BINDURA UNIVERSITY OF SCIENCE EDUCATION

Faculty of Science Education

Department of Mathematics and Science Education

JUN 2025

HBSCED-Physics

PH403 (1) Atomic and Laser Physics

Duration: Three (3) Hours

INTSRUCTIONS

- *Answer ALL questions in Section A and any THREE questions from Section B. Section A carries 40 marks and each question of Section B carries 20 marks.*
- *Show ALL formulae and substitutions in ALL calculations.*
- *Leave your answers correct to 2 decimal places*

You may not start to read the questions printed on the subsequent pages until instructed to do so by the Invigilator.

SECTION A

(Answer **ALL** questions in this section.)

QUESTION 1 (40 MARKS)

a) A medium absorbs 0.5% of the light that passes through it for each millimetre of medium length. Determine its absorption coefficient (α). (3)

(i) Consider the energy levels E_1 and E_2 of a two-level system. Determine the population ratio of the two levels if they are in thermal equilibrium at room temperature, 27°C, and the transition frequency associated with this system is $10^{15}Hz$. (3)

(ii) Which transition is likely to occur, spontaneous or stimulated emission, at the same temperature given above if the pump supplies microwave photons of frequency $3 \times 10^{10}Hz$. Give a clear account of how you reach your conclusion. (5)

b) Consider the dynamics of the Bohr model of the atom;

(i) Find the radius of the first Bohr orbit. Leave your answer in nanometres. (6)

(ii) Find the corresponding energy of the electron in this particular orbit in electron volts (eV). (6)

c) Consider the dynamics of the Bohr model of the atom;

(i) Find the radius of the first Bohr orbit. Leave your answer in nanometres. (6)

(ii) Find the corresponding energy of the electron in this particular orbit in electron volts (eV). (6)

(i) A He-Ne laser operates in threshold condition. Reflection coefficients of the mirrors are: 0.999, and 0.97. Length of the laser is 50 [cm] and active medium gain is 1.02. Calculate the loss factor M. (5)

SECTION B

(Answer **ANY THREE** questions from this section)

QUESTION 2 (20 MARKS)

a) Explain the difference between allowed and forbidden transitions. (2)

b) Compare and contrast the magnetic dipole (M1) and electric quadruple (E2) transitions. Under what conditions do these transitions occur frequently. (6)

c) In the ground state $\psi(r) = \frac{1}{\sqrt{\pi a_0{}^3}} e^{-r/a_0}$. Determine the probability of finding the electron in the region between r and $\Delta r = 0.04a_0$ at the positions $r = a_0$ and $r = 1.5a_0$ (8)

d) Compare the probability that the electron in the ground state of a hydrogen atom is in the region $0 < r < 3.5a_0$ (4)

QUESTION 3 (20 MARKS)

a) Briefly explain the meaning of the terms; *two-level system* and *three-level system* in the context of lasers. (4)

b) Given the following equations for a two-level system:

$$\frac{dN_2}{dt} = W_p(N_1 - N_2) - \frac{N_2}{\tau}$$

$$-\frac{dN_1}{dt} = W_p(N_1 - N_2) - \frac{N_2}{\tau}$$

$N_1 - N_2 = \Delta N$ and $N_1 + N_2 = N$ =constant

(i) In the steady state, show that

$\Delta N = \frac{N}{1+2W_p\tau}$ (5)

(ii) Hence explain why population inversion is not possible in a two level system. (5)

c) Given that for a three-level laser system;

$\frac{N_2-N_1}{N} = \left[\frac{W_p(W_{32}-W_{21})-W_{21}(W_{31}+W_{32})}{W_s(3W_p+2W_{31}+2W_{32})+W_p(2W_{21}+W_{32})+W_{21}(W_{31}+W_{32})}\right]$,

(i) What do you understand by the term 'critical pumping rate' in the context of a three-level laser system? (2)

(ii) Hence obtain an expression for the critical pumping rate (W_{pc}) for the three-level laser system.

QUESTION 4 (20 MARKS)

Give examples of applications for which the following laser properties are useful;

- Monochromaticity (5)
- Beam divergence (5)
- Beam coherence (specify type of coherence) (5)
- Intensity. In your accounts, describe in brief how each property is useful for each of the applications you have selected and include definitions for each property. (5)

QUESTION 5 (20 MARKS)

A Hydrogen atom has the following characteristics: electronic charge , space permittivity and a radius of the orbit . With an aid of diagrams, clearly show that the total energy of a Hydrogen electron is given by;

$$E_T = -\frac{e^2}{8\pi\varepsilon_0 r}$$

Describe in detail all the terms used in the derivation. (20)

THE END

Some useful constants

Constant	Value
Boltzmann constant	$1.38 \times 10^{-23}\, m^2 2\, kgs^{-2}K^{-1}$
Planck's constant	$6.63 \times 10^{-34} m^2 kg\,/\,s$
Speed of light in a vacuum	$3 \times 10^8 ms^{-1}$

Some useful formulae

$T(°C) = T(K) - 273.15$, $A_e = B\frac{8\pi h_p f^3}{c^3}$, $\Delta\tau_p \approx \frac{2\pi}{M_c\delta\omega} = \frac{2\pi}{\Delta\omega_o}$, $p_x = \frac{2L}{\lambda_{p_x}}$, $g_n = 1 - \frac{L}{R_n}$,

$I_3 = I_o R_1 R_2 e^{2(\beta-\alpha)L}$

$A_e = Be(f)\left(e^{\frac{h_p f}{k_B T}} - 1\right)$, $\Delta t = \frac{2L}{c}$, $\Delta v = \frac{c}{2nL}$, $N = N_o e^{\frac{hf}{k_B T}}$, $c = v\lambda$, $\delta\omega = \frac{\pi c}{L}$