



**SCHOOL OF COMPUTING AND ENGINEERING SCIENCES**  
**BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING**  
**END OF SEMESTER I EXAMINATION**  
**BEE 2102: PHYSICAL ELECTRONICS**

**Date: 29<sup>th</sup> October 2024**

**Time: 15:30-18:00 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 and values***

Simplest wavefunction  $\psi_{1s}(r) = \frac{1}{\sqrt{\pi a_0^3}} e^{-r/a_0}$

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

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

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

$\hbar = 1.054 \times 10^{-34} J.s$

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  $Z = 74u$

Speed of light,  $c = 3.0 \times 10^8 m/s$

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  $\mu_0 = 1.26 \times 10^{-6} T \cdot m/A$

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

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

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

Wavelength of sodium light  $\lambda = 5890 \text{ \AA}$

$1 \text{ \AA} = 10^{-10} m$

### QUESTION 1 (30 MARKS)

- a) State Pauli's exclusive principle (1 mark)
- b) An electron in a hydrogen atom makes a transition from the second level energy level to the ground level. Find
- (i) The wavelength of the emitted photon (3 marks)
  - (ii) The frequency of the emitted photon (2 marks)
- c) Suppose that the momentum of a certain particle can be measured to an accuracy of one part in a thousand. Determine the minimum uncertainty in the position of the particle if the particle has a mass of  $5 \times 10^{-3} kg$  and is moving with a speed of  $2 m/s$ . (4 marks)
- d) A particle of mass  $m$  is confined to a one-dimensional box of length  $L$ . Given that the particle wavefunction is given as  $\psi(x) = \sqrt{\frac{2}{L}} \sin(n\pi x/L)$ , where  $n = 1, 2, 3, \dots$ . By imposing the boundary conditions, find the expectation value of  $x$  of the particle in the state characterized by the quantum number  $n$ . (5 marks)
- e) Each atom of gold contributes one free electron to the metal for conduction. Calculate the Fermi energy (in  $eV$ ) of gold (3 marks)
- f) Consider a hydrogen atom in the  $l = 2$  state. Calculate the corresponding angles between angular momentum and the  $z$ -axis (4 marks)
- g) Define a term quantum dot as used in nanotechnology (1 mark)
- h) The  $J = 0$  to  $J = 1$  rotational transition of the CO molecule occurs at a frequency of  $2.30 \times 10^{11} Hz$ . Using this information, calculate
- (i) The moment of inertia of the molecule (3 marks)
  - (ii) The bond length of the molecule (4 marks)

### QUESTION 2 (15 MARKS)

- a) X-rays having an energy of  $300 \text{ keV}$  undergo Compton scattering from a target. The scattered rays are detected at  $37.0^\circ$  relative to the incident rays. Find
- (i) The Compton shift at this angle (3 marks)
  - (ii) The energy of the scattered rays (5 marks)
  - (iii) The energy of the recoiling electron (1 marks)
- b) Using well labelled diagrams, discuss the differences between the band structures of metals, insulators and semiconductors. (6 marks)

### QUESTION 3 (15 MARKS)

- a) Explain the three conditions that must be satisfied for simulated emission of radiation to occur in a helium-neon gas laser. (3 marks)
- a) Consider an electron in the ground state of a hydrogen atom
- (i) Show that the most probable value of  $r$  corresponds to Bohr radius  $a_0$ , and corresponding to maximum of the plot of  $P_{1s}(r)$  versus  $r$  (6 marks)
  - (ii) Calculate the probability of finding the electron in the ground state outside this Bohr radius (6 marks)

### QUESTION 4 (15 MARKS)

- a) A radio station operates at a frequency of  $103.7 \text{ MHz}$  with a power output of  $200 \text{ kW}$ . Determine the rate of emission of quanta from the station (3 marks)
- b) 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. (6 marks)
- c) Using the free-electron theory for electrons in copper wire and assuming that the mean free path is  $1 \text{ mm}$  at  $T = 27^\circ\text{C}$ , determine
- (i) The average thermal speed of the electrons (3 marks)
  - (ii) Electron drift velocity given an external electric field of  $10 \text{ V/m}$  (3 marks)

**QUESTION 5 (15 MARKS)**

- a) The electron concentration in Si at  $T = 300K$  is  $n_o = 5 \times 10^4 \text{ cm}^{-3}$ . Given that the intrinsic carrier concentration in silicon (Si) is  $n_i = 1.5 \times 10^{10} \text{ cm}^{-3}$ , determine the
- (i) Hole concentration  $p_o$  (2 marks)
  - (ii) Position of the Fermi energy level,  $E_F$ , with respect to the intrinsic Fermi energy level,  $E_{Fi}$ . (3 marks)
- b) Estimate the strength of the magnetic field produces by the electron's orbital motion which leads to two sodium lines (588.955 nm and 589.592 nm). (6 marks)
- c) 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)