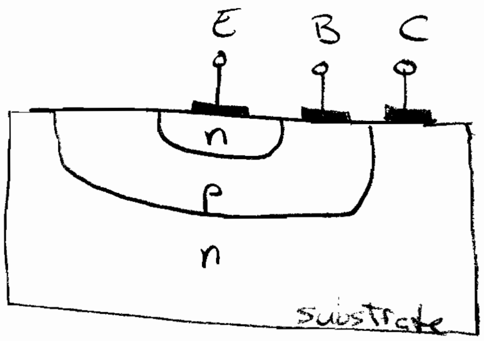
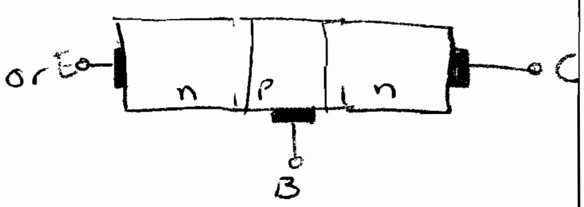
① a) BJT Cross Section



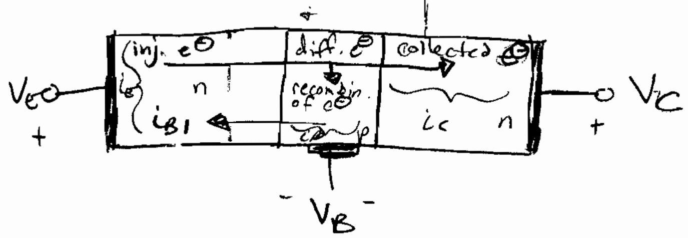
planar process model



crude model

b) In a BJT, there is always some thermal drift current across the pn junctions, but it is very small and will be neglected in the description below.

Forward bias on the emitter-base junction causes current to flow across that junction. Some electrons diffuse to the junction (CB) and are swept across.

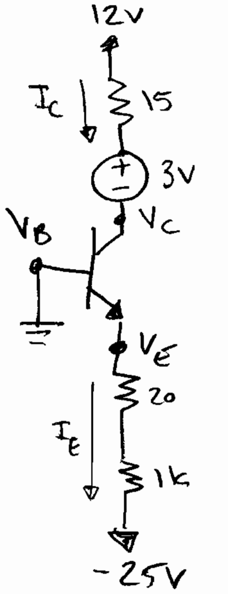


Forward Bias V_{BE} causes an exponential current to flow in the i_C terminal. Collector current is independent of the collector voltage as long as V_{BC} is reverse biased.

② 1) Sat,
2) Active
3) Active / cutoff edge
4) Active
5) Cutoff
6) Active
7) Sat / Active Edge
8) Cutoff

(3) $|V_{BE}| = 0.7 \quad \beta = 100$

a)



$V_B = 0V$

$V_C = 12V - I_C(15\Omega) - 3V = 9V - I_C(15\Omega)$

$V_E = -25V + I_E(1020\Omega)$

Assume Active

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

$\therefore V_C = 9V - I_E \cdot \frac{100}{101} 15\Omega$

Also from active mode $V_{BE} \cong 0.7V$

$\therefore V_E \cong -0.7V$

$\Rightarrow \frac{24.3V}{1020\Omega} = I_E = 23.8 \text{ mA}$

$I_C = \frac{I_E}{\alpha} = \frac{I_E(\beta+1)}{\beta} = 24.1 \text{ mA}$

$I_B = \frac{I_C}{\beta} = 241 \mu A$

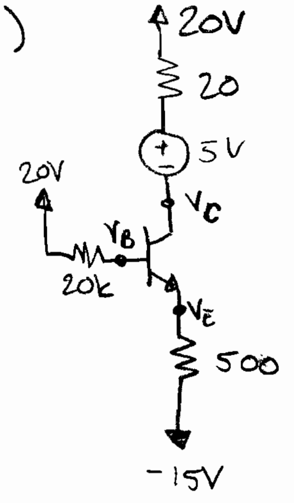
$I_B = 241 \mu A$	$V_B = 0V$
$I_C = 24.1 mA$	$V_C = 8.64V$
$I_E = 23.8 mA$	$V_E = -0.724$

$V_{BE} = 0.724 \approx 0.7$

$V_{CE} = 9.36 > 0.7$

✓ active on

b)



Equivalent Circuit

Assume Active On

$V_C = 15V - 20I_C$

$V_E = -15V + 500 I_E = -15V + \frac{500 I_C}{\alpha}$

$V_B = 20V - 20k I_B = 20V - \frac{20k\, I_C}{\beta}$

$V_{BE} = 0.7 = 35V - I_C\left(\frac{20k}{\beta} + \frac{500}{\alpha}\right)$

$\frac{34.3}{\frac{20k}{\beta} + \frac{500}{\alpha}} = I_C = 48.7\,mA$

$I_B = 487\,\mu A \quad I_E = 49.2\,mA$

$V_C = 14.0V \quad V_E = 9.59V \quad V_B = 10.3V$

$V_{BE} = 10.3 - 9.59 = 0.71 \approx 0.7$ ✓

$V_{CE} = 14.0 - 10.3 = 3.7 > 0.7$ ✓ Active on

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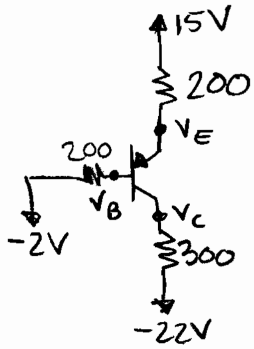
c)



Equivalent Circuit

Assume Active On (pnp)

$15V - I_E(200) = V_E$

$-2V + I_B(200) = V_B$

$-22V + I_C(300) = V_C$

$V_{EB} = 0.7 = 17V - \frac{I_C}{\alpha}(200) + \frac{I_C}{\beta}(200)$

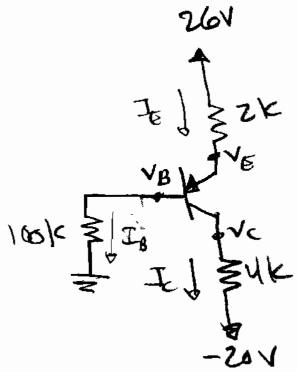
$I_C = \frac{0.7 - 17V}{-200\left(\frac{1}{\alpha} - \frac{1}{\beta}\right)} = 79.9\,mA = I_C$

$I_B = 799\,\mu A \quad I_E = 80.7\,mA$

$V_E = -1.14 \quad V_B = -1.84 \quad V_C = 1.97$

$|V_{EB}| = 0.7 \quad |V_{CB}| \cong 3V > 0.7$ Active on.

d)



Equiv. Circuit

Assume Active on.

$V_B = I_B(100k)$

$V_E = 26V - I_E(2k)$

$V_C = -20V + I_C(4k)$

$V_E - V_B = 0.7\ V$

$\beta I_B - I_C = 0A$

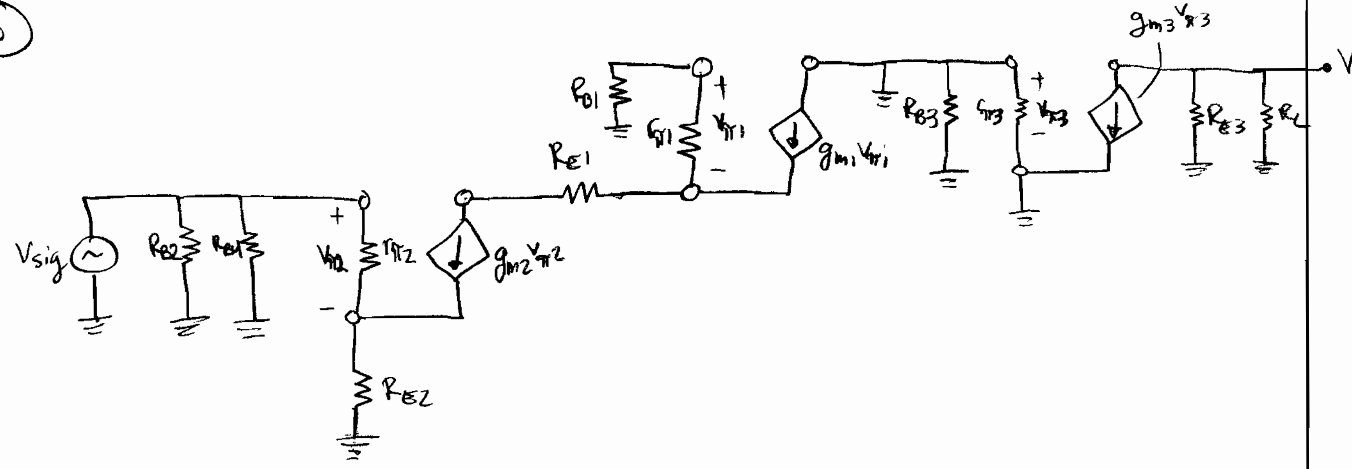
$\frac{\beta}{\beta+1} I_E - I_C = 0A$

$V_E = 9.08\ V$	$I_E = 8.5mA$
$V_B = 8.38\ V$	$I_B = 84\ \mu A$
$V_C = 13.51\ V$	$I_C = 8.4mA$

$V_{EB} = 0.7V$ and $|V_{CE}| > 0.7$ ✓

Active on ✓

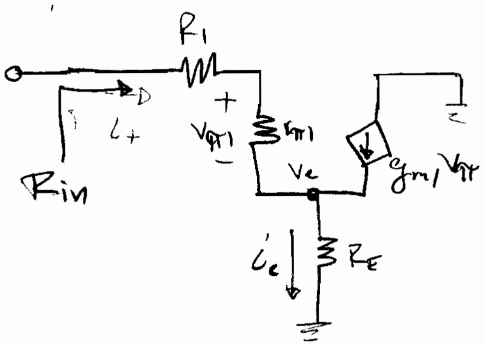
(5)



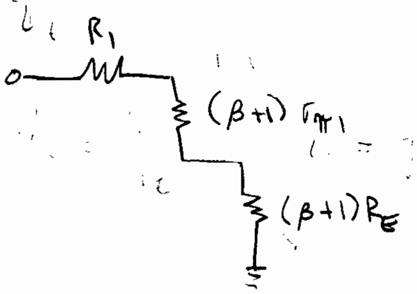
(6) a) $r_{\pi1} = \frac{V_T}{I_{B1}} = \frac{25mV \cdot 20}{1mA} = \boxed{500\,\Omega}$

$$g_{m2} = \frac{I_{C2}}{V_T} = \frac{2mA}{25mV} = \boxed{80\,m\Omega^{-1}}$$

b)



Use Resistance Reflection



$$\boxed{R_{in} = R_1 + (\beta+1)(r_{\pi1} + R_E)}$$

c) $$\frac{V_o}{V_{\pi 2}} = -g_{m2} R_L$$

$$\frac{V_{\pi 2}}{V_{\pi 1}} = \frac{-g_{m1} R_3}{R_3 + r_{\pi 2}}$$

$$I_{in} = \frac{V_{sig}}{R_{in}}$$

$$V_{\pi 1} = r_{\pi 1} I_{in} = \frac{r_{\pi 1} V_{sig}}{R_{in}}$$

$$\frac{V_{sig}}{V_{\pi 1}} = \frac{R_{in}}{r_{\pi 1}}$$

$$\frac{V_{sig}}{V_o} = \frac{R_{in}}{r_{\pi 1}} \left(\frac{-g_{m1} R_3}{R_3 + r_{\pi 2}} \right) \left(-g_{m2} R_L \right) = \boxed{\frac{g_{m1} g_{m2} R_{in} R_3 R_L}{r_{\pi 1} (R_3 + r_{\pi 2})}}$$