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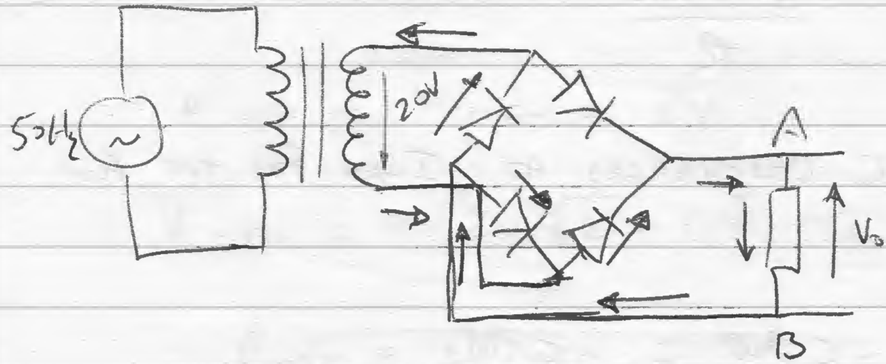
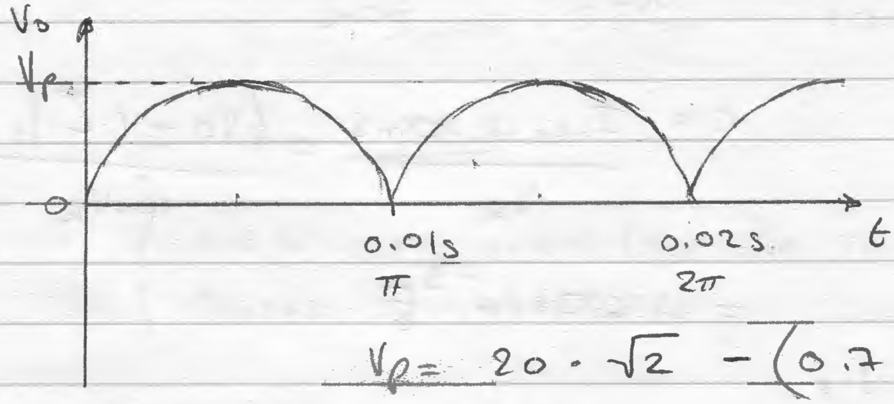
Q1 a i



1

ii



1 SHAPE
1 TIME
1 PK APP. LABEL
1 CALC.

$$V_p = 20 \cdot \sqrt{2} - (0.7 \times 2)$$
$$= \underline{26.88\ V}$$

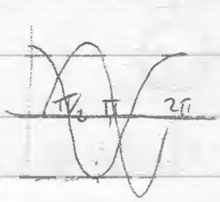
iii

$$V_{Av} = \frac{1}{T/2} \int_0^{T/2} \cancel{V_p \sin(\omega t)\, dt}$$ 2

$$= \frac{1}{\frac{1}{2}(2\pi/\omega)} \int_0^{\pi/\omega} V_p \sin(\omega t)\, dt$$ 2

$$= \frac{\cancel{\omega}}{\pi} \left[-\frac{V_p}{\cancel{\omega}} \cos(\omega t) \right]_0^{\pi/\omega}$$ 1

$$= \frac{V_p}{\pi} \left[(+1) + (+1) \right]$$



$$= \frac{2V_p}{\pi}$$ 1

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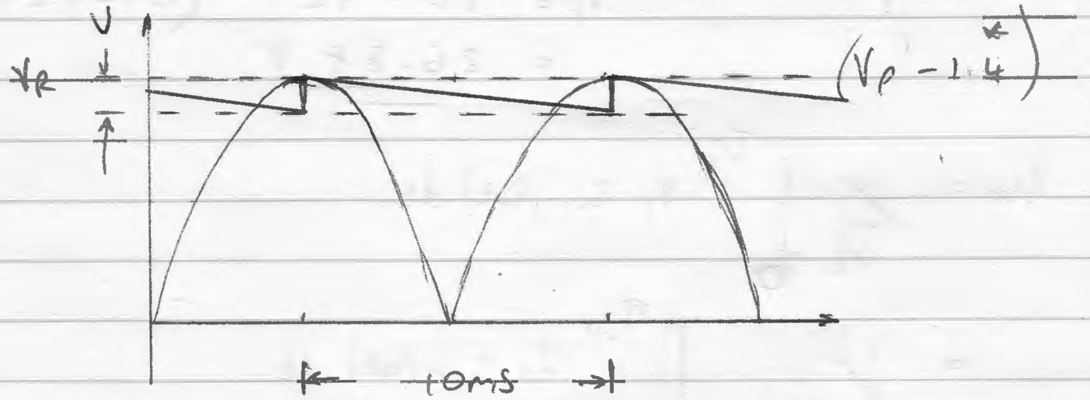
Q1 a iv $\quad I_{MAX} = \dfrac{V_P - 1.4^*}{R}$ 2

ASSUME C DISCHARGES AT I_{MAX} FOR THE FULL 10mS.

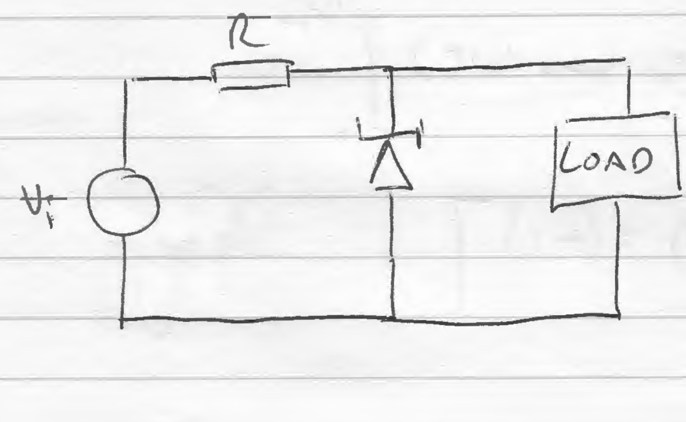
$$I_{MAX} = \frac{C\,dV}{dt} = \frac{C \cdot V_R}{10mS}$$ 2

$$\therefore C = \frac{I_{MAX} \times 10mS}{V_R} = \frac{(V_P - 1.4^*) \times 10mS}{R \cdot V_R}$$ 1

$$= 6.7 \times 10^{-3}\ F$$ 1



Q1 b i



$I_{L(MIN)} = 5mA$

$I_{L(MAX)} = 10mA$

$I_{Z(MIN)} = 2mA$

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Q1bi (CONT'D)

$V_{i\,max} - V_{i\,min} = 2V.$ 1

$V_{i\,min} = 20\sqrt{2} - 1.4^{*} - 2 = 24.9V$ 1

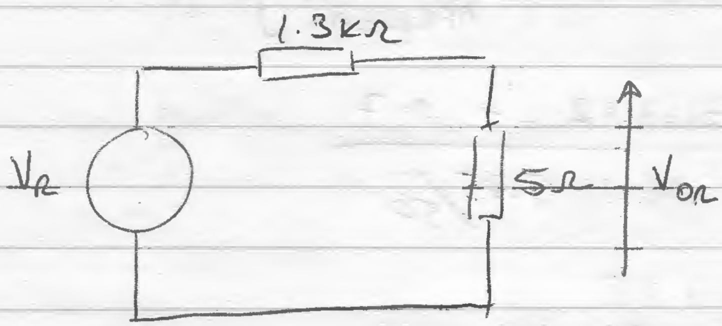
$R_{max} = \dfrac{V_{i\,min} - 9V}{I_{L\,max} + I_{Z\,min}} = \dfrac{24.9 - 9}{10mA + 2mA}$ $2^{(*2)}$

$= \underline{\underline{1.3k\Omega}}$ 1

(1.4K IF 1.4V DROP DUE TO RECTIFIER DIODES IS NEGLECTED)

*2 SECOND MARK IS FOR IMPLICIT JUSTIFICATION OF $I_{L\,max}$ AS OPPOSED TO $I_{L\,min}$.

Q1bii



1

$V_{OR} = V_R \cdot \dfrac{5}{5 + 1.3k} = 2 \cdot \dfrac{5}{1305}$ 1

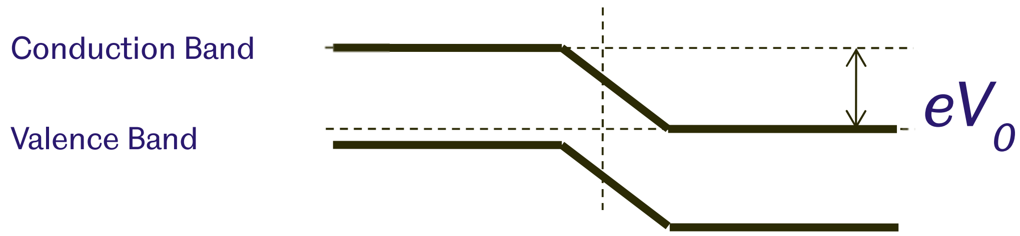
$= \underline{\underline{7.6\,mV \text{ pk-pk}}}$ 1

<u>EEE118 Exam solutions 2016</u>

Question 2:

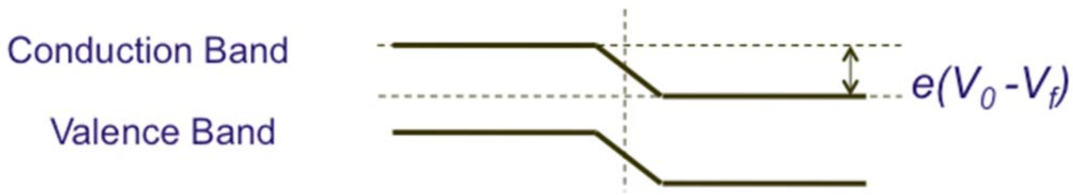
(a)

i) <u>Open circuit</u>



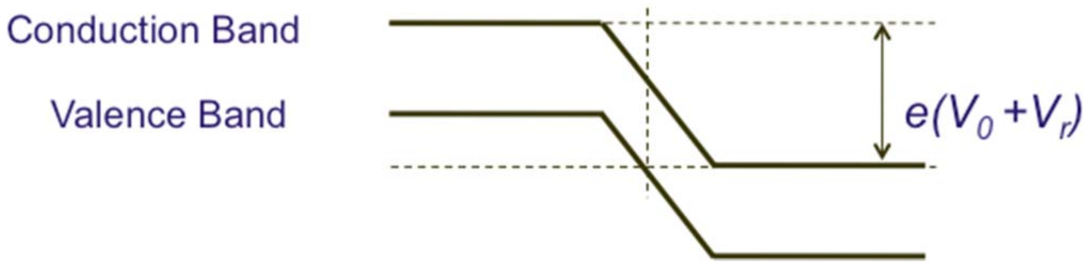
1 mark each

ii) <u>Forward Bias</u>



a.

iii) <u>Reverse Bias</u>



<u>Explanation:</u>

Open circuit, zero applied bias diode has inbuilt voltage V_0 and drift and diffusion currents are balanced hence no net current flows

In forward bias the junction voltage is reduced by V_f. This leads to a reduction in the potential barrier for electrons and holes and diffusion current increases strongly (exponentially).

In reverse bias, the junction voltage is increased by V_r. This increases the barrier potential for electrons and holes and reduces the diffusion current. The drift current remains approximately the same, and hence a small reverse bias current flows due to drift.

2 mark each

(b) $I = I_0 \left[e^{\frac{eV}{kT}} - 1 \right]$

$0.02 = I_0 \left[e^{\frac{e}{kT}(0.2)} - 1 \right]$, $\frac{kT}{e} = 0.026\,eV$

(i)

$\Rightarrow 0.02 = I_0 \left[e^{\frac{0.2}{0.026}} - 1 \right]$

$= I_0 \times 2190$

$\Rightarrow I_0 = 9.1 \times 10^{-6}\,A$

$J_0 = 9\,Am^{-2}$

$A = \frac{I_0}{J_0} = \frac{9.1 \times 10^{-6}}{9} \approx 1 \times 10^{-6}\,m^2 = 1\,mm^2$

$\boxed{A = 1mm^2}$

3 marks

(ii)

$C = \frac{\epsilon A}{W} \Rightarrow \frac{1}{C^2} = \frac{W^2}{\epsilon^2 A^2}$

$W^2 = \frac{2\epsilon(V_0 - V)}{e}\frac{1}{N_d}$ for case where $N_a \gg N_d$

$\therefore \frac{1}{C^2} = \frac{2}{\epsilon e A^2 N_d}(V_0 - V)$

$\Rightarrow$ slope $= \frac{2}{\epsilon e A^2 N_d}$

$1.177 \times 10^{+19} = \frac{2}{12(8.85 \times 10^{-12})(1.6 \times 10^{-19})(10^{-6})^2 (N_d)}$

$N_d = \frac{1.177 \times 10^{41}}{1.177 \times 10^{19}} = 1 \times 10^{22}\,m^{-3}$

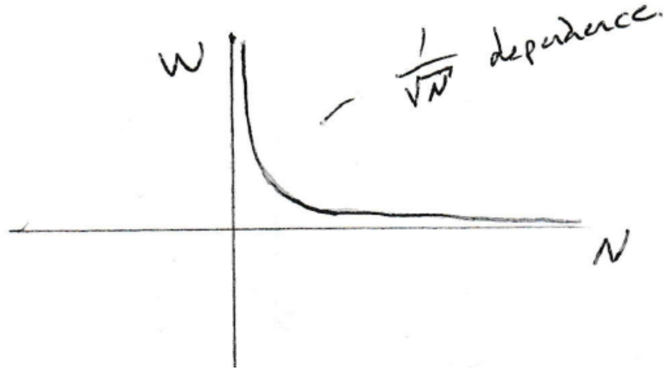
$\boxed{N_d = 1 \times 10^{22}\,m^{-3}}$

7 marks

(c) $W = \left[\frac{2 \varepsilon V_0}{q} \left(\frac{N_a + N_d}{N_a N_d} \right) \right]^{1/2}$, $N_a = N_d = N$

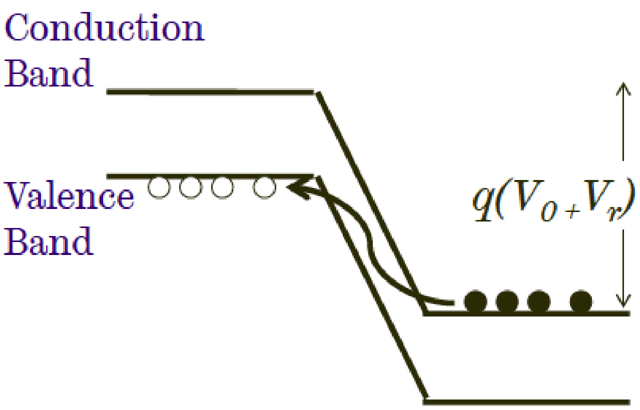
3 marks

$W = \text{const} \times \left(\frac{1}{N} \right)^{1/2}$



(d)

3 marks



At high reverse bias, the electrons in the can tunnel from the n-region across the barrier and into empty energy states in the valence band of the p-region.
At high p-type doping levels there are more available states in the valence band and it is therefore more likely an electron can tunnel into these states.

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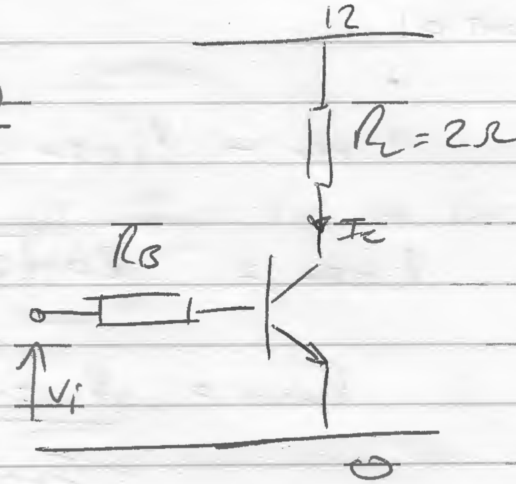
3a i

$$I_{C(ON)} = \frac{V_{SUPPLY} - V_{CE(SAT)}}{R_L}$$



$= 5.85\,A$ 1

ii $P = I^2 R$

$= 5.85^2 \cdot 2$

$= 68.445$ WATTS 1

iii LARGEST R_B IS ACTUALLY A SMALL NUMBER AND IS OBTAINED USING THE LOWEST POSSIBLE hFE.

$$R_{B(MAX)} = \frac{V_I - V_{BE\,SAT}}{\underbrace{I_C / h_{FE(MIN)}}_{I_B \ldots}}$$ 2

$$= \frac{12 - 0.7}{5.85/50}$$ 1

$= 96.58\,\Omega$ 1

iv $P = I \cdot V$

$= 5.85 \cdot V_{CE(SAT)}$

$= 5.85 \cdot 0.3$ 1

$= 1.755$ WATTS

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Q3a v POWER LOSS MUST BE THE SAME... 1

$P = I^2 R \qquad R = \frac{P}{I^2} = \frac{1.755}{5.85^2}$ 1

$R = \underline{\underline{0.0513\,\Omega}}$ 1

6i ASSUME I_B IS NEGLIGIBLE...

$V_B = 20 \times \frac{R_2}{R_1 + R_2} = 20 \cdot \frac{30}{150} = \underline{\underline{4V}}$ 1

$I_C \approx I_E = \frac{V_B - 0.7}{R_E} = \frac{4 - 0.7}{3.3k\Omega} = \underline{1mA}$ 1

$V_C = V_{CC} - I_C R_L = 20 - 8.2 = \underline{\underline{11.8\,V}}$ 1

$g_m = \frac{e I_C}{kT} = \frac{1.6\times10^{-19} \cdot 1\times10^{-3}}{1.38\times10^{-23} \cdot 300}$

$= \underline{\underline{38.64\ mA/V}}.$

$r_{be} = \frac{\beta}{g_m} = \frac{400}{38.64\,mA/V} = \underline{\underline{10.35\,k\Omega}}$

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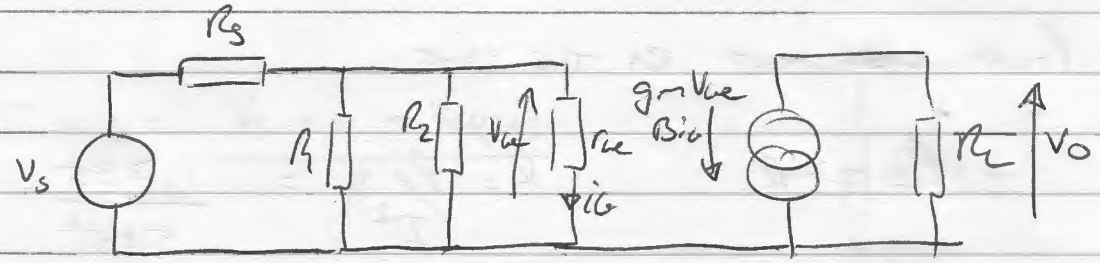
Q3b ii



iii C_1 COUPLES SIGNALS INTO THE AMPLIFIER AND PREVENTS DC CURRENT FLOWING FROM SOURCE TO AMPLIFIER OR THE OTHER WAY ROUND THEREBY UPSETTING THE BIASING CONDITIONS. 1

C_2 DECOUPLES R_E FROM THE SIGNAL'S POINT OF VIEW. THIS ALLOWS SIGNALS TO EXPERIENCE THE FULL GAIN AVAILABLE BUT ALLOWS THE DESIGNER TO MAINTAIN CONTROL OF THE DC CONDITIONS EVEN AS h_{FE} & TEMPERATURE VARY. 2

iv
$$\frac{V_o}{V_{be}} = -g_m R_L = -315.7$$ 1

$$\frac{V_{be}}{V_s} = \frac{r_{be} // R_1 // R_2}{R_S + R_1 // R_2 // r_{be}} = \frac{7.26\,k\Omega}{2.2\,k\Omega + 7.26\,k\Omega}$$ 1

$$= 0.767.$$

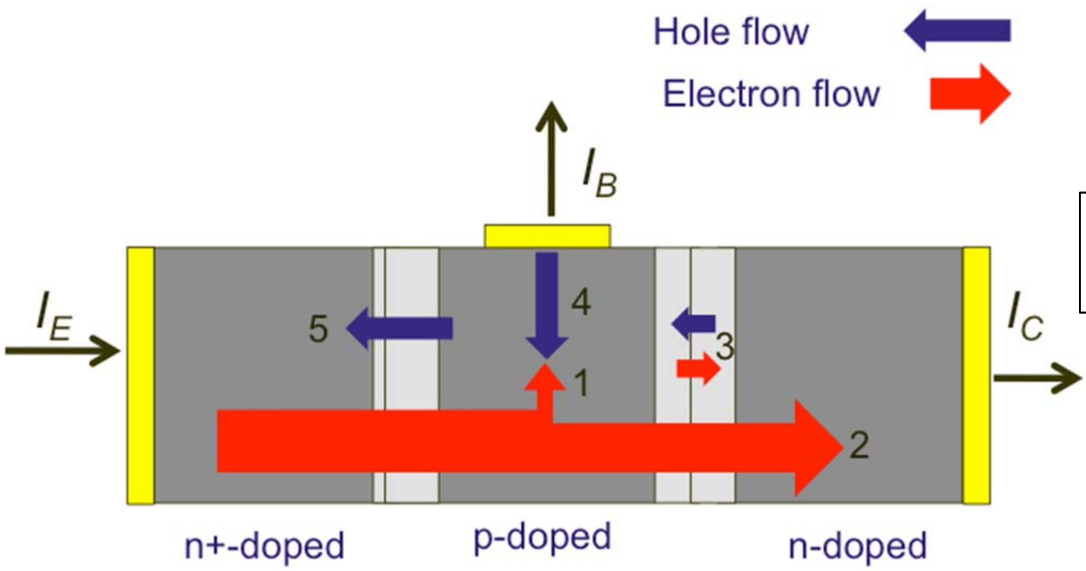
$$\frac{V_o}{V_s} = \frac{V_o}{V_{be}} \cdot \frac{V_{be}}{V_s} = -315.7 \cdot 0.767$$

$$= \underline{\underline{-242}}$$ 1

Question 4:

(a) Emitter-base junction in forward bias, base-collector junction in reverse bias.

2 marks



4 marks

i) Hole current from emitter to base reduces gain, as this current does not appear in the collector
Electrons can recombine with majority holes in the base, and are lost to collector current

2 marks

ii) Ensure the emitter doping is much greater than base doping
Base width should be smaller than the minority carrier diffusion length

2 marks

(b)

7 marks

$V_c = 45\,V$

$I_c = \left(\frac{45}{150}\right) = 0.3\,A$

$\beta = \text{gain} = \frac{I_c}{I_b} = \frac{0.3}{0.003} = \underline{100}$

Must calculate $B = \frac{\alpha}{\gamma}$

$\beta = 100 = \frac{\alpha}{1-\alpha} \Rightarrow \alpha = 0.99$

$B = \frac{\alpha}{\gamma} = \frac{0.99}{0.997} = 0.99298$

(c) $B = 1 - \frac{1}{2}\left(\frac{L_b}{L_e}\right)^2$ is relation to base length.

8 marks

Call B_1 original, and B_2 new

$B_1 = 1 - \frac{1}{2}\left(\frac{L_b}{L_e}\right)^2, \therefore \frac{1}{2}\left(\frac{L_b}{L_e}\right)^2 = 1 - B_1$

$B_2 = 1 - \frac{1}{2}\left(\frac{2L_b}{L_e}\right)^2, \therefore 4\left(\frac{1}{2}\left(\frac{L_b}{L_e}\right)^2\right) = 1 - B_2$

$\Rightarrow \frac{1-B_2}{1-B_1} = 4$

$4 - 4B_1 = 1 - B_2$

$\Rightarrow \underline{B_2 = 4B - 3}$

$\therefore B_2 = 4(0.99298) - 3 = 0.97192$

$\alpha_2 = B_2\gamma = 0.969$

$\boxed{\beta_2 = \frac{\alpha_2}{1-\alpha_2} = 31.26}$

Question 5:

6 marks

(a) Conduction band is the lowest *unoccupied* band of energy levels for electrons in a semiconductor. Or, the conduction band is where free electrons in a semiconductor reside.
Valence band is the highest *occupied* band of energy levels for electrons in a semiconductor. Or the valence band is where free holes in a semiconductor reside.

The band gap of a semiconductor is the energy gap between the top of the valence band and the bottom of the conduction band

2 marks

(b) A hole is a positive charge equivalent to a missing electron in the valence band of a semiconductor. It occurs in the valance band.

4 marks

(c) An intrinsic semiconductor is one in which free electrons and hoes are generated by thermal excitation across the band gap, and where the number of electrons is equal to the number of holes.
An extrinsic semiconductor is one where majority electrons or holes are present due to donor or acceptor impurity atoms in the semiconductor

6 marks

(d) $n_i = CT^{3/2} e^{-\frac{E_g}{2kT}}$ E_g in electron volts.

$1 \times 10^{16} = C(293)^{3/2} e^{-\frac{1.12}{2k(293)}}$

$\Rightarrow \underline{C = 8.38 \times 10^{21}}$

$n_i^{350k} = (8.38 \times 10^{2})(350)^{3/2} e^{-\frac{1.12}{2k(350)}}$

$\boxed{n_i = 4.81 \times 10^{17} m^{-3}}$

Conductivity increases because there are more free carriers in the conduction and valence bands.

7 marks

(e) $n_1 = C T_1^{3/2} e^{-\frac{E_g}{2kT_1}}$

$n_2 = C T_2^{3/2} e^{-\frac{E_g}{2kT_2}}$

Ignoring the $T^{3/2}$ term $\Rightarrow \frac{n_2}{n_1} = e^{-\frac{E_g}{2kT}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)}$

$$\ln\left(\frac{n_2}{n_1}\right) = \ln(1000) = 6.91 = -\frac{E_g}{2k}\left(\frac{1}{T_2} - \frac{1}{293}\right)$$

$$= 6492\left(\frac{1}{T_2} - \frac{1}{293}\right)$$

$$\Rightarrow \boxed{T_2 = 426\,k}$$

Using full equation at this temperature

$$\underline{n_i} = C T^{3/2} e^{-\frac{E_g}{2kT}} = \underline{1.77 \times 10^{18}\, m^{-3}}$$

∴ error is 77%.

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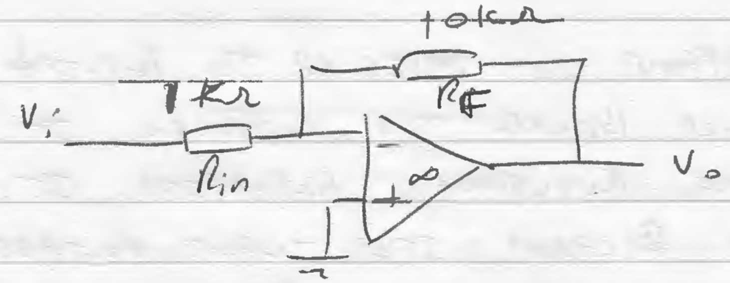
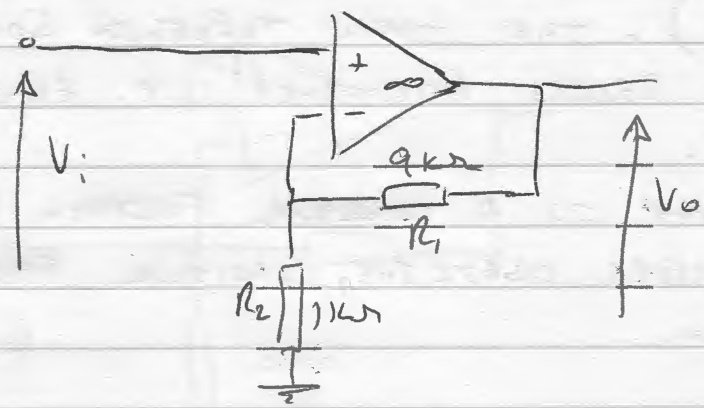
Q6ai



$$\frac{V_o}{V_i} = \frac{-R_F}{R_{in}} = -\frac{10k\Omega}{1k\Omega} = -10\,V/V$$ 4

ii



$$\frac{V_o}{V_i} = \frac{R_1 + R_2}{R_2} = \frac{9k + 1k}{1k} = 10\,V/V$$ 4

bi $V_o = A_v\left(V^+ - V^-\right)$ 1

V_o - OUTPUT VOLTAGE 1

V^+ - NON - INVERTING INPUT +

V^- - INVERTING INPUT

A_v - OPEN LOOP GAIN 1

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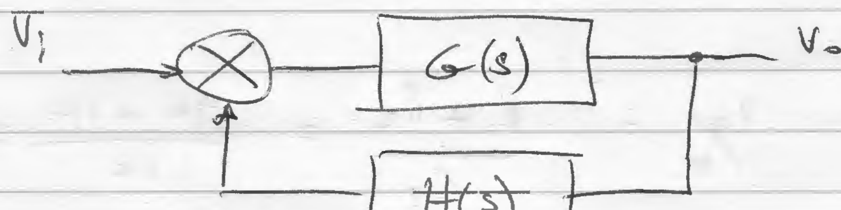
Q6b ii THE OPAMP IS DESIGNED TO AMPLIFY THE DIFFERENCE BETWEEN TWO VOLTAGES. IT IS THEREFORE A VOLTAGE AMPLIFIER. IT SHOULD RECEIVE ITS INPUT VOLTAGES WITHOUT LOADING THE SOURCE(S) DRIVING IT. THEREFORE IT SHOULD HAVE VERY HIGH INPUT RESISTANCE (IDEALLY INFINITE). 1 1

THE OPAMP, LIKE ALL VOLTAGE AMPLIFIERS, SHOULD APPEAR AS A THÉVENIN SOURCE TO ITS LOAD (OUTPUT). THE IDEAL THÉVENIN SOURCE HAS NO SERIES RESISTANCE i.e. ZERO OUTPUT RESISTANCE. 1

THE OPAMP IS A CLASSICAL FEEDBACK SYSTEM. IT THEREFORE OBEYS THE CLASSICAL FEEDBACK EQUATION.



$$V_o / V_i = \frac{G(s)}{1 \pm G(s)H(s)}$$ 1

IF $G(s)$ IS VERY LARGE THE EQUATION APPROXIMATES AS,

$$V_o / V_i = 1 / H(s).$$

WE CAN CONTROL $H(s)$ BY MAKING IT FROM RESISTORS.

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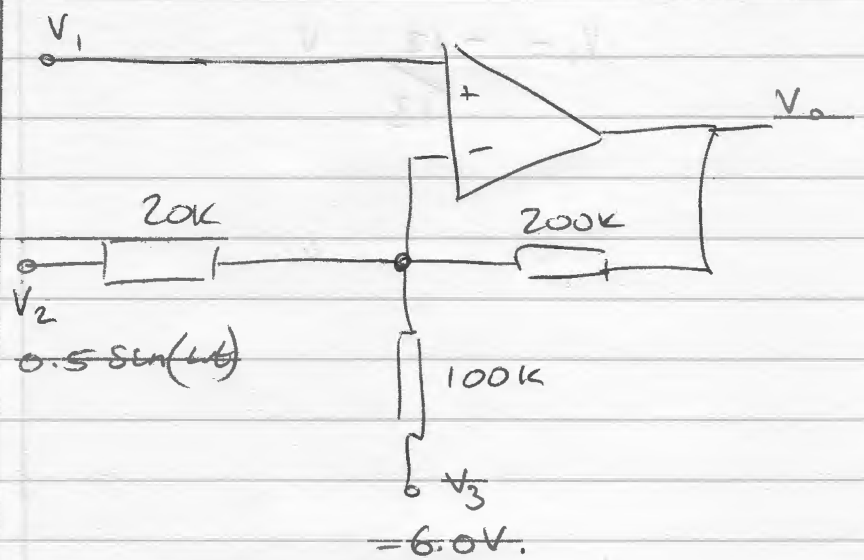
6b ii (CONT'D)

IF H(S) IS IN CONTROL OF THE CIRCUIT PARAMETERS THE EXACT VALUE OF G(S) IS NOT IMPORTANT AND ANY AMPLIFIER CAN BE EXCHANGED FOR ANOTHER SIMILAR BUT NOT IDENTICAL ONE WITH NO LOSS IN DESIGN PERFORMANCE.

6c i



AC ONLY SO DC CAN BE IGNORED

$$\frac{V_o}{V_2} = \frac{-200\,k}{20\,k} \therefore V_o = 0.5 \cdot \frac{-200}{20} \sin(\omega t)$$

$$= -5 \cdot \sin(\omega t)$$

ii DC ONLY SO AC IS IGNORED

$$\frac{V_o}{V_3} = \frac{-200}{100} = -2. \qquad V_o\Big|_{V_3} = +12V$$

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$$V_o\Big|_{V_1} = \frac{200k + \frac{100k \cdot 20k}{100k + 20k}}{\frac{100k \cdot 20k}{100k + 20k}}$$ 1

$$= \frac{200k + 16.66k}{16.66k} = 13 \ V/V.$$ 1

TO YIELD $V_o = 0$ $V_o\Big|_{V_1} + V_o\Big|_{V_3}$ MUST SUM TO ZERO $\therefore$

$$V_1 = -\frac{12}{13} \ V$$ 1