EECE - HW 5 Solutions

Problem 1:

a) $n >> p$, therefore: $n + N_A = p + N_D \approx N_D$

$\rightarrow n \approx N_D - N_A = 10^{17} cm^{-3} - 10^{15} cm^{-3} = \boxed{9.9 \times 10^{16} cm^{-3} = n}$

$$p = \frac{n_i^2}{n} = \frac{(1.45 \times 10^{10} cm^{-3})^2}{9.9 \times 10^{16} cm^{-3}} = \boxed{2.124 \times 10^{-3} cm^{-3} = p}$$

b) $N_A = N_D \longrightarrow \boxed{n = p = n_i = 1.45 \times 10^{10} cm^{-3}}$

Problem 2

equation 4.1: $i_E = I_{ES} \cdot \left(e^{\frac{v_{BE}}{V_T}} - 1\right)$

$$v_{BE} = V_T \cdot \ln\left(\frac{i_E}{I_{ES}} + 1\right) = 26 \times 10^{-3} \cdot \ln\left(\frac{10 \times 10^{-3}}{10^{-13}} + 1\right)$$

$\boxed{v_{BE} = 658.54 \, mV}$

From page 212 in the book:

$v_{BC} = v_{BE} - v_{CE} = 0.65854V - 10V = \boxed{-9.341 \, V = v_{BC}}$

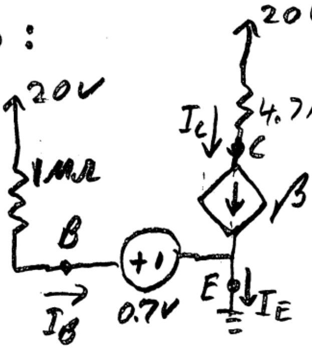
The transistor operates in the active region because $v_{CE} > 0.2V$ and $i_B = (1-\alpha) \cdot i_E > 0$, where $\alpha = \frac{\beta}{1+\beta} = \frac{100}{101} = \boxed{0.990099 = \alpha}$

$i_B = (1 - 0.990099) \cdot 10 \times 10^{-3} A = \boxed{99.0099 \, \mu A = i_B}$

$i_C = \alpha \cdot i_E = 0.990099 \times 10 mA = \boxed{9.90099 \, mA = i_C}$

Problem 3

a) $\underline{\beta=100}$, equivalent circuit assuming operation it the active region:



$I_B = \frac{20V-0.7V}{1\times10^6\Omega} = 19.3\mu A$

check: $I_B > 0$
(condition 1)

$I_c = \beta I_B = 100\cdot I_B = 1.93mA$

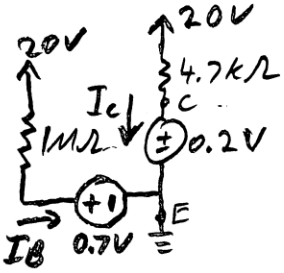
$\boxed{I_c = 1.93mA}$

$V_c = 20V - I_c\cdot 4.7k\Omega = 10.929V$

$V_{CE} = V_c - 0V = \boxed{10.93V = V_{CE}}$

check 2: $V_{CE} > 0.2V \rightarrow$ confirms active mode

$\underline{\beta = 300}$, assuming saturation:



$I_B = \frac{20V-0.7V}{1\times10^6\Omega} = 19.3\mu A > 0$ (condition 1 is met)

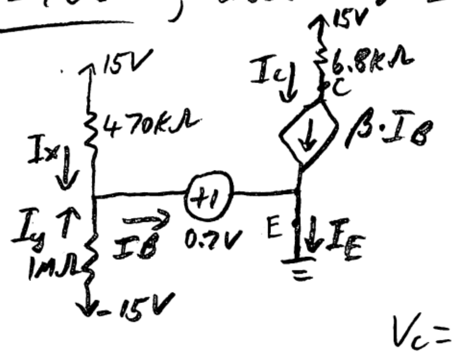
$I_c = \frac{20V-0.2V}{4.7\times10^3\Omega} = \boxed{4.213mA = I_c}$

check condition 2: $\beta\cdot I_B > I_c > 0$

↳ $5.79mA > 4.213mA > 0$

$\boxed{V_{CE} = 0.2V}$ Confirms saturation mode

b) $\underline{\beta=100}$, assuming active:



$I_x = \frac{15V-0.7V}{470\times10^3\Omega} = 30.426\mu A$

$I_y = \frac{-15V-0.7V}{1\times10^6\Omega} = -15.7\mu A$

$I_B = I_x + I_y = 14.73\mu A > 0$ (condition 1 is met)

$I_c = \beta\cdot I_B = \boxed{1.473mA = I_c}$

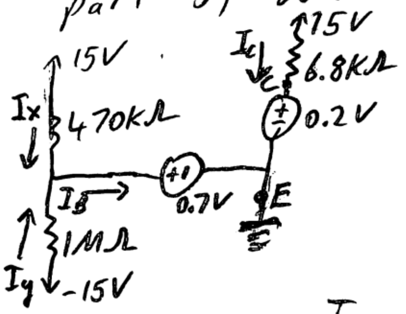
$V_c = 15V - I_c\times 6.8k\Omega = 4.987V$

$V_{CE} = V_c - 0V = \boxed{4.987V = V_{CE}}$

$V_{CE} > 0.2V \rightarrow$ confirms active mode

... Problem 3 cont.:

part b) with $\beta = 300$, assuming saturation:



$$I_x = \frac{15V - 0.7V}{470k\Omega} = 30.426\mu A$$

$$\boxed{V_{CE} = 0.2V}$$

$$I_y = \frac{-15V - 0.7V}{1M\Omega} = -15.7\mu A$$

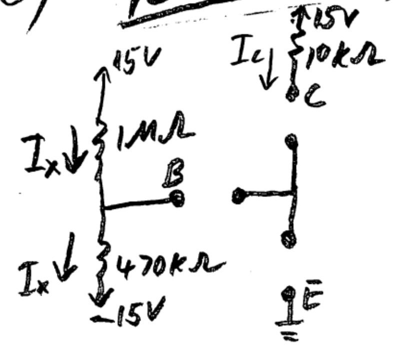
$$I_B = I_x + I_y = 14.73\mu A > 0 \quad \text{(condition 1 is met)}$$

$$I_c = \frac{15V - 0.2V}{6.8k\Omega} \approx \boxed{2.176 \text{ mA} = I_c}$$

The BJT is in saturation because condition 2 is satisfied:

$$\beta \cdot I_B > I_c > 0 \rightarrow 4.419mA > 2.176mA > 0$$

c) $\beta = 100$, assuming cutoff:



$$I_x = \frac{15V - (-15V)}{1M\Omega + 470k\Omega} = 20.408\mu A$$

$$V_B = 15V - I_x \cdot 1M\Omega = -5.408V$$

$$V_{BE} = V_B - \overset{0V}{\cancel{V_E}} = -5.408V < 0.5V$$

↳ condition 1 is satisfied

$$V_{BC} = V_B - V_C = -5.408V - 15V = -20.408V \rightarrow \text{confirms cutoff}$$

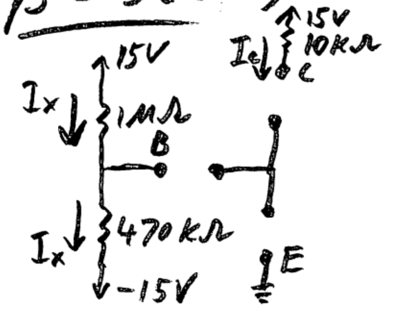
↳ condition 2 is met

$V_{BC} < 0.5V$

$$\boxed{I_c = 0}$$

$$V_{CE} = V_c - 0V = \boxed{15V = V_{CE}}$$

$\beta = 300$, assuming cuttoff:



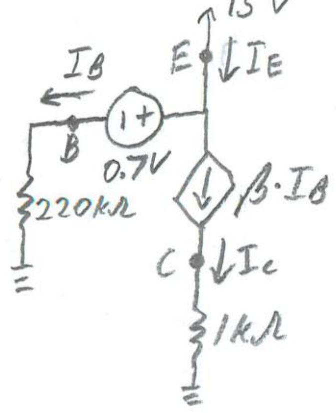
→ same analysis as with $\beta = 300$

$$\boxed{I_c = 0}$$

$$\boxed{V_{CE} = 15V}$$

... Problem 3 cont.:

d) $\underline{\beta = 100}$, assuming $\underline{\text{active}}$:



KVL: $0 = -I_B \cdot 220k\Omega - 0.7V + 15V$

$\rightarrow I_B = \frac{15V - 0.7V}{220 \times 10^3 \Omega} = 65 \times 10^{-6} A$

$I_B > 0$ → condition 1 is met

$I_c = \beta \cdot I_B = 100 \cdot 65 \mu A = \boxed{6.5 mA = I_c}$

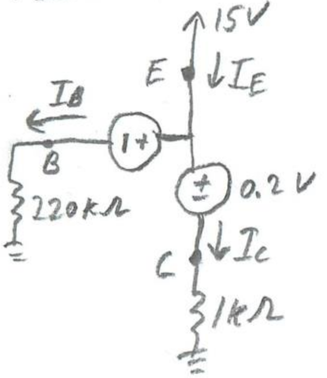
$V_c = I_c \cdot 1k\Omega = 6.5V$

$V_{CE} = V_c - V_E = 6.5V - 15V = \boxed{-8.5V = V_{CE}}$

check of condition 2: $V_{CE} < -0.2V$ → confirms active mode

$\underline{\beta = 300}$, assuming saturation:

$I_B = \frac{15V - 0.7V}{220k\Omega} = 65 \mu A > 0$ (condition 1 is met)



KVL: $0 = -15V + 0.2V + I_c \cdot 1k\Omega$

$\rightarrow I_c = \frac{15V - 0.2V}{1000 \Omega} = \boxed{14.8 mA = I_c}$

check for condition 2:

$\beta \cdot I_B > I_c > 0$

$19.5mA > 14.8mA > 0$ → confirms saturation

$V_c = 14.8mA \cdot 1k\Omega = 14.8V$

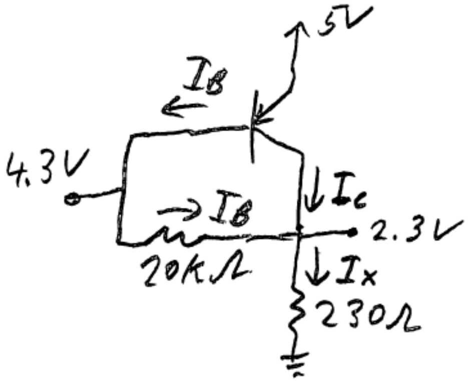
$V_{CE} = V_c - V_E = 14.8V - 15V = -0.2V$

$$\boxed{V_{CE} = -0.2V}$$

Problem 4

$$I_B = \frac{4.3V - 2.3V}{20k\Omega} = 100\mu A$$

$$I_x = \frac{2.3V}{230\Omega} = 10mA$$

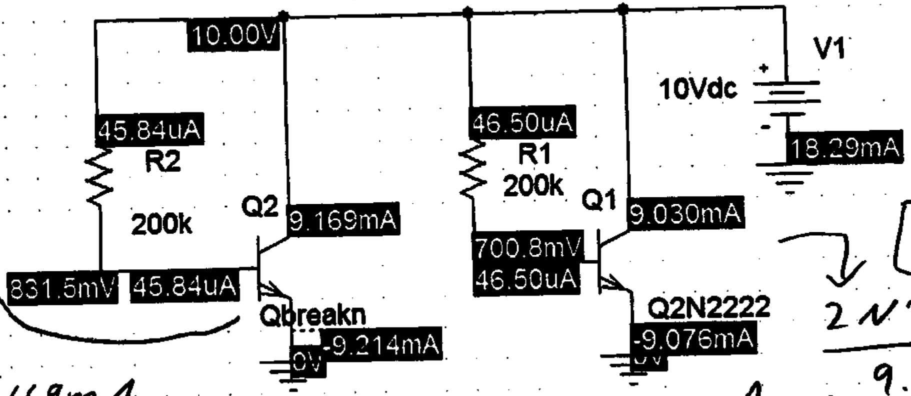


KCL: $I_x = I_B + I_c$

$$\hookrightarrow I_c = I_x - I_B = 10mA - 100\mu A = 9.9mA$$

$$\beta = \frac{I_c}{I_B} = \frac{9.9mA}{100\mu A} = \boxed{99 = \beta}$$

Problem 5, Part b)



Part b)

Qbreakn:

$$\beta_{oc} = \frac{9.169mA}{45.84\mu A}$$

$$\boxed{\beta_{oc} = 200.02}$$

Part a)

2N2222:

$$\beta_{oc} = \frac{9.03mA}{46.50\mu A}$$

$$\boxed{\beta_{oc} = 194.2}$$

Problem 5, Part c)

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****     BJT MODEL PARAMETERS
******************************************************************************

         Qbreakn        Q2N2222
         NPN            NPN
    IS   100.000000E-18 14.340000E-15
    BF   200            255.9
    NF   1              1
    VAF                 74.03
    IKF                 .2847
    ISE                 14.340000E-15
    NE                  1.307
    BR   1              6.092
    NR   1              1
    RB                  10
    RC                  1
    CJE                 22.010000E-12
    MJE                 .377
    CJC                 7.306000E-12
    MJC                 .3416
    TF                  411.100000E-12
    XTF                 3
    VTF                 1.7
    ITF                 .6
    TR                  46.910000E-09
    XTB                 1.5
    CN   2.42           2.42
    D    .87            .87
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part c

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****    OPERATING POINT INFORMATION     TEMPERATURE =  27.000 DEG C

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**** BIPOLAR JUNCTION TRANSISTORS

NAME       Q_Q1       Q_Q2
MODEL   Q2N2222     Qbreakn
IB        4.65E-05   4.58E-05
IC        9.03E-03   9.17E-03
VBE        7.01E-01   8.32E-01
VBC       -9.30E+00  -9.17E+00
VCE        1.00E+01   1.00E+01
→ BETADC 1.94E+02   2.00E+02
GM         3.40E-01   3.54E-01
RPI        5.99E+02   5.64E+02
RX         1.00E+01   0.00E+00
RO         9.23E+03   1.00E+12
CBE         1.78E-10   0.00E+00
CBC         3.01E-12   0.00E+00
CJS        0.00E+00   0.00E+00
→ BETAAC  2.04E+02   2.00E+02
CBX/CBX2    0.00E+00   0.00E+00
FT/FT2      2.99E+08   5.64E+18
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part c)

⑧

Problem 5, Part d)

CHARACTERISTICS

T_j = 25 °C unless otherwise specified. ← temperature

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
I_{CBO}	collector cut-off current 2N2222	I_E = 0; V_{CB} = 50 V	–	10	nA
		I_E = 0; V_{CB} = 50 V; T_{amb} = 150 °C	–	10	µA
I_{CBO}	collector cut-off current 2N2222A	I_E = 0; V_{CB} = 60 V	–	10	nA
		I_E = 0; V_{CB} = 60 V; T_{amb} = 150 °C	–	10	µA
I_{EBO}	emitter cut-off current	I_C = 0; V_{EB} = 3 V	–	10	nA
h_{FE}	DC current gain ↑ β_{DC}	I_C = 0.1 mA; V_{CE} = 10 V	35	–	
		I_C = 1 mA; V_{CE} = 10 V	50	–	
		I_C = 10 mA; V_{CE} = 10 V ⟶	75	–	
		I_C = 150 mA; V_{CE} = 1 V; note 1	50	–	
		I_C = 150 mA; V_{CE} = 10 V; note 1	100	300	
h_{FE}	DC current gain 2N2222A	I_C = 10 mA; V_{CE} = 10 V; T_{amb} = −55 °C	35	–	
h_{FE}	DC current gain 2N2222 2N2222A	I_C = 500 mA; V_{CE} = 10 V; note 1	 30 40	 – –	
V_{CEsat}	collector-emitter saturation voltage 2N2222	I_C = 150 mA; I_B = 15 mA; note 1	–	400	mV
		I_C = 500 mA; I_B = 50 mA; note 1	–	1.6	V
V_{CEsat}	collector-emitter saturation voltage 2N2222A	I_C = 150 mA; I_B = 15 mA; note 1	–	300	mV
		I_C = 500 mA; I_B = 50 mA; note 1	–	1	V
V_{BEsat}	base-emitter saturation voltage 2N2222	I_C = 150 mA; I_B = 15 mA; note 1	–	1.3	V
		I_C = 500 mA; I_B = 50 mA; note 1	–	2.6	V
V_{BEsat}	base-emitter saturation voltage 2N2222A	I_C = 150 mA; I_B = 15 mA; note 1	0.6	1.2	V
		I_C = 500 mA; I_B = 50 mA; note 1	–	2	V
C_c	collector capacitance	I_E = i_e = 0; V_{CB} = 10 V; f = 1 MHz	–	8	pF
C_e	emitter capacitance 2N2222A	I_C = i_c = 0; V_{EB} = 500 mV; f = 1 MHz	–	25	pF
f_T	transition frequency 2N2222 2N2222A	I_C = 20 mA; V_{CE} = 20 V; f = 100 MHz	 250 300	 – –	 MHz MHz
F	noise figure 2N2222A	I_C = 200 µA; V_{CE} = 5 V; R_S = 2 kΩ; f = 1 kHz; B = 200 Hz	–	4	dB

beta:

for this case

} notice the variation