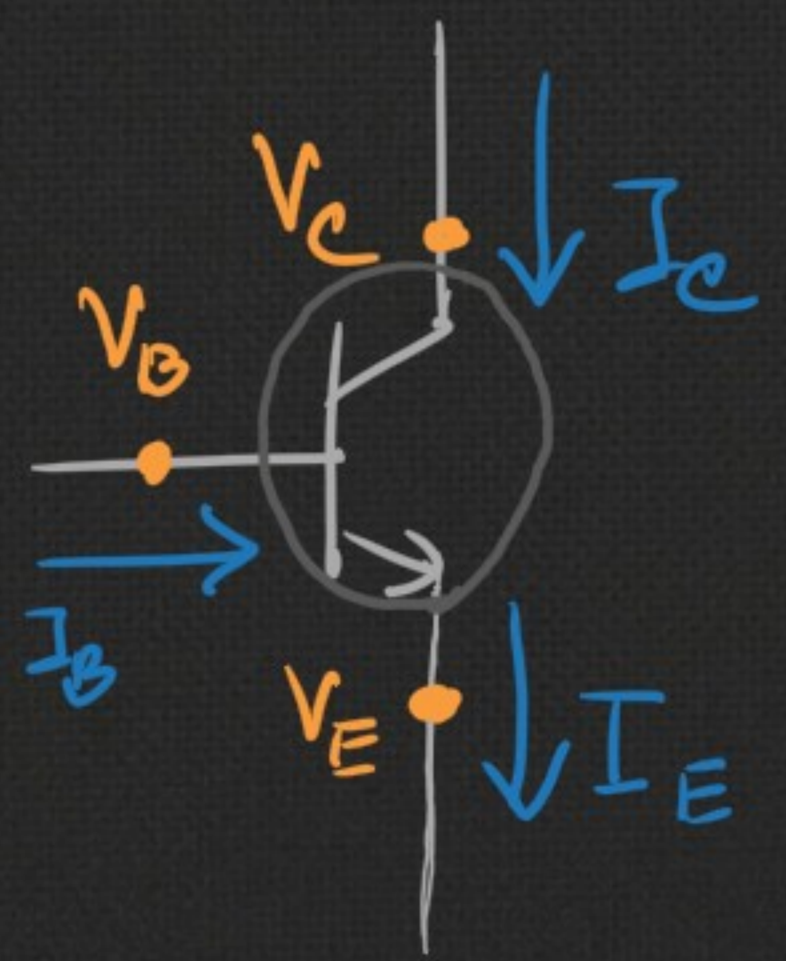
BJT in DC



KCL at supernode BCE ⇒

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

↳ True for any mode.

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

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

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

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

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, $I_C \simeq I_E$.

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, $V_{CC} - 0.2V$.

↳ That is, 0.2V less than supply

How to solve circuits with BJT?

⇒ 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

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

You must show $V_{CE} > 0.2$

② If assume in SATURATION

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

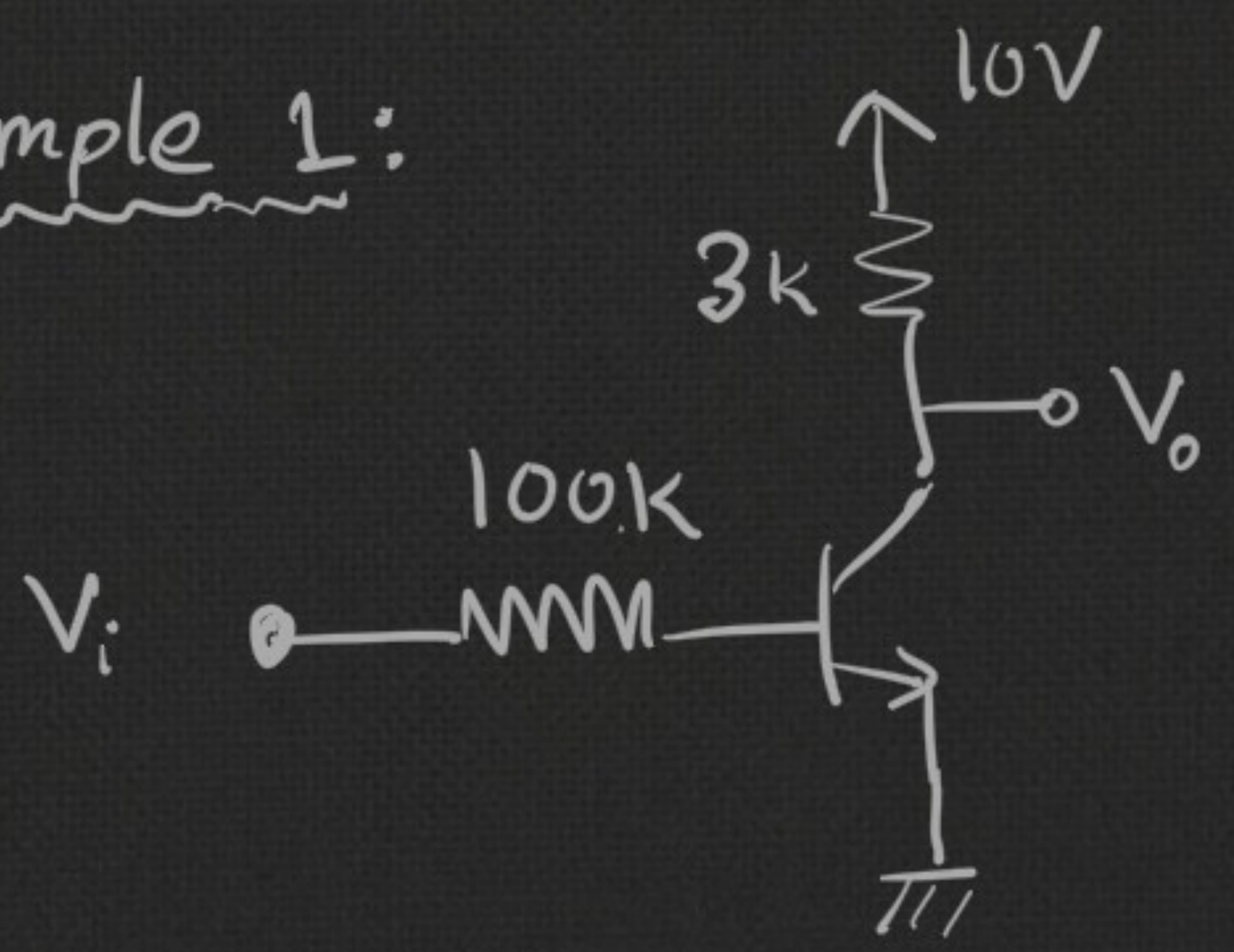
You must show $I_C < \beta I_B$, that is $\frac{I_C}{I_B} < \beta$

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

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

*must show ⇒ condition

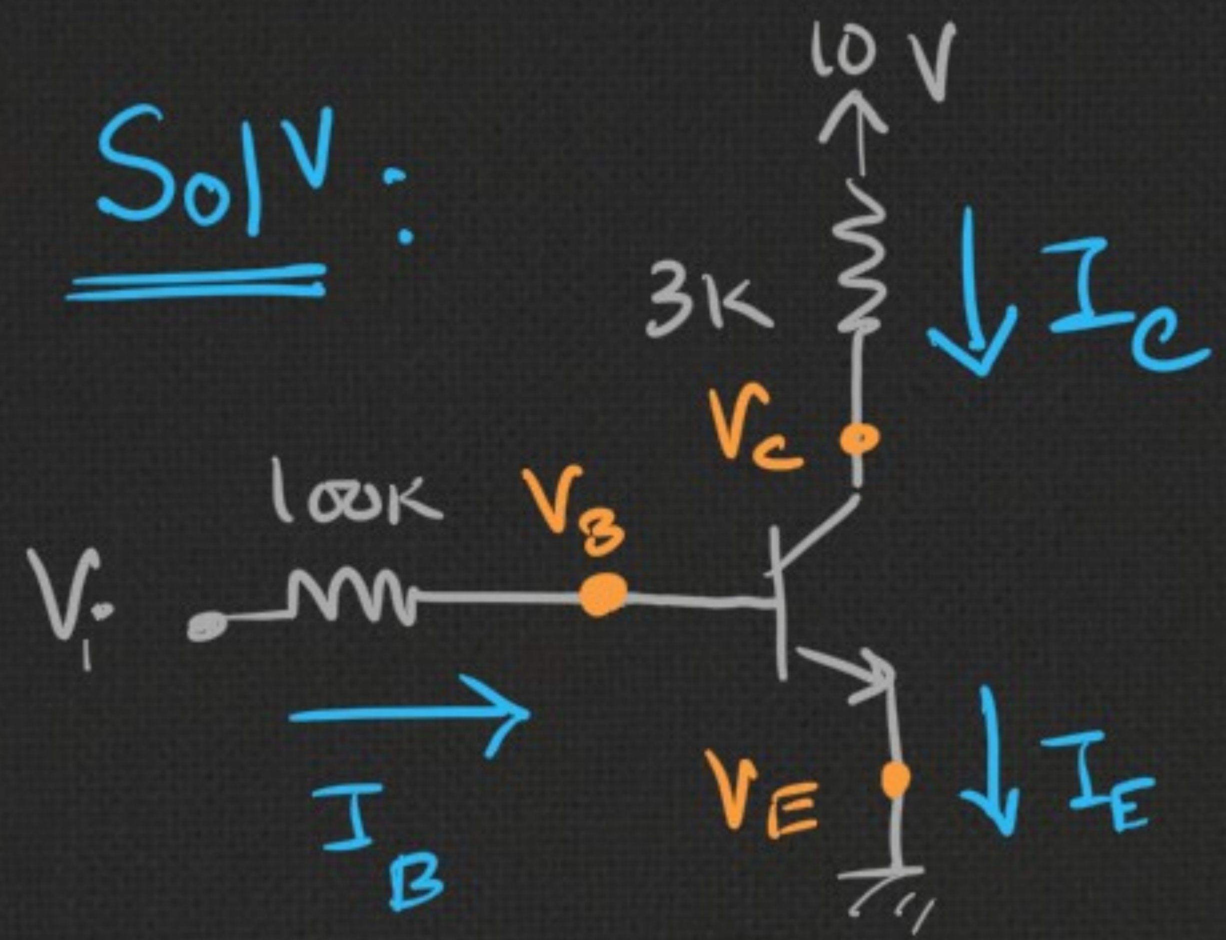
Example 1:



$\beta = 100$

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

Sol^n:



$\boxed{V_o = V_C}$

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

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

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

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

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 $\Rightarrow V_{BE} = 0.8V$

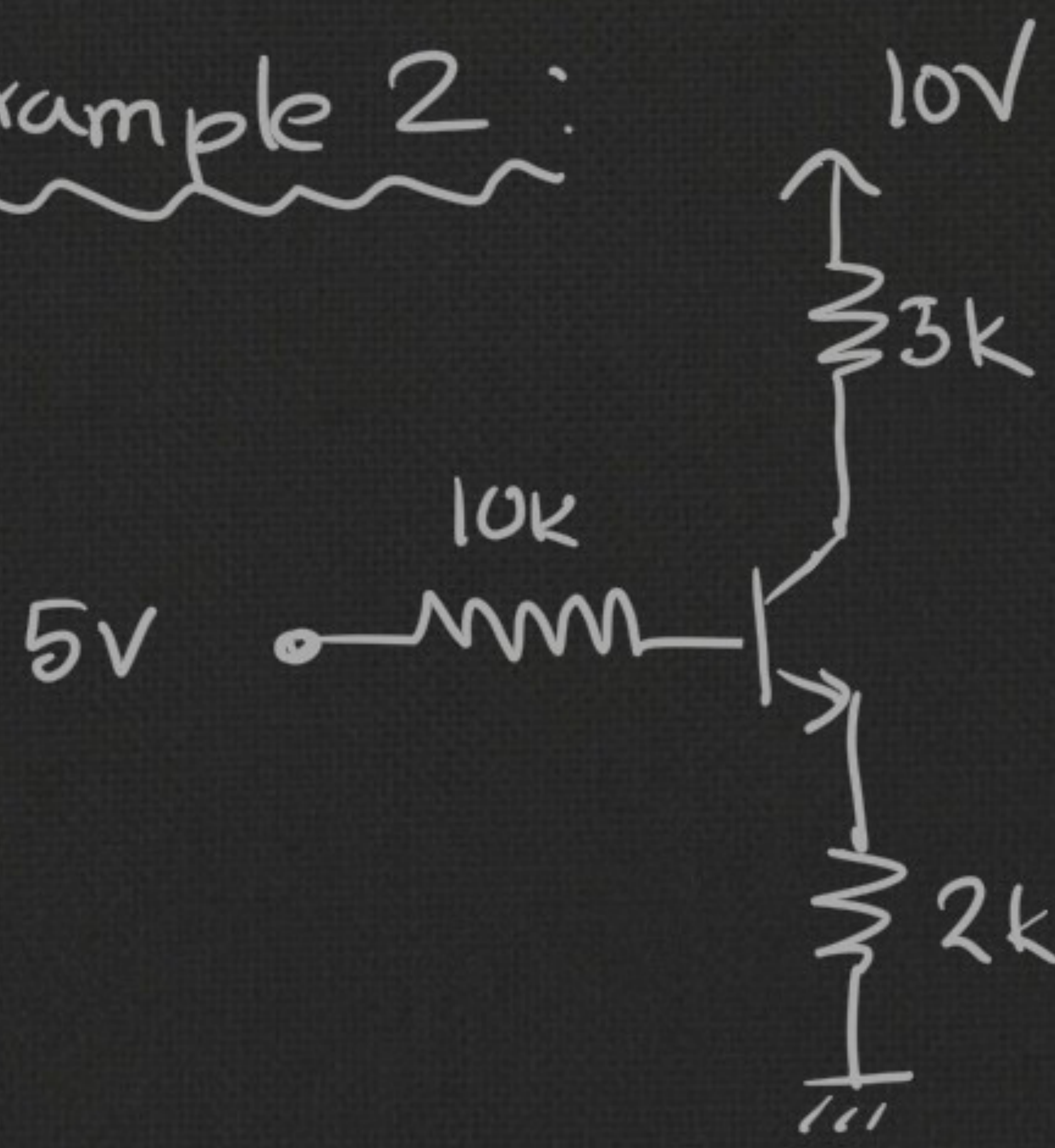
$$I_B = \frac{V_i - V_B}{R_B} = \frac{5 - 0.8}{100} = 0.043 mA$$

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

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. :)

Example 2:



$\beta = 100$

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

Sol^n: Assume in ACTIVE

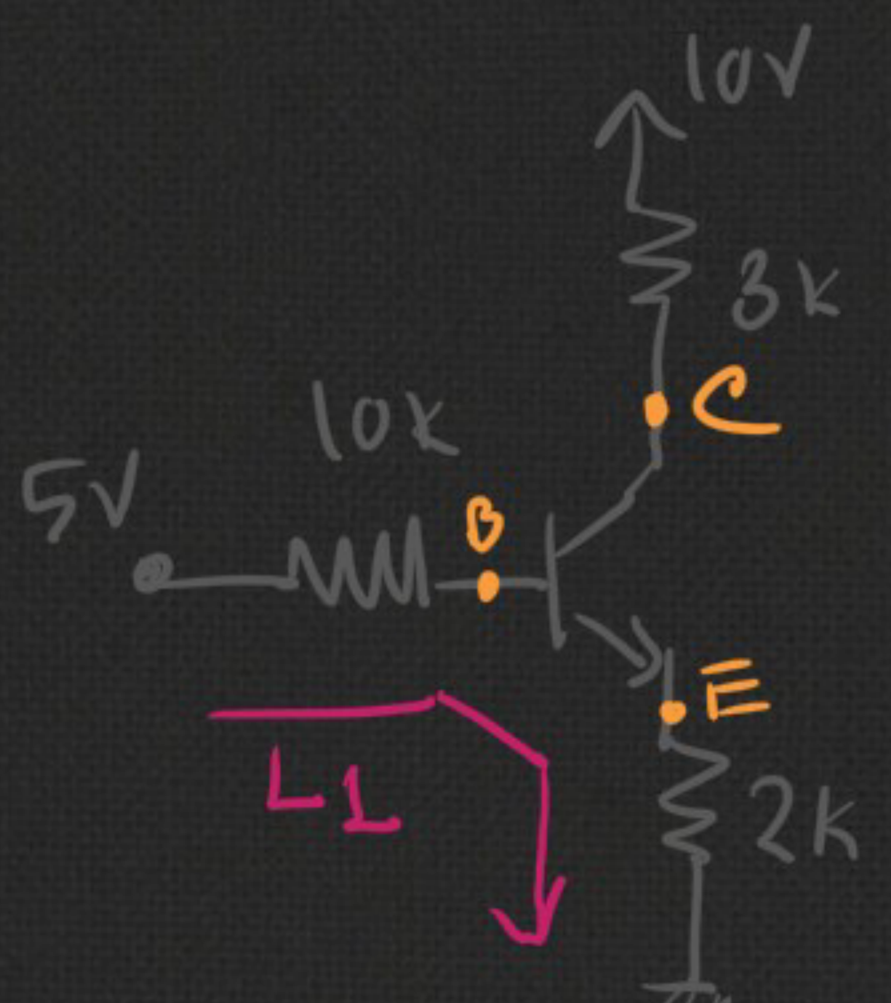
[redacted]

$$\Rightarrow I_C = \alpha I_E \quad \text{—} (1)$$

$$I_C = \beta I_B \quad \text{—} (11)$$

from (1) and (11), $\beta I_B = \alpha I_E$

$$\Rightarrow I_E = \frac{\beta}{\alpha} I_B \quad \text{—} (111)$$



Writing KVL along $L_1 \Rightarrow$

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

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

from (111)

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

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

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

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

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

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

$\Rightarrow V_E = 4.04\,V$

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

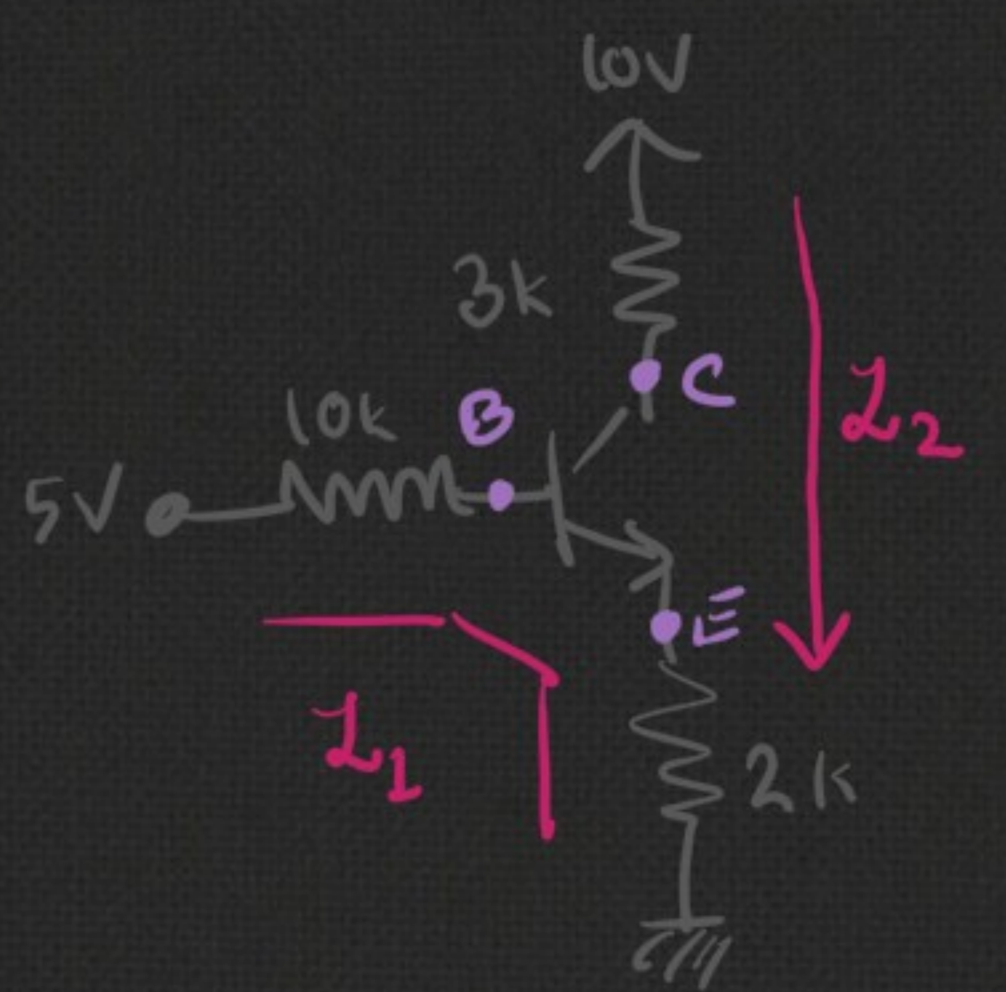
$\Rightarrow V_C = 4V$

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

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

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

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



KVL along $\mathcal{L}_1$

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

$$\Rightarrow 5 = 10 I_B + 0.8 + 2 I_E \quad \text{—— (I)}$$

KVL along $\mathcal{L}_2$

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

$$\Rightarrow 10 = 3 I_C + 0.2 + 2 I_E \quad \text{—— (II)}$$

$\boxed{\text{PTO}}$

From KCL ⇒

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

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

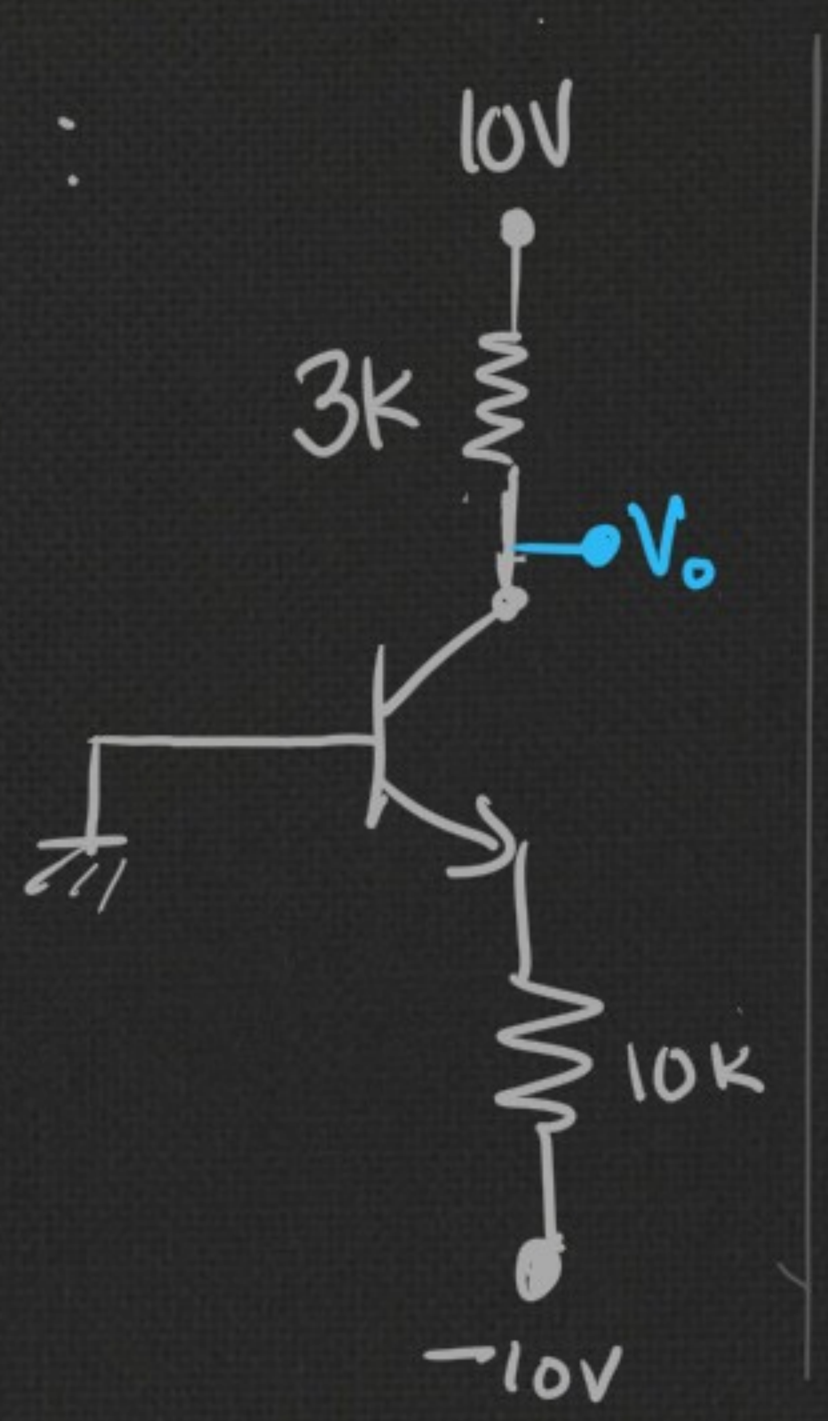
$$I_B = 0.03\ mA$$

$$I_C = 1.95\ mA$$

$$I_E = 1.98\ mA$$

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

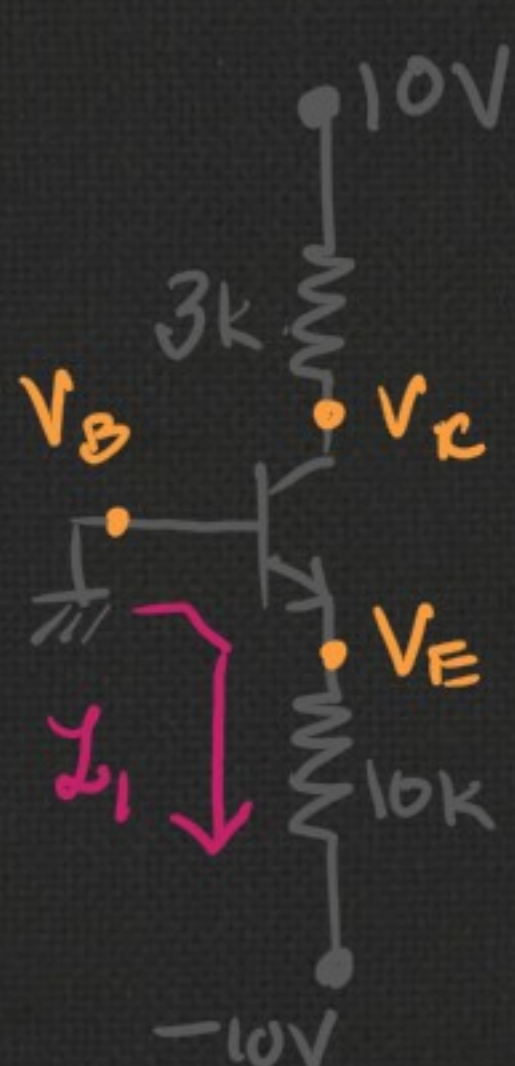
Example 3:



$\beta = 100$

Find I_B, I_C, I_E and V_o

Soln:



Base connected to GND

$\therefore V_B = 0V$

Assume BJT **ACTIVE**

$\therefore V_{BE} = 0.7V$

$\Rightarrow V_B - V_E = 0.7V$

$\Rightarrow V_E = -0.7V$

$\beta = 100$

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

$= 0.99$

KVL along L_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, $10 - V_c = 3I_c$

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

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!