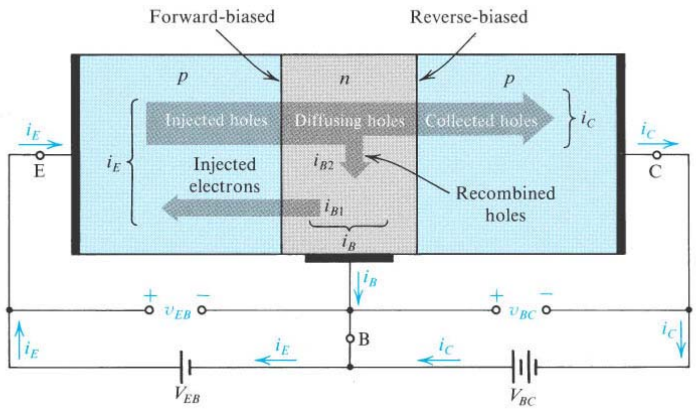
Lecture 11: PNP Bipolar Junction Transistor Physical Operation. BJT Examples.

The second type of BJT is formed from *pnp* doped regions as

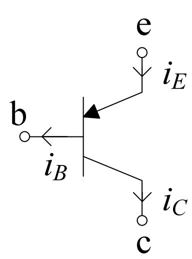


(Fig. 6.10)

Differences between *pnp* and *npn* BJTs are:

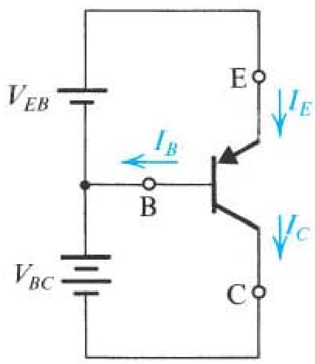
- Biasing voltages are applied oppositely to the *npn*, though still forward biasing EBJ and reverse biasing the CBJ for active mode operation, for example.
- Current is primarily composed of holes (in the *p* type regions) rather than electrons as in the *npn* BJT.
- The current direction conventions are i_E into the emitter while i_C and i_B are out from the device.

The circuit symbol for the *pnp* BJT is



Once again, the filled arrow is always located on the emitter and helps us to remember the direction of the emitter current. Notice that the currents are pointed in **opposite directions** compared to the *npn* BJT.

For biasing in the active mode, a possible circuit is



(Fig. 6.13b)

As with the *npn*, for the *pnp* BJT in the active mode and with the current convention shown above

$$i_C = \alpha i_E \tag{6.7),(1}$$

$$i_B = (1-\alpha) i_E \tag{2}$$

$$i_C = \beta i_B \tag{6.2),(3}$$

$$\beta = \frac{\alpha}{1-\alpha} \tag{6.10),(4}$$

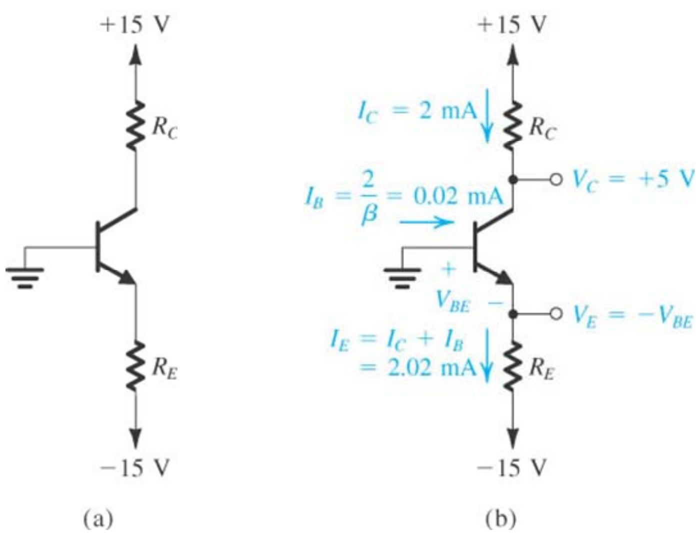
$$\alpha = \frac{\beta}{\beta+1} \tag{6.8),(5}$$

Consequently, we need to only memorize this one set of equations for use with both *npn* and *pnp* BJTs, plus the current conventions for these two BJTs.

Examples

We'll now consider a few examples of the DC analysis of *npn* and *pnp* BJT circuits.

Example N11.1 (text Example 6.2). Design the following circuit so that $I_C = 2$ mA and $V_C = 5$ V. For this particular transistor, $\beta = 100$ and $V_{BE} = 0.7$ V at $I_C = 1$ mA.



(Fig. 6.15)

The "design" of this circuit is to determine the R_C and R_E that provide the specified I_C and V_C.

For I_C = 2 mA, then

$$\frac{15 - V_C}{R_C} = 2 \text{ mA} \quad \text{or} \quad R_C = \frac{15-5}{2\times 10^{-3}} = 5 \text{ k}\Omega.$$

We're assuming that the transistor is in the active mode with the EBJ forward biased and the CBJ reversed biased.

For the forward biased EBJ junction,

$$i_C = I_S e^{\frac{v_{BE}}{V_T}} \tag{6.1),(6}$$

It's given that at $I_C = 1$ mA, $V_{BE} = 0.7$ V. What is V_{BE} when $I_C = 2$ mA? Using (6) for two different i_C and v_{BE} we find that

$$\frac{i_{C1}}{i_{C2}} = e^{\frac{v_{BE1} - v_{BE2}}{V_T}} \quad \text{or} \quad \frac{v_{BE1} - v_{BE2}}{V_T} = \ln\left(\frac{i_{C1}}{i_{C2}}\right)$$

Therefore,

$$v_{BE2} = v_{BE1} + V_T \ln\left(\frac{i_{C1}}{i_{C2}}\right) \tag{7}$$

For this particular case,

$$V_{BE2} = 0.7 + 25\times 10^{-3} \ln\left(\frac{2}{1}\right) = 0.717 \text{ V}$$

This is not much of an increase from 0.7 V, which is what we typically observe when the BJT is in the active mode. (It's common to assume $V_{BE} = 0.7$ V when a BJT operates in the active mode.)

Consequently, $$V_E = -0.717 \text{ V}$$

Next, $$i_C = \alpha i_E \quad \Rightarrow \quad i_E = \frac{i_C}{\alpha} = \frac{\beta + 1}{\beta} i_C$$

then $$I_E = \frac{100+1}{100} \cdot 2 \text{ mA} \quad \text{or} \quad I_E = 2.02 \text{ mA}$$

We can use this emitter current to select the proper resistor R_E:

$$I_E = \frac{V_E - (-15 \text{ V})}{R_E}$$

or $$R_E = \frac{-0.717+15}{2.02 \times 10^{-3}} = 7.07 \text{ k}\Omega$$

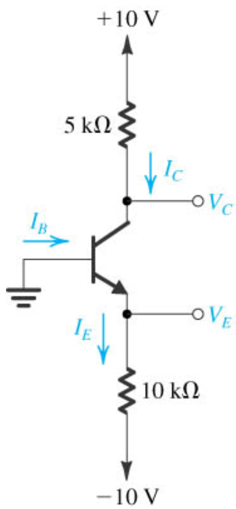
That completes the design.

One last thing, though. Notice how small the base current I_B is relative to I_C and I_E:

$$I_B = I_C - I_E = 20 \text{ μA}.$$

This is typical of BJTs operating in the active mode.

Example N11.2 (text Exercise 6.13). Determine I_E, I_B, I_C, and V_C in the circuit below if $\beta = 50$ and $V_E =$ -0.7 V.



(Fig. E6.13)

Because V_B = 0, then the given V_E means the BJT may be operating in the active mode since V_{BE} = 0.7 V. (It could also be operating in the saturation mode.) We'll assume active mode operation for now, and confirm this assumption when we're finished.

(i) Compute I_E.

$$I_E = \frac{-0.7-(-10)}{10,000} = 0.93 \text{ mA}$$

(ii) Compute I_C.

$$I_C = \alpha I_E = \frac{\beta}{\beta+1} I_E = \frac{50}{51}\cdot 0.93 \text{ mA} = 0.91 \text{ mA}$$

(iii) Compute I_B.

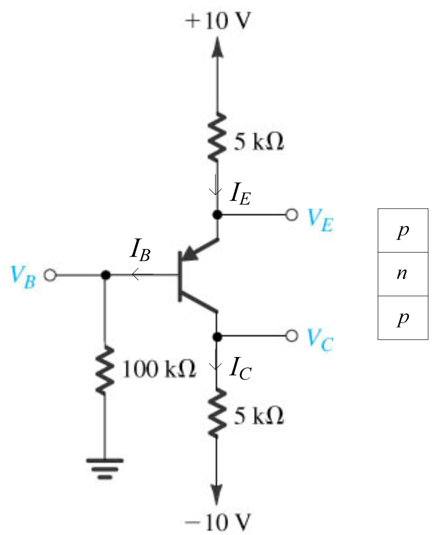
$$I_C = \beta I_B \quad \Rightarrow \quad I_B = \frac{I_C}{\beta} = \frac{0.91 \text{ mA}}{50} = 18.2\ \mu\text{A}$$

(iv) Compute V_C.

$$V_C = 10 - 5,000 \cdot I_C = 5.45 \text{ V}$$

Note that since $V_{CB} = V_C - V_B = 5.45 - 0 = 5.45$ V is greater than zero (thus reverse biasing the CBJ) and the EBJ is forward biased, the *npn* BJT is indeed operating in the active mode, as assumed.

Example N11.3 (text Exercise 6.14). Given that $V_B = 1.0$ V and $V_E = 1.7$ V, determine α (and β) for the transistor in the circuit below. Also calculate V_C.



(Fig. E6.14)

Because $V_{EB} = V_E - V_B = 0.7$ V, the *pnp* transistor may be operating in the active mode, which is what we will assume.

(i) Determine α and β. We'll use the relationships $i_C = \alpha i_E$ and $i_C = \beta i_B$ to determine α and β.

From the circuit, $$I_B = \frac{V_B}{100 \times 10^3} = \frac{1.0}{100 \times 10^3} = 10\ \mu\text{A}$$

and $$I_E = \frac{10-1.7}{5,000} = 1.66 \text{ mA}$$

Using KCL:

$$I_C = I_E - I_B = 1.66\times10^{-3} - 10\times10^{-6} = 1.65 \text{ mA}.$$

Therefore,

$$\beta = \frac{I_C}{I_B} = \frac{1.65\times10^{-3}}{10\times10^{-6}} = 165$$

and $$\alpha = \frac{I_C}{I_E} = \frac{1.65\times10^{-3}}{1.66\times10^{-3}} = 0.994$$

Alternatively, $$\alpha = \frac{\beta}{\beta+1} = 0.994$$

(ii) Compute V_C.

$$V_C = -10 \text{ V} + 5,000\cdot I_C = -10 \text{ V} + 5,000\cdot 1.65\times10^{-3}$$

or $$V_C = -1.75 \text{ V}.$$

Note that this V_C means that the CBJ is reversed biased by the voltage $1.0-(-1.75)=2.75$ V. Hence, the active mode operation for the *pnp* BJT is the proper assumption since we've already determined that the EBJ is forward biased.