**Student ID:**______________________**Student Name:** ___________________________

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**EHB222E INTRODUCTION TO ELECTRONICS (11128, 11129, 11131, 15436)**

**Midterm Exam 1 ✐ 1 December 2020 ⏲ 12.15-14.30 (upload time included)**

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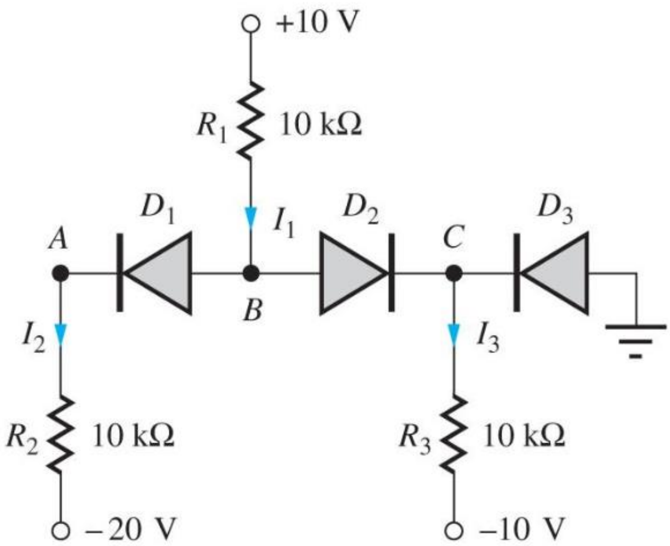
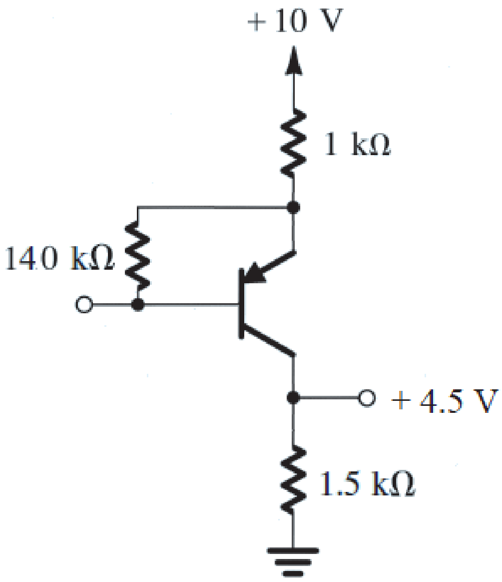
1. Use modified diode model ($V_D$ = 0,7V) for the diodes on the right. Calculate $I_1$, $I_2$, and $I_3$ currents. (25p)

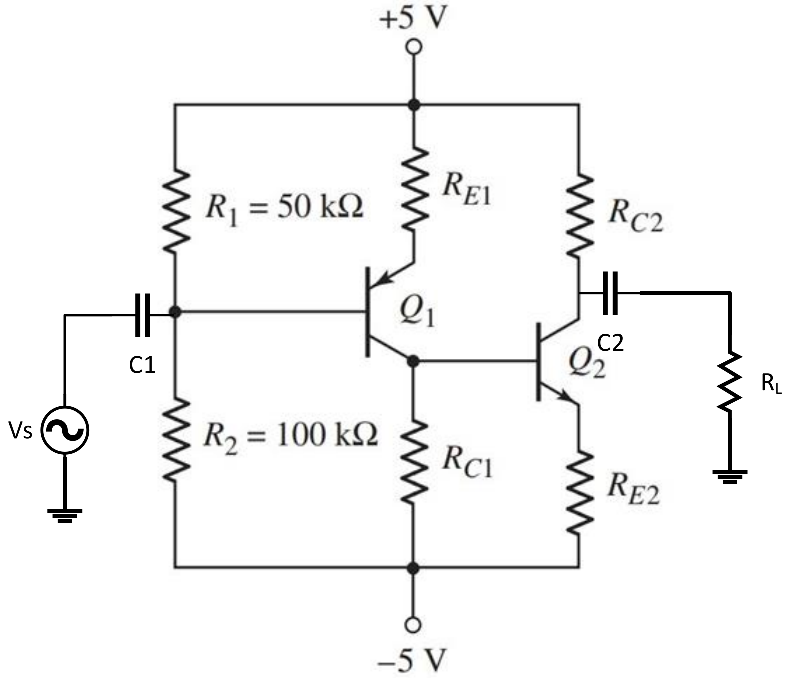



2. Measurements on the circuit above left produced labelled voltages as indicated. Find the values of $I_B$, $I_E$, $I_C$ and β for the transistor. ($|V_{BE}|$ = 0,7 V) (25p)

3. Junction area of a Si diode is 0,25 mm$^2$ with doping concentrations of $N_D = 10^{17}$ /cm$^3$, and $N_A = 10^{15}$ /cm$^3$, respectively. $n_i$ = 1,5 $10^{10}$ /cm$^3$, q = 1,602 $10^{-19}$ C, $V_T$ = 25 mV, $\varepsilon_r$ = 12, $\varepsilon_o$ = 8,85 $10^{-14}$ F/cm, $\mu_n$ =1350 cm$^2$/Vs, $\mu_p$ = 480 cm$^2$/Vs, $\tau_n = \tau_p$ = 1 μsec.
   a. Find minority and majority carrier concentrations in p and n-typed doped regions. (6)
   b. Find Barrier potential. (3p)
   c. Find depletion width. How much of w is in the n-type doped area, how much in p-typed?. (6p)
   d. Find either specific conductances or specific resistances of both typed doped regions. (6p)
   e. Find saturation or dark current. (3p)
   f. Find junction capacitance when the diode is (6p)
      i. Unbiased
      ii. Reverse biased with 3,5 V
      iii. Forward biased with 0,2 V.

**GOOD LUCK EVERYONE**




4. For the transistor given in the circuit above, parameters are:
   - $\beta = 100$
   - $|V_{BE}| = 0,7$ V
   - $I_{C1} = I_{C2} = 0,8$ mA
   - $V_{EC,Q1} = 3,5V$
   - $V_{CE,Q2} = 4,0V$

Determine $R_{C1}$, $R_{E1}$, $R_{C2}$ and $R_{E2}$. (30p)

SOLUTIONS:

1.

Let's assume $D_1, D_3$ are on and $D_2$ is off.

$V_C = -0.7V \Rightarrow I_3 = \dfrac{-0{,}7V - (-10V)}{10k\Omega} = 993mA$

$10V - R_1 . I_1 - 0.7V - I_2 . R_2 = -20V \;;\quad I_1 = I_2$

$29{,}3V = (R_1 + R_2) I_1 \Rightarrow \quad I_1 = \dfrac{29{,}3V}{20k\Omega} = 1{,}465mA$

$V_B = 10V - R.I_1 = -4.65V \quad \Rightarrow V_B < V_C$

If $V_B < V_C$ assumption for $D_2$ is correct.

The direction of current flows of $I_3$ and $I_2$ are correct. So, assumptions for $D_1$ and $D_3$ are correct.

2.

$I_C = \dfrac{4{,}5V}{1{,}5K} = \boxed{3mA}$ 5p

$I = I_C = I_E - I_B$

$V_E = 10V - I.1K$

$\boxed{V_E = 10V - 3V = 7V}$ 5p

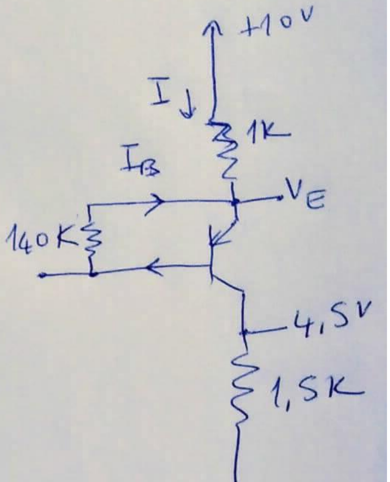
$I_B = \dfrac{7V - 0{,}7V}{140K} = \boxed{45\mu A}$ 5p

$I_E = 3mA + 45\mu A$

$\boxed{I_E = 3{,}045\ mA}$ 5p

$\beta = \dfrac{I_C}{I_B} = \dfrac{3mA}{0{,}045mA} = 66{,}67$

$\boxed{\beta \cong 67}$ 5p



3. Step by step (a) through (f)

| doping | Majority carriers | Minority carriers |
|---|---|---|
| n | $n_n = N_D = 10^{17}\ /cm^3$ | $p_n = n_i^2\ /\ N_D = 2{,}25\ 10^3/cm^3$ |
| p | $p_p = N_A = 10^{15}\ /cm^3$ | $n_p = n_i^2\ /\ N_A = 2{,}25\ 10^5/cm^3$ |

$$V_B = -V_T \cdot ln\left[\frac{n_i^2}{N_A N_D}\right] = 671\ \text{mV}$$

$$w = \sqrt{\frac{2\varepsilon_0\varepsilon_r V_B}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)} = 9{,}48 \cdot 10^{-5}\ \text{cm} = 948\ \text{nm}.$$

Since $N_D/N_A = 100/1$ thus $x_p/x_n = 100/1$ and therefore

$x_p = (100/101)\ w =$ 939 nm and $x_n = (1/101)\ w =$ 9 nm

Majority carriers considered $\sigma_n = \mu_n n_n q = 21{,}6\ {}^1/_{\Omega cm}$ $and\ \sigma_p = \mu_{pn} p_p q = 0{,}07\ {}^1/_{\Omega cm}$

$I_s = -q\left[\frac{D_n}{L_n}\frac{n_i^2}{N_A} + \frac{D_p}{L_p}\frac{n_i^2}{N_D}\right] = 5{,}27\ fA$, from $V_T = \frac{D}{\mu}$, you can find $D_n = 33{,}8$ , and $D_p = 12{,}0$ (guess your units!!!)

And from $L = \sqrt{D\tau}$ you can find $L_n = 5{,}81\ 10^{-3}$ cm = 0,58 µm and $L_p = 3{,}46\ 10^{-3}$ cm = 0,35 µm

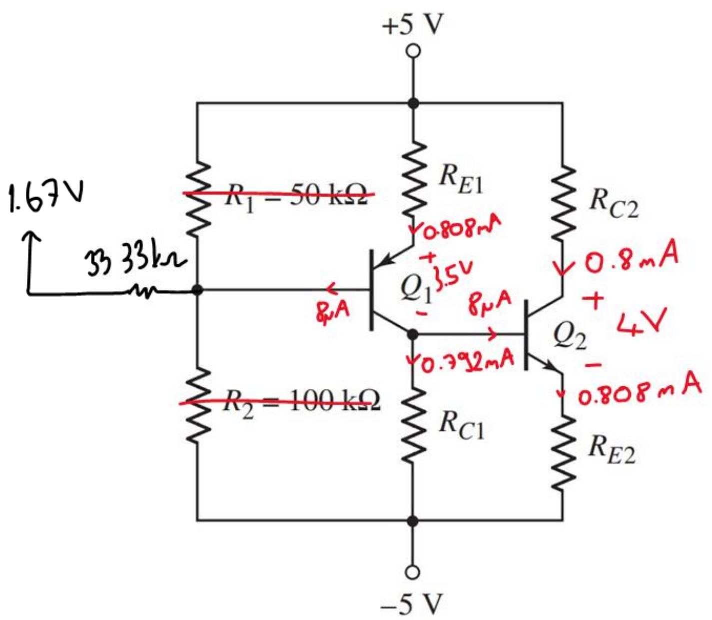
Junction capacitance can be found from $C_j = \varepsilon\frac{A}{w}$

That means you need to find w in all three cases:

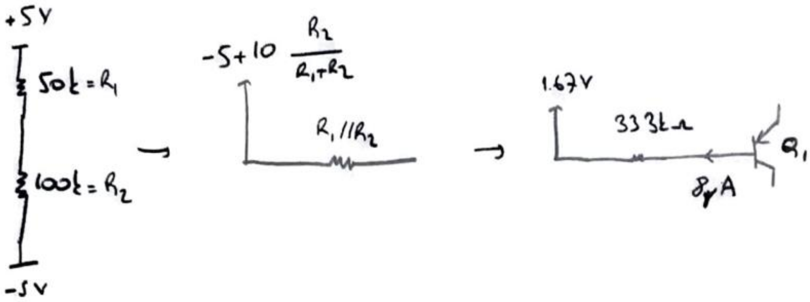
$w(unbiased) = \sqrt{\frac{2\varepsilon_0\varepsilon_r V_B}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)} =$ 948 nm Thus Cj = 256 fF

$w(-3{,}5V) = \sqrt{\frac{2\varepsilon_0\varepsilon_r (V_B+3{,}5V)}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)} =$ 2,36 µm Thus Cj = 103 fF

$w(+0{,}2V) = \sqrt{\frac{2\varepsilon_0\varepsilon_r (V_B-0{,}2V)}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)} =$ 794 nm Thus Cj = 306 Ff




4.




$$\frac{V_{B1}-1.67V}{33.3k\Omega} = 8\mu A \rightarrow V_{B1} \cong 1.936V$$

$$V_{E1} \cong 2.636V \cong V_{B1}+0.7V$$

$$V_{C1} \cong V_{E1}-3.5V \cong -0.864V \cong V_{B2}$$

$$V_{E2} = V_{B2}+0.7V = -0.164V$$

$$V_{C2} = V_{E2}+4V = 3.836V$$

$$R_{E1} = \frac{(5-2.636)V}{0.808mA} = 2.93k\Omega$$

$$R_{C1} = \frac{-0.864V+5V}{0.792mA} = 5.22k\Omega$$

$$R_{C2} = \frac{5-3.836}{0.8} = 1.455k\Omega$$

$$R_{E2} = \frac{(-0.164+5)V}{0.808mA} = 5.985k\Omega$$