

MBARARA UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

PHY1208

ATOMIC PHYSICS

TEST 1

TIME: 2 HOURS

INSTRUCTIONS

Attempt all questions

Do not write anything on the question paper

Where necessary, assume:

Boltzmann constant: $k_B = 1.4 \times 10^{-23} \text{ J K}^{-1}$

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

Stefan-Boltzmann constant: $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

Permittivity of free space: $\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$

Speed of light in vacuum: $c = 3.0 \times 10^8 \text{ m s}^{-1}$

Electron mass: $m_e = 9.11 \times 10^{-31} \text{ kg}$

Electron charge: $e = 1.60 \times 10^{-19} \text{ C}$

Coulomb constant: $k = 1/(4\pi\epsilon_0)$

Nuclear data (where required):

Proton = 1.007825 u

Neutron = 1.008665 u

${}_{20}^{38}\text{Ca} = 37.976329 \text{ u}$

1 u = 931.5 MeV/c²

Question 1

- (a) Explain briefly what you understand by black body radiation. (2 marks)
- (b) Demonstrate the behavior of black body radiation at different temperatures with respect to wavelength. (2 marks)
- (c) State the Wien's displacement law. (1 mark)
- (d) Considering the sun to be a blackbody with a surface temperature of 6000 K, calculate the rate at which energy is radiated from it. (2 marks)
- (e) Describe the occurrence of the Ultraviolet catastrophe in black body radiation using Rayleigh-Jeans' law. (4 marks)
- (f) Assume that a system consists of a very large number of linear harmonic oscillators that interact slightly and are in equilibrium at temperature T . Furthermore, assume that the distribution of energy among these oscillators is given by the Boltzmann distribution $f(\varepsilon) = Ce^{-\varepsilon/kT}$ where k is the Boltzmann constant, and C is a constant. Derive the expression for the average energy value $\bar{\varepsilon}$ of these oscillators, assuming:
- (i) there is a continuous distribution of energy among these oscillators (4 marks)
- (ii) that the linear harmonic oscillators have no continuous distribution of energy but are limited to discrete values of the quantum of energy $h\nu$. (5 marks)
- (Hints: $\int_0^{\infty} e^{-ax} dx = \frac{1}{a}$; $1 + e^{-x} + e^{-2x} + e^{-3x} + \dots = \frac{1}{1-e^{-x}}$)

Question 2

- (a) State Larmor's theorem. (1 mark)
- (b) Using Larmor's theorem, show that the change in angular momentum is given by

$$\Delta W = \frac{eB}{2m_e}$$

where e is the electronic charge, B the magnetic flux density, and m_e is the mass of the electron. (5 marks)

- (c) What is the Zeeman effect?
- (d) Differentiate between the normal and anomalous Zeeman effects. (5 marks)
- (e) Explain in detail the origin of the Zeeman effect in spectral lines.
- (f) Find the minimum magnetic field needed for the Zeeman effect to be observed in a spectral line of 400 nm wavelength when the spectrometer whose resolution of 0.020 nm is used.
- Hint: $df = \frac{eB}{4\pi m}$; df is the change in f . (Take $m = 9.11 \times 10^{-31}$ kg)

Question 3

- (a) Define the following as applied to nuclear structure:
- (i) nuclear binding energy
 - (ii) radioactive decay
 - (iii) nuclear energy
- (b) A nucleus of ${}_{20}^{38}\text{Ca}$ is split into its constituent parts
- (i) Write down the equation to represent the splitting process
 - (ii) Find the total binding energy needed to split the nucleus and hence
 - (iii) Find the binding energy per nucleon.
- (c) State any two advantages and disadvantages of nuclear energy.

Question 4

- (a) Define quantum numbers as applied to orbital theory.
- (b) Outline the various quantum numbers and briefly explain what each represents or caters for.

Question 5

- (a) State Bohr's postulates for the atom represented in Figure 1 (schematic representation of electron in uniform circular motion about nucleus of charge $+Ze$).
- (b) Use the postulates to show that:
- (i) the radius of the n^{th} allowed orbit is given by

$$r_n = \frac{n^2 h^2}{kZe^2 m}$$

(4.5 marks)

- (ii) the velocity in the n^{th} allowed orbit is given by

$$v_n = \frac{kZe^2}{nh}$$

(1.5 marks)

- (iii) the total energy of the electron in the n^{th} orbit is given by

$$E_n = -\frac{k^2 Z^2 e^4 m}{2n^2 h^2}$$

(3 marks)

- (c) Give 3 successes and 3 failures of Bohr's model of the atom. (6 marks)
- (d) Consider an electron which undergoes a transition from level 1 to 2; show that

$$\frac{1}{\lambda} = \frac{me^4}{8ch^3\epsilon_0^2} \left[\frac{1}{n_2^2} - \frac{1}{n_1^2} \right]$$

(4 marks)

(e) Derive the expression for de Broglie wavelength. (4 marks)

(f) An electron moves at a speed of $3.6 \times 10^7 \text{ m s}^{-1}$; find the percentage gain in mass. (2 marks)

(g) Compute the lowest energy for He^+ . (4 marks)

Question 6

(a) Using the total energy expression derived from Bohr's model, calculate the ionization energy of the hydrogen atom ($Z = 1$, $n = 1$). (3 marks)

(b) State the physical meaning of this ionization energy. (2 marks)

Question 7

(a) State the Rayleigh-Jeans law for the spectral energy density of blackbody radiation. (2 marks)

(b) Derive the Rayleigh-Jeans law starting from the classical average energy per mode $\bar{\epsilon} = kT$ and the number of standing wave modes in a cavity. (5 marks)

Question 8

(a) Using the quantum numbers n , l and m_l , explain how they determine the size, shape and spatial orientation of an atomic orbital. (4 marks)

(b) How many orbitals are possible in the $n = 3$ shell? List all possible combinations of (n, l, m_l) . (3 marks)