KISII UNIVERSITY

UNIVERSITY EXAMINATIONS

SPECIAL EXAMINATION

THIRD YEAR EXAMINATION FOR THE AWARD OF THE DEGREE OF BACHELOR OF EDUCATION (SCIENCE)

SECOND SEMESTER 2021/2022

(JULY, 2022)

PHYS 323: ATOMIC AND MOLECULAR PHYSICS

STREAM: Y3 S2 **TIME: 2 HOURS**

DAY: WEDNESDAY, 3:00 PM – 5:00 PM **DATE: 20/07/2022**

INSTRUCTIONS:

1. ***Do not write anything on this question paper.***
2. ***Answer Question ONE (Compulsory) and any other TWO questions.***
3. ***The following constants may be useful:***

$\hbar$=1.055 x 10^{-34} Kgm^2/s = 6.58 x 10^{-16}eV.s
h= 6.63 x 10^{-34} Js
Speed of light = 2.99979 x 10^8 m/s^2
Atomic mass of carbon-12 =12u
Atomic mass of Oxygen -16 = 16u
Mass of an electron, m_e=0.0005486u
Mass of neutron, m_n=1.008665u
Electron charge, e=1.6021773 X 10^{-19}C
Rydberg constant R=0.011nm^{-1}
$1u = 1.66 \times 10^{-27}$ Kg

QUESTION ONE [30MARKS]

a. Calculate the first two longest wavelengths of the Balmer series. [4marks]

b. The empirical formula below fits a given observed spectrum of a star where R is the Rydberg constant. Show that these lines are originating from He^+according to Bohr's theory. [5marks]

$$\frac{1}{\lambda} = R\left(\frac{1}{(n_f/2)^2} - \frac{1}{(n_i/2)^2}\right)$$

c. State two deficiencies of Bohr model [2marks]

d. Using de Broglie relation, derive Bohr condition $mvr = n\hbar$ for the angular momentum of an electron in a hydrogen atom. [3marks]

e. What is the electronic configuration of the following atoms? [2marks]
 (i) Mg (Z=12),
 (iii) Ni (Z=28)

f. Calculate the $\lambda[K_\alpha]$ for Na (Z=11) according to Moseley's law. [3marks]

g. Evidence for space quantization was provided by the Stern–Gerlach experiment. Sketch and briefly describe the key features of the experiment. Explain what was observed in the experiment and give its implication. [9marks]

h. Calculate the angle between the *z*-axis and spin angular momentum **S** of the electron in the up and down spin states. [3marks]

QUESTION TWO

(a) (i) Find the wavelength of light emitted by hydrogen as predicted by Rydbergformula with n = 5 and n' = 2. [3marks]

(ii) State four deficiencies of Bohr model [4marks]

(b) The electron in a hydrogen atom at rest makes a transition from the n =3 energy state to the n =2 ground state. Find the wavelength, frequency, and energy (eV) of the emitted photon. [4marks]

(c) The Balmer series for the hydrogen atom corresponds to electronic transitions that terminate in the state of quantum number n =2.
 (i) Find the longest-wavelength photon emitted and determine its energy.[4marks]
 (ii) Find the shortest-wavelength photon emitted in the Balmer series. [3marks]
 (iii) Which region of the spectrum does the wavelengths in (i) and (ii). [2marks]

QUESTION THREE

(a) Calculate the magnetic energy and the Larmor frequency for an electron in the n=2 state of hydrogen atom in a magnetic field strength of B=2T. [3marks]

(b) Obtain an expression for the Bohr magneton. What is its value? [7marks]

(c) Evidence for space quantization was provided by the Stern–Gerlah experiment. Sketch and briefly describe the key features of the experiment. Explain whatwas observed in the experiment and give its implication. [10marks]

QUESTION FOUR

(a) Two atoms whose nuclear separation is r are slowly brought closer to each other until an equilibrium position r_0 is reached.

(i) Name the potential energies acting on the two atoms as they approach one another. [2marks]

(ii) Sketch a graph showing the variation of the above potential energies until the system is in equilibrium position. [2marks]

(iii) On the same diagram sketch the net Potential energy on the system. [1mark]

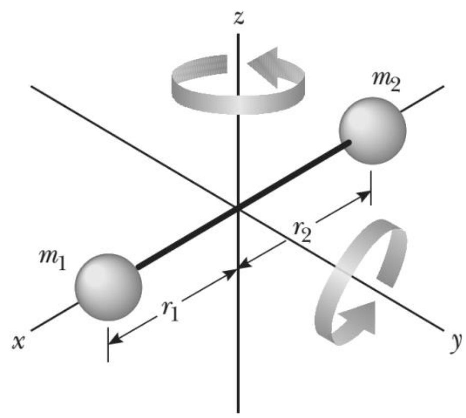
(b) Explain the following types of molecular bonds:

(i) Dipole-Dipole bond [2marks]

(ii) Dispersion bond [2marks]

(iii) Hydrogen bond [2marks]

(c) Figure below shows a diatomic molecule of masses m_1 and m_2 rotating about its center of mass at velocities v_1 and v_2 respectively.



(i) Show that the rotation is quantized and that the allowed energy of rotation is given as

$$E_{rot} = \frac{l(l+1)\hbar^2}{2I} \qquad l = 0,1,2...$$

where l is the rotational quantum number and I is the moment of inertia. [5marks]

(ii) Find an expression for the moment of inertia if the axis of rotation passes through the center of mass and that atomic separation is R [4marks]

QUESTION FIVE

(a) Distinguish between normal and anomalous Zeeman Effects. [1marks]

(b) Consider an atomic electron in the $l=3$ state. Calculate

(i) the magnitude of the total angular momentum $|\mathbf{L}|$. [2marks]

(ii) the allowed values of L_z. [2marks]

(iii) the allowed values of θ. [2marks]

(c) Carbon monoxide (CO) absorbs energy at 1.153×10^{11} Hz, due to a transitionbetween the $l=0$ and $l=1$ rotational states.

(i) What is the corresponding wavelength? [1mark]

(ii) In which part of the electromagnetic spectrum does this lie? [1mark]

(iii) What is the energy (in eV)? [1mark]

(iv) Calculate the reduced mass μ.(C=12 times, andO=16 times the unified atomic mass constant.) [2marks]

(v) Calculate the interatomic distancefor this molecule. [2marsk]

(d) The CO molecule shows a strong absorption line at the frequency 6.42×10^{13} Hz.

(i) Calculate the effective force constant for this molecule. [3marks]

(ii) What is the classical amplitude of vibration for a CO molecule in the n= 0 vibrational state? [3marks]