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: 2011**

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 terms:

(i) Alpha particles
Alpha particles are positively charged particles consisting of two protons and two neutrons ($^{4}_{2}He$), emitted during radioactive decay.

(ii) Beta particles
Beta particles are high-energy, high-speed electrons (β^-) or positrons (β^+) emitted from the nucleus during radioactive decay.

(iii) Isotope
Isotopes are atoms of the same element with the same number of protons but different numbers of neutrons, resulting in different atomic masses.

(iv) Nuclear fission
Nuclear fission is a process in which a heavy nucleus splits into two or more lighter nuclei, releasing a large amount of energy.

(b) A radioactive isotope of polonium, ^{218}Po decays according to the following scheme:

$^{218}_{84}Po \rightarrow$ α-emission $\rightarrow X \rightarrow \beta^-$-emission $\rightarrow Y \rightarrow \beta^-$-emission $\rightarrow Z$.

(i) Deduce the mass numbers and atomic numbers of X, Y, and Z.

- X: After α-emission, mass number decreases by 4, atomic number decreases by 2.
  $X = {}^{214}_{82}Pb$

- Y: After β^--emission, atomic number increases by 1.
  $Y = {}^{214}_{83}Bi$

- Z: After another β^--emission, atomic number increases by 1.
  $Z = {}^{214}_{84}Po$

(ii) What is the relationship between the elements Po and Z?

- Po and Z are the same element, indicating a radioactive decay cycle that regenerates polonium.

(c) The element europium, Eu exists in nature as two isotopes: ^{151}Eu with a mass of 150.9196 a.m.u and ^{153}Eu with a mass of 152.9196 a.m.u. If the average atomic mass of europium is 151.96 a.m.u, calculate the percentage relative abundances of the two isotopes.

Let x be the fraction of ^{151}Eu and (1-x) be the fraction of ^{153}Eu.

(150.9196)(x) + (152.9196)(1-x) = 151.96

Solving for x:
x = 0.47 (47% ^{151}Eu)
1 - x = 0.53 (53% ^{153}Eu)

2. (a) What is the meaning of the following quantum numbers?

(i) m
The magnetic quantum number determines the orientation of an orbital in space.

(ii) s
The spin quantum number represents the spin of an electron (+½ or -½).

(b) List all possible values of ℓ and m when n is 3.

- ℓ = 0, 1, 2
- m values:
  - For ℓ = 0, m = 0
  - For ℓ = 1, m = -1, 0, +1
  - For ℓ = 2, m = -2, -1, 0, +1, +2

(c) When an electron jumps from a certain higher energy level E_2 to its ground state E_1, green light in the Balmer series is emitted. If the energy released during this transition is 4.071×10^{-19} J, determine the:

(i) Wavelength of the green light.

Using $E = hc/\lambda$,

$\lambda = hc/E$

$= (6.626 \times 10^{-34}\ J{\cdot}s \times 3.0 \times 10^{8}\ m/s) / (4.071 \times 10^{-19}\ J)$
$= 488$ nm

(ii) Higher energy level, E_2, from which the electron jumps to the ground energy level E_1.

Using the Rydberg equation:
$1/\lambda = R_H (1/n_1^2 - 1/n_2^2)$

Solving for n_2 gives $n_2 = 4$ (electron jumps from n = 4 to n = 2).

3. (a) What do you understand by the following types of bonds?

(i) Dative covalent bond
A bond where both electrons come from one atom (also called a coordinate bond).

(ii) Inter - molecular hydrogen bond
A hydrogen bond that occurs between different molecules, such as between water molecules.

(iii) Covalent bond
A chemical bond where two atoms share electrons.

(iv) Intra - molecular hydrogen bond
A hydrogen bond that occurs within a single molecule, as in ortho-hydroxybenzaldehyde.

(b) (i) At 110 °C and 454 mmHg, 0.11 g of ethanoic acid vapour occupies 63.7 cm^3. At 156°C and 458 mmHg, 0.081 g of ethanoic acid vapour occupies 66.4 cm^3. Calculate the molar mass of ethanoic acid in the vapour phase at each temperature.

Using PV = nRT and M = mRT/PV, calculating for both cases:

- Molar mass at 110°C = 120 g/mol
- Molar mass at 156°C = 60 g/mol

(ii) Give the interpretation of the results in 3 (b) (i) above.

At 110°C, the molar mass is higher, indicating dimerization of ethanoic acid. At 156°C, the molar mass is closer to the expected monomer value of 60 g/mol.

4. (a) State the following:

(i) Graham's law of gas diffusion
The rate of diffusion of a gas is inversely proportional to the square root of its molar mass.

(ii) Dalton's law of partial pressures
The total pressure of a gas mixture equals the sum of the partial pressures of individual gases.

(b) A 3.20 m^3 vessel contains a mixture of 86.2 g of oxygen and 1.5 g of hydrogen at 88°C. Calculate the total pressure in the vessel.

Using PV = nRT,
- Moles of O_2 = 86.2 g / 32 g/mol = 2.69 mol
- Moles of H_2 = 1.5 g / 2 g/mol = 0.75 mol

Total n = 2.69 + 0.75 = 3.44 mol
P = (3.44 × 0.0821 × 361) / 3.20

= 32.0 atm

(c) Gas A of a certain volume diffuses for 580.8 s while the same volume of gas J diffuses for 300 s under identical experimental conditions. Calculate the relative molecular mass of gas J if the relative molecular mass of gas A is 120.

Using Graham's Law:

Rate_A / Rate_J = sqrt(M_J / M_A)
$(300 / 580.8)^2 = M_J / 120$
M_J = 32.4 g/mol

5. (a) (i) State the partition law.

The partition law states that when a solute is distributed between two immiscible solvents at equilibrium, the ratio of its concentrations in each solvent remains constant at a given temperature.

(ii) Explain the meaning of miscible solutions.

Miscible solutions are solutions in which two or more liquids completely dissolve in each other in all proportions without forming separate layers, such as ethanol and water.

(b) 18 g of compound X distribute themselves between water and equal volume of an immiscible solvent Y so that 2 g of X are in water. Calculate to the nearest integer, the percentage of X left in water if 1000 cm^3 of water containing 1 g of X are extracted by three extractions with 100 cm^3 of Y.

Using the partition coefficient formula:
K = (concentration of X in Y) / (concentration of X in water)

For each extraction step, the amount left in water follows:
Final percentage of X left in water ≈ 8%

6. (a) (i) State the following:

(i) Equilibrium law
The equilibrium law states that at equilibrium, the ratio of the concentrations of products to reactants, each raised to its stoichiometric coefficient, remains constant.

(ii) Le Chatelier's principle
Le Chatelier's principle states that if a system at equilibrium is subjected to an external change (such as concentration, temperature, or pressure), the equilibrium will shift to counteract the disturbance.

(b) In the preparation of ethyl ethanoate shown in the equation below, concentrated H_2SO_4 is often added to the mixture.

$C_2H_5OH + CH_3COOH \rightleftharpoons CH_3COOC_2H_5 + H_2O$

(i) State two functions of concentrated H_2SO_4 in the production of the compound.

1. Acts as a catalyst to speed up the reaction.
2. Removes water from the equilibrium, shifting the reaction forward to produce more ester.

(ii) What will be the effect of adding NaOH(aq) instead of conc. H_2SO_4 in the production of the compound?

NaOH(aq) will react with the carboxylic acid to form sodium ethanoate instead of producing ethyl ethanoate, thereby preventing esterification.

(c) (i) When 1.00 mol/dm³ of CH_3COOH were heated with 0.18 mol of C_2H_5OH in a 1 dm³ closed vessel, 0.829 mol CH_3COOH remained at equilibrium. Calculate the value of Kc.

$Kc = [CH_3COOC_2H_5][H_2O] / [CH_3COOH][C_2H_5OH]$

$= (0.18 \times 0.18) / (0.829 \times 1.00)$
$= 0.0391$

(ii) What mass of ethyl ethanoate should be present in the equilibrium mixture formed under the same experimental conditions as 6 (b) (i) above if 0.30 moles of ethanol were heated with 0.20 moles of ethanoic acid in a 1.0 dm³ closed vessel?

Using the ICE table method and solving for equilibrium concentrations,
Mass of ethyl ethanoate at equilibrium = approximately 26.1 g.

7. (a) Explain why the first element in each group of the main periodic table shows properties which are not exhibited by other group elements.

The first element in each group of the periodic table exhibits unique properties due to:
- Small atomic size, leading to high ionization energy and electronegativity.
- Absence of d-orbitals, limiting their ability to expand their valency.
- Stronger hydrogen bonding and covalent bonding compared to other elements in the group.

(b) Account for the following observations and give chemical reactions whenever necessary:

(i) The second electron affinity is always positive.
- The second electron affinity is positive because an additional electron is being added to an already negatively charged ion, requiring extra energy to overcome the electrostatic repulsion.

(ii) Magnesium carbonate decomposes readily when heated while sodium carbonate has no action to heat.
- Magnesium carbonate decomposes because Mg^{2+} has a high charge density, polarizing the CO_3^{2-} ion, weakening the bond:

$MgCO_3$ -----> $MgO + CO_2$

- Sodium carbonate is more stable because Na^+ has a lower charge density and does not strongly polarize the carbonate ion.

(iii) Aluminium utensils rust quite easily.
- Aluminium forms a protective Al_2O_3 layer, but if exposed to acidic or alkaline conditions, it corrodes.

$4Al + 3O_2$ -----> $2Al_2O_3$

(iv) Water is a covalent compound but has a high boiling point.
- Water molecules form strong hydrogen bonds, which require more energy to break, leading to a higher boiling point.

(v) Hydrogen gas is evolved when magnesium metal is placed in a beaker containing ammonium chloride.
- Magnesium displaces hydrogen from ammonium chloride due to its higher reactivity:

$Mg + 2NH_4Cl$ -------> $MgCl_2 + 2NH_3 + H_2$

(c) (i) Justify the periodicity of properties of elements in the periodic table based on electronic configuration.
- Periodic trends in atomic size, ionization energy, and electronegativity are due to the electron configuration and effective nuclear charge, which influence how strongly electrons are attracted to the nucleus.

(ii) What are s, p, and d block elements of the periodic table?
- s-block elements: Groups 1 and 2, where valence electrons occupy the s-orbital.
- p-block elements: Groups 13 to 18, where valence electrons occupy the p-orbital.
- d-block elements: Transition metals (Groups 3 to 12), where valence electrons occupy the d-orbital.

8. (a) Account for the following:

(i) Zinc and iron are both d-block elements but iron can be magnetized while zinc cannot.
- Iron has unpaired d-electrons, which allow it to align magnetic domains, making it ferromagnetic.
- Zinc has fully filled d-orbitals ($3d^{10}$), preventing magnetization.

(ii) Iron (III) sulfate is green while zinc sulfate is white.
- Iron (III) sulfate appears green due to d-d electron transitions in Fe^{3+} ions, which absorb visible light.
- Zinc sulfate is white because Zn^{2+} has a completely filled d^{10} configuration, preventing d-d transitions.

(b) (i) Manganese is said to exhibit variable oxidation numbers. List them.
- Manganese oxidation states: +2, +3, +4, +6, +7.

(ii) Write the electronic configuration of manganese. (Atomic number = 25)
- Mn: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^2$

(iii) Give examples of compounds in which manganese exhibits different oxidation states. (Give example in each case.)
- +2: $MnCl_2$ (Manganese (II) chloride)
- +3: Mn_2O_3 (Manganese (III) oxide)
- +4: MnO_2 (Manganese (IV) dioxide)
- +6: K_2MnO_4 (Potassium manganate)
- +7: $KMnO_4$ (Potassium permanganate)

9. (a) State the following:

(i) Zeeman effect
- The splitting of spectral lines into multiple components in the presence of a magnetic field.

(ii) Pauli's exclusion principle
- No two electrons in an atom can have the same set of quantum numbers; each electron must have a unique set.

(iii) Hund's rule of maximum multiplicity
- In a given subshell, electrons occupy orbitals singly before pairing to minimize electron repulsion.

(b) (i) What is effective nuclear charge?
- The net positive charge experienced by an electron in an atom, considering the shielding effect of inner electrons.

(ii) The first ionization energy of aluminium is less than that of magnesium. Giving reasons, compare the second ionization energy of aluminium to that of magnesium.
- Aluminium has a lower first ionization energy than magnesium because its valence electron is in the 3p orbital, which is farther from the nucleus and easier to remove.
- The second ionization energy of aluminium is higher than that of magnesium because removing a second electron requires disrupting a stable noble gas configuration in Al^+.

(c) Explain why the Cl-C-O bond angle in Cl_2CO is 124° and not 120°.
- The presence of highly electronegative chlorine atoms causes a stronger electron withdrawal effect, increasing repulsion and widening the Cl-C-O bond angle beyond the expected 120° for trigonal planar geometry.

10. (a) Account for the uniqueness of hydrogen in the periodic table.
- Hydrogen is unique because:
  - It has one electron like alkali metals but forms covalent bonds like nonmetals.
  - It can lose or gain an electron, behaving as both a metal and a nonmetal.
  - It exists as a diatomic molecule (H_2).

(b) (i) List all the isotopes of hydrogen and explain how they differ from one another.
- Protium (^1H): Has one proton and no neutrons.
- Deuterium (^2H): Has one proton and one neutron.
- Tritium (^3H): Has one proton and two neutrons (radioactive).

(ii) Give the products of the following reactions:

$NaOH + D_2O$ ----> $NaOD + HDO$

$NH_4Cl + D_2O$ ---> $ND_4Cl + HDO$

$NH_4Cl + H_2O$ ----> $NH_4OH + HCl$

$D + H$ ----> HD

$H + H$ -----> H_2

(c) Distinguish between ortho and para hydrogen.
- Ortho-hydrogen: Hydrogen molecules where nuclear spins are parallel.
- Para-hydrogen: Hydrogen molecules where nuclear spins are antiparallel.

11. (a) Name the following compounds according to the IUPAC system.

(i) $CH_2(OH)CH_2CH_2OH$
- 1,3-Propanediol

(ii) $CH_3CH(OH)CH_2Cl$
- 3-Chloro-2-propanol

(iii) $CH_3CH(OH)CH(OH)CH_3$
- 2,3-Butanediol

(b) Compound X containing a carbon-carbon double bond would react with the following reagents:

(i) Y to form 2 - bromo - 2 - methylbutane
(ii) Z to form $(CH_3)_2CHC(OH)(CH_3)_2$
(iii) W to form 2 - chloro - 2 - methylbutane.

Name compound X and reagents Y, Z, and W.

- X = 2-Methyl-2-butene
- Y = HBr (Hydrobromic acid)
- Z = H_2O/H^+ (Hydration using acid catalyst)
- W = HCl (Hydrochloric acid)

(c) Indicate a chemical test which may be used to distinguish the members of each of the following pairs. Indicate the member of the pair that gives the positive test or greater reaction.

(i) Phenol (C_6H_5OH) and Alcohol ($C_6H_{11}OH$)
- Test: Ferric chloride test ($FeCl_3$)
- Positive result: Phenol gives a purple/violet coloration.

(ii) Methyl ether ($H_3C\text{-}O\text{-}CH_3$) and Formaldehyde ($O{=}CH_2$)
- Test: Tollens' test (Ammoniacal silver nitrate)
- Positive result: Formaldehyde forms a silver mirror.

12. (a) Explain briefly the following terms:

(i) Nucleophiles
- Nucleophiles are electron-rich species that donate a pair of electrons to form a bond with an electron-deficient atom, typically a carbon. Examples include OH^-, CN^-, and NH_3.

(ii) Nucleophilic substitution
- A reaction in which a nucleophile replaces a leaving group (e.g., halide) in a molecule. Example:

$$CH_3CH_2Br + OH^- \rightarrow CH_3CH_2OH + Br^-$$

(b) Arrange the following compounds in order of increasing easiness in substitution of the halogen atom by an electrophile. Give reasons for your arrangement.

CH_3Br, CH_3Cl, CH_3F, CH_3I.

- Increasing order of substitution: $CH_3F < CH_3Cl < CH_3Br < CH_3I$
- Reason: The C-X bond strength decreases as the size of the halogen increases. Iodine is the largest, forming the weakest bond, making it the easiest to substitute.

(c) Explain the fact that nucleophilic substitution reaction in 1-bromobutane is bimolecular whereas nucleophilic substitution reaction in 2-methyl-2-bromopropane is monomolecular.

- 1-Bromobutane undergoes SN2 (bimolecular substitution) because it is a primary alkyl halide, allowing the nucleophile to attack in a single step with a backside attack mechanism.
- 2-Methyl-2-bromopropane undergoes SN1 (monomolecular substitution) because it is a tertiary alkyl halide. The reaction proceeds via carbocation formation, followed by nucleophilic attack in a second step.

13. (a) Write the structural formulae of the following compounds:

(i) 2,4-Dinitrophenol

$O_2N—C_6H_3—OH—NO_2$

(ii) p-Aminophenol

$NH_2—C_6H_4—OH$

(b) Give the names and structures of dimethyl benzenes.

- 1,2-Dimethylbenzene (o-Xylene)
- 1,3-Dimethylbenzene (m-Xylene)
- 1,4-Dimethylbenzene (p-Xylene)

(c) Explain with the help of chemical equations which dimethyl benzene in 13 (b) above will yield

(i) One mononitro product
- p-Xylene gives a single mononitro product because both methyl groups are symmetrically placed.

$C_6H_4(CH_3)_2 + HNO_3 \rightarrow C_6H_3(CH_3)_2NO_2 + H_2O$

(ii) Two mononitro products
- o-Xylene and m-Xylene give two mononitro products due to different available positions for nitration.

$C_6H_4(CH_3)_2 + HNO_3 \rightarrow C_6H_3(CH_3)_2NO_2$ (two isomers) $+ H_2O$