(p.1)

EECE - HW 5 Solutions

Problem 1:

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

$\rightarrow n \approx N_D - N_A = 10^{18}\ cm^{-3} - 10^{16}\ cm^{-3} = \boxed{9.9 \times 10^{17}\ cm^{-3} = n}$

$$p = \frac{n_i^2}{n} = \frac{(1.45 \times 10^{10}\ cm^{-3})^2}{9.9 \times 10^{17}\ cm^{-3}} = \boxed{2.124 \times 10^{2}\ cm^{-3} = p}$$

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 $\alpha = \frac{\beta}{1+\beta} = \frac{100}{101} = \boxed{0.990099 = \alpha}$

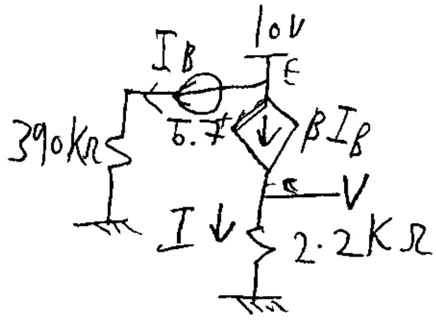
$$i_B = (1 - 0.990099) \cdot 10 \times 10^{-3} A = \boxed{99.0099\ \mu A = i_B}$$

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

Problem 3 ②

a) $\beta = 100$

equivalent circuit assuming operation in active:-



$$I_B = \frac{10 - 0.7}{390K\Omega} = 23.8462\,\mu A$$

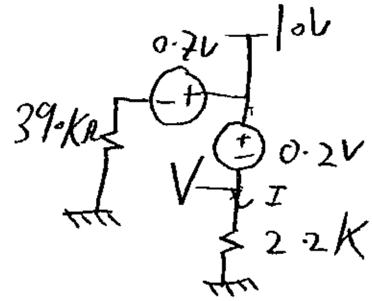
$$\boxed{I = \beta I_B = 2.38\,mA} > 0$$

$$\boxed{V = V_C = 2.38 \times 2.2 = 5.25\,V}$$

$$V_{EC} = 10 - 5.25 = 4.75\,V > 0.2V \rightarrow \text{active.}$$

$\beta = 300$

assume saturation



$$\boxed{I_C = \frac{10 - 0.2}{2.2} = 4.45455\,mA}$$

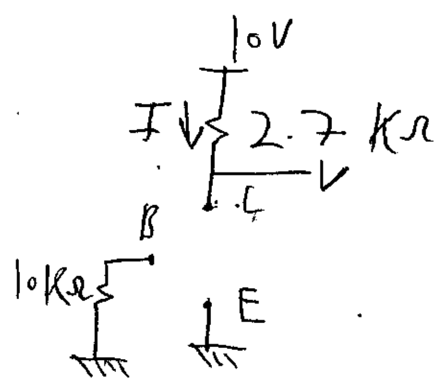
$$\boxed{V = 10 - 0.2 = 9.8V}$$

$$\beta I_\beta > I_C > 0 \rightarrow I_B = \frac{10 - 0.7}{390K} = 23.8462\,\mu A$$

$$\beta I_B = 7.15385\,mA > I_C \rightarrow \text{saturation}$$

b) $\beta = 100$

assume cutoff



$$\boxed{V = 10V = V_C}$$

$$V_B = 0V$$

$$\boxed{I = 0A}$$

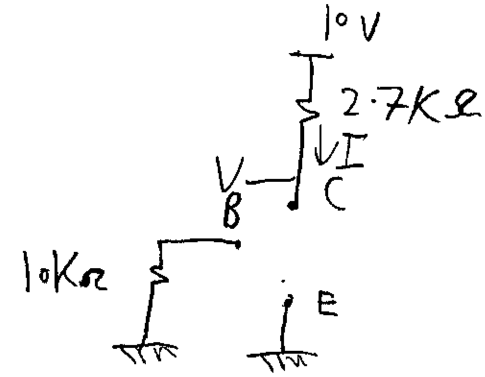
$$V_{BE} = 0 - 0 = 0V < 0.5V \rightarrow \text{Cond } 1$$

$$V_{BC} = 0 - 10 = -10V < 0.5V \rightarrow \text{Cond } 2 \rightarrow \therefore \text{cut off.}$$

$\boxed{\text{Cont. problem 3}}$

b) $\beta = 300$

assume cutoff.



$V_B = 0V$

$V_C = 10V$

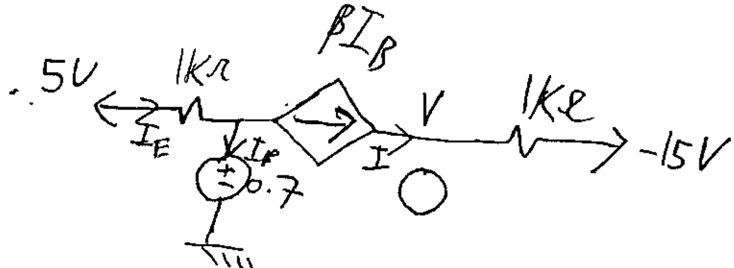
$V_E = 0V$

$\boxed{\therefore I = I_C = 0A}$, $\boxed{V = V_C = 10V}$

$V_{BE} = 0 - 0 = 0V < 0.5V \rightarrow$ Cond 1. $\rightarrow$ cut off.

$V_{BC} = 0 - 10 = -10V < 0.5V \rightarrow$ Cond 2 $\rightarrow$

c) $\beta = 100$ assume active



$I_E = I_B + I_C$

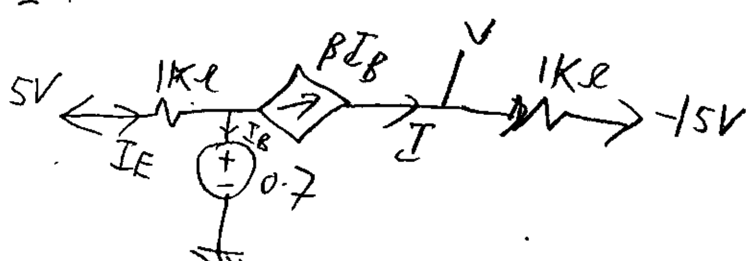
$\frac{5V - 0.7V}{1K} = I_B + \beta I_B \rightarrow I_B = 42.5743 \mu A.$

$\boxed{I = I_C = \beta I_B = 4.25743 mA.}$ $> 0A$

$\boxed{V = -15V + I \times 1K = -10.7426 \ V.}$

$V_{EC} = 0.7 - (-10.7426) = 11.4426V > 0.2V \rightarrow$ active

$\beta = 300$ assume Active



$I_E = I_B + I_C$

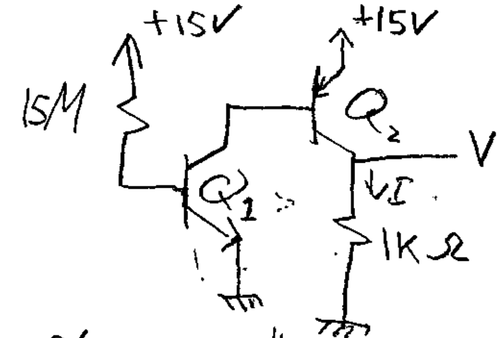
$\frac{5 - 0.7}{1K} = I_B + \beta I_B \rightarrow I_B = 14.2857 \mu A$

$\boxed{I = I_C = \beta I_B = 4.28571 mA}$ $> 0A$

$\boxed{V = -15V + I \times 1K = -10.7143 V}$

$V_{EC} = 0.7 - (-10.7143) = 11.4143V > 0.2V$ $\rightarrow$ active

Cont. problem 3



d) $\beta = 100$

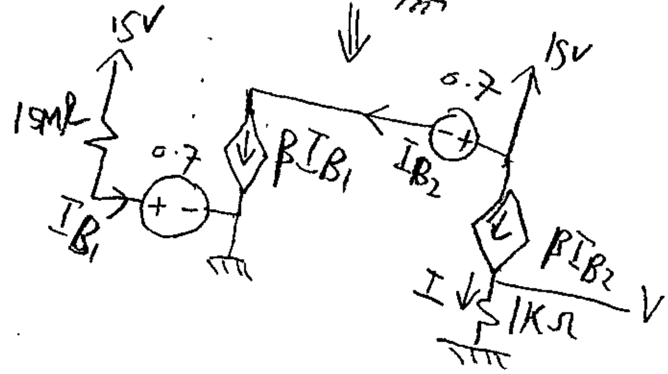
assume Q_1 active, Q_2 active

$$I_{B1} = \frac{15-0.7}{15M\Omega} = 0.95333\,\mu A$$

$$I_{B2} = \beta I_{B1} = 95.3333\,\mu A$$

$$\boxed{I = I_{C2} = \beta I_{B2} = 9.53\,mA}$$

$$\boxed{V = I \times 1K = 9.53\,V}$$



$15-0.7 = V_{CE1} > 0.2V \rightarrow$ active

$I_{C1} = \beta I_{B1} = 95.3333\,\mu A > 0A \rightarrow$ active

$V_{EC_2} = 15 - I \times 1K = 5.46667\,V > 0.2V \rightarrow$ active

$I_{C_2} = I = 9.53mA > 0A \rightarrow$ active

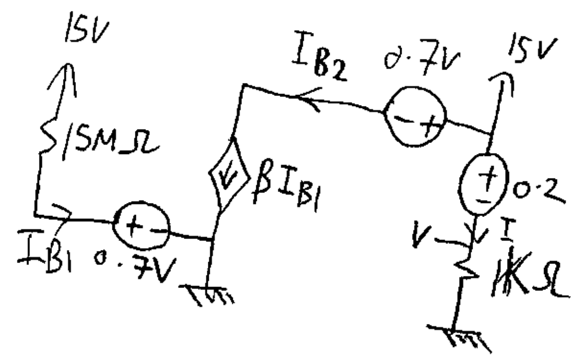
$\beta = 300$ assume Q_1 active, Q_2 in saturation

$$I_{B1} = \frac{15-0.7}{15M\Omega} = 0.95333\,\mu A$$

$$I_{B2} = \beta I_{B1} = 286\,\mu A$$

$$\boxed{I = \frac{15-0.2}{1K} = 14.8\,mA}$$

$$\boxed{V = 15-0.2 = 14.8V}$$



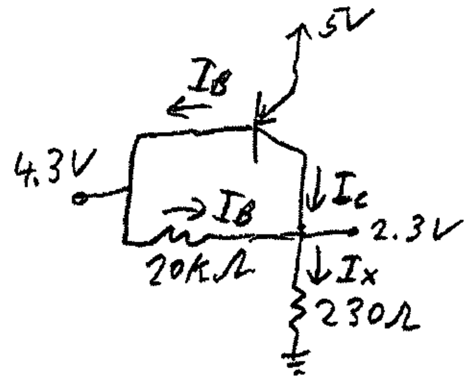
$V_{CE1} = 15-0.7 = 14.3V > 0.2V \rightarrow$ Active

$I_{C1} = \beta I_{B1} = 286\,\mu A > 0 \rightarrow$ Active

$I = I_{C_2} > 0A$, $\beta I_{B_2} = 85.8\,mA > I_{C_2} \rightarrow$ saturation

Problem 4:

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



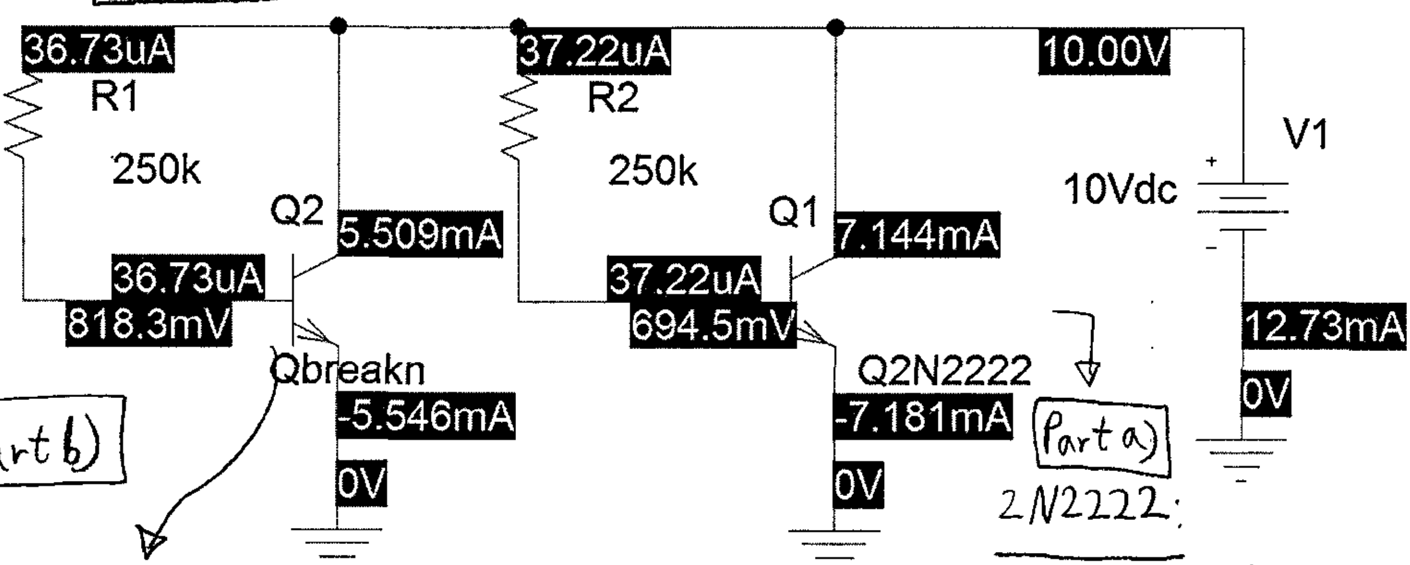
$$I_x = \frac{2.3V}{230\Omega} = 10mA$$

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 a)

2N2222:

$$\beta_{DC} = \frac{7.144mA}{37.22\mu A}$$

$$\beta_{DC} = 191.94$$

QbreakN:

$$\beta_{DC} = \frac{5.509mA}{36.73\mu A}$$

$$\boxed{\beta_{DC} = 149.986}$$

**** BJT MODEL PARAMETERS

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Problem 5 Part c)

	Qbreakn	Q2N2222
	NPN	NPN
IS	100.000000E-18	14.340000E-15
BF	150	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

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

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**** BIPOLAR JUNCTION TRANSISTORS

NAME	Q_Q1	Q_Q2
MODEL	Q2N2222	Qbreakn
IB	3.72E-05	3.67E-05
IC	7.14E-03	5.51E-03
VBE	6.95E-01	8.18E-01
VBC	-9.31E+00	-9.18E+00
VCE	1.00E+01	1.00E+01
BETADC	1.92E+02	1.50E+02
GM	2.70E-01	2.13E-01
RPI	7.51E+02	7.04E+02
RX	1.00E+01	0.00E+00
RO	1.17E+04	1.00E+12
CBE	1.49E-10	0.00E+00
CBC	3.01E-12	0.00E+00
CJS	0.00E+00	0.00E+00
BETAAC	2.03E+02	1.50E+02
CBX/CBX2	0.00E+00	0.00E+00
FT/FT2	2.83E+08	3.39E+18

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Problem 5, Part d)

NPN switching transistors 2N2222; 2N2222A

CHARACTERISTICS

T_j = 25 °C unless otherwise specified.

temperature

beta;

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	I_C = 0.1 mA; V_{CE} = 10 V	35	–	
	β_{DC}	I_C = 1 mA; V_{CE} = 10 V	50	–	
	For this case	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	I_C = 10 mA; V_{CE} = 10 V; T_{amb} = −55 °C			
	2N2222A		35	–	
h_{FE}	DC current gain	I_C = 500 mA; V_{CE} = 10 V; note 1			
	2N2222		30	–	
	2N2222A		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	I_C = i_c = 0; V_{EB} = 500 mV; f = 1 MHz			
	2N2222A		–	25	pF
f_T	transition frequency	I_C = 20 mA; V_{CE} = 20 V; f = 100 MHz			
	2N2222		250	–	MHz
	2N2222A		300	–	MHz
F	noise figure	I_C = 200 μA; V_{CE} = 5 V; R_S = 2 kΩ; f = 1 kHz; B = 200 Hz			
	2N2222A		–	4	dB

notice the variation