5.62

$I_b = 175\mu A$ $I_S = 4\times10^{-16} A$, $\beta_F = 50$, $\beta_R = 0.5$

a) $V_{CE} = 3V$

$$I_e = I_S\left[\exp\left(\frac{V_{BE}}{V_T}\right) - \cancel{\exp\left(\frac{V_{BC}}{V_T}\right)}\right] + \frac{I_S}{\beta_F}\left(\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right)$$

V_{BC} should be negative because V_{CE} will be on the order of the p-n junction on voltage. Therefor the V_{BC} term in I_e can be neglected.

in forward active, $I_e = (1+\beta_F) I_B$
$= (51)(175\mu A)$
$I_e = 8.93\, mA$

$$8.93mA = I_S\left[\exp\left(\frac{V_{BE}}{0.025V}\right)\right] + \frac{I_S}{50}\left(\exp\left(\frac{V_{BE}}{0.025}\right) - 1\right)$$ w/ I_S as above

Solve for V_{BE}

$\boxed{V_{BE} = 0.768\, V}$

b)
① $0 = i_c = I_S\left[\exp\left(\frac{V_{BE}}{V_T}\right) - \exp\left(\frac{V_{BC}}{V_T}\right)\right] - \frac{I_S}{\beta_R}\left[\exp\left(\frac{V_{BC}}{V_T}\right) - 1\right]$

② $175\mu A = i_b = \frac{I_S}{\beta_F}\left(\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right) - \frac{I_S}{\beta_R}\left(\exp\left(\frac{V_{BC}}{V_T}\right) - 1\right)$

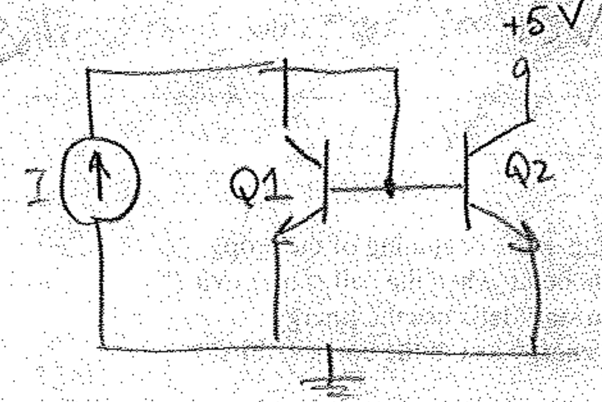
Rearrange ② to get ③ ③ $\exp\left(\frac{V_{BC}}{V_T}\right) = \frac{\beta_R}{I_S}\left(i_b - \frac{I_S}{\beta_F}\left(\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right) - \frac{I_S}{\beta_R}\right)$

Plug ③ into ① and solve for V_{BE}, $\boxed{V_{BE} = 0.680\, V}$

$V_{CEsat} = V_{BE} + V_{CB}$ when BJT in saturation (BJT saturation different than MOSFET saturation) like MOSFET triode.

Solve ③ for V_{BC}, substituting for $V_{BE} = 0.680V$,
$V_{BC} = 0.652V$. $V_{CE} = V_{CB} + V_{BE} = -V_{BC} + V_{BE} = -0.652 + 0.680 = \boxed{0.0275V}$
V_{CEsat}.

5.65



$I = 25\mu A$, $\beta_F = 60$

Because $V_{CE1} = V_{BE1}$ and $V_{BE1} > 0$, Q1 is in forward active
Because $V_{CE2} > V_{BE2}$ and $V_{BE2} > 0$, Q2 is also forward active

In forward active $I_B \approx \frac{I_S}{\beta_F} \exp\left(\frac{V_{BE}}{V_T}\right)$. Therefore, Because Q1 and Q2 are identical, and $V_{BE1} = V_{BE2}$, $I_{B1} \approx I_{B2}$

~~Now,~~ $\cancel{I = I_{C1} + I_{B1} + I_{B2}}$

Also, in forward active, $I_C = \beta_F I_B$, so $I_{C1} \approx I_{C2}$

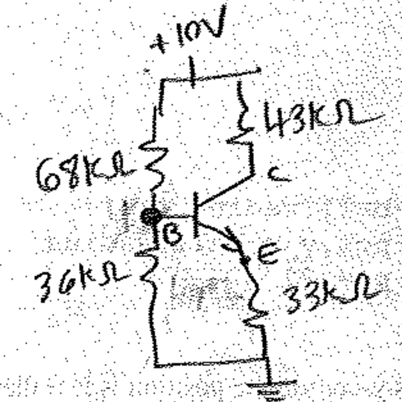
so

$$I = I_{C1} + I_{B1} + I_{B2}$$
$$I = I_{C2} + \frac{I_{C2}}{\beta_F} + \frac{I_{C2}}{\beta_F} = I_{C2}\left(\frac{\beta_F + 2}{\beta_F}\right)$$
$$I_{C2} = I\left(\frac{\beta_F}{\beta_F + 2}\right) = 25\mu A\left(\frac{60}{62}\right)$$
$$\boxed{I_{C2} = 24.2\mu A}$$

5.93 part a

$V_{BE} = 0.7V$

$\beta_F = 50$



Transistor most likely in forward active.

To find base current, use Loop #1

① $V_B = V_{BE} + I_e(38k\Omega) = V_{BE} + (\beta+1)I_B(38k\Omega)$

$\frac{10V - V_B}{68k\Omega} = \frac{V_B}{36k\Omega} + I_B$ (Node equation at Base)

② $I_B = \frac{10V}{68k} - \frac{V_B}{68k} - \frac{V_B}{36k} = \frac{10V}{68k} - V_B\left(\frac{1}{68k} + \frac{1}{36k}\right)$

substitute ② into ①, solve for V_B,

$\boxed{V_B = 3.43V}$ substitute in ②, calculate $\boxed{I_B = 1.41\mu A}$

$V_E = V_B - V_{BE} = 3.43V - 0.7V = \boxed{2.73V = V_E}$

$I_C = \beta I_B = 50(1.41\mu A) = \boxed{70.4\mu A = I_C}$

$I_e = (\beta+1)I_B = 51(1.41\mu A) = \boxed{71.8\mu A = I_e}$

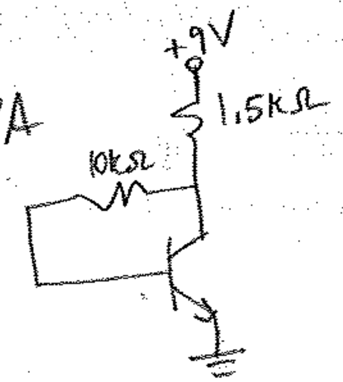
$V_C = 10V - I_C(43k\Omega) = \boxed{6.97V = V_C}$

$V_C - V_E > 0$, so forward active is verified.

5.96 part (a)

$\beta_F = 40$

use $I_S = 10^{-16}$ A from front



$$9V + (I_C + I_B)\,1.5k\Omega + I_B\,(10k\Omega) + V_{BE} = 0$$

① $9V + (1+\beta) I_B (1.5k\Omega) + I_B (10k\Omega) + V_{BE} = 0$

In forward active ② $I_B \approx \frac{I_S}{\beta} \exp\left(\frac{V_{BE}}{V_T}\right)$ — use $V_T = 0.025$ V for room temp (~ 290 K)

plug ② into ①, solve for I_B

$\boxed{I_B = 115\,\mu A}$

plug I_B into ①, solve for V_{BE},

$\boxed{V_{BE} = 0.786V}$

$I_C = \beta I_B = (40)(115\mu A) = \boxed{4.59\,mA = I_C}$

$I_E = (\beta+1) I_B = (41)(115\mu A) = \boxed{4.71\,mA = I_E}$

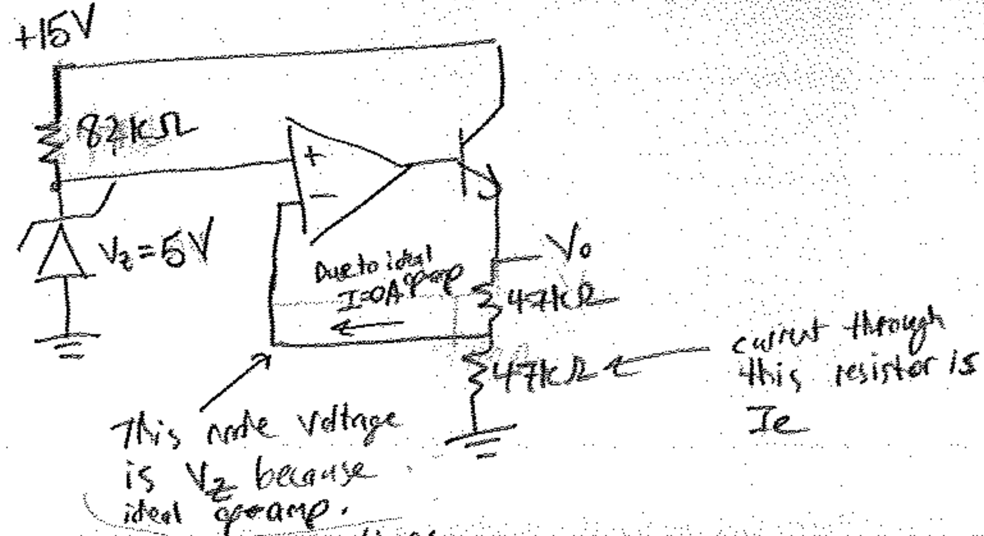
$\boxed{V_E = 0V}$ $\boxed{V_B = V_{BE} = 0.786V}$

$V_C = V_{CE} = 9V - (I_B + I_C)(1.5k\Omega) = 9V - (\beta+1) I_B (1.5k\Omega)$

$= 9V - I_E (1.5k\Omega)$

$\boxed{V_C = V_{CE} = 1.94V}$

5.105



Ideal op-amp assumptions:

- No current flows in or out of the op-amp inputs
- The voltage between the input terminals of the op-amp is zero.

The emitter current is

$$I_e = \frac{V_z}{47k\Omega} = \frac{5V}{47k\Omega} = \boxed{106\mu A = I_e}$$

$$V_o = I_e(47k\Omega + 47k\Omega) = 2V_z = \boxed{10V = V_o}$$

Power Supply current

$$I_{supply} = I_e + \frac{15V - 5V}{82k\Omega} = 106\mu A + 122\mu A = \boxed{228\mu A = I_{supply}}$$