UNIVERSITY OF SWAZILAND
FACULTY OF SCIENCE
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

MAIN EXAMINATION 2009

TITTLE OF PAPER: **ELECTRICAL CIRCUITS**

COURSE CODE: **E310**

TIME ALLOWED: **THREE** HOURS

INSTRUCTIONS:

1. Answer **QUESTION 1** and **ANY THREE** from QUESTIONS **2 - 5.**
2. Each question carries 25 marks

This paper has 6 pages including this page

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QUESTION 1

A Chose and write down only the letter containing the right answers to each of the following questions below:

i) A resistor is an example of a(an)

a) bilaterial component.
b) active component.
c) passive component.
d) both a and c.

ii) To apply Superposition theorem, all components must be

a) the active type.
b) both linear and bilateral.
c) grounded.
e) both nonlinear and unidirectional.

iii) Thevenin's Theorem states that an entire resistive network connected to a pair of terminals can be replaced with

a) a single current source in parallel with a single resistance.
b) a single voltage source in parallel with a single resistance.
c) a single voltage source in series with a single resistance.
d) a single current source in series with a single resistance.

iv) When solving for the Thevenin equivalent resistance, R_{TH}

a) all voltage sources must be opened.
b) all voltage sources must be shotcircuited.
c) all voltage sources must be converted to current sources.
d) none of the above.

v) Norton's Theorem states that an entire network connected to a pair of terminals can be replaced with

a) a single current source in parallel with a single resistance.
b) a single voltage source in parallel with a single resistance.
c) a single voltage source in series with a single resistance.
d) a single current source in series with a single resistance.

vi) The current through an inductor

a) sometimes lags the voltage by 90 degrees.
b) always lags the voltage by 90 degrees.
c) sometimes leads the voltage by 90 degrees.
d) always leads the voltage by 90 degrees.

vii) The voltage across a capacitor

a) sometimes lags the current by 90 degrees.
b) always lags the current by 90 degrees.
c) sometimes leads the current by 90 degrees.
d) always leads the current by 90 degrees.

(**14 marks**)

B i) Draw a delta network and a wye network and give the six formulas needed to convert from one to the other.

Determine whether the following are linear or non linear.

ii) Ohm's law and
iii) The power dissipated by a resistor as a function of current

(11 marks)

QUESTION 2

A) i) State the superposition theorem.

ii) State how to calculate V_{TH} and R_{TH} in Thevenin equivalent circuits.

iii) State the method of calculating I_N and R_N for a Norton equivalent circuit.

(12 marks)

B) For the circuit shown in figure 1,

i) By employing the current divider principle, calculate the current flowing through, and the voltage drop across R_L in the circuit in figure 1.

ii) Use Thevenin's theorem to calculate the current flowing through and the voltage drop across R_L in the circuit in figure 2.

iii) State the advantage of calculating the load current and voltage drop by the method used in B) ii over that used in B) i above.

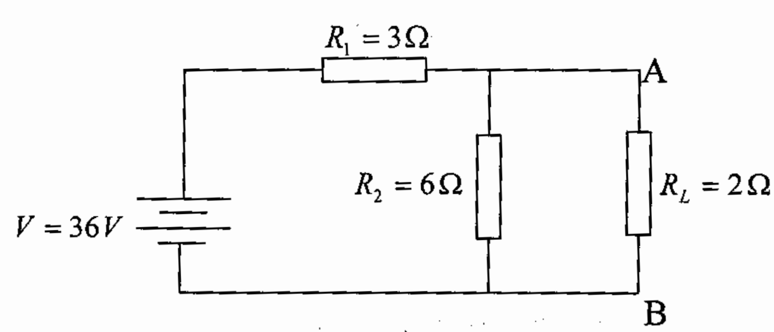

Figure 1

(13 marks)

QUESTION 3

A) For the circuit shown in figure 2, calculate the current flowing though and the voltage drop across R_3 using

i) Kirchoff's laws.

ii) the superposition theorem.

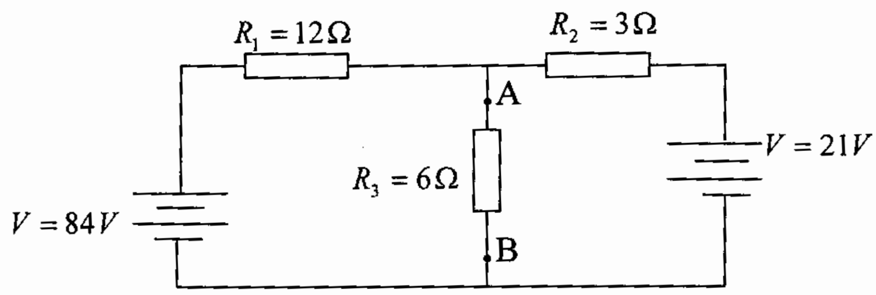

Figure 2

(12 marks)

B) For the circuit shown in figure 3:

i) Determine the mathematical expressions for the variation of the current in the inductor following the closure of the switch at time $t = 0$ on to point 1;

ii) when the switch is closed unto position 2 at $t = 100ms$, determine the new expression for the inductor current and also for the voltage across R_2;

iii) Sketch the current waveform for $t = 0$ to $t = 200ms$

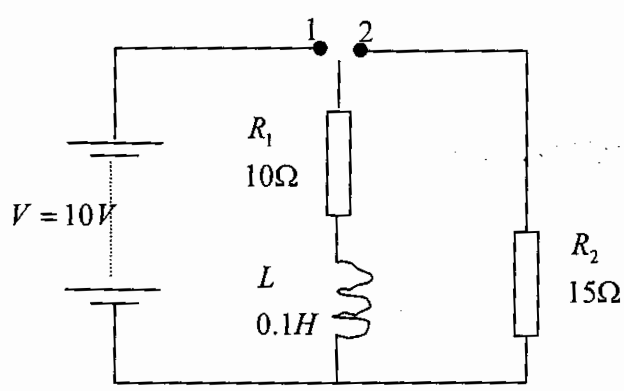

Figure 3

(13 marks)

QUESTION 4

A) The instantaneous values of two alternating voltages are represented respectively by $v_1 = 60\sin\theta\ volts$ and $v_2 = 40\sin(\theta - \pi/3)\ volts$. Derive an expression for the instantaneous values of:

i) the sum

ii) the difference of these voltages

(10 marks)

B) Derive an expression for the impedance Z of

i) a series circuit comprising a resistor R and an inductor L.

ii) a series circuit comprising a resistor R and a capacitor C.

iii) a series circuit comprising a resistor R, an inductor L and a capacitor C.

(15 marks)

QUESTION 5

A) Consider the simple RC circuit of figure 4.

i) Obtain an expression for the magnitude and phase of the circuit gain, where ω is the frequency of the supply voltage.

ii) Sketch the frequency (amplitude and phase) response.

(10 marks)

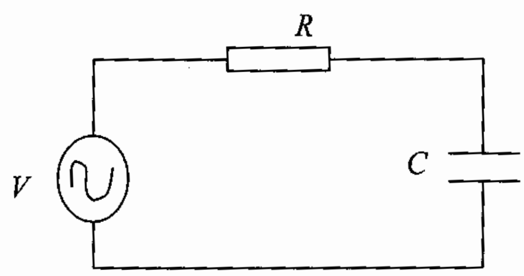

Figure 4

B) Consider the simple RC circuit of figure 5.

i) Obtain an expression for the magnitude and phase of the circuit gain, where ω is the frequency of the supply voltage.

ii) Sketch the frequency (amplitude and phase) response.

(10 marks)

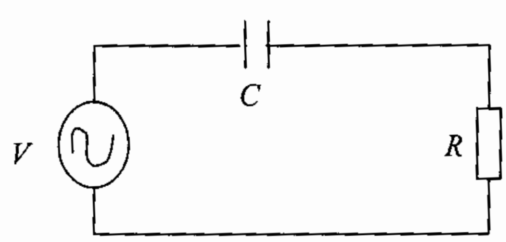

Figure 5

C) Sketch the voltage output amplitude versus frequency for a low pass RC filter having a resistor of $1k\Omega$ and a capacitor of $400\,pF$ supplied from a $12V$ a.c. source. What is the half power frequency?

(5 marks)

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MAIN EXAMINATION 2009/2010

TITLE OF PAPER: ELECTRONIC MATERIALS & DEVICES I

COURSE NUMBER: E321

TIME ALLOWED : THREE HOURS

ANSWER ANY FOUR QUESTIONS . ALL QUESTIONS CARRY EQUAL MARKS

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Question One

(a) (i) Calculate the energy of a photon with wavelength 5000 A. Express your answer in both electron volt and in joules. (3 marks)

(ii) An oscillator has a resonant frequency of 10 MHz.

1. What is the energy of the quantum of radiation associated with this oscillator in eV? (2 marks)
2. How many quanta of energy is 10^{-6} J? (1 mark)

(iii) Write down the Fermi - Dirac distribution function for a system of fermions at temperature of T Kelvin. What is the physical meaning of this function? (4 marks)

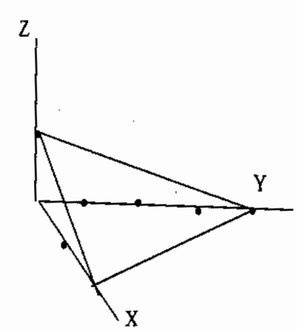
(iv) Define Fermi energy. Show that the probability of occupation of an energy state ΔE above the Fermi energy is equal to the probability of occupation of the state ΔE below the Fermi level. (4 marks)

(b) (i) Draw a unit cell of an bcc lattice. (2 marks)

(ii) State with reason whether or not the unit cell you have drawn is primitive or non-primitive. (2 marks)

(iii) Find the nearest neighbour distance of this lattice. (3 marks)

(iv) Find the Miller indices of the plane in the figure below. (2 marks)



(v) Calculate the spacing between two such planes if the lattice constant is 2 Å. (2 marks)

Question Two

(a). (i) Write down the equation for the density of states N(E)d(E) for a system of electrons. (1 mark)

(ii) If f(E)d(E) is the distribution function of the electrons what is the total energy of the system? (1 mark)

(iii) Calculate the effective density of states in the conduction band of silicon at 300 K. (Assume effective mass of electron is equal to its rest mass). (5 marks)

(b) Using appropriate expressions for the effective density of states, N_C and N_V, show that: the relation $n_0\, p_0 = n_i^2$, is valid for extrinsic semiconductors. [n_0, p_0 are the equilibrium electron and hole concentrations of an extrinsic semiconductor and n_i is the intrinsic carrier concentration].

Given: $n_0 = N_C \exp\left[-\frac{E_C - E_F}{kT}\right]$; $p_0 = N_v \exp\left[-\frac{E_F - E_v}{kT}\right]$

(8 marks)

(c) A uniformly doped silicon sample has a donor concentration of $5\text{x}10^{15}$ cm^{-3} and an acceptor concentration of $1.1\text{x}10^{16}$ cm^{-3}. Assume that all dopant atoms are ionized.

(i) Calculate the electron and hole equilibrium concentrations n_o and p_o, respectively.
(ii) Determine the position of the Fermi level in the sample.
(iii) Draw the resulting band diagram of the sample.

[given: $n_i = 1.5\ \text{x}10^{10}$ cm^{-3}] (10 marks)

Question Three

(a) Explain how ***Hall voltage*** is produced in a rectangular uniformly doped n - type semiconductor. (Draw necessary diagrams).

(5 marks)

(b) A Hall voltage of 6 mV was obtained in a semiconductor sample of length 2 cm, thickness of 0.4 cm and width 0.8 cm, when a current of 75 mA was flowing along its length. Magnetic field applied across its length was 5×10^{-5} weber cm^{-2} and the applied voltage was 1.5 V. Calculate

(i) the Hall constant,
(ii) the carrier concentration of the sample, and
(iii) the Hall mobility.

(9 marks)

(c) (i) Define the terms ***mean free path*** and ***carrier mobility*** of a semiconductor.

(4 marks)

(ii) The hole diffusion coefficient of a silicon sample is 12 cm^2s^{-1}. An electric field of 200 V cm^{-1} is applied to the sample. Determine the:
mobilty, relaxation time, and ***drift velocity*** of holes in the sample.

(7 marks)

[Take T = 300K]

Question Four

(a) Discuss ***photo-generation of excess carriers*** in the semiconductor sample.
Sketch a diagram showing the variation of the optical absorption coefficient of the sample with photon energy.

(5 marks)

(b) Distinguish between the following recombination processes in semiconductors.

(i) direct and indirect
(ii) radiative and non- radiative

(4 marks)

(c) Excess holes generated at one end of a semiconductor sample by irradiation, diffuse along its length after the irradiation source is switched off. Write down an expression showing how the hole concentration varies with length of the sample. State what each symbol represent.

(4 marks)

(d) A silicon sample doped with 10^{15} donors cm^{-3} is illuminated producing 2×10^{13} cm^{-3} excess pairs.

(i) Calculate the non-equilibrium electron and hole concentrations, n and p.

(4 marks)

(ii) Find the position of the electron and hole quasi- Fermi levels.

(4 marks)

(iii) Calculate the change in conductivity of the sample. (4 marks)

Question Five

(a) Draw energy band diagrams of p - type and n - type semiconductor samples.

(i) when they are separate and (2 marks)
(ii) when they are joined together to form a p-n junction. (2 marks)

(b) Sketch diagrams to show:

(i) the electric field, and

(ii) the potential distributions, in an abrupt p-n junction.

(3 + 3 marks)

(c) Distinguish between a rectifying junction and an ohmic junction. (4 marks)

(d) An abrupt silicon p-n junction of area of cross section 0.2 mm^2 has acceptor concentration of 10^{24} m^{-3} and donor concentration of 10^{21} m^{-3} at 300 K. Calculate:

(i) the built-in voltage,
(ii) the depletion layer width,
(iii) the maximum electric field in the depletion region, and
(vi) the depletion layer capacitance.

(11 marks)

APPENDIX A

SOME USEFUL EQUATIONS.

$$f(E) = \frac{1}{1 + \exp\left(\frac{E - E_F}{kT}\right)}$$

$$\sigma = q(\mu_n n + \mu_p p)$$

$$n = n_i \exp\left(\frac{E_{Fn} - E_i}{kT}\right);$$

$$p = n_i \exp\left(\frac{E_i - E_{Fp}}{kT}\right);$$

$$V_i = \frac{kT}{q} \ln \frac{N_a N_d}{n_i^2}$$

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

$$C_j = A\left[\frac{\varepsilon q N_a N_d}{2V_i (N_a + N_d)}\right]^{1/2}$$

$$Jp(x) = q\left[\mu_p p(x) E(x) - D_p \frac{dp(x)}{dx}\right]$$

$$\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = \frac{kT}{q}$$

$$E_I = 13.6\left(\frac{m_e^*}{m_0}\right)\left(\frac{\varepsilon_0}{\varepsilon_s}\right)^2 eV$$

$$N_{c,v} = 2\left(\frac{2\pi mkT}{h^2}\right)^{3/2}$$

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APPENDIX B

PHYSICAL CONSTANTS

Quantity	Symbol	Value
Angstrom unit	Å	1 Å = 10^{-8} cm = 10^{-10} m
Avogadro number	N	6.023×10^{23}/mol
Boltzmann constant	k	8.620×10^{-5} eV/K = 1.381×10^{-23} J/K
Electronic charge	q	1.602×10^{-19} C
Electron rest mass	m_o	9.109×10^{-31} kg
Electron volt	eV	1 eV = 1.602×10^{-19} J
Gas constant	R	1.987 cal/mole-K
Permeability of free space	μ_o	1.257×10^{-6} H/m
Permittivity of free space	ϵ_o	8.850×10^{-12} F/m
Planck constant	h	6.626×10^{-34} J-s
Proton rest mass	m_p	1.673×10^{-27} kg
$h/2\pi$	$\hbar$	1.054×10^{-34} J-s
Thermal voltage at 300 K	V_T	0.02586 V
Velocity of light in vacuum	c	2.998×10^{10} cm/s
Wavelength of 1-eV quantum	λ	1.24 μm

TABLE 4.2
Properties of Ge, Si and GaAs at 300 K

Property	Ge	Si	GaAs
Atomic/molecular weight	72.6	28.09	144.63
Density (g cm^{-3})	5.33	2.33	5.32
Dielectric constant	16.0	11.9	13.1
Effective density of states			
Conduction band, N_C (cm^{-3})	1.04×10^{19}	2.8×10^{19}	4.7×10^{17}
Valence band N_V (cm^{-3})	6.0×10^{18}	1.02×10^{19}	7.0×10^{18}
Electron affinity (eV)	4.01	4.05	4.07
Energy gap, E_g (eV)	0.67	1.12	1.43
Intrinsic carrier concentration, n_i (cm^{-3})	2.4×10^{13}	1.5×10^{10}	1.79×10^{6}
Lattice constant (Å)	5.65	5.43	5.65
Effective mass			
Density of states m_e^*/m_o	0.55	1.18	0.068
m_h^*/m_o	0.3	0.81	0.56
Conductivity m_e/m_o	0.12	0.26	0.09
m_h/m_o	0.23	0.38	
Melting point (°C)	937	1415	1238
Intrinsic mobility			
Electron (cm^2 V^{-1} sec^{-1})	3900	1350	8500
Hole (cm^2 V^{-1} sec^{-1})	1900	480	400