BJT DC ANALYSIS

To make use of the BJT we need to provide dc biasing. For example, to use it as an amplifier, we need to be sure it is operating in the linear (forward active) region.

To determine that dc biasing has been done correctly, we do a dc analysis of the circuit. This is done by:

- deactivating ac sources

  ac voltage sources → short
  ac current sources → open

- replacing reactive elements with dc equivalents

  C → open
  L → short

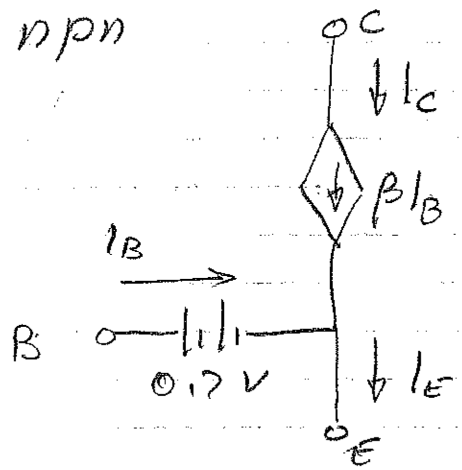
- guess & test: we replace the BJT with a model appropriate for the operating region we think the device is in, and test to see if our assumptions are correct.

The appropriate models for this last step are summarized in the figures from Hambley, 2 ed (FIG 4.19). We repeat them here for convenience.

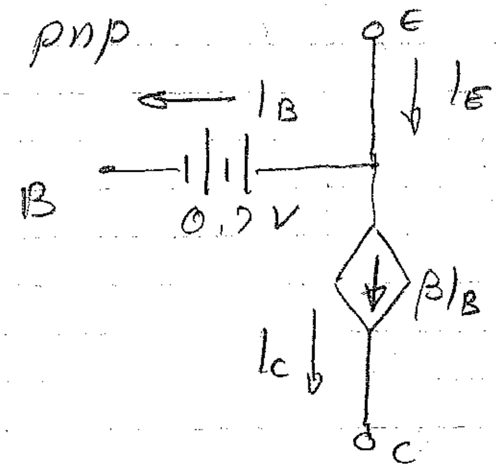
(From Hambley, 2ed, Fig 4.19)

ACTIVE REGION (FORWARD ACTIVE or LINEAR)

npn



pnp



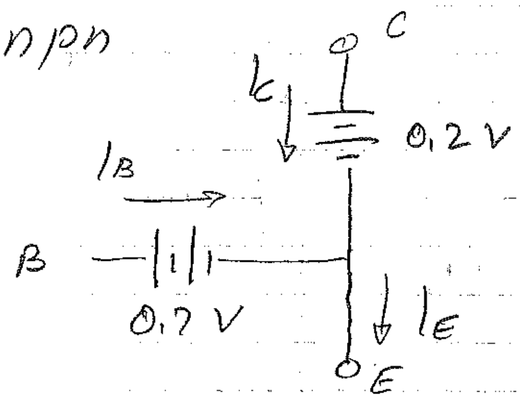
TEST FOR: npn: $I_B > 0$, $V_{CE} > 0.2\ V$; pnp: $I_B > 0$, $V_{CE} < -0.2\ V$

NOTE: We are assuming here a B-E diode threshold voltage of 0.7 V. This value depends on the BJT and in another case may take a different value.

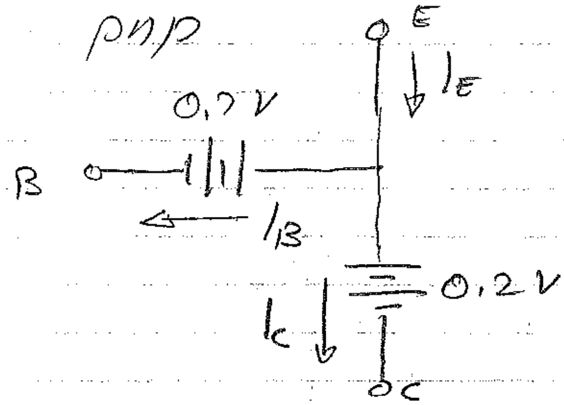
The condition on V_{CE} is based on the assumed saturation voltage, which here is ± 0.2 V. This parameter is also dependent on the BJT. It takes whatever value is specified for $V_{CE\,SAT}$.

SATURATION REGION

npn



pnp

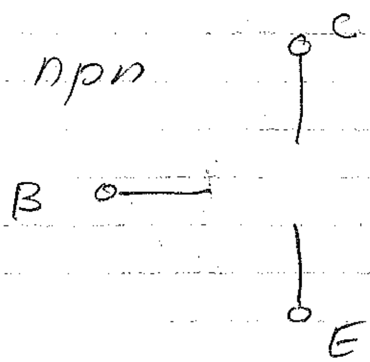


TEST FOR: $I_B > 0$, $\beta I_B > I_C > 0$ (npn); $I_B > 0$, $\beta I_B > I_C > 0$ (pnp)

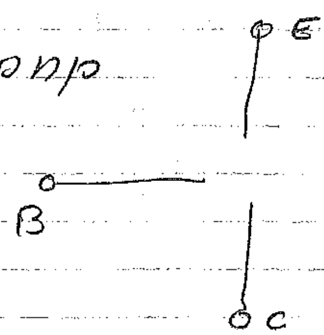
See previous comments concerning the BE threshold voltage and $V_{CE\,SAT}$. Note also the condition that for saturation, the I_C / I_B ratio is <u>not</u> equal to β.

CUTOFF

npn

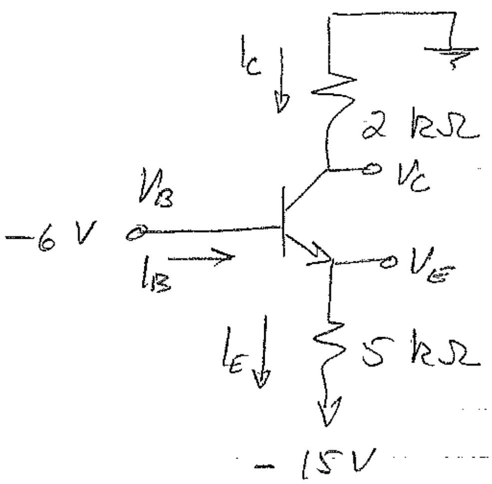


pnp



TEST FOR: $V_{BE} < 0.5$ V, $V_{BC} < 0.5$ V (npn); $V_{BE} > -0.5$ V, $V_{BC} > -0.5$ V (pnp)

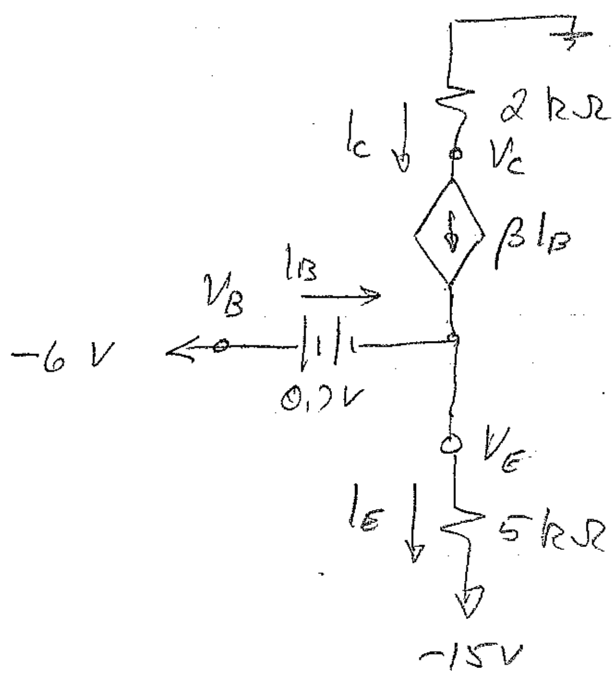
EXAMPLE



$\beta = 100.$

$V_{CESAT} = 0.2V$

ASSUME ACTIVE MODE



$$I_E = \frac{-6.7-(-15)}{5k} = 1.66 \text{ mA}$$

$$I_E = I_B + \beta I_B \Rightarrow I_B = \frac{I_E}{\beta+1} = 16.4 \text{ μA}$$

$I_C = \beta I_B = 1.64\ mA$

$V_C = -2000\ I_C = -3.29\ V$

$V_E = -6.7\ V \qquad V_B = -6\ V \qquad$ (givens)

TEST: $\quad I_B > 0$ ✓

$$V_{CE} = V_C - V_E = -3.29 - (-6.7) = 3.41\ V$$

Note that V_{CB} is consistent with electron flow from base to collector, as must be the case for active operation.

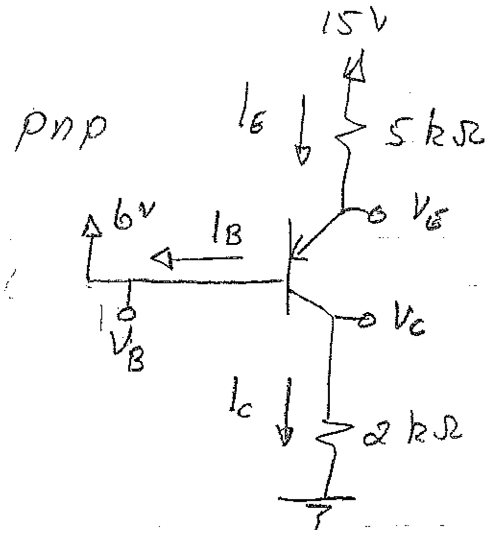
$I_C = \beta I_B = 1.64\ mA$

$V_C = 2000\, I_C = 3.29\ V$

$V_E = 6.7\ V$

$V_{CE} = -3.41\ V < -0.2\ V$ ✓

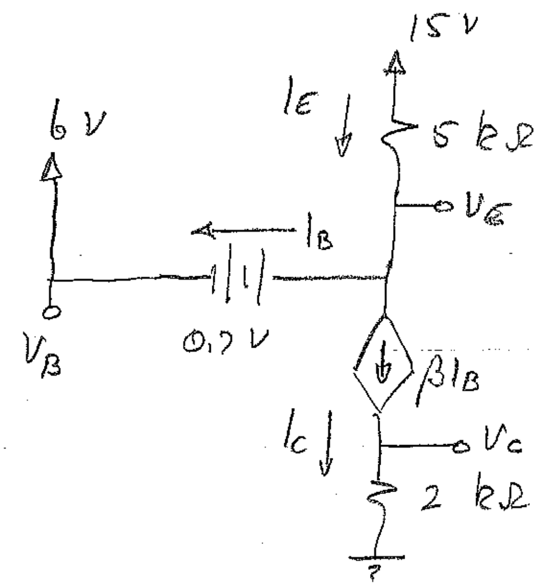
EXAMPLE



$\beta = 100$

$V_{CESAT} = -0.3\ V$

Assume ACTIVE mode

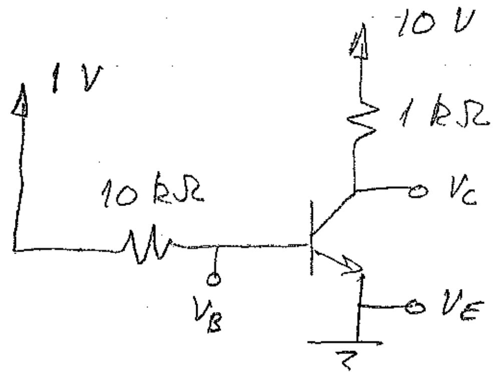


$$-15 + 5000\, I_E + 0.7 + 6 = 0$$

$$I_E = \frac{15 - 6.7}{5k} = 1.66\ mA$$

$$I_B = \frac{I_E}{\beta + 1} = 16.4\ \mu A \quad \checkmark$$

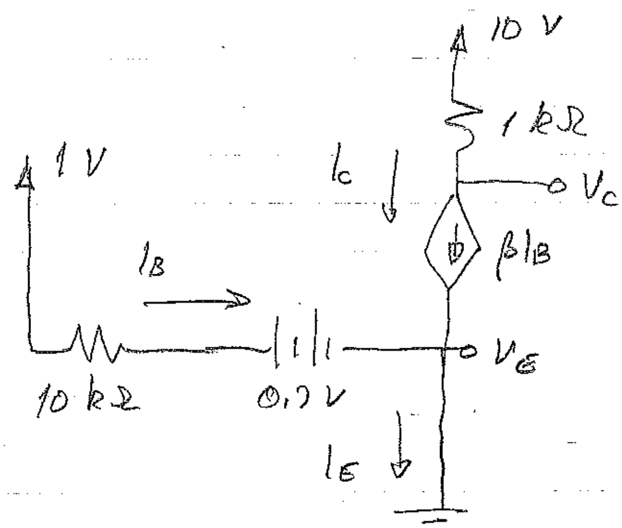
EXAMPLE



$\beta = 50$

$V_{CE\,SAT} = 0.2\ V$

Assume ACTIVE mode.



$$-1 + 10000\, I_B + 0.7 = 0$$

$$I_B = \frac{1-0.7}{10k} = 30\ \mu A$$

$$I_C = \beta I_B = 1.5\ mA$$

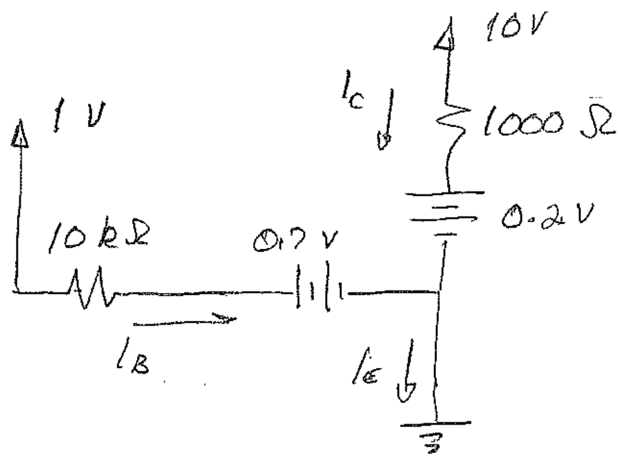
$$I_E = (\beta+1) I_B = 1.53\ mA$$

$V_C = 10 - 1000 I_C = 8.5\,V > 0.2\,V$ ✓

$V_B = 1 - 10k\, I_B = 0.7\,V$

$V_E = 0$

ASSUME SATURATION



$$-1 + 10000 I_B + 0.7 = 0$$

$$I_B = 30\,\mu A > 0 \quad ✓$$

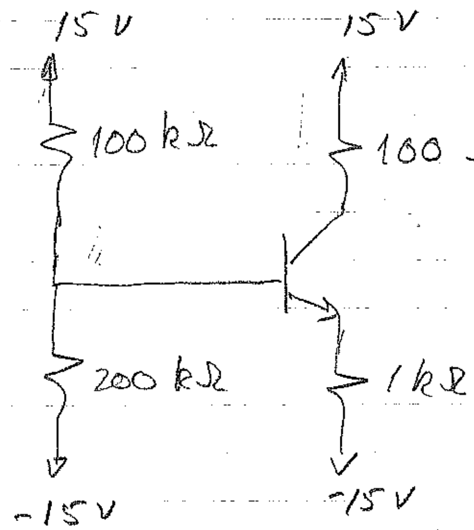
$$I_C = \frac{10 - 0.2}{1000} = 9.8\,mA$$

$$I_E = I_C + I_B \cong 9.8\,mA$$

We need $\beta I_B > I_C$: $50 I_B = 1.5\,mA \overset{?}{>} 9.8\,mA$ X

So test for current magnitudes fails and saturation is wrong.

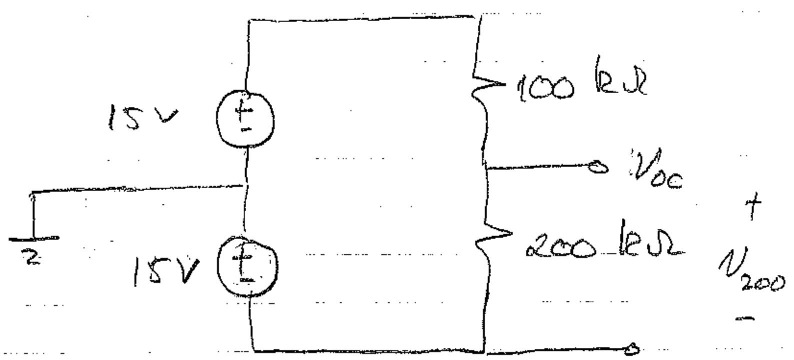
EXAMPLE



$\beta = 100$

$V_{CE\,SAT} = 0.3\ V$

Replace base circuit with Thevenin; re-draw circuit first to see how this works.



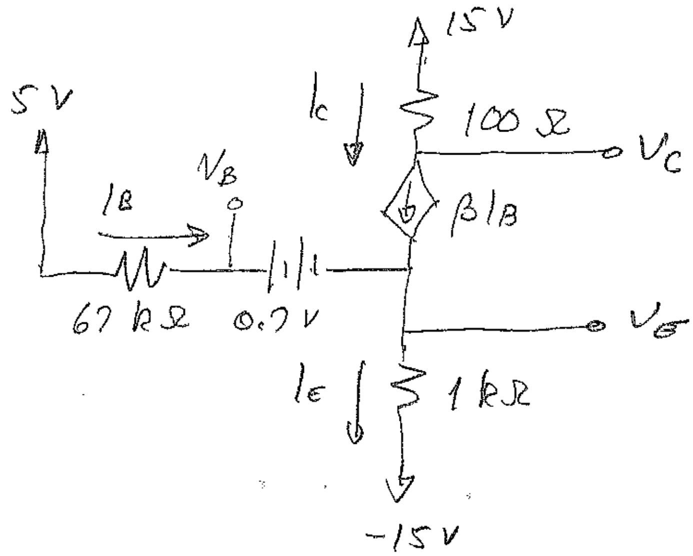
$$V_{200} = (30\ V) \cdot \frac{200k}{200k + 100k}$$

$$= 20\ V$$

$$V_{oc} = V_{200} - 15 = 5\ V.$$

$$R_{eq} = 200k \,\|\, 100k = 66.7\ k\Omega$$

Now assume ACTIVE mode ...



$$-5 + 67000 I_B + 0.7 + 1000 I_E - 15 = 0$$

$$I_E = (\beta + 1) I_B$$

$\Rightarrow$

$$67000 I_B + 1000(101) I_B = 19.3$$

$$I_B = 0.115 \text{ mA}$$ ✓

$$I_E = 11.6 \text{ mA}$$

$$I_C = \beta I_B = 11.5 \text{ mA}$$

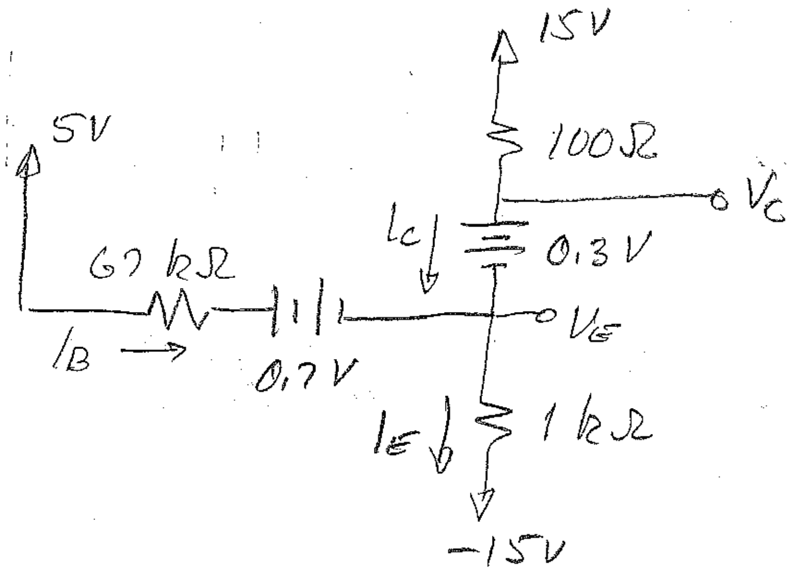
$$V_C = 15 - 100 I_C = 13.85 \text{ V}$$

$$V_E = 1000 I_E - 15 = -3.40 \text{ V}$$

$$V_{CE} = 17.25 \text{ V}$$ ✓

$$> 0.3 \text{ V}$$

Previous example assuming saturation:



A KVL around the base-emitter loop gives:

$$-5 + 67000 I_B + 0.7\,V + 1000 I_E - 15 = 0$$

Because we are in saturation, $I_E \neq (\beta+1) I_B$.
So to solve this we need additional equations:

$$I_E = \frac{V_E - (-15)}{1000}$$

$$V_E = V_C - 0.3$$

$$V_C = 15 - 1000 I_C$$

$$I_C = I_E - I_B$$

This is a bit messy. A better alternative is to use a KCL at V_E (node-voltage method):

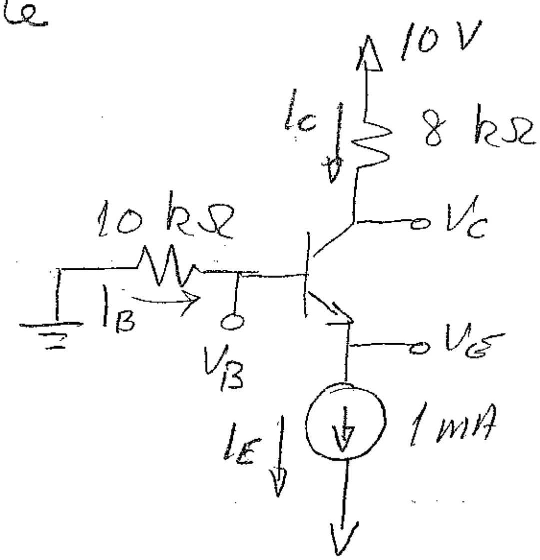
$$0 = \frac{V_E + 15}{1000} + \frac{V_E - 5 - (-0.7)}{67\,000} + \frac{V_E - 15 - (-0.3)}{100}$$

The other terminal currents and voltages follow easily. Either way, the results here are:

$$V_E = 11.99 \text{ V}$$

$$I_B = -0.115 \text{ mA}$$! OOPS - wrong assumption

Example



$\beta = 100$

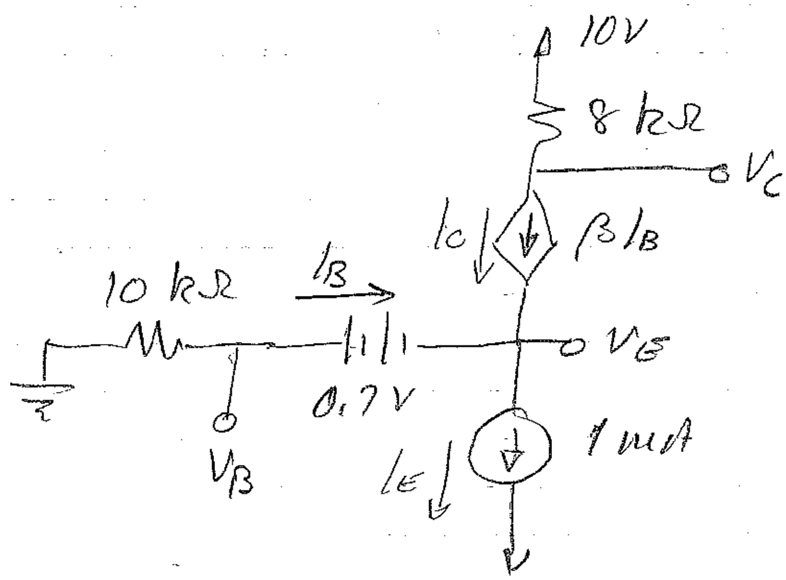
$V_{CESAT} = 0.3\ V$

FIND V_B, V_C, V_E

I_C, I_B, I_E

Biasing here is accomplished using both a voltage source and a current source.

Guess LINEAR region



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

$$I_E = 1\,mA \Rightarrow I_C = 0.99\,mA$$

$$\therefore \quad I_B = I_E - I_C = 0.01\,mA \quad \checkmark$$

$$V_B = -10000\, I_B = -0.1\,V$$

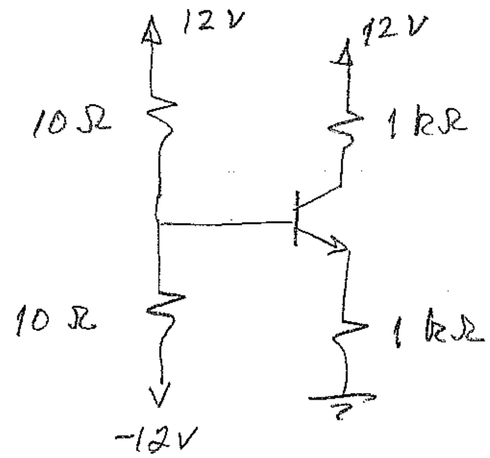
$$V_E = V_B - 0.7 = -0.8\,V$$

$$V_C = 10 - 8000\, I_C = 2.1\,V$$

$$V_{CE} = V_C - V_E = 2.1 - (-0.8) = 2.9\,V \quad \checkmark$$

So, this is the LINEAR region.

EXAMPLE

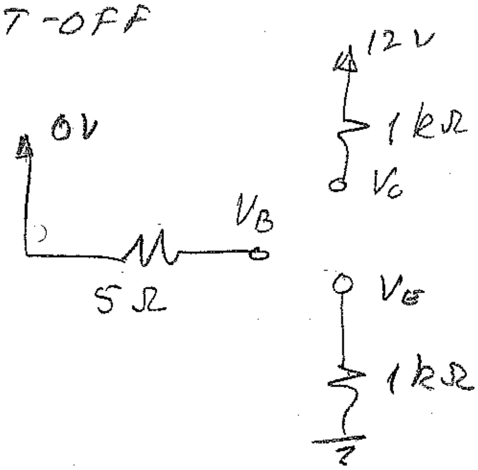


$\beta = 100$

$V_{CE\,SAT} = 0.3\,V$

Looking at base bias circuit, we note that Thevenin equivalent voltage is 0, and the emitter is grounded. Hmmm...

Assume CUT-OFF



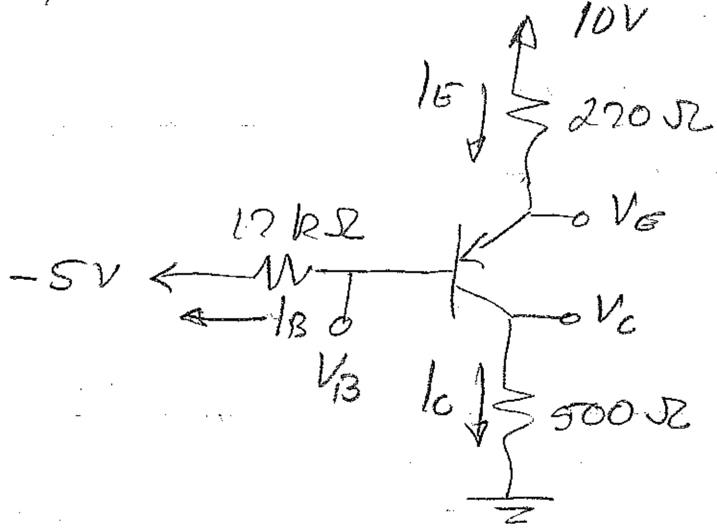
$V_B = 0$

$V_C = 12V$

$V_E = 0$

- so BE junction is OFF and CB junction is reverse biased $\Rightarrow$ CUTOFF is correct.

Example



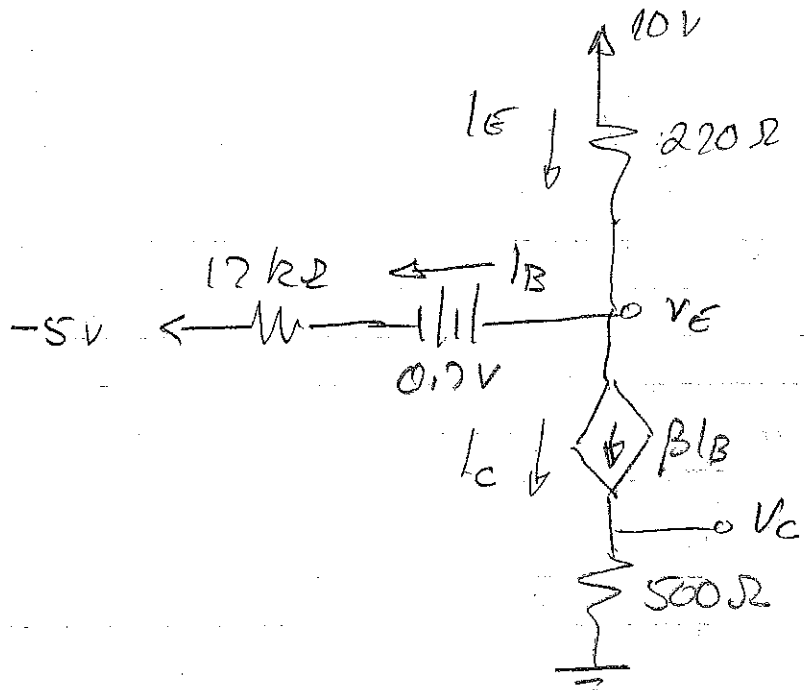
$\beta = 80$

$V_{CESAT} = 0.2\ V$

FIND V_B, V_E, V_C

I_B, I_E, I_C

Clearly the EB junction is ON. Let's guess LINEAR.



KVL: $-10 + 220\, I_E + 0.7 + 17000\, I_B - 5 = 0$

$I_E = (\beta + 1)\, I_B$

$$-10 + 270(81) I_B + 0.7 + 17000 I_B - 5 = 0$$

$$I_B = \frac{10+5-0.7}{17000 + 270(81)} = 0.368 \, mA \quad ✓$$

$$V_{CE} = V_C - V_E = 500 I_C - (10 - 270 I_E)$$

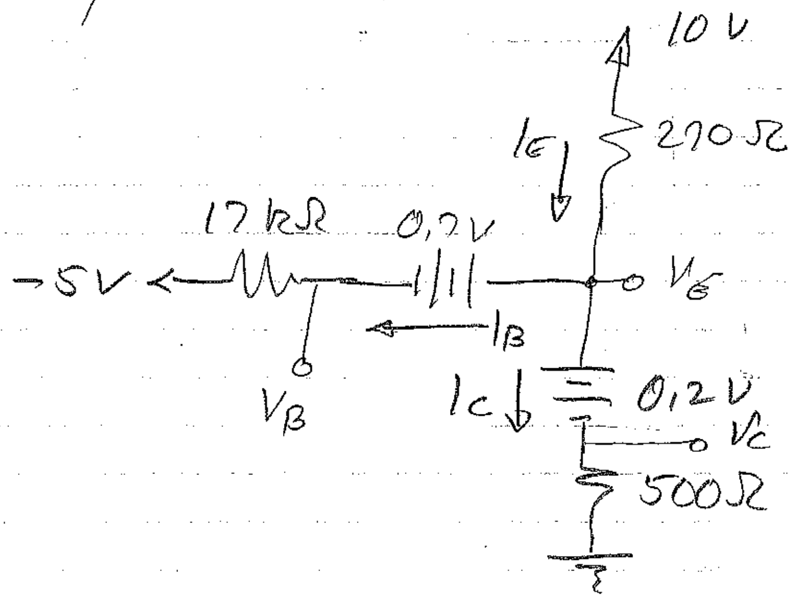
$$= 500(\beta I_B) - (10 - 270(\beta+1) I_B)$$

$$= 16.2 - 10 + 8.83$$

$$= 12.8 \, V \quad ✗$$

$V_{CE} < -0.2 V$ for LINEAR region, which is not satisfied here.

Try SATURATION



Node voltage equation for V_E:

$$\frac{V_E - 0.2}{500} + \frac{V_E - 10}{270} + \frac{V_E + 5 - 0.7}{17000} = 0$$

This is messy but solveable: $\underline{\underline{V_E}} = 6.45\ V$

So $\underline{\underline{V_C}} = V_E - 0.2 = 6.25\ V$; $\underline{\underline{V_B}} = V_E - 0.7 = 5.75\ V$

[We could guess that the last term is negligible because the base resistance (17 kΩ) is large. If we do that, we have

$$\frac{V_E - 0.2}{500} + \frac{V_E - 10}{270} = 0$$

$$\Rightarrow \quad V_E = 6.56\ V$$

This is pretty close to our previous result and will not change the operating region.]

Now

$$\underline{\underline{I_B}} = \frac{V_E + 5 - 0.7}{17000} = 0.632\ mA \checkmark$$

$$\underline{\underline{I_C}} = \frac{V_E - 0.2}{500} = 12.5\ mA$$

$$\beta I_B = 50.6\ mA > I_C \quad \checkmark$$

$$\underline{\underline{I_E}} = I_B + I_C = 13.13\ mA$$