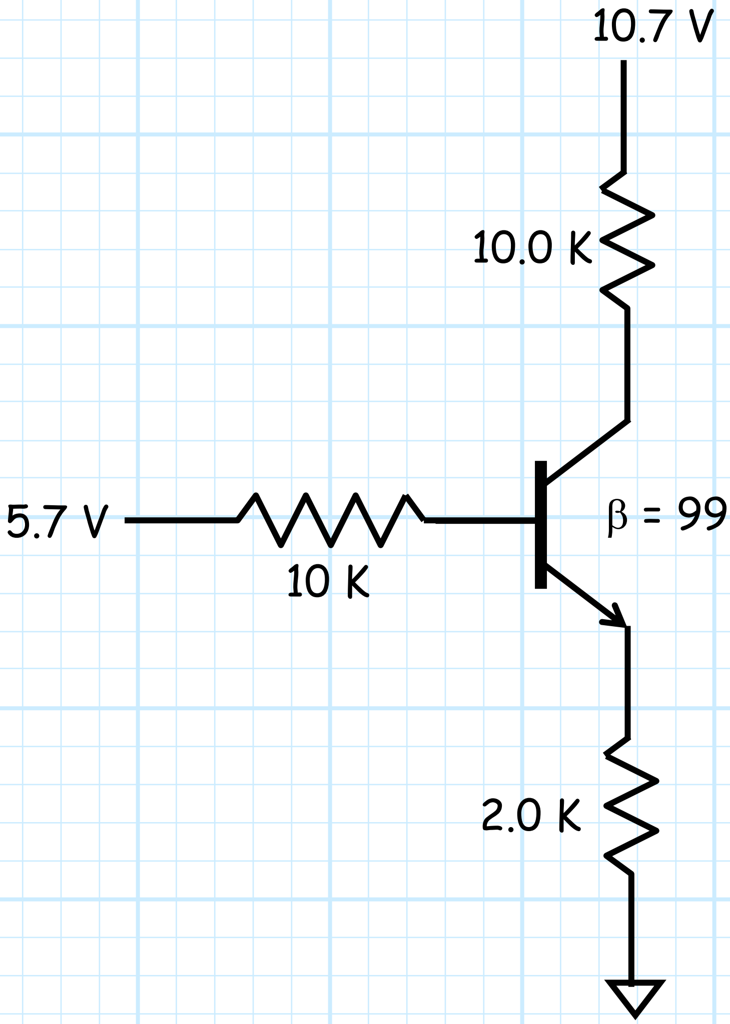
Example: A BJT Circuit in Saturation

Determine all **currents** for the BJT in the circuit below.



*Hey! I remember this circuit, its just like a **previous example**. The BJT is in **active** mode!*

Let's see if you are correct! ASSUME it is in active mode and ENFORCE V_{CE} = 0.7 V and $i_C = \beta\ i_B$.

The B-E KVL is therefore:

$$5.7 - 10\ i_B - 0.7 - 2\ (99+1)\ i_B = 0$$

Therefore $i_B = 23.8\ \mu A$

See! Base current i_B = 23.8 μA, just like before. Therefore collector current and emitter current are again $i_C = 99 i_B$ = 2.356 mA and i_E = 100 i_B = 2.380 mA. Right ?!

Well **maybe**, but we still need to CHECK to see if our assumption is correct!

We know that $i_B = 23.8\ \mu A > 0$ ✓ , but what about V_{CE} ?

From collector-emitter KVL we get:

$$10.7 - 10\, i_C - V_{CE} - 2\, i_E = 0$$

Therefore,

$$V_{CE} = 10.7 - 10(2.36) - 2(2.38) = -17.66 \text{ V} < 0.7 \text{ V} \quad \text{X}$$

Our assumption is **wrong** ! The BJT is **not** in active mode.

In the previous example, the collector resistor was **1K** , whereas in this example the collector resistor is **10K**. Thus, there is 10X the **voltage drop** across the collector resistor, which **lowers** the collector voltage so much that the BJT cannot remain in the active mode.

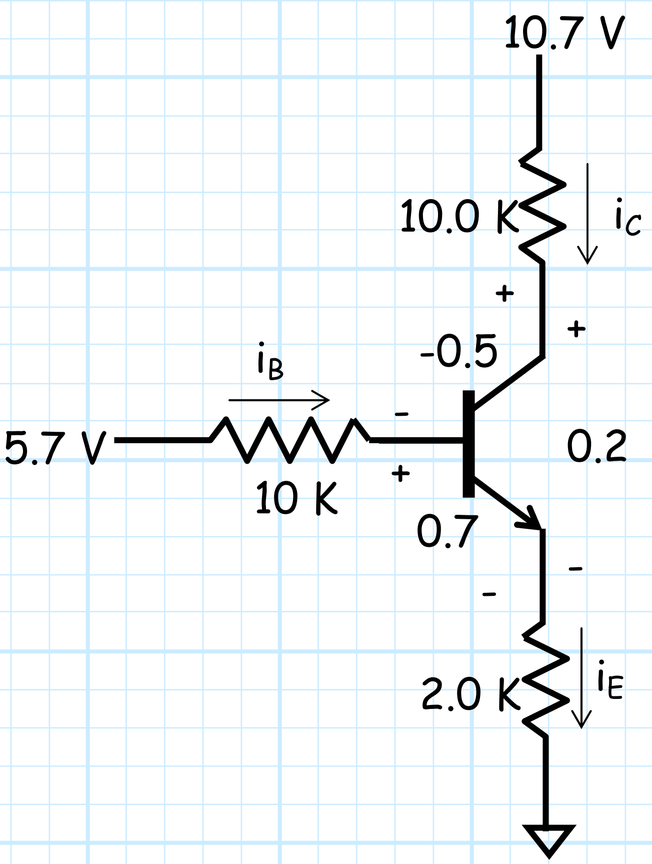
Q: *So what do we do **now** ?*

A: Go to **Step 5**; change the assumption and try it again!

Lets ASSUME instead that the BJT is in **saturation**. Thus, we ENFORCE the conditions:

$$V_{CE} = 0.2 \text{ V} \qquad V_{BE} = 0.7 \text{ V} \qquad V_{CB} = -0.5 \text{ V}$$

Now lets ANALYZE the circuit !



Note that we **cannot** directly determine the currents, as we **do not** know the base voltage, emitter voltage, or collector voltage.

But, we **do** know the **differences** in these voltages!

For example, we know that the collector voltage is 0.2 V **higher** than the emitter voltage, but we **do not** know what the collector or emitter voltages are!

Q: *So, how the heck do we ANALYZE this circuit !?*

A: Often, circuits with BJTs in **saturation** are somewhat more **difficult** to ANALYZE than circuits with **active** BJTs. There are often **many approaches**, but all result from a logical, systematic application of **Kirchoff's Laws**!

ANALYSIS EXAMPLE 1 - Start with **KCL**

We **know** that $i_B + i_C = i_E$ (KCL)

But, what **are** i_B, i_C, and i_E ??

Well, from **Ohm's Law**:

$$i_B = \frac{5.7 - V_B}{10} \qquad i_C = \frac{10.7 - V_C}{10} \qquad i_E = \frac{V_E - 0}{10}$$

Therefore, combining with KCL:

$$\frac{5.7 - V_B}{10} + \frac{10.7 - V_C}{10} = \frac{V_E}{10}$$

Look what we have, **1 equation** and **3 unknowns**.

→ We need **2** more **independent** equations involving V_B, V_C, and V_E!

Q: ***Two more*** *independent equations !? It looks to me as if we have written all that we can about the circuit using Kirchoff's Laws.*

A: True! There are no more **independent** circuit equations that we can write using KVL or KCL ! But, recall the hint sheet:

*"Make sure you are using **all** available information".*

There is more **information** available to us – the ENFORCED conditions!

$$V_{CE} = V_C - V_E = 0.2 \Rightarrow V_C = V_E + 0.2$$

$$V_{BE} = V_B - V_E = 0.7 \Rightarrow V_B = V_E + 0.7$$

Two more **independent** equations! Combining with the earlier equation:

$$\frac{5.7 - (0.7 + V_E)}{10} + \frac{10.7 - (0.2 + V_E)}{10} = \frac{V_E}{10}$$

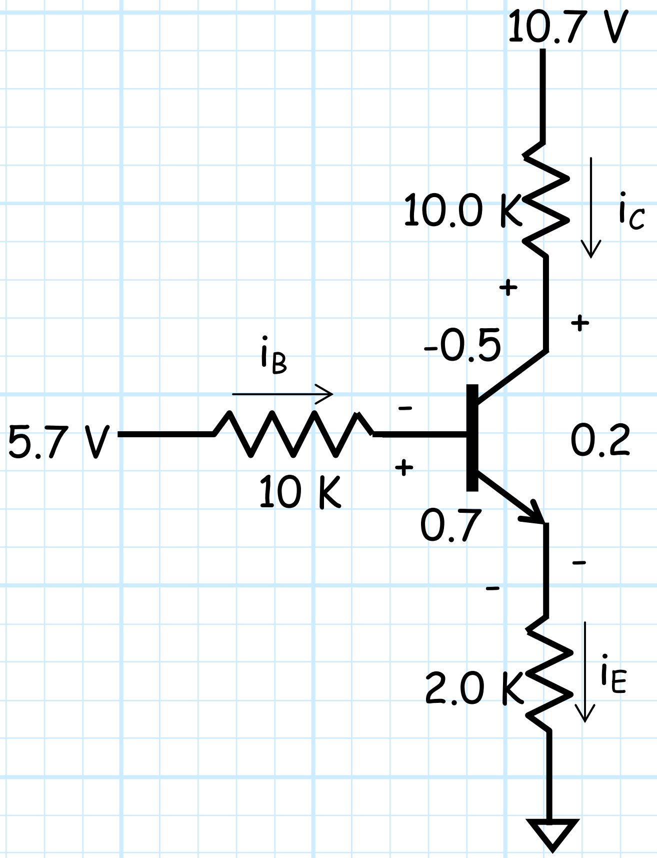
One equation and **one** unknown ! Solving, we get $\mathbf{V_E = 2.2\ V}$.

Inserting this answer into the above equations, we get:

$$V_B = 2.9\ V \qquad V_C = 2.4\ V$$

$$i_C = 0.83\ mA \qquad i_B = 0.28\ mA \qquad i_E = 1.11\ mA$$

ANALYSIS EXAMPLE 2 - Start with **KVL**



We can write the KVL equation for any **two** circuit legs:

B-E KVL:

$$5.7 - 10\, i_B - 0.7 - 2\, i_E = 0.0$$

C-E KVL:

$$10.7 - 10\, i_C - 0.2 - 2\, i_E = 0.0$$

Note the ENFORCED conditions are **included** in these KVL equations.

Simplifying, we get these **2** equations with **3** unknowns:

$$5.0 = 10\, i_B + 2\, i_E$$

$$10.5 = 10\, i_C + 2\, i_E$$

We need **one more** independent equation involving i_B, i_C, and i_E.

Try KCL !

$$i_B + i_C = i_E$$

Inserting the KCL equation into the 2 KVL equations, we get:

$$5.0 = 12\, i_B + 2\, i_C$$

$$10.5 = 2\, i_B + 12\, i_C$$

Solving, we get the **same answers** as in analysis example 1.

> **Lesson:** There are **multiple** strategies for analyzing these circuits; use the ones that you feel most **comfortable** with !

However you ANALYZE the circuit, you **must** in the end also CHECK your results.

First CHECK to see that **all** currents are **positive**:

$i_C = 0.83$ mA > 0 ✓ $i_B = 0.28$ mA > 0 ✓ $i_E = 1.11$ mA > 0 ✓

Also CHECK **collector current**:

$$i_C = 0.83 \text{ mA} < \beta\, i_B = 27.7 \text{ mA} \checkmark$$

Our solution is **correct** !!!