THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATIONS COUNCIL OF TANZANIA

ADVANCED CERTIFICATE OF SECONDARY EDUCATION EXAMINATION

132/1 **CHEMISTRY 1**

(For Both School and Private Candidates)

Time: 3 Hours **ANSWERS** **Year: 2010**

Instructions

1. This paper consists of sections A, B and C with total of fourteen questions

2. Each question carries ten marks.

1. (a) Define the following:

(i) Isotopes
Isotopes are atoms of the same element with the same number of protons but different numbers of neutrons, leading to different atomic masses.

(ii) Atomic number
The atomic number (Z) of an element is the number of protons in the nucleus of an atom, which determines the element's identity.

(iii) Mass number
The mass number (A) of an atom is the sum of its protons and neutrons. It represents the total nucleons in an atom.

(iv) Radioactivity
Radioactivity is the spontaneous emission of radiation (alpha, beta, or gamma rays) by an unstable atomic nucleus as it decays into a more stable form.

(b) Explain why ${}^{13}_{6}Z$ and ${}^{14}_{6}Z$ atoms have identical chemical properties but ${}^{90}_{40}X$ and ${}^{91}_{41}X$ have different chemical properties.

- ${}^{13}_{6}Z$ and ${}^{14}_{6}Z$ are isotopes of the same element (same atomic number), meaning they have the same electronic configuration and chemical properties.
- ${}^{90}_{40}X$ and ${}^{91}_{41}X$ belong to different elements with different atomic numbers, so they have different chemical properties due to different electron configurations.

(c) X is a radioactive element which undergoes transition as follows:

X ----> β^- emission ----> Y ----> β^- emission ----> Z ----> α emission ----> W.

If the atomic number of X is 17 and its mass number is 37, what are the atomic numbers and mass numbers of the isotopes Y, Z, and W?

- Y: After β^- emission, atomic number increases by 1 → ${}^{17}Cl$ ----> ${}^{18}Ar$ (Y = ${}^{18}Ar^{37}$).
- Z: After another β^- emission, atomic number increases by 1 → ${}^{18}Ar$ ----> ${}^{19}K$ (Z = ${}^{19}K^{37}$).
- W: After α emission, atomic number decreases by 2, mass number decreases by 4 → ${}^{19}K^{37}$ ----> ${}^{17}Cl^{33}$ (W = ${}^{17}Cl^{33}$).

(d) Describe three applications of radioactivity.

1. Medical applications: Used in cancer treatment (radiotherapy) and medical imaging (PET scans).
2. Industrial applications: Used in thickness control of materials, leak detection, and sterilization of equipment.

3. Archaeological applications: Carbon-14 dating helps determine the age of fossils and ancient artifacts.

2. (a) Electronic configuration of silver violates Aufbau's building principle. Justify this statement and explain briefly the observed violation.

- The expected electronic configuration of silver (Z = 47) is [Kr] $4d^9$ $5s^2$, but the actual configuration is [Kr] $4d^{10}$ $5s^1$.
- This happens because a completely filled d-orbital ($4d^{10}$) is more stable than a partially filled one ($4d^9$), so one electron from the 5s orbital moves to the 4d orbital.

(b) (i) Define the term quantum number.
- A quantum number is a set of values that describe the position, energy, and spin of an electron in an atom.

(ii) What are the four properties described by quantum numbers?

1. Principal quantum number (n): Indicates the energy level of an electron.
2. Azimuthal quantum number (l): Describes the shape of an orbital.
3. Magnetic quantum number (m): Determines the orientation of an orbital in space.
4. Spin quantum number (s): Indicates the spin direction of an electron (+½ or -½).

(c) Why do ionization energies increase from left to right across the periodic table?

- As we move across a period, the atomic number increases, leading to a greater nuclear charge and stronger attraction between the nucleus and electrons.
- The atomic radius decreases, making it harder to remove an electron, thereby increasing ionization energy.

3. (a) Define the following, giving one example in each case:

(i) Hydrogen bond
A hydrogen bond is a weak intermolecular force that occurs between a hydrogen atom covalently bonded to a highly electronegative atom (N, O, or F) and another electronegative atom.
Example: Hydrogen bonding in water (H_2O).

(ii) Coordinate bond
A coordinate bond (dative covalent bond) is a covalent bond where both shared electrons come from one atom.
Example: NH_3 ----> BF_3 complex.

(iii) Polar covalent bond
A polar covalent bond is a bond in which electrons are unequally shared due to a difference in electronegativity.
Example: HCl (hydrogen chloride).

(iv) Electrovalent bond
An electrovalent bond (ionic bond) is a bond formed by the complete transfer of electrons between atoms, resulting in oppositely charged ions.
Example: NaCl (sodium chloride).

(b) (i) Describe the conditions necessary for the formation of hydrogen bonds. How does the described bond differ from other intermolecular forces?

- Conditions for hydrogen bonding:
  - A hydrogen atom must be bonded to a highly electronegative element (N, O, or F).
  - The electronegative atom must have a lone pair of electrons.

- Difference:
  - Hydrogen bonding is stronger than van der Waals forces but weaker than covalent bonds.

(ii) With the help of diagrams, show the type of hybridization, geometry, and bond angle found in methane, ethane, and ethylene molecules.

- Methane (CH_4): sp^3 hybridization, tetrahedral shape, bond angle = 109.5°.
- Ethane (C_2H_6): sp^3 hybridization, tetrahedral shape, bond angle = 109.5°.
- Ethylene (C_2H_4): sp^2 hybridization, trigonal planar shape, bond angle = 120°.

(iii) By using diagrams, explain why NH_3 and CH_4 have tetrahedral geometrical structures but the bond angle in CH_4 (109.5°) is greater than in NH_3.

- Both NH_3 and CH_4 have sp^3 hybridization and tetrahedral geometry.
- NH_3 has a lone pair on nitrogen, which repels bonding pairs more strongly, reducing the bond angle to 107°.
- CH_4 has no lone pairs, so the bond angle remains 109.5°.

4. (a) State the following:

(i) The equilibrium law
At equilibrium, the rate of the forward reaction equals the rate of the reverse reaction, and the ratio of the concentrations of products to reactants remains constant at a given temperature.

(ii) Le Chatelier's principle
If an external change (concentration, pressure, or temperature) is applied to a system at equilibrium, the system shifts in a direction that counteracts the change.

(b) Explain briefly the following:

(i) Dynamic equilibrium

A state where the forward and reverse reactions occur at the same rate, with no overall change in concentrations.

(ii) Reaction quotient
A ratio of product concentrations to reactant concentrations at any given time, used to determine whether a reaction is at equilibrium.

(c) Dinitrogen tetroxide in its liquid state was used as one of the fuels on the Lunar lander expeditions for NASA space vessels. In the gas phase, it decomposes to gaseous nitrogen dioxide as shown in the following equation:

$N_2O_4(g) \text{ ----> } 2NO_2(g)$

Solving for P NO_2,
$P\ NO_2 = \sqrt{(Kp \times P\ N_2O_4)} = \sqrt{(0.133 \times 2.71)} = 0.60$ atm

5. (a) Define the following terms:

(i) Colligative properties
Colligative properties are properties of solutions that depend only on the number of solute particles in a solvent and not on their identity. These properties include boiling point elevation, freezing point depression, vapor pressure lowering, and osmotic pressure.

(ii) Ideal solution
An ideal solution is a solution that follows Raoult's law at all concentrations and temperatures. This means that the interactions between solute and solvent molecules are similar to those between the solvent molecules themselves, leading to no heat absorption or release upon mixing.

(b) List the following in order of increasing boiling points: 0.03M hexane, 0.03M potassium chloride, and 0.03M acetic acid.

- Hexane has the lowest boiling point because it is a non-polar hydrocarbon with only weak van der Waals forces.
- Acetic acid has a higher boiling point due to hydrogen bonding between its molecules.
- Potassium chloride has the highest boiling point because it is an ionic compound that requires significant energy to break its electrostatic forces.
- Therefore, the order is: hexane < acetic acid < potassium chloride.

(c) (i) The melting point of camphor is 176.5°C. When 0.125 g of sulfur is finely ground with 3.62 g of camphor, the resultant mixture melts at 171.4°C. What is the molecular weight of sulfur in camphor?

- The molecular weight of sulfur is determined using the freezing point depression formula:

$\Delta T = Kf \times m$
where $\Delta T = 176.5 - 171.4 = 5.1°C$
Kf (for camphor) is a known constant
m = molality = moles of sulfur per kg of camphor.

(ii) Water and ethanol form an azeotropic mixture of composition 95.6 percent ethanol, which boils at 78.15°C. Sketch a well-labeled temperature-composition curve for the water-ethanol mixture. Explain whether it is possible to obtain pure ethanol from a water-ethanol mixture.

- An azeotrope is a mixture of two or more liquids that have the same composition in the liquid and vapor phase, making it impossible to separate them by simple distillation.
- In the ethanol-water system, ethanol forms a minimum-boiling azeotrope at 78.15°C with 95.6 percent ethanol and 4.4 percent water.
- This means that simple distillation cannot produce absolute ethanol, and additional drying agents like molecular sieves or azeotropic distillation using benzene are required to remove the remaining water.

6. (a) Give a brief explanation of the following terms:

(i) Mole
A mole is the amount of a substance containing Avogadro's number (6.022×10^{23}) of particles (atoms, molecules, or ions). It is a fundamental unit in chemistry used to measure the quantity of substances.

(ii) Molarity
Molarity (M) is the number of moles of solute dissolved in one liter of solution. It is expressed as:

M = moles of solute / liters of solution.

(iii) Avogadro's constant
Avogadro's constant (6.022×10^{23} mol^{-1}) is the number of atoms, ions, or molecules in one mole of a substance. It establishes the link between macroscopic measurements and atomic-scale quantities.

(iv) A molar solution
A molar solution is a solution containing one mole of solute per liter of solution. For example, a 1M NaCl solution contains 1 mole of sodium chloride in one liter of water.

(b) One-eighth of a mole of a certain hydrated salt contains 11.2 g of water. Calculate the number of molecules of water of crystallization of the salt.

- One mole of the salt contains: 11.2 g × 8 = 89.6 g of water.
- One mole of water weighs 18 g, so the number of moles of water in one mole of salt is:

89.6 g / 18 g/mol = 4.98 ≈ 5 molecules of water of crystallization.

(c) The atomic radius of sodium is 1.86×10^{-8} cm, and the molar volume of sodium is 23.68 cm^3. If 68.52 percent of this volume is the actual volume occupied by sodium atoms, calculate Avogadro's constant.

- The volume of one sodium atom is given by:

  Volume = $4/3 \times \pi \times (1.86 \times 10^{-8}\ cm)^3$
  Total volume occupied = 68.52 percent of 23.68 cm^3
  Avogadro's number is then determined by dividing total molar volume by the volume of one atom.

7. (a) The empirical formula of nicotine, a poisonous compound found in tobacco, is C_5H_7N. Its molecular weight is 162. What is the molecular formula of the compound?

- The empirical formula weight of $C_5H_7N = (5 \times 12) + (7 \times 1) + (1 \times 14) = 81$.
- The molecular formula is determined by:

  Molecular formula = (molecular weight / empirical formula weight) × empirical formula
  $= (162 / 81) \times C_5H_7N = C_{10}H_{14}N_2$.

(b) How many grams of oxygen are required to burn 57.0 g of octane?

- The balanced combustion equation for octane (C_8H_{18}) is:
  $2C_8H_{18} + 25O_2$ ----> $16CO_2 + 18H_2O$
- The molar mass of octane is 114 g/mol.
- The amount of oxygen required is determined using stoichiometric calculations.

(c) What is the arrangement of electrons in $^{60}_{27}Co$, which is used in cancer therapy?

- The atomic number of cobalt is 27, so its electron configuration is:
  $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7\ 4s^2$.

(d) One mechanism for the removal of excess heat generated by metabolic processes in the body is the evaporation of water by sweat. In a hot, dry climate, as much as 1.5 liters of water per day may be lost by one person. Calculate the amount of heat required to evaporate this water at T = 46°C.

- Given $\Delta Hvap = 43.02$ kJ/mol,
- Convert 1.5 liters to mass (assuming density = 1 g/mL), then to moles,
- Multiply moles by $\Delta Hvap$ to get total heat required.

8. (a) In what ways does the chemistry of hydrogen resemble that of

(i) Alkali metals
- Hydrogen has one valence electron, similar to alkali metals.
- It forms H^+ ions, similar to Na^+ and K^+.

- It reacts with non-metals to form covalent compounds, just like alkali metals.

(ii) Halogens
- Hydrogen forms diatomic molecules (H_2) like halogens (F_2, Cl_2).
- It can gain one electron to form hydride ions (H^-), similar to halide ions (Cl^-, Br^-).

(b) Explain the meaning of the following terms:

(i) Lone pair electrons
Lone pair electrons are valence electrons not involved in chemical bonding. They affect molecular shape and reactivity.

(ii) Electronegativity
Electronegativity is the ability of an atom to attract bonding electrons in a molecule. It influences bond polarity.

(iii) Electron affinity
Electron affinity is the energy change when an atom gains an electron to form a negative ion.

(c) Describe two industrial methods for the preparation of hydrogen.

1. Electrolysis of water:
   $2H_2O$ ----> $2H_2 + O_2$ (using electricity).
2. Steam reforming of methane:
   $CH_4 + H_2O$ ----> $CO + 3H_2$ (using a catalyst).

9. (a) State the allotropic properties of carbon.

- Carbon exists in multiple allotropic forms, including diamond, graphite, graphene, fullerenes, and amorphous carbon.

(b) Account for the following:

(i) Ba and Mg are group two elements, but $Mg(NO_3)_2$ does not impart color to the Bunsen flame while $Ba(NO_3)_2$ does.
- Magnesium has a small ionic radius, and its excitation energy is high, so it does not emit visible light, while barium emits a green flame.

(ii) K^+ and Ca^{2+} have the same number of electrons, but K^+ is larger.
- K^+ has a lower nuclear charge than Ca^{2+}, causing weaker attraction to electrons and a larger radius.

(iii) Be is in period two and group two, while Al is in period three and group thirteen, but their compounds resemble each other.

- This is due to diagonal relationships, where elements in adjacent groups but different periods exhibit similar properties due to similar charge densities.