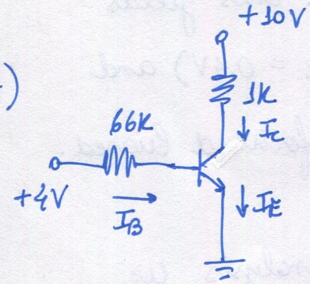
Sep 18, 2017

ENEL 469 - Practice Problems Set #1 - Solutions

A)



Identifying given voltages: $V_{BB} = 4V$ and $V_{CC} = 10V$.

Assume $V_{BE} = 0.7V$, so $V_B = 0.7V$ and $I_B = \frac{V_{BB} - V_B}{66k} \Rightarrow$

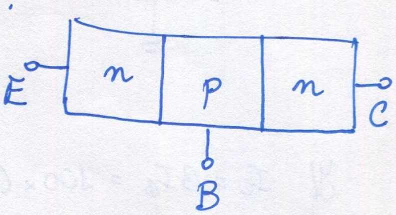
$\Rightarrow I_B = \frac{4 - 0.7}{66k} = 50\mu A$. Then, $I_C = \beta I_B = 5mA$.

$I_E = I_C + I_B = 5.05mA$, therefore $V_C = V_{CE} = V_{CC} - (1k) I_C \Rightarrow$

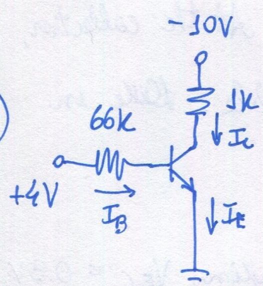
$\Rightarrow V_{CE} = 10 - 5 = 5V$.

Finally, $V_{CB} = V_C - V_B = 5 - 0.7 = 4.3V$.

Since $V_{BE} = 0.7V > 0$ (or $V_B > V_E$), BE junction is forward biased. However, $V_{CB} = 4.25V > 0$ (or $V_C > V_B$), meaning that CB junction is reverse biased. Remember that in the CB junction, the collector (C) is the n-type semiconductor, whereas the base (B) is the p-type semiconductor:



B)

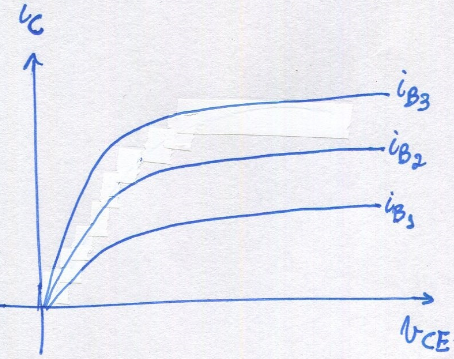


Similarly to (A), $V_{BB} = 4V$ and, assuming $V_{BE} = 0.7V$, then $V_B = 0.7V$ and $I_B = \frac{V_{BB} - V_B}{66k} = \frac{4 - 0.7}{66k} = 50\mu A$. So, $I_C = \beta I_B = 5mA$ and $I_E = I_C + I_B = 5.05mA$.

In this case, $V_C = V_{CE} = V_{CC} - (1k) I_C$, where $V_{CC} = -10V$. So, we get $V_{CE} = -10 - (1k)(5mA) = -15V$, which is not acceptable.

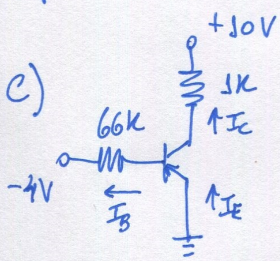
Assuming we still have $V_B = V_{BE} = 0.7V$ and $I_B = 50\mu A$, we shall take $|V_{CE}| = 0.3V$ or $V_C = 0.3V$. This yields $V_{CB} = V_C - V_B = 0.3 - 0.7 = -0.4V$ (or $V_{BC} = 0.4V$) and indeed both junctions BE and CB are forward biased.

However, due to polarization ($V_{CC} = -10V$ and $V_{EE} = 0V$), if there is any current flowing in the collector-emitter path, it should be flowing upwards, but this is inconsistent with the BJT model. In other words, the emitter (having higher voltage than the collector) is not capable of sending majority carriers (electrons) to be collected at the collector. Therefore, all currents are actually zero: $I_E = 0$, $I_C = 0$ and $I_B = 0$.



Another way of interpreting this problem is by looking at the composite collector current (i_C) vs. composite collector-emitter voltage (v_{CE}) characteristic curves of a BJT, for different values of composite base current (i_B).
If $v_{CE} < 0$, there is no collector current: $I_C = 0$!

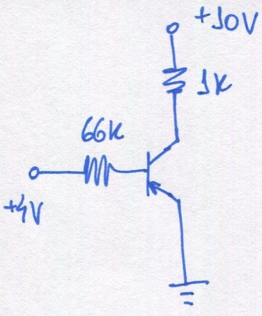
c)



Now we have a pnp transistor, so we start assuming $V_{EB} = 0.7V$, or $V_B = -0.7V$. Then, the base current (flowing to the left, or out of the transistor) is given by $I_B = \dfrac{V_B - V_{BB}}{66k} = \dfrac{-0.7-(-4)}{66k} = 50\mu A$.

If $I_C = \beta I_B = 100 \times (50\mu A) = 5mA$, then $I_E = I_C + I_B = 5.05 mA$. At the collector, $V_C = V_{CE} =$ $= V_{CC} + (1K) I_C = 10 + (1k)(5m) = 15V$, which is not acceptable. This case is very similar to the previous (B), and we can assume $V_{EC} = 0.3V$, yielding $V_C = -0.3V$, $V_{CB} = V_C - V_B = -0.3 - (-0.7) = 0.4V$ and concluding that both junctions BE and CB are forward biased. However, as previously discussed, the polarization is not properly set to make current flow (upwards in this pnp transistor), so all currents must be zero.

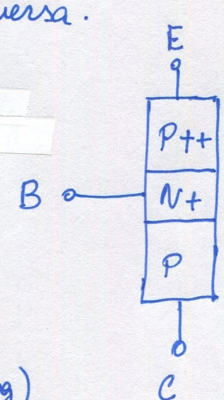
D)



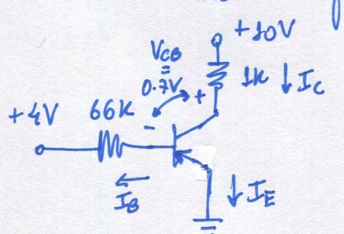
Since this is a pnp transistor and $V_E = 0V$, we should have $V_B < 0$, which is not the case, so we cannot have $V_{BE} = -0.7V$ (or $V_{EB} = 0.7V$). In other words, BE junction is reverse biased.

However, we can note that due to biasing ($V_{CC} = 10V$ and $V_{BB} = 4V$), the CB junction seems to be forward biased. So, let's assume for this case that the BJT may be flipped; i.e., collector is working as emitter and vice-versa*.

With this configuration, β will be much smaller (typically, in the range of $5 \sim 10$) due to different concentrations of dopping in emitter and collector:



Then, if we assume $V_{CB} = 0.7V$ (it will be less due to doping), we can write the following:



$$\begin{cases} V_{CC} = (1K)I_C + V_{CB} + (66K)I_B + V_{BB} \\ I_E = \beta' \cdot I_B \\ I_C = I_E + I_B \end{cases}$$

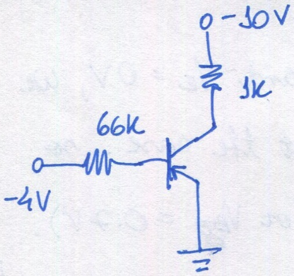
* note how these equations have changed!

Using $\beta' = 5$, we write $I_C = (\beta'+1)I_B = 6I_B$ and first equation yields $10 = 1000 \cdot 6I_B + 0.7 + 66000\,I_B + 4 \Rightarrow 72000\,I_B = 5.3 \Rightarrow I_B = 73.6\mu A$. Thus, $I_E = 5 \times (73.6\mu A) = 368\mu A$ and $I_C = I_E + I_B = 441.6\mu A$.

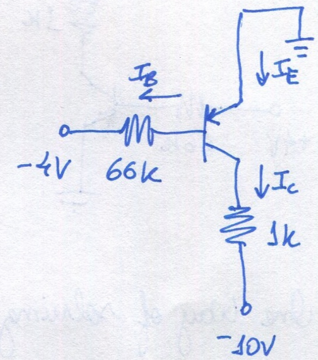
Also, $V_{CE} = V_C - V_E = V_C = V_{CC} - (1K)I_C = 10 - (1K)(441.6\mu) \approx 9.56\ V$. In this case, BC junction is forward biased. We can calculate $V_B = V_{BB} + (66K)I_B = 4 + (66K)(73.6\mu) \approx 8.86V$ and conclude that $V_{BE} = 8.86V$ (or $V_{EB} = -8.86V$). Therefore, BE junction is reverse biased.

You can simulate this circuit to check the concepts here explained!

E)

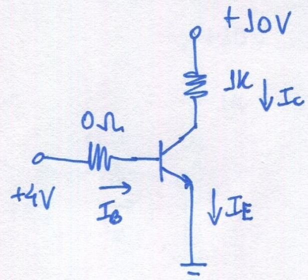


Even though this circuit seems to be wrongly biased, the power supplies actually work well. A better way of seeing it is flipping the entire circuit vertically:



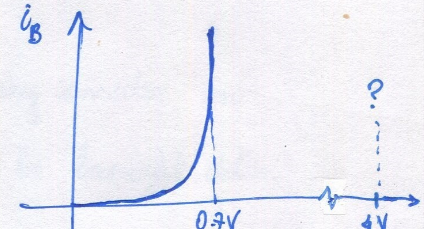
Assuming $V_{EB} = 0.7V$, we get $V_B = -0.7V$. Therefore, $I_B = \frac{V_B - V_{BB}}{66k} = \frac{-0.7-(-4)}{66k} =$ $= 50\mu A$. Then, $I_C = \beta I_B = 100 \times (50\mu A) = 5mA$ and $I_E = I_C + I_B = 5.05mA$. In this case, $V_C = (1k)I_C + V_{CC} = (1k)(5m) - 10 = -5V$, so $V_{CE} = V_C - V_E =$ $= -5V$. We can also see that BE junction is forward biased ($V_{BE} = -0.7V$) and CB junction is reverse biased ($V_B > V_C$), $V_{CB} = V_C - V_B = -4.3V$.

F)



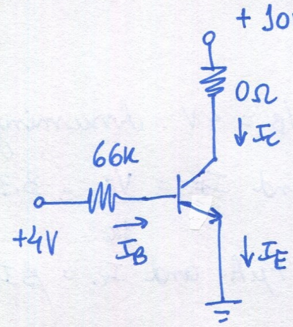
This circuit does not limit the base current because $R_B = 0\Omega$. One can see that $V_B = 4V$ directly and, as $V_E = 0V$, we have $V_{BE} = 4V$.

By looking at the $i_B \times u_{BE}$ characteristic curve, we see that $V_{BE} = 4V$ is way too far from the traditional $0.6 \sim 0.8V$ biasing. This means that the initial base current would be so high that the transistor would burn instantly.



This configuration is not practical and not at all recommended, as at least one limiting resistor must be added (either at the base or at the emitter).

G)

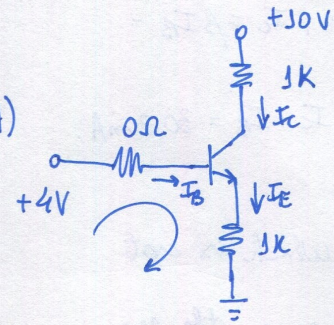


Even though this case looks like the previous one (F), it is not quite the same : the 66KΩ resistor limits the base current, so both collector and emitter currents are also limited.

As we have calculated several times before, once we assume $V_B = V_{BE} = 0.7V$, we obtain $I_B = \frac{4-0.7}{66K} = 50\mu A$. Thus, $I_C = 100\, I_B = 5mA$ and $I_E = I_C + I_B = 5.05\, mA$. Junction BE is forward biased.

Since $R_C = 0\Omega$, we obtain directly $V_C = 10V$, and $V_{CE} = 10V$. Also, $V_{CB} = V_C - V_B = 10 - 0.7 = 9.3\, V$, so CB junction is reverse biased.

H)



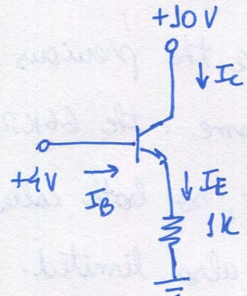
Even though $R_B = 0\Omega$ in this case, the base current is limited by the emitter resistor $R_E = 1K\Omega$.

Directly, $V_B = 4V$. Assuming $V_{BE} = 0.7V$, $V_E = 3.3V$. Then, $I_E = \frac{V_E}{1K} = 3.3\, mA$.

Combining $I_E = I_C + I_B$ and $I_C = \beta I_B$, we obtain $I_E = (\beta+1) I_B$ or $I_B = \frac{I_E}{\beta+1} = \frac{3.3\, mA}{101} \approx 32.7\mu A$. Also, $I_C = 100\, I_B \simeq 3.27\, mA$.

Since $V_C = V_{CC} - (1K) I_C = 10 - (1K)(3.27m) = 6.73\, V$, we obtain $V_{CE} = V_C - V_E = 6.73 - 3.3 = 3.43V$ and $V_{CB} = V_C - V_B = 6.73 - 4 = 2.73\, V$. Therefore, CB junction is reverse biased. As previously assumed, BE junction is forward biased.

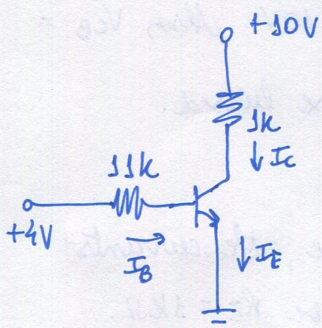
I)



Similarly to the circuit (H), $V_B = 4V$. Assuming $V_{BE} = 0.7V$, then $V_E = 3.3\ V$ and $I_E = \frac{V_E}{1k} = 3.3mA$. Also, $I_B = \frac{I_E}{\beta+1} = \frac{3.3mA}{101} \approx 32.7\mu A$ and $I_C = \beta I_B =$
$= 3.27mA$.

In this case, $V_C = 10V$ and $V_{CE} = V_C - V_E = 10 - 3.3 = 6.7V$. Besides, $V_{CB} = V_C - V_B = 10 - 4 = 6V$, which indicates that CB junction is reverse biased. As before, BE junction is forward biased.

J)



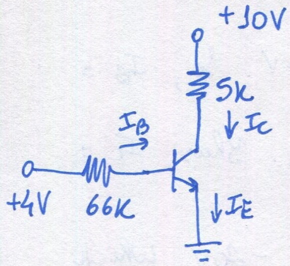
Assuming $V_{BE} = 0.7\ V$, then $V_B = 0.7V$ and $I_B =$
$= \frac{V_{BB} - V_B}{11K} = \frac{4-0.7}{11K} = 0.3mA$. Then, $I_C = \beta I_B =$
$= 100 \times (0.3mA) = 30mA$ and $I_E = I_C + I_B = 30.3mA$.

In this case, $V_C = V_{CC} - (1K)I_C = 10 - (1K)(30m) = -20V$, which is not possible. Note that because $R_B = 11K\Omega$ is smaller in this case, the currents I_B (and I_C) are larger, bringing V_C down.

We now have, in this case, both BE and CB junctions forward biased. Thus, $V_{BE} = 0.7V$ and $V_{CE} = 0.3V$. The base current is still $I_B = 0.3mA$, but $I_C = \frac{V_{CC} - V_{CE}}{1K} = \frac{10 - 0.3}{1K} = 9.7mA$. Therefore, $I_E = I_C + I_B = 10\ mA$.

Finally, $V_{CB} = V_C - V_B = 0.3 - 0.7 = -0.4V$.

Also note that, in this case, $\beta' = \frac{I_C}{I_B} = \frac{9.7mA}{0.3mA} \approx 32.3 < 100$. You might also encounter β' being referred to as β_{forced}!

K) 

In this case, R_B is set back to $66k\Omega$, but let's see the effect of the $5k\Omega$-resistor at the collector...

Assuming $V_{BE} = 0.7V$, then $V_B = 0.7V$ and $I_B = \dfrac{V_{BB} - V_B}{66k} = \dfrac{4 - 0.7}{66k} = 50\mu A$.

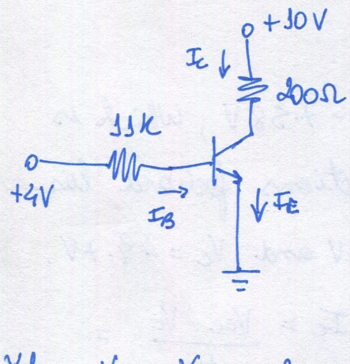
So, $I_C = \beta I_B = 5mA$ and $V_C = V_{CC} - (5K)I_C = 10 - (5K)(5m) = -15V$, which is impossible. We thus conclude that 5K is too much for this path!

Once more, we assume both BE and CB junctions forward biased:

$V_{BE} = 0.7V$ and $V_{CE} = 0.3V$, so that $V_B = 0.7V$, $V_C = 0.3V$ and $V_{CB} = -0.4V$.

Keeping $I_B = 50\mu A$, we recalculate I_C: $I_C = \dfrac{V_{CC} - V_C}{5K} = \dfrac{10 - 0.3}{5K} = 1.94mA$.

Note again that $\beta' = \dfrac{I_C}{I_B} = \dfrac{1.94mA}{50\mu A} = 38.8 < 100$.

L) 

This analysis starts as the case (J). We assume $V_{BE} = 0.7V$ (BE junction forward biased) and obtain $V_B = 0.7V \Rightarrow I_B = \dfrac{V_{BB} - V_B}{11k} = \dfrac{4 - 0.7}{11K} = 0.3mA$.

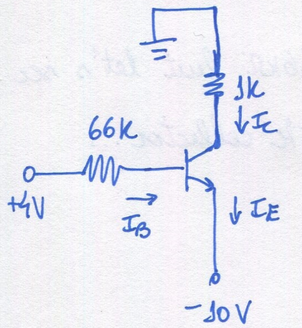
Then, $V_C = V_{CC} - 200 I_C$, where $I_C = \beta I_B = 30mA$. So, $V_C = 10 - 200(30m) = 4V$.

Since $V_{CB} = V_C - V_B = 4 - 0.7 = 3.3V > 0$, CB junction is reverse biased.

Besides, $V_{CE} = V_C = 4V$.

Note that despite the fact that R_B is lowered to $11k\Omega$, the voltage V_C does not drop under unnacceptable values, because $R_C = 200\Omega$ is also kept low.

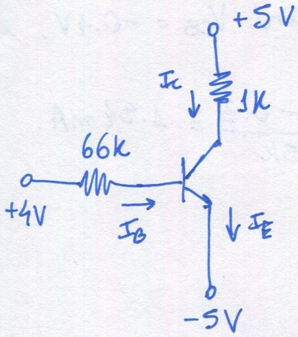
M)



Assuming $V_{BE} = 0.7V$, then $V_B = -9.3V$. So, $I_B = \frac{V_{BB} - V_B}{66k} = \frac{4-(-9.3)}{66k} \approx 0.2\ mA$. Thus, $I_C = \beta I_B \approx 20\ mA$ and $V_C = -(1k)I_C = -20V$, which is impossible.

So, we must assume both BE and CB junctions forward biased, obtaining $V_{BE} = 0.7V$ and $V_{CE} = 0.3V$. In this case, $I_B \approx 0.2mA$ still, but $V_C = V_{CE} + V_{EE} = 0.3 - 10 = -9.7V$. So, $I_C = \frac{0 - V_C}{1k} = 9.7\ mA$. Finally, $V_{CB} = V_C - V_B = -9.7 - (-9.3) = -0.4V$.

N)



Assuming $V_{BE} = 0.7V$ (BE junction forward biased), we get $V_B = -4.3V$. So, $I_B = \frac{V_{BB} - V_B}{66K} = \frac{4-(-4.3)}{66K} \approx 125.8\ \mu A$. Then, $I_C = 100 I_B \approx 12.58\ mA$.

Now, we calculate $V_C = V_{CC} - (1k)I_C = 5 - (1k)(12.58m) = -7.58V$, which is impossible. So, again, we assume both BE and CB junctions forward biased, obtaining $V_{BE} = 0.7V$ and $V_{CE} = 0.3V$. Then, $V_B = -4.3V$ and $V_C = -4.7V$. Clearly, $V_{CB} = V_C - V_B = -0.4V$, and the collector current is $I_C = \frac{V_{CC} - V_C}{1k} = \frac{5-(-4.7)}{1k} = 9.7\ mA$, while the base current is still the same, $I_B \approx 125.8\ \mu A$.

Note that usually symmetric power supplies work out well (e.g., $\pm 5V$), but in this case, the gap between $V_{BB} = +4V$ and $V_{EE} = -5V$ is bigger, so $R_B = 66\ k\Omega$ should be larger to keep I_B (and I_C) at a lower value.

* Final comment: even though we have used $|V_{CE}| = 0.3V$ in the cases where both BE and BC junctions were forward biased, $|V_{CE}| = 0.2V$ is a better choice and will be used from now on.