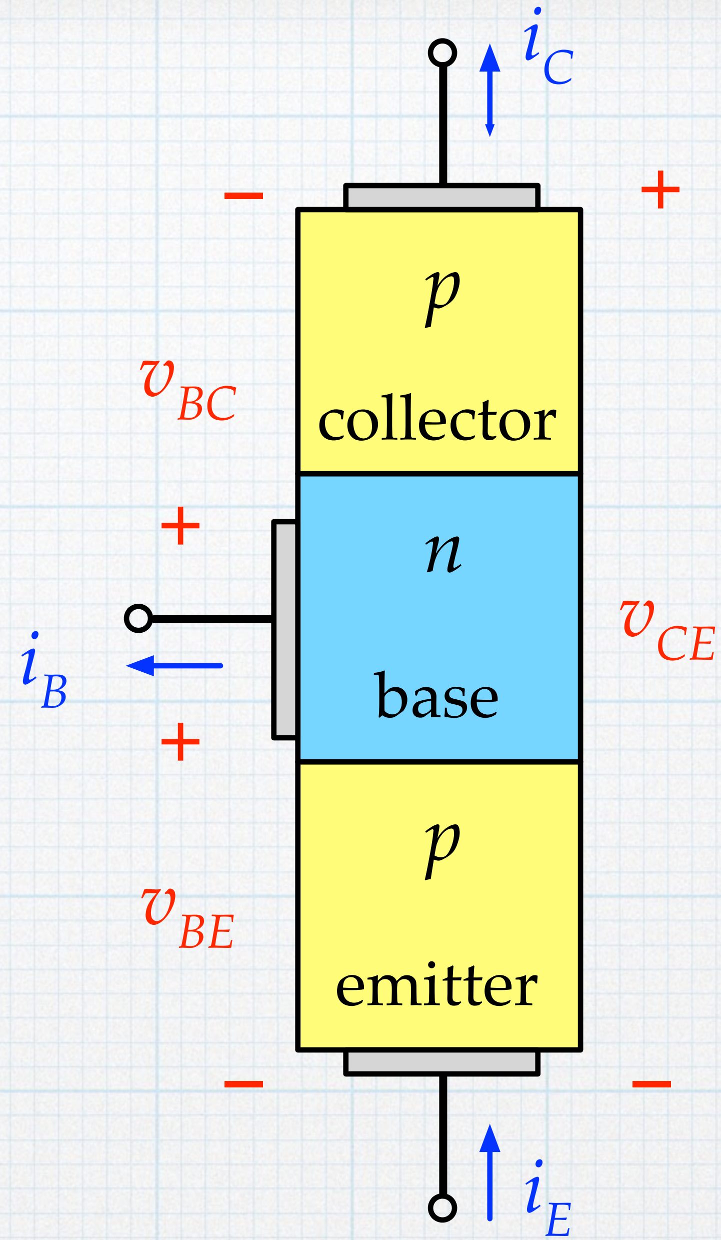
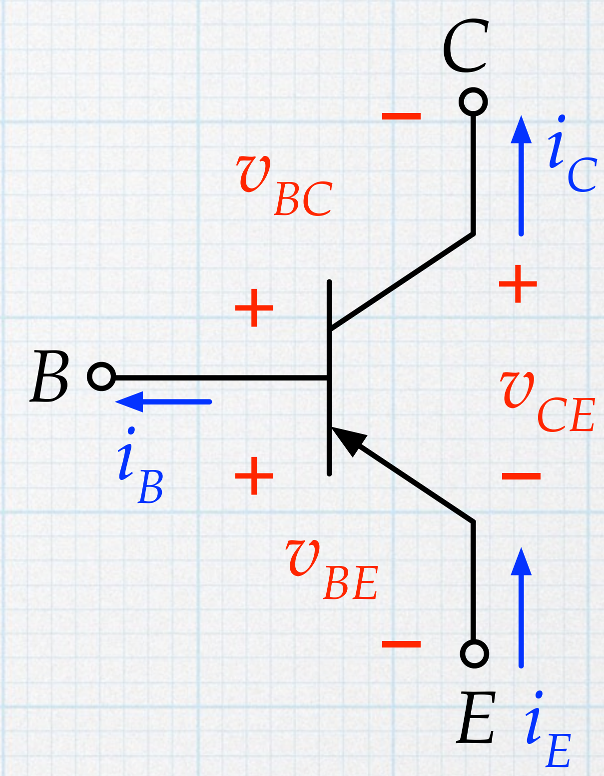
Terminology - pnp

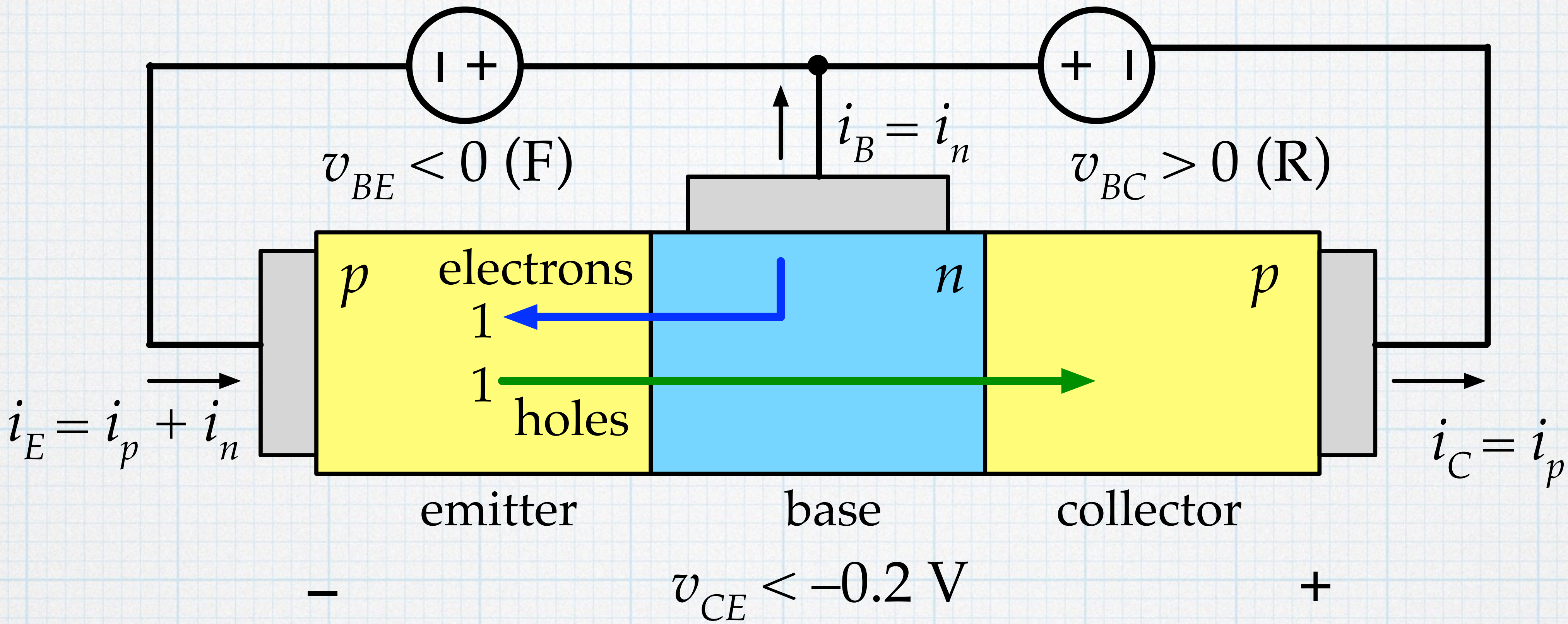
In a *pnp* BJT, the sandwich structure is reversed — the electrons and holes swap roles, and everything reverses. This can lead to lots of "sign confusion". As an example, consider forward active operation in a *pnp*.





To forward bias the base/emitter junction, the *p*-type emitter must be at a higher voltage than the *n*-type base, meaning that $v_{BE} < 0$. To reverse bias the base/collector junction, the base must be at a higher voltage than the collector: $v_{BC} > 0$ (or more correctly, greater than ≈ -0.5 V). Taken together, these requirements mean that $v_{CE} < -0.2$ V. Also, the carriers are all flowing in the opposite directions from the *npn* case — base and collector currents are "out" and emitter current is "in".

pnp - forward-active



$$i_B = i_n \approx I_{SN1} \exp\left(\frac{v_{EB}}{kT/q}\right)$$

$$i_C = i_p \approx I_{SP1} \exp\left(\frac{v_{EB}}{kT/q}\right)$$

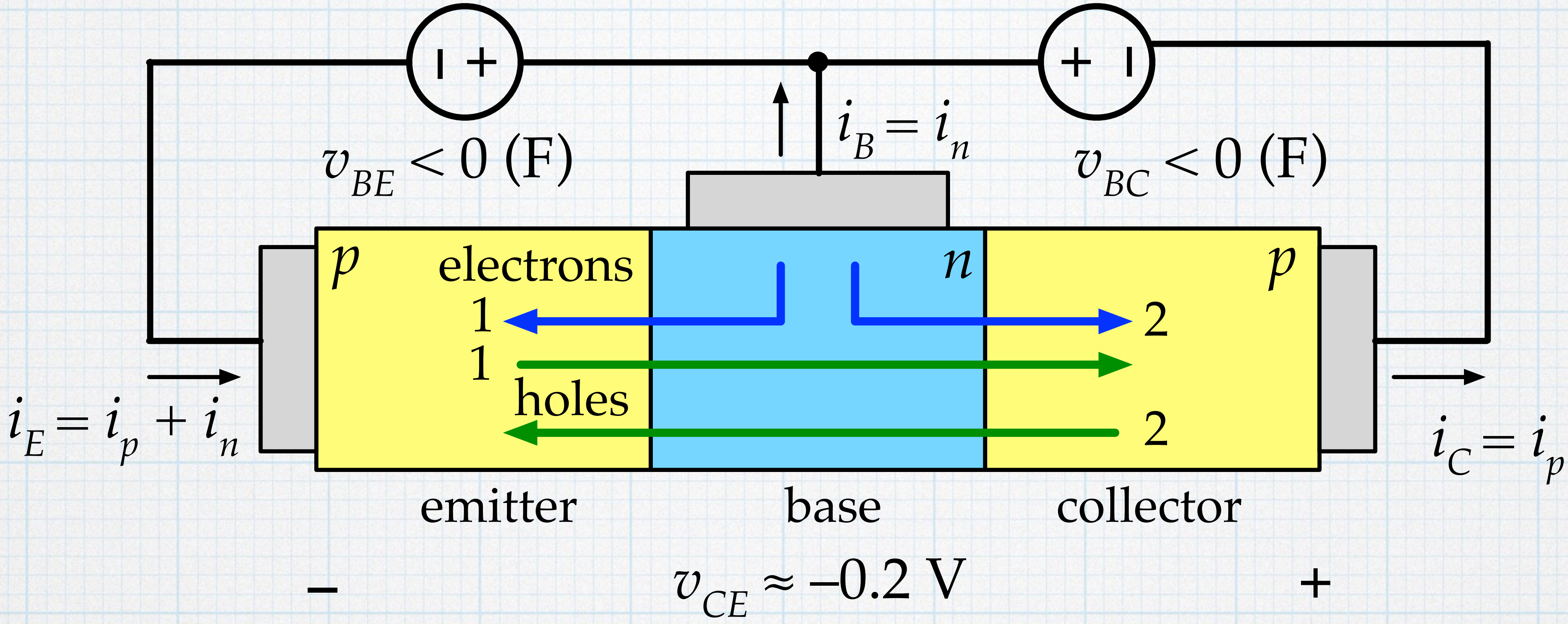
$$i_E = i_n + i_p \approx [I_{SN1} + I_{SP1}] \exp\left(\frac{v_{EB}}{kT/q}\right)$$

Everything depends on B-E forward bias.

$$\beta_F = \frac{i_C}{i_B} = \frac{I_{SP1}}{I_{SN1}}$$

Simplifying approximation: Let $v_{BE} = -0.7$ V. Find i_B (or i_E). Use $i_C = \beta_F \cdot i_B$ and $i_E = i_B + i_C = (\beta_F + 1) \cdot i_B$ from there. Check: $v_{CE} < -0.2$ V.

pnp - saturation



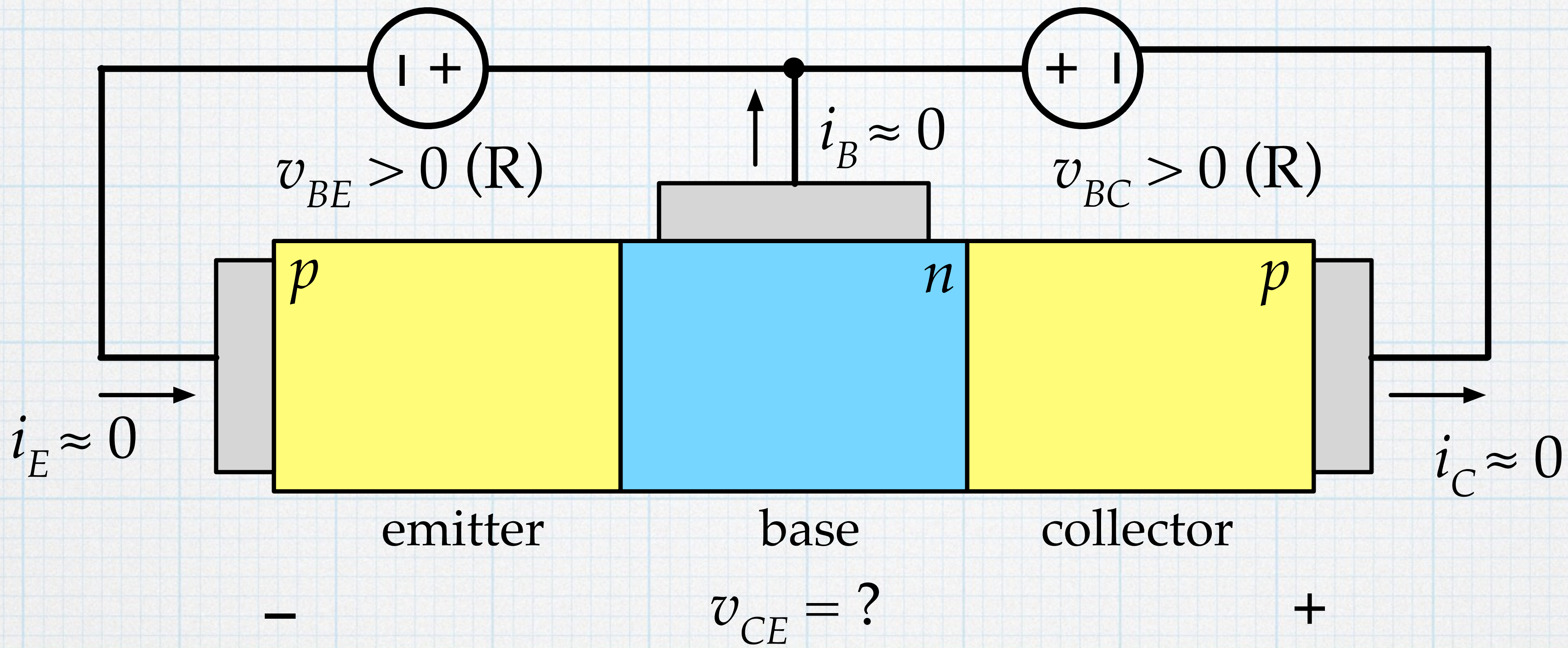
$$i_B = i_{n1} + i_{n2} \approx I_{SN1} \exp\left(\frac{v_{EB}}{kT/q}\right) + I_{SN2} \exp\left(\frac{v_{CB}}{kT/q}\right)$$

$$i_C = i_{p1} - i_{p2} - i_{n2} \approx I_{SP1} \exp\left(\frac{v_{EB}}{kT/q}\right) - [I_{SN2} + I_{SP2}] \exp\left(\frac{v_{CB}}{kT/q}\right)$$

$$i_E = i_{p1} + i_{n1} - i_{p2} \approx [I_{SP1} + I_{SN1}] \exp\left(\frac{v_{EB}}{kT/q}\right) - I_{SP2} \exp\left(\frac{v_{CB}}{kT/q}\right)$$

Simplifying approximations: Let $v_{BE} = -0.7$ V and $v_{CE} = -0.2$. Solve for the currents. Check: $i_C / i_B < \beta_F$.

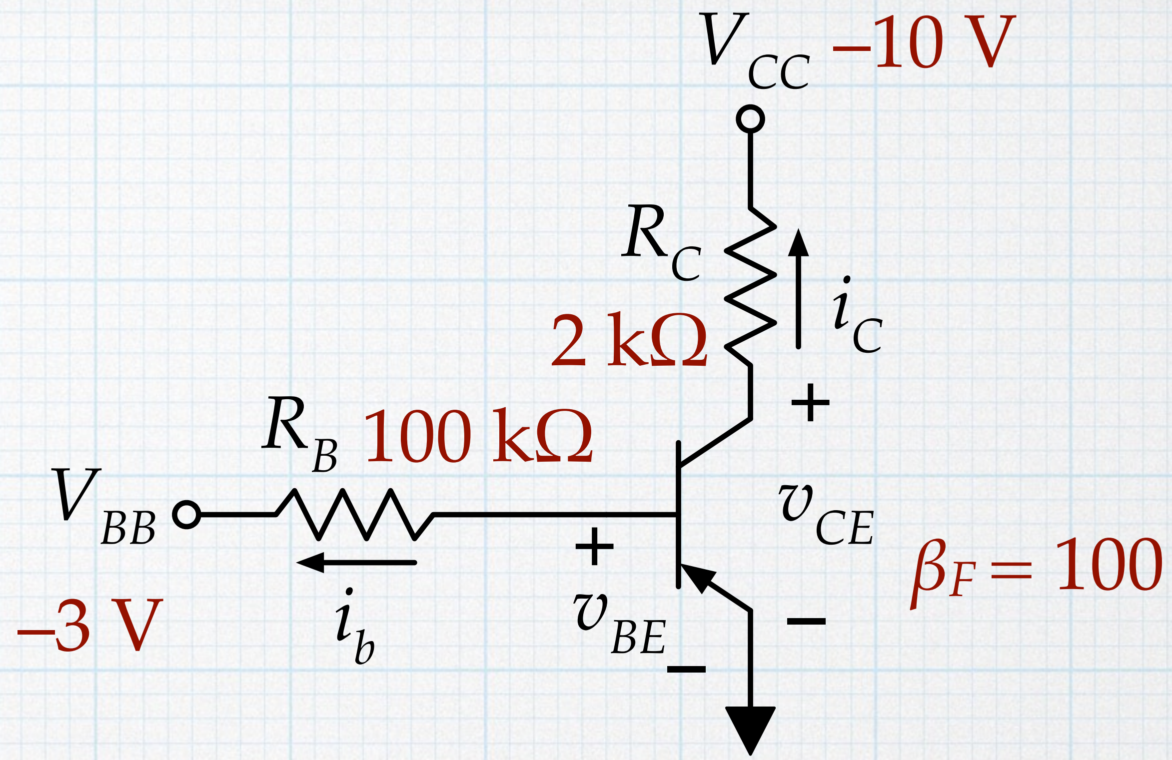
pnp - off



If both junctions are reverse-biased, then there are no currents (or very, very small reverse-leakage scale currents). The transistor is essentially an open circuit.

As in the *npn* case, we generally will not use the *pnp* in reverse-active mode.

pnp - example



Looks similar to an *npn*-type circuit, but with negative supplies.

Guess forward active:
$v_{BE} = -0.7$ V, $i_C = \beta_F i_B$.

Be careful with polarities!

$$V_{BB} + i_B R_B - v_{BE} = 0$$

$$i_B = \frac{v_{BE} - V_{BB}}{R_B}$$

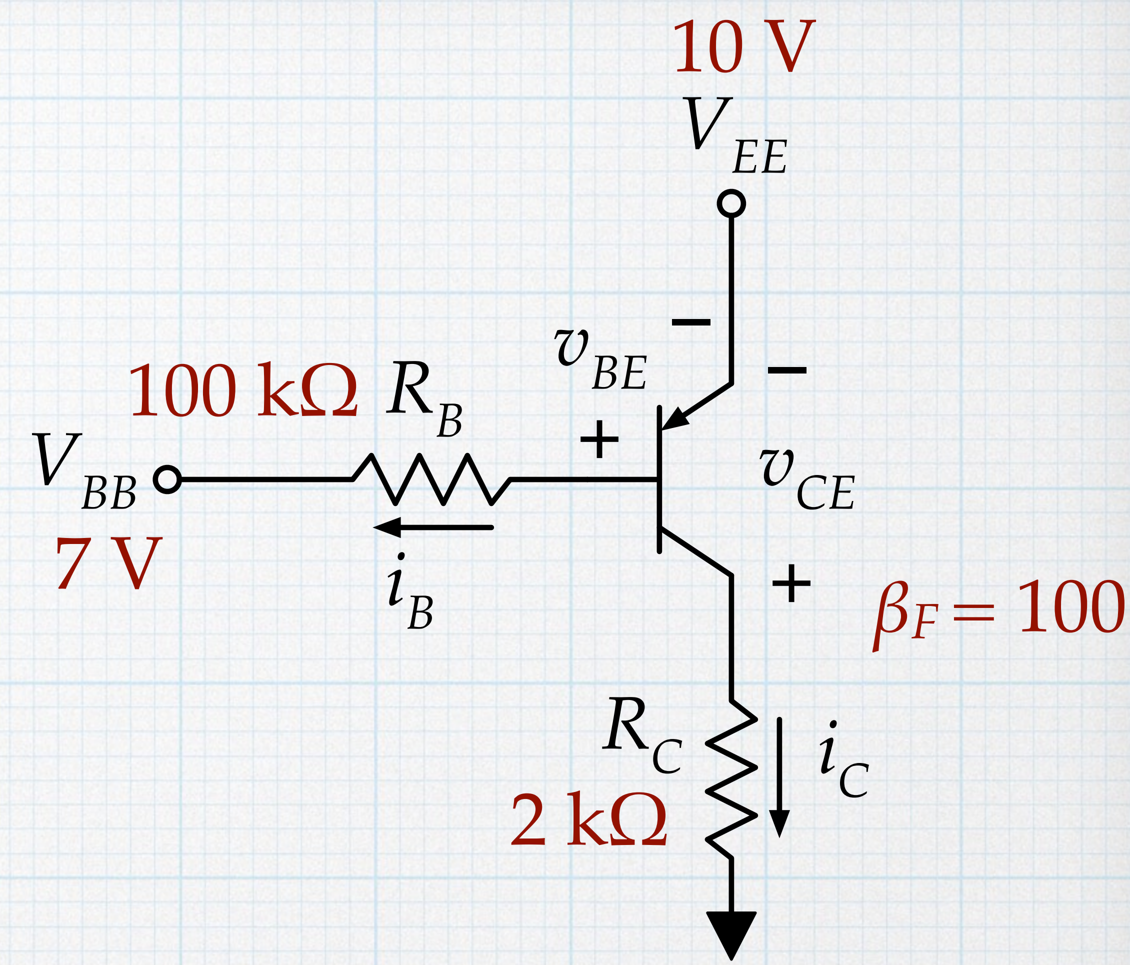
$$= \frac{-0.7\text{ V} - (-3\text{ V})}{100\text{ k}\Omega} = 23\ \mu\text{A}$$

$$i_C = \beta_F i_B = 2.3\text{ mA} \;\; \rightarrow i_E = \left(\beta_F + 1\right) i_B = (100 + 1)\,(23\mu\text{A}) = 2.32\text{ mA}$$

$$v_{CE} = V_{CC} + i_C R_C = -10\text{ V} + (2.3\text{ mA})\,(2\text{ k}\Omega) = -5.4\text{ V}$$ FA – check.

pnp - example

However, it is more typical to use positive supplies and turn the pnp "upside down".



Guess forward active:
$v_{BE} = -0.7$ V, $i_C = \beta_F i_B$.

Be even more careful with polarities!

$$V_{BB} + i_B R_B - v_{BE} = V_{EE}$$

$$i_B = \frac{V_{EE} - V_{BB} + v_{BE}}{R_B}$$

$$= \frac{10\text{ V} - 7\text{ V} + (-0.7\text{ V})}{100\text{ k}\Omega} = 23\ \mu\text{A}$$

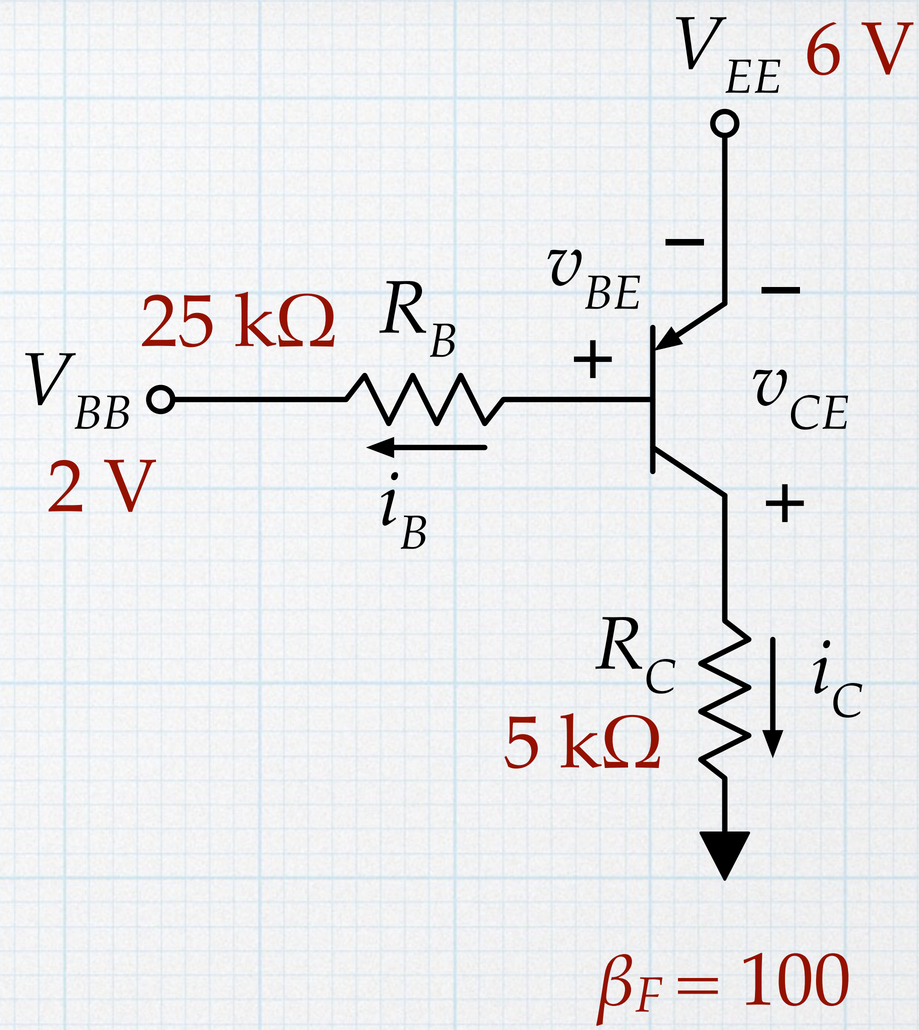
$$i_C = \beta_F i_B = 2.3\text{ mA} \quad \rightarrow i_E = \left(\beta_F + 1\right) i_B = (100 + 1)\,(23\mu\text{A}) = 2.32\text{ mA}$$

$$v_{CE} = i_C R_C - V_{EE} = (2.3\text{ mA})\,(2\text{ k}\Omega) - 10\text{ V} = -5.4\text{ V}$$ FA – check.

pnp - example

Looks similar to previous example.

Guess forward active: v_{BE} = –0.7 V, $i_C = \beta_F i_B$.



$$V_{BB} + i_B R_B - v_{BE} = V_{EE}$$

$$i_B = \frac{V_{EE} - V_{BB} + v_{BE}}{R_B}$$

$$= \frac{6\text{ V} - 2\text{ V} + (-0.7\text{ V})}{25\text{ k}\Omega} = 132\ \mu\text{A}$$

$i_C = \beta_F i_B$ = (100)(0.132 mA) = 13.2 mA.

$v_{CE} = i_C R_C - V_{EE}$ = (13.2 mA.)(5 kΩ) – 6 V = +60 V.   Noooo!

The *pnp* must be in saturation, so that $v_{CE} \approx$ –0.2 V.

The base current calculation is unchanged: i_B = 132 μA.

$$i_C = \frac{V_{EE} + v_{CE}}{R_C} = \frac{6\text{ V} + (-0.2\text{ V})}{5\text{ k}\Omega} = 1.16\text{ mA}$$

$i_E = i_C + i_B$ = 1.29 mA i_C / i_B = (1.16 mA)/0.132 mA) = 8.8

pnp - example

One more time, guess forward active:
$v_{BE} = -0.7\text{ V}$, $i_E = (\beta_F+1)i_B$.

Around the base-emitter loop:

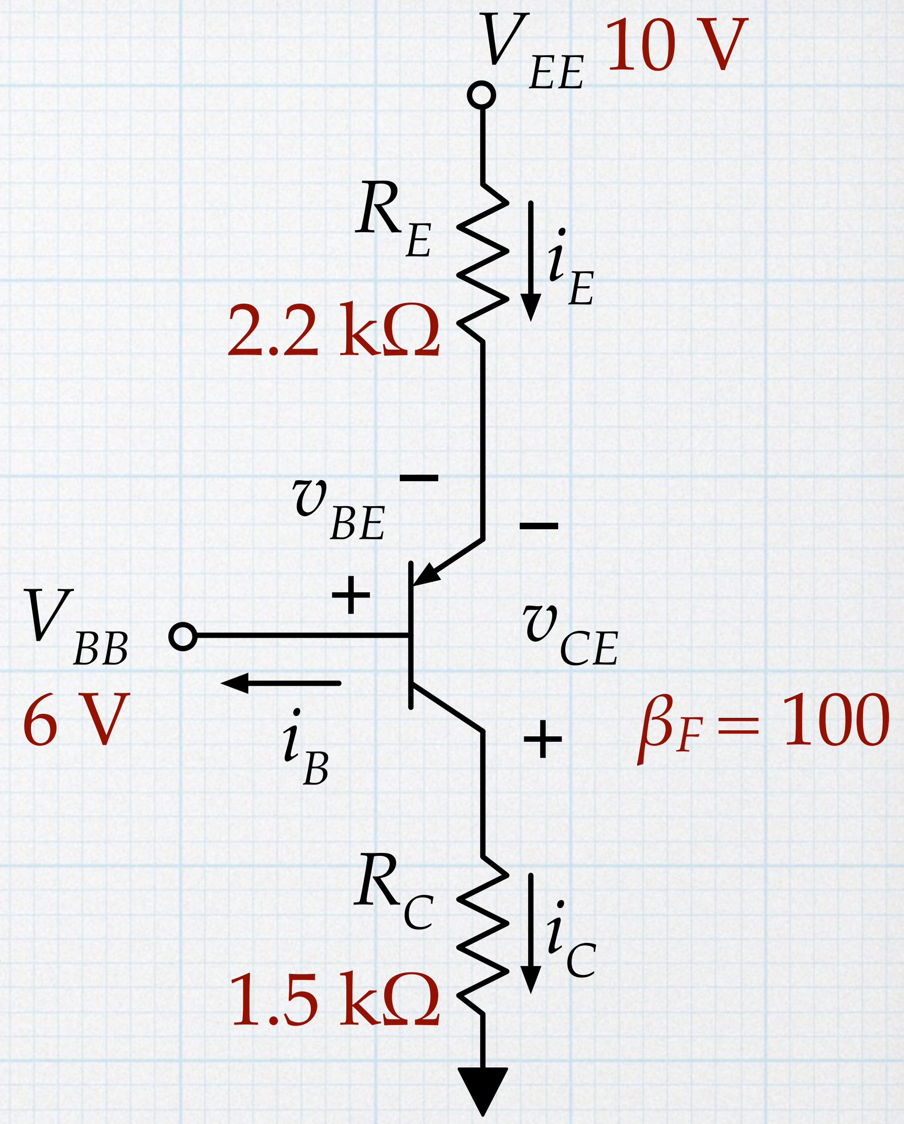
$$V_{BB} - v_{BE} + i_E R_E = V_{EE}.$$

$$i_E = \frac{V_{EE} - V_{BB} + v_{BE}}{R_E}$$

$$= \frac{10\text{ V} - 6\text{ V} + (-0.7\text{ V})}{2.2\text{ k}\Omega} = 1.5\text{ mA}$$

$$i_B = \frac{i_E}{\beta_F + 1} = \frac{1.5\text{ mA}}{101} = 14.85\ \mu\text{A}$$

$$i_C = \beta_F i_B = (100)(14.85\ \mu\text{A}) = 1.49\text{ mA}$$



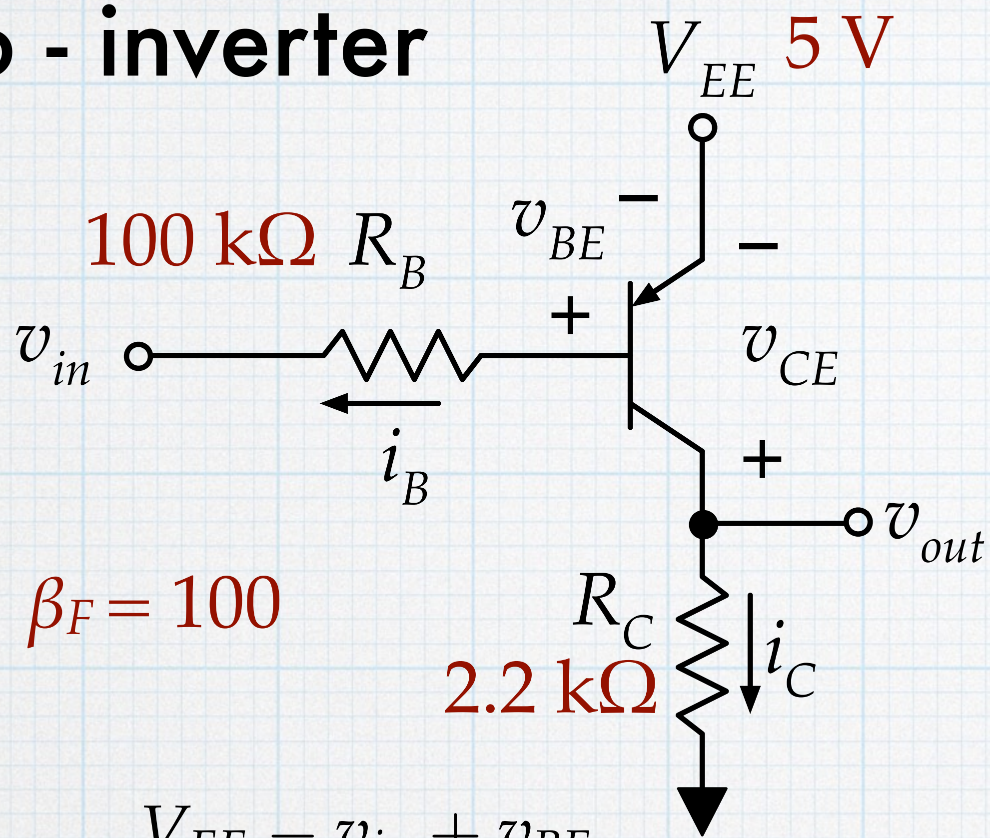
Check:

$$V_{EE} - i_E R_E + v_{CE} - i_C R_C = 0.$$

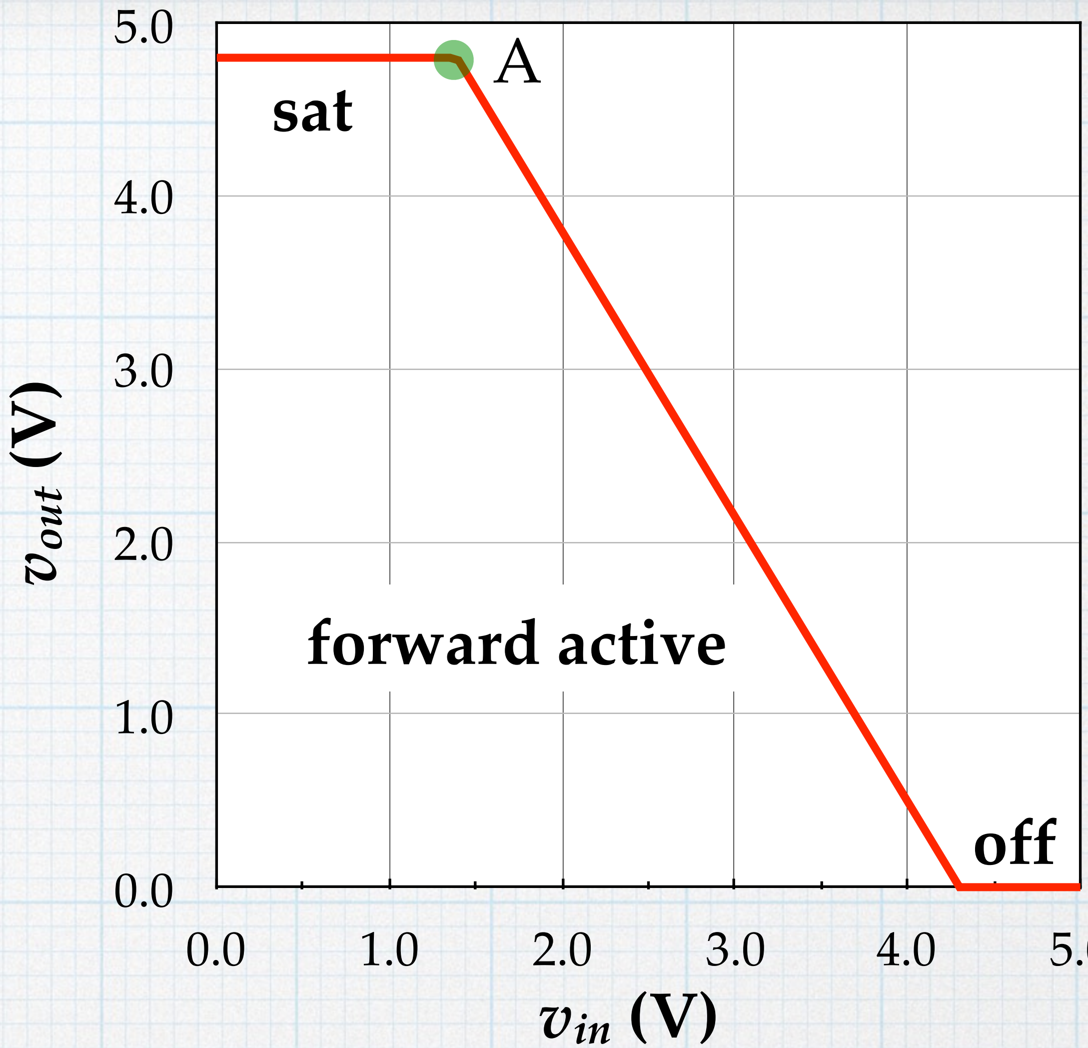
$$v_{CE} = i_C R_C + i_E R_E - V_{EE} = (1.49\text{ mA})(1.5\text{ k}\Omega) + (1.50\text{ mA})(2.2\text{ k}\Omega) - 10\text{ V}$$

$= -4.465$ V → Yes! In forward active.

pnp - inverter



$$i_B = \frac{V_{EE} - v_{in} + v_{BE}}{R_B}$$



- If the *pnp* is in saturation, then $v_{out} = V_{EE} + v_{CE}(\text{sat}) \approx V_{EE} - 0.2$ V. This happens when v_{in} is small, such that $V_{EE} - v_{in}$ is big.
- If the *pnp* is in forward active, then $v_{out} = i_C R_C = \beta_F R_C i_B$. The output voltage drops as the input voltage increases.
- If the *pnp* is off, then all currents are 0, and $v_{out} = 0$. This happens when v_{in} is big, such that $V_{EE} - v_{in} < 0.7$ V.
- Transition from sat to FA (pt. A) when $v_{in} = v_A$, where v_A satisfies:

$$V_{EE} - v_{CE}\,(sat) = \beta_F R_C \frac{V_{EE} - v_A + v_{BE}}{R_B}$$