



STRATHMORE UNIVERSITY
SCHOOL OF COMPUTING AND ENGINEERING SCIENCES
BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING
END OF TERM II EXAMINATION
BEE 2102: PHYSICAL ELECTRONICS

29th July 2024

15.30 – 17.30 Hours

Instruction:

1. This paper consists of **FIVE** questions.
2. Answer question 1 (Compulsory) and **ANY** other **TWO** questions
3. Show all your working in a systematic manner, where necessary, use diagrams to illustrate your concepts.
4. Use mathematical tables where necessary

Important constants

Charge of an electron or proton, q_{e^-} or $q_{e^+} = 1.6 \times 10^{-19} C$

Mass of an electron $m_e = 9.1095 \times 10^{-31} kg$

Mass of a neutron $m_n = 1.67 \times 10^{-27} kg$

Planck's constant, $h = 6.626 \times 10^{-34} J.s$

Rydberg constant, $R_H = 1.097 \times 10^{-7} m^{-1}$

Atomic mass unit of carbon $m = 12 u$

Atomic mass unit of oxygen $m = 16 u$

Atomic number of tungsten $Z = 74$

Coulomb constant, $k_e = 8.99 \times 10^9 N.m^2/C^2$

Boltzmann Constant, $k_B = 8.61 \times 10^{-5} eV/K = 1.38 \times 10^{-23} J/K$

Permeability constant $\mu_o = 1.26 \times 10^{-6} T.m/A$

Electron concentration in Gold, $n_e = 5.90 \times 10^{28} m^{-3}$

$1 eV = 1.60 \times 10^{-19} J$

$$1 u = 1.66 \times 10^{-27} kg$$

QUESTION 1 (30 MARKS)

- (i) Define the following three processes of atomic transitions (3 marks)
- a. Stimulated emission
 - b. Spontaneous emission
 - c. Stimulated absorption
- (ii) The electron of an atom makes a transition from $n=3$ level to the ground state. Find
- a. The wavelength of the emitted photon (2 marks)
 - b. The frequency of the emitted photon (1 marks)
- (iii) Consider a hydrogen atom in the $l = 2$ state. Calculate the corresponding angles between angular momentum and the z -axis (3 marks)
- (iv) The $J = 1$ to $J = 2$ rotational transition of the CO molecule occurs at a frequency of $2.30 \times 10^{11} Hz$. Using this information, calculate
- a. The moment of inertia of the molecule (3 marks)
 - b. The bond length of the molecule (3 marks)
- (v) An electron is confined to two impenetrable walls $0.200 nm$ apart
- a. Determine the energy level (in eV) for the state $n = 2$ (3 marks)
 - b. Find the speed of the electron in this state (2 marks)
- (vi) The electron concentration in Si at $T = 300K$ is $n_o = 5 \times 10^4 cm^{-3}$. Given that the intrinsic carrier concentration in silicon (Si) is $n_i = 1.5 \times 10^{10} cm^{-3}$, determine
- a. Hole concentration p_o (2 marks)
 - b. The position of the Fermi energy level E_F with respect to the intrinsic Fermi energy level E_{Fi} . (3 marks)
- (vii) Estimate the wavelength of the characteristic x-ray emitted from tungsten target when an electron drops from M shell to a vacancy in the K shell. (5 marks)

QUESTION 2 (15 MARKS)

- (i) State Hund's rule (1 mark)
- (ii) Quantum dots are now being used in nanotechnology in place of semiconductors
- a. Describe a quantum dot. (1 marks)

- b. Using potential energy diagram, describe how the quantum dot is utilized in resonant tunnelling transistor to amplify voltage/current. (5 marks)
- (iii) X-rays having an energy of 300 keV undergo Compton scattering from a target. The scattered rays are detected at 37.0° relative to the incident rays. Find
- The Compton shift at this angle (3 marks)
 - The energy of the scattered rays (4 marks)
 - The energy of the recoiling electron (1 marks)

QUESTION 3 (15 MARKS)

- (i) Electrons are ejected from a metallic surface with speeds of up to $4.60 \times 10^5 \text{ m/s}$ when light of a wavelength 625 nm is used. Calculate the cutoff frequency for this surface. (4 marks)
- (ii) Lightning produces a maximum air temperature on the order of 10^4 K . Using Wien's displacement law, calculate the wavelength of the thermally produced photons radiated with the greatest intensity by this source (2 marks)
- (iii) An electron of charge q and mass m is acted upon by an alternating field $E_0 e^{i\omega t}$,
- Show that drift velocity $\langle v \rangle$ is given as (4 marks)

$$\langle v \rangle = \frac{qE_0\tau(1 - i\omega\tau)}{m(1 + \omega^2\tau^2)}$$

- Taking the real part of the equation obtained in (a), show that the alternating conductivity σ is related to direct current conductivity σ_0 by

$$\sigma = \frac{\sigma_0}{1 + \omega^2\tau^2}$$

- Sketch a graph of σ as a function of $\omega\tau$ (2 marks)

QUESTION 4 (15 MARKS)

- (i) Using well labelled diagrams, discuss the differences between the band structures of metals, insulators and semiconductors. (6 marks)
- (ii) The speed of an electron is measured to be $5.00 \times 10^3 \text{ m/s}$ to an accuracy of 0.003% . Find the minimum uncertainty in determining the position of this electron. (3 marks)
- (iii) Calculate the de Broglie wavelength of a 0.05 eV "thermal" neutrons (3 marks)

- (iv) Each atom of gold contributes one free electron to the metal for conduction. Calculate the Fermi energy of gold (3 marks)

QUESTION 5 (15 MARKS)

- (i) The wave function for a quantum particle is given by $\psi(x) = Ax$ between $x = 0$ and $x = 1.00$, and $\psi(x) = 1$ elsewhere. Find
- The value of the normalization constant A . (3 marks)
 - The probability that the particle will be found between $x = 0.300$ and $x = 0.400$ (3 marks)
 - The expectation value of the particle's position (3 marks)
- (ii) Using the free-electron theory for electrons in copper wire and assuming that the mean free path is 1 mm at $T = 27^\circ\text{C}$, determine
- The average thermal speed of the electrons (3 marks)
 - Electron drift velocity given an external electric field of 10 V/m (3 marks)