Q1 (a) Bookwork.

The conductivity at 0K (zero) would be expected to be zero. All the electrons would be in bonds and there would be no thermal energy to allow them to escape. As the temperature is raised thermal energy increases and some electrons will escape and be free to move around the material, leaving behind a hole in a bonding state which is +ve charged and also free to move. Both these particles will be able to conduct electricity and so the conductivity rises.

(b) Bookwork, all info on examination sheet.

$$\sigma = nq\mu_e + pq\mu_h.$$

$$n = p = n_i = 1.45 \times 10^{16} m^{-3}, \quad \mu_e = 0.07\ m^2 V^{-1} s^{-1}, \quad \mu_h = 0.045\ m^2 V^{-1} s^{-1}$$

$$\sigma = 1.63 \times 10^{-4} + 1.05 \times 10^{-4}$$

$$\sigma = 2.68 \times 10^{-4}\ \Omega^{-1} m^{-1}$$ [3]

(c) Applied Bookwork

The total conductivity

$$\sigma = n_p q \mu_e + p q \mu_h$$

$$p = 10^{21}\ m^{-3}$$

$$n_p = \frac{n_i^2}{p} = 2.1 \times 10^{11}\ m^3$$

$$\sigma_T = \sigma_n + \sigma_p \qquad \sigma_n = 2.36 \times 10^{-9}$$
$$\sigma_p = 7.2 \times 10^{0}$$

$$\sigma_n \ll \sigma_p \quad \therefore \quad \sigma_T = 7.2\ \Omega^{-1} m^{-1}$$

Fractional contribution from holes ~~100%~~ $= \frac{\sigma_p}{\sigma_n + \sigma_p} \approx 1$

Fractional contribution from electrons $= \frac{\sigma_n}{\sigma_n + \sigma_p} \approx \frac{\sigma_n}{\sigma_p} = 3.3 \times 10^{-10}$

(d) Hidden.

$$G = Bnp$$

In thermal $\equiv^m$ $\quad G = B n_i p_i$

Under illumination, $G' = 10^6 G$

$$G' = B n' p'$$

$$\frac{G'}{G} = \frac{n' p'}{n_i^2}$$ [2]

$$n' = p'$$ [1]

$$\therefore \frac{G'}{G} = \frac{n'^2}{n_i^2}$$

$$10^6 = \frac{n'^2}{n_i^2}$$

$$\therefore n' = 10^3 n_i$$ [1]

From part (b) $\sigma = 2.68 \times 10^{-4}\ \Omega^{-1} m^{-1}$

$$\therefore \sigma' = 2.68 \times 10^{-1}\ \Omega^{-1} m^{-1}$$ [1] [5]

The reason for the increase is due to absorption of light creating electron-hole pairs as photons provide the energy for electrons to escape from their bonds [2]

~~2(a) Given~~

~~$p_{(p)} = p_n \exp\left(\frac{qV_0}{kT}\right)$ $n_{(n)} = n_p \exp\left(\frac{qV_0}{kT}\right)$~~

~~Under forward bias we first need to know the number of excess electrons holes and electrons holes crossing the junction, δp_0~~

As ~~junction~~

2 (a) BOOKWORK, although proof in notes does not assume $I_{h_0} \gg I_{e_0}$ which can be made here, simplifying the proof.

$$p_{(p)} = p_n \exp\left(\frac{qV_0}{kT}\right)$$

As p^+-n we can assume $I_{h_0} \gg I_{e_0}$ and therefore need only consider the hole current.

Under forward bias V, the excess holes injected across the junction δp_0 can be given by $\delta p_0 = p_{n0} - p_n$

where $p_{(p)} = p_{n0} \exp\left(\frac{q(V_0 - V)}{kT}\right)$

$$\delta p_0 = \frac{p_{(p)}}{p_{n0} \exp \frac{q(V_0-V)}{kT}} - \frac{p_{(p)}}{p_n \exp\left(\frac{qV_0}{kT}\right)}$$

∴ Substituting again for $p_{(p)}$

$$\delta p_0 = p_n \left[\exp\left(\frac{qV}{kT}\right) - 1\right] \qquad [3]$$

Now the the total charge ~~injected across the~~ existing in the n-type material Q_p will be given by

$$Q_p = qA \int_0^{\infty} \delta p(x)\, dx$$

where $\delta p(x) = \delta p_0 \exp\left(-x/L_h\right)$

$$Q_p = qA\,\delta p_0 \int_0^\infty \exp\left(-x/L_h\right)dx.$$

$$= qA\,\delta p_0 L_h. \qquad [3]$$

~~This charge is exists for the~~

On average the charges exist for τ_h

$$\therefore\ I = I_h \qquad (\text{assuming } I_e \ll I_h)$$

$$= \frac{qAL_h}{\tau_h}\delta p_0$$

and hence

$$I = \left[\frac{qAL_n p_n}{\tau_h}\right]\left[\exp\left(\frac{qV}{kT}\right) - 1\right] \qquad [2]$$

(b) APPLIED BOOKWORK, rectifiers not explicitly explained in course.

In a rectifier an a.c. signal is applied across the diode. ~~In~~ for half the cycle the diode will be reverse biased, so no current will flow, apart from a small leakage current as the built in potential ~~a~~ across the junction will be larger. In the other half of the cycle the diode is forward biased and the built in potential will be eventually overcome with electrons and holes being injected across the junction and recombining allowing a significant current to flow. ~~Hence this~~

[5]

(c) HIDDEN

$$V_{peak} = \sqrt{2}\, V_{rms} = 7.1V$$

At V_{peak}, $I_{peak} = 100mA = I_o\left[\exp\left(\frac{qV}{kT}\right) - 1\right]$

$$0.1 = 10^{-12}\left[\exp\left(\frac{qV}{kT}\right) - 1\right] \quad [2]$$

$$10^{11}(+1) = \exp\left[\frac{1.60\times10^{-19}}{1.38\times10^{-23}\times300} V_d\right]$$

$$\ln(10^{11}) = 38.7\, V_d$$

$$V_d = \frac{25.3}{38.7} = \underline{\underline{0.7V}} \quad [2]$$

V_d = Voltage drop across diode.

There are two diodes for each half of the cycle

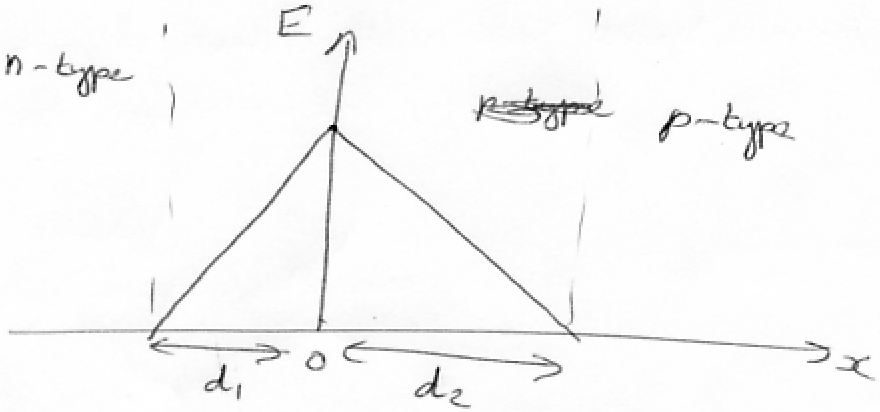
$\therefore$ the voltage drop at I_{peak} = $2V_d = 1.4V$ [1]

$\therefore$ D.C. Voltage across load = $5.7V$ [1]

3(a) BOOKWORK

$$\frac{dE}{dx} = \rho/\varepsilon = \frac{N_d q}{\varepsilon} = -\frac{N_a q}{\varepsilon}$$

$x<0$ $x>0$ [2]



[1]

For $-d_1 \leq x \leq 0$

$$E(x) = \int \frac{N_d q}{\varepsilon}\, dx = \frac{N_d q x}{\varepsilon} + C \quad [1]$$

B.C. that $E=0$ at $x=-d_1$

$$\therefore\ C = \frac{N_d q d_1}{\varepsilon}$$

$$E(x) = \frac{N_d q (x+d_1)}{\varepsilon} \quad [1]$$

$E_{max} = \frac{N_d q d_1}{\varepsilon} = \frac{N_a q d_2}{\varepsilon}$

Similarly for $0 \leq x \leq d_2$

$$E(x) = \frac{-N_a q (x - d_2)}{\varepsilon} \quad [1]$$

$$V_0 = -\int_{-d_1}^{d_2} E(x)\, dx = \text{Area under } E(x) \text{ curve}$$

$$V_0 = \tfrac{1}{2} d_1 \frac{N_d q d_1}{\varepsilon} + \tfrac{1}{2} d_2 \frac{N_a q d_2}{\varepsilon} \quad [1]\ [1]$$

Let $N_d >> N_a$ and $\therefore d_1 << d_2$ $V_0 = \frac{q N_a d^2}{2\varepsilon}$, $d = \sqrt{\frac{2\varepsilon_0\varepsilon_r V_0}{q N_a}}$

b) Applied bookwork

For b-e junction forward biassed and n^+p

$$\therefore \quad d = \sqrt{\frac{2\varepsilon_0 \varepsilon_r (V_0 - V)}{q N_a}} \qquad [1]$$

$$[1]$$

As $V_{be} = V_0 \qquad d = 0.$

For c-b junction reverse biased and $p^+ - n$

$$\therefore \quad d = \sqrt{\frac{2\varepsilon_0 \varepsilon_r (V_0 + V)}{q N_d}} \qquad [1]$$

As $V_{cb} = 9.2V \qquad N_d = 1 \times 10^{23}\ m^{-3}$ [1]

$$d = 3.6 \times 10^{-7}\ m. \qquad [1]$$

(c) More difficult ~~applied pro~~ application of bookwork students have to apply known equation

$$\frac{d_p}{d_n} = \frac{N_d}{N_a} \qquad [1]$$

d_2 d_1

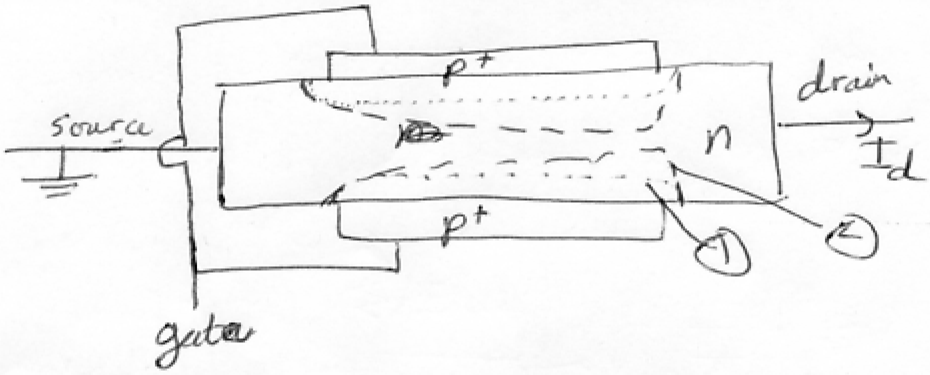
From above $d_n = 3.6 \times 10^{-7}\ m$

$$d_p = \frac{N_d}{N_a} d_n = 1.8 \times 10^{-8}\ m \qquad [2]$$

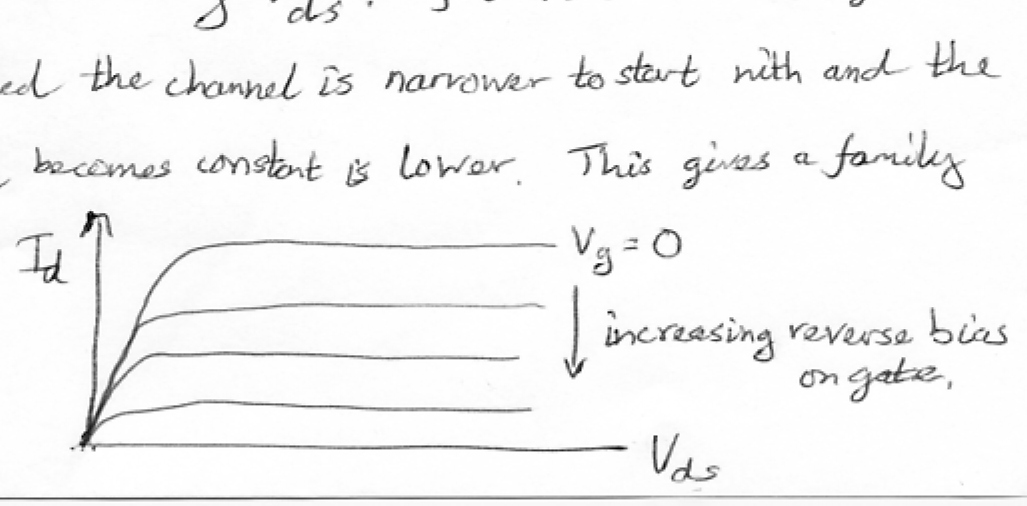
(d) HIDDEN
As V_{CE} increases the base region thickness will effectively decrease slightly as the depletion region around the C-B junction increases. This reduction in the base thickness should cause the transistor gain to increase slightly [4]

4 (a) Bookwork

The physical structure should be shown as below, ~~with~~ or as a single channel device on an insulating substrate

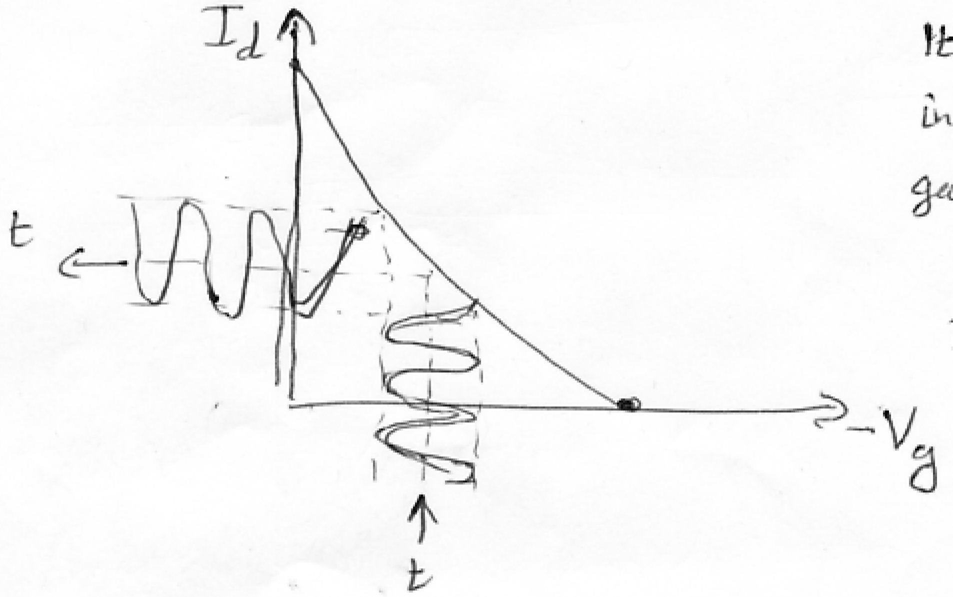


Under low V_{ds} current will flow through the n-channel with some small voltage drop due to the resistance of the channel. As V_{ds} increases the gate-drain voltage will become more reverse biased and hence the depletion region will grow from the dotted line ① to the dashed line ② hence the channel is constricted and the resistance increase. Eventually the situation is ~~reached~~ reached whereby the constriction is such that I_d ~~...~~ remains constance for ever increasing V_{ds}. If a reverse biased gate Voltage is applied the channel is narrower to start with and the point where I_d becomes constant is lower. This gives a family of curves below



(b) More advanced bookwork. [B]

In the JFET we wish to characterise the change in output drain current, against the change in input gate voltage. The transfer characteristic is a plot of this function:



It shows how the input voltage on the gate can ~~step~~ transfer to the output current in the amplifier region.

The transconductance is the slope of this line at the quiescent point, given by

$$g_m = \left.\frac{\partial I_d}{\partial V_g}\right|_{V_g}$$

This allows us to write

$$\hat{i}_d = g_m v_{gs}$$ [5]

(c)

At the Quiescent point $I_d = \dfrac{\text{Voltage drop across } R_L}{R_L}$

$$= \frac{\cancel{7.5}\,15 - 7.5\text{ V}}{1.5\text{ k}\Omega}$$

$$= 5\text{ mA}$$ [1]

$i_{d\,(pk-pk)} = g_m V_{gs\,(pk-pk)}$

$$= 0.12 \times 0.01 = 1.2\text{ mA}$$ [2]

$I_d + i_d$ varies between 4.4 and 5.6 mA [1]

∴ V_{drop} across R_L varies between 6.6 and 8.4 V

∴ $V_{out} = 1.8$ V (peak-peak) [1]

$$V_{gain} = \frac{V_{out}}{V_{in}} = \frac{1.8}{0.01} = \underline{\underline{180}}$$ [1]