MAASAI MARA UNIVERSITY

MAIN EXAMINATIONS 2023/2024

FIRST YEAR FIRST SEMESTER EXAMINATION

FOR

THE DEGREE OF BACHELOR OF SCIENCE IN CHEMISTRY, AND BACHELOR OF BACHELOR OF EDUCATION (SCIENCE)

CHE1103-1: ATOMIC STRUCTURE

DATE: /December/ 2023 **TIME:**

Duration: 2 Hours

INSTRUCTIONS

1. This paper contains **FOUR** (4) questions in two sections A and B.
2. Section A is compulsory
3. Answer question **ONE (1)** in section A and any **Two** (2) questions from section B.
4. Do not forget to write your Registration Number.

List of Constants:

Planck's constant, $h = 6.63\times10^{-34}$ J · s; Rydberg constant for hydrogen $R = 1.097\times10^{7}$ m^{-1}; speed of light, $c = 3.00\times10^{8}$ m/s; Avogadro constant (L) = 6.022×10^{23} mol^{-1}. $\mathbf{R_H}$ is the Rydberg constant with a value of 2.18×10^{-18}J.

Question ONE (30 Marks)

a. Define/state the terms below:

i. The Heisenberg uncertainty principle ***(2 Marks)***
ii. An Orbital ***(2 Marks)***

iii. Hund's rule ***(2 Marks)***

b. i. At any given time, hydrogen's electron can occupy just one orbital. Given a quantum of energy and the hydrogen atom, explain the phenomena of ground and excited states of the hydrogen atom. ***(3 Marks)***

ii. A mass spectrometer can be used to investigate the isotopes in an element.

I. Define the term *relative atomic mass* of an element. ***(2 marks)***

II. Element **X** has a relative atomic mass of 47.9. Identify the block in the Periodic Table to which element **X** belongs and give the electron configuration of an atom of element **X**. Calculate the number of neutrons in the isotope of **X** which has a mass number 49. ***(3 marks)***

c. i. State and explain the general trend in the first ionization energies of the Period 3 elements sodium to chlorine. ***(3 marks)***
ii. State how the element sulfur deviates from the general trend in first ionization energies across Period 3. Explain your answer. ***(3 marks)***
iii. A general trend exists in the first ionization energies of the Period 2 elements lithium to fluorine. Identify **one** element which deviates from this general trend. ***(1 mark)***
d. Draw and label the five shapes of the d orbitals of the d subshell. ***(6 Marks)***

e. How much energy does one electron with a principal quantum number of n= 2 have? ***(3 Marks)***

Question TWO (20 marks)

a. Explain the impact of the following theories on the current view of electrons in atoms:

i. Louis de Broglie's wave particle duality, ***(3 Marks)***
ii. The Heisenberg uncertainty principle ***(3 Marks)***
iii. Quantum mechanical model of the atom ***(6 Marks)***

b. i. Using pictorial diagrams of s orbitals, explain on how the s orbitals at the various energy levels differ. ***(4 Marks)***

ii. Explain the term degenerate orbitals using p sublevel. ***(4 Marks)***

Question THREE (20 Marks)

a. Articulate on how Ernest Rutherford's **gold foil experiment** contributed to the structure of the atom. ***(10 Marks)***
b. i. Write the electron configuration of the Mg^{+} ion. ***(2 marks)***
ii. State the meaning of the term *first ionization energy*. ***(2 marks)***

iii. Write an equation, including state symbols, to show the reaction that occurs

(3 Marks)

iv. Explain why the second ionization energy of magnesium is greater than the first ionization energy of magnesium. ***(3 marks)***

Question FOUR (20 Marks)

a. State and explain the three postulates of the Bohr model of the atom ***(5 Marks)***

b. How does Bohr's model of the atom explain the line spectrum of hydrogen? ***(10 Marks)***

c. An emission spectrum gives one of the lines in the Balmer series of the hydrogen atom at 410 nm. This wavelength results from a transition from an upper energy level to n=2. What is the principle quantum number of the upper level? ($R=1.097x10^{7}$ m^{-1})

(5 Marks)

END

CHE1103: ATOMIC STRUCTURE Marking Scheme 70/70

Question ONE (30 Marks)

a. Define/state the terms below:

i. The Heisenberg uncertainty principle ***(2 Marks)***

It states that it is fundamentally impossible to know precisely ✓1both the velocity and position of a particle at the same time. ✓1

ii. An Orbital ***(2 Marks)***

A region in space around the nucleus of an atom, ✓1 where there is at least a 95% chance of finding an electron. ✓1

iii. Hund's rule ***(2 Marks)***

It states that, electrons filling degenerate atomic orbitals, ✓1 they do so singly with parallel spins before pairing starts. ✓1

b. i. At any given time, hydrogen's electron can occupy just one orbital. Given a quantum of energy and the hydrogen atom, explain the phenomena of ground and excited states of the hydrogen atom. ***(3 Marks)***

- ✓ ***When hydrogen is in the ground state, the electron occupies the 1s orbital. ✓1***
- ✓ ***When the atom gains a quantum of energy, ✓1the electron is excited to one of the unoccupied orbitals and hence hydrogen atom is excited. ✓1***

ii. A mass spectrometer can be used to investigate the isotopes in an element.

i. Define the term *relative atomic mass* of an element. ***(2 marks)***

Average/mean mass of (1) atom(s) (of an element) 1/12 mass of one atom of ^{12}C✓2
OR
(Average) mass of one mole of atoms 1/12 mass of one mole of ^{12}C
OR
(Weighted) average mass of all the isotopes 1/12 mass of one atom of $_{12}$C
OR
Average mass of an atom/isotope compared to C-12 on a scale in which an atom of C-12 has a mass of 12

(2 marks)

ii. Element **X** has a relative atomic mass of 47.9. Identify the block in the Periodic Table to which element **X** belongs and give the electron configuration of an atom of element **X**. Calculate the number of neutrons in the isotope of **X** which has a mass number 49. ***(3 marks)***

d block ✓1
[Ar] $3d_2 4s_2$ ✓1
27✓1

c. i. State and explain the general trend in the first ionization energies of the Period 3 elements sodium to chlorine. ***(3 marks)***

Increase✓½
Bigger nuclear charge (from Na to Cl)/more protons ✓1
electron (taken) from same (sub)shell/ similar or same shielding/ ✓½

electron closer to the nucleus/smaller atomic radius✓1

(3 marks)

ii. State how the element sulfur deviates from the general trend in first ionisation energies across Period 3. Explain your answer. ***(3 marks)***

Lower ✓1

Two/pair of electrons in (3)p orbital or implied ✓1

repel (each other) ✓1

(3 marks)

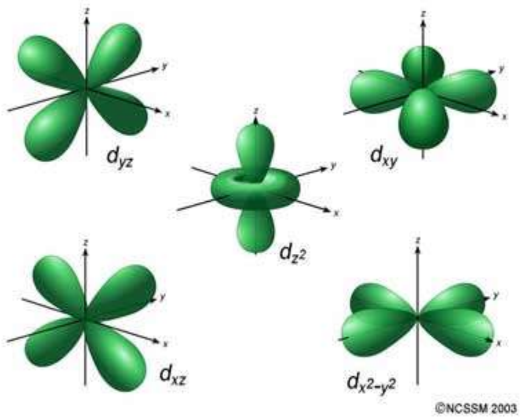
iii. A general trend exists in the first ionization energies of the Period 2 elements lithium to fluorine. Identify **one** element which deviates from this general trend. ***(1 mark)***

Boron/B or oxygen/O/O_2 ✓1

(1 mark)

d. Draw and label the five shapes of the d orbitals of the d subshell. ***(6 Marks)***

- ***d sublevel: Four of the five d orbitals have the same shape but lie in different planes. The d_z^2 orbital has its own unique shape. ✓1***



✓5

Q. e. How much energy does one electron with a principal quantum number of n= 2 have? ***(3 Marks)***

$$E_n = -\frac{Rhc}{n^2}$$

or

$$E_n = -\frac{(1.097x10^7\ m^{-1} * (6.63x10^{-34}\ J{\bullet}s) * (3.0x10^8\ m{\bullet}s^{-1})}{2^2}$$

$= 5.5x10^{-19}\ J$ ✓3

Question TWO (20 marks)

a. Explain the impact of the following theories on the current view of electrons in atoms:
   iv. Louis de Broglie's wave particle duality, ***(3 Marks)***

- ✓ ***Louis de Broglie hypothesized that particles, including electrons, could also have wavelike behaviors.*** ✓***1***
- ✓ ***Thus, he showed that, Wavelength (λ) is inversely proportional to mass of an electron.*** ✓***1***
- ✓ ***Electrons do not behave like particles flying through space.*** ✓½
- ✓ ***We cannot, in general, describe their exact paths.*** ✓½

v. The Heisenberg uncertainty principle ***(3 Marks)***

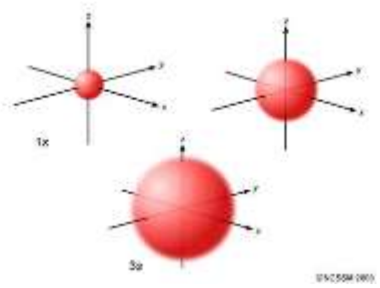
- ✓ ***Heisenberg showed it is impossible to take any measurement of an object without disturbing it.***
- ✓ ***The only quantity that can be known is the probability for an electron to occupy a certain region around the nucleus.***

vi. Quantum mechanical model of the atom ***(6 Marks)***

- ✓ ***Schrödinger treated electrons as waves in a model called the quantum mechanical model of the atom.*** ✓***1***
- ✓ ***Bohr orbits were replaced with quantum-mechanical orbitals.*** ✓½
- ✓ ***Orbitals are different from orbits in that they represent probability maps that show a statistical distribution of where the electron is likely to be found.*** ✓***1***
- ✓ ***In the quantum-mechanical model, a number and a letter specify an orbital.*** ✓***1***
- ✓ ***The lowest-energy orbital is called the 1s orbital.*** ✓½
- ✓ ***It is specified by the number 1 and the letter s.*** ✓½
- ✓ ***The number is called the Principal quantum number (n) and it indicates the relative size and energy of atomic orbitals.*** ✓½
- ✓ ***n specifies the atom's major energy levels, called the principal energy levels.*** ✓½
- ✓ ***Energy sublevels are contained within the principal energy levels.*** ✓½

b. i. Using pictorial diagrams of s orbitals, explain on how the s orbitals at the various energy levels differ. ***(4 Marks)***

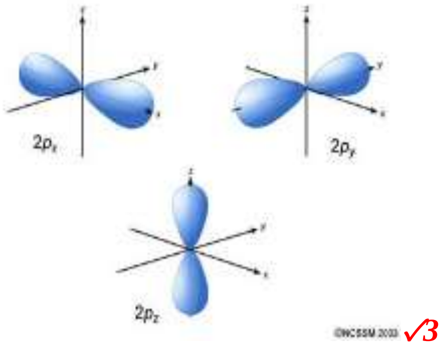
- ***s sublevel: All orbitals are spherical, and their sizes increases with increasing principal quantum number.*** ✓***1***



✓***3***

ii. Explain the term degenerate orbitals using p sublevel. ***(4 Marks)***

- ***p* sublevel: The three *p* orbitals are dumbbell-shaped and are oriented along the three perpendicular x,y and z axes**√1

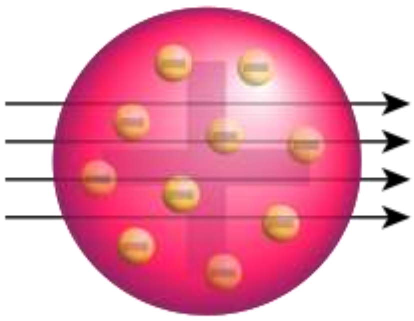


√3

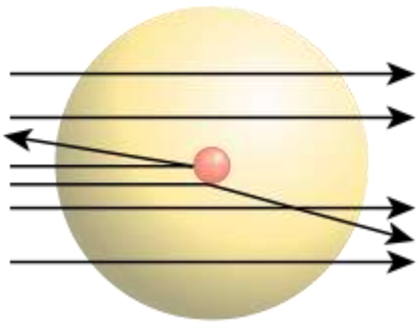
Question THREE (20 Marks)

a. Articulate on how Ernest Rutherford's **gold foil experiment** contributed to the structure of the atom. ***(10 Marks)***

Alpha particles, which are heavy and positively charged (helium nuclei), were fired at a very thin layer of gold. √1


√2

Expected


√2

Outcome

Observations

- ✓ ***Most of the alpha particles passed straight through, as expected.*** √1
- ✓ ***Surprisingly, a few alpha particles were deflected back the way they came.*** √1

Conclusions

- ✓ ***Atoms have a nucleus, very small and dense, containing the positive charge and most of the atom's mass.*** √1
- ✓ ***The atom consists of mostly empty space.*** √1
- ✓ ***The electrons are attracted to the nucleus, but remain far outside it.*** √1

b. i. Write the electron configuration of the Mg^{+} ion. ***(2 marks)***

$1s^2\ 2s^2 2p_x^2 2p_y^2 2p_z^2 3s^1$ √2 ***(2 marks)***

ii. State the meaning of the term *first ionization energy*. ***(2 marks)***

Energy/enthalpy (needed) to remove one mole of electrons from ✓1
one mole of atoms/compounds/molecules/elements ✓1
OR
Energy to form one mole of positive ions from one mole of atoms
OR
Energy/enthalpy to remove one electron from one atom
In the gaseous state (to form 1 mol of gaseous ions)

(2 marks)

iii. Write an equation, including state symbols, to show the reaction that occurs when the **second** ionisation energy of magnesium is measured. ***(3 marks)***

$Mg^{+}(g) \rightarrow Mg^{2+}(g) + e^{(-)}$ ✓1
$Mg^{+}(g) + e^{(-)} \rightarrow Mg^{2+}(g) + 2e^{(-)}$ ✓1
$Mg^{+}(g) - e^{(-)} \rightarrow Mg^{2+}(g)$ ✓1

(3 marks)

iv. Explain why the second ionization energy of magnesium is greater than the first ionization energy of magnesium. ***(3 marks)***

Electron being removed from a positive ion (therefore need more ✓1
energy)/ electron being removed is closer to the nucleus/Mg^{+} ✓1
smaller (than Mg)/Mg^{+} more positive than Mg ✓1

(3 marks)

Question FOUR (20 Marks)

a. State and explain the three postulates of the Bohr model of the atom ***(5 Marks)***

He suggested that electrons could only have certain classical motions:

- ***i. Electrons in atoms orbit the nucleus. ✓1***
- ***ii. The electrons can only orbit stably, without radiating, in certain orbits ✓1 (called by Bohr the "stationary orbits") at a certain discrete set of distances from the nucleus.***

  These orbits are associated with definite energies and are also called energy shells or energy levels. ✓1In these orbits, the electron's acceleration does not result in radiation and energy loss as required by classical electromagnetics. The Bohr model of an atom was based upon Planck's quantum theory of radiation. ✓½

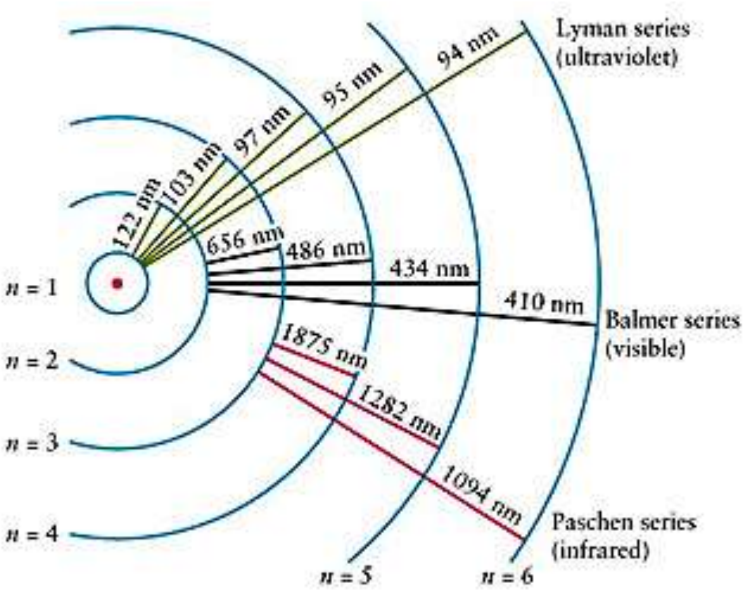
- ***iii. Electrons can only gain and lose energy by jumping from one allowed orbit to another, absorbing or emitting electromagnetic radiation with a frequency ν ✓1 determined by the energy difference of the levels according to the Planck relation: $E=h\nu$, where h is Planck's constant. ✓½***

b. How does Bohr's model of the atom explain the line spectrum of hydrogen? ***(10 Marks)***

It is due mainly to the allowed orbits of the electrons and the "jumps" of the electron between them: ✓1
Explanation:

Bohr tells us that the electrons in the Hydrogen atom can only occupy discrete orbits ***✓1*** ***around the nucleus (not at any distance from it but at certain specific,*** ***✓1******quantized, positions or radial distances each one corresponding to an energetic state of your H atom) where they do not radiate energy.*** ***✓1***

When the electron moves from one allowed orbit to another it emits or absorbs photons ***✓1*** ***of energy matching exactly the separation between the energies of the given orbits*** ***✓1*** ***(emission/absorption spectrum).***
We see these photons as lines of coloured light (the Balmer Series, for example) in emission or dark lines in absorption. ***✓1***



✓3

c. An emission spectrum gives one of the lines in the Balmer series of the hydrogen atom at 410 nm. This wavelength results from a transition from an upper energy level to n=2. What is the principle quantum number of the upper level? ($R=1.097x10^7$ m^{-1}) ***(5 Marks)***

$(1/\lambda) = R*[\ 1/(2^2) - 1/(n^2)\ ]$, $R=1.097x10^7\ m^{-1}$, $\lambda=410nm$✓1

$(1/410nm) = (1.097x10^7\ m^{-1}) * [\ 1/(2^2) - 1/(n^2)\ ]$ ✓1

$[\ (1/4.10x10^{-7}m) / (1.097x10^7\ m^{-1})\ ] - [\ (1/4)\ ] = [\ -1/(n^2)\ ]$ ✓1

$-1/-0.02778 = n^2$ ✓1

$36 = n^2$, n=6 --> The emission resulted from a transition from energy level 6 to energy level ✓1

END