THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATION COUNCIL OF TANZANIA

ADVANCED CERTIFICATE OF SECONDARY EDUCATION EXAMINATION

132/1 **CHEMISTRY 1**

(For Both Private and School Candidates)

Duration: 3 Hour. **ANSWERS** **Year: 2025**

Instructions

1. This paper consists of **ten (10)** questions**.**
2. Answer all questions in section A and two questions from section B.
3. Write your **Examination Number** on every page of your answer booklet(s).

1. (a) Describe five unique properties of carbon atom which enable it to form so many compounds.

Carbon has a valency of four, which allows it to form four covalent bonds with other atoms, including other carbon atoms. This makes it highly versatile in building complex molecules with different shapes and lengths.

Carbon exhibits catenation, the ability to form stable long chains and rings with itself. This property allows carbon to act as a backbone for a wide range of organic molecules, enabling the existence of millions of carbon-based compounds.

Carbon atoms can form single, double, and triple covalent bonds. This capacity for multiple bonding gives rise to structural diversity in organic compounds, ranging from saturated hydrocarbons to complex unsaturated and aromatic systems.

Carbon forms strong and stable covalent bonds with a variety of other nonmetals, such as hydrogen, oxygen, nitrogen, sulfur, and halogens. These bonds are not easily broken, making carbon compounds chemically stable and widespread.

Carbon exists in different allotropic forms like diamond, graphite, graphene, and fullerenes. These forms exhibit different physical properties due to the variation in bonding, further demonstrating carbon's adaptability and importance in materials and chemistry.

1. (b) The names of the following organic compounds are incorrect. Draw the structural formula for each compound and assign its correct IUPAC name.

(i) 2,2-dimethyl-3-pentene
The name 2,2-dimethyl-3-pentene incorrectly places the double bond at a higher position number than necessary. The double bond should get the lowest possible number. The correct IUPAC name is 3,3-dimethyl-1-butene, and the structure shows a four-carbon chain with two methyl groups on the third carbon and a double bond starting at carbon 1.

(ii) 3-ethyl-4-heptene
In the case of 3-ethyl-4-heptene, the position of the double bond should again be given the lowest number during numbering. When numbered correctly from the end closest to the double bond, the correct name becomes 4-ethyl-3-heptene.

(iii) 2-methyl-4-heptene
For 2-methyl-4-heptene, the longest chain includes seven carbon atoms, but the numbering does not give priority to the double bond. Re-numbering to give the double bond the lowest number and then placing the methyl group accordingly, the correct IUPAC name is 4-methyl-2-heptene.

(iv) 2,2,3-methylbutane

The name 2,2,3-methylbutane is not valid, as it implies three substituents on a four-carbon chain but incorrectly uses the prefix. The correct name for the compound with two methyl groups at carbon 2 and one at carbon 3 on a butane chain is 2,2,3-trimethylbutane.

(v) 5-methyl-3-bromo-3-ethylhexane

For 5-methyl-3-bromo-3-ethylhexane, the substituents are not ordered correctly and violate IUPAC naming rules. The correct IUPAC name is 3-bromo-3-ethyl-5-methylhexane, where substituents are listed in alphabetical order, and numbering is done from the end nearest the functional groups.

2. (a) "Hydrogen bonding is essential in sustaining life." In four points, briefly justify this statement.

Hydrogen bonding allows water molecules to stick together through cohesion, giving water a high surface tension. This is essential in transporting water and dissolved nutrients in plants through capillary action, especially from roots to leaves.

Hydrogen bonding gives water a high specific heat capacity, which enables it to absorb and store large amounts of heat with minimal temperature change. This property helps maintain stable temperatures in living organisms and aquatic ecosystems.

In biological molecules like DNA, hydrogen bonds between nitrogenous bases hold the two strands of the DNA double helix together. These bonds are strong enough to maintain structure but weak enough to allow separation during replication and transcription.

Proteins rely on hydrogen bonding to maintain their secondary and tertiary structures. These bonds help in folding proteins into their functional three-dimensional shapes, which is crucial for enzyme activity and cellular processes.

(b) (i) Why is $AlCl_3$ covalent while AlF_3 is ionic?

$AlCl_3$ is covalent because the aluminium ion has a high charge density and polarizes the larger chloride ion, leading to electron sharing. In contrast, fluorine is small and highly electronegative, so AlF_3 forms ionic bonds with minimal electron cloud distortion.

(ii) Identify the shape of the molecule and a type of hybrid orbital shown by the underlined atom; BeF_2, NO_3^- and BF_3.

In BeF_2, the beryllium atom is sp hybridized, and the molecular shape is linear with a bond angle of 180°.

In NO_3^-, the nitrogen atom is sp^2 hybridized, and the molecular shape is trigonal planar with bond angles of approximately 120°.

In BF_3, the boron atom is also sp^2 hybridized, and the molecule is trigonal planar due to the three bonding pairs and absence of lone pairs on the central atom.

3. (a) (i) Establish whether the reaction system had attained equilibrium or not, when the sample was analyzed.

The reaction is: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
$Kc = 1.5\ mol^2\ dm^{-6}$ at 375 °C
Concentrations:
$[N_2] = 0.25\ mol \div 3.5\ dm^3 = 0.0714\ mol/dm^3$
$[H_2] = 0.0032\ mol \div 3.5\ dm^3 = 0.000914\ mol/dm^3$
$[NH_3] = 6.42 \times 10^{-4}\ mol \div 3.5\ dm^3 = 1.834 \times 10^{-4}\ mol/dm^3$

Reaction quotient $Qc = [NH_3]^2 \div ([N_2] \times [H_2]^3)$
$Qc = (1.834 \times 10^{-4})^2 \div (0.0714 \times (0.000914)^3)$
Numerator $= 3.364 \times 10^{-8}$
Denominator $= 0.0714 \times 7.645 \times 10^{-10} = 5.456 \times 10^{-11}$
$Qc \approx 617$

Since $Qc > Kc$ ($617 > 1.5$), the system has not reached equilibrium.

(ii) State the direction of the reaction.

Because $Qc > Kc$, the concentration of products is too high. The system will shift to the left to form more reactants and reduce the concentration of ammonia.

(b) Given the following system at equilibrium:
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -188\ kJ\ mol^{-1}$

(i) If the pressure of the system is increased, the equilibrium will shift to the right to reduce the pressure by favoring the side with fewer moles of gas, which is the product side. Therefore, SO_3 concentration will increase.

(ii) If a noble gas is added and the pressure increases due to volume changes, the partial pressures of reactants and products remain unchanged. Therefore, there will be no effect on the concentration of SO_3.

(iii) If more SO_3 is added to the system, the equilibrium will shift to the left to reduce the concentration of SO_3, thus decreasing its overall concentration.

(iv) If the temperature of the system is increased, the equilibrium will shift to the left (endothermic direction) because the forward reaction is exothermic. Therefore, the concentration of SO_3 will decrease.

4. (a) Determine the maximum number of electrons that can be associated with each of the following sets of quantum numbers:

For $n = 4, l = 2$:
$l = 2$ represents the d-subshell, which has five orbitals. Each orbital holds 2 electrons, so maximum = 10 electrons.

For $n = 2, l = 1, m_l = -1$:
This specifies one p-orbital ($l = 1, m_l = -1$). Each orbital holds 2 electrons, so maximum = 2 electrons.

For $n = 3, l = 2, m_l = -2, m_s = -½$:
This specifies a single electron with those quantum numbers. Only one electron can have all four values identical. So, maximum = 1 electron.

(b) Excited hydrogen atom gives many emission lines. One of the series of lines called Brackett series occurs in the infrared region. It occurs when an electron jumps from higher energy orbitals to energy level n = 4. Calculate the wavelength of the lowest energy lines of this series.

The lowest energy line in the Brackett series corresponds to the transition from n = 5 to n = 4.
Use the Rydberg formula:
$1/\lambda = RZ^2(1/n_1^2 - 1/n_2^2)$, where $R = 1.097 \times 10^7\ m^{-1}$, $Z = 1$
$1/\lambda = 1.097 \times 10^7\ (1/4^2 - 1/5^2) = 1.097 \times 10^7\ (1/16 - 1/25)$
$= 1.097 \times 10^7\ (0.0625 - 0.04) = 1.097 \times 10^7 \times 0.0225 = 2.468 \times 10^5$

$\lambda = 1 \div 2.468 \times 10^5 = 4.05 \times 10^{-6}\ m = 4050\ nm$
Answer: Wavelength = 4050 nm

5. (a) Use the kinetic equation to deduce Graham's law.

The kinetic equation for gas particles is given by $KE = ½mv^2$, where m is the mass of a gas particle and v is its velocity. At constant temperature, the average kinetic energy of different gases is equal. So:
$½m_1v_1^2 = ½m_2v_2^2$
$\rightarrow m_1v_1^2 = m_2v_2^2$
$\rightarrow v_1^2/v_2^2 = m_2/m_1$
$\rightarrow v_1/v_2 = \sqrt{(m_2/m_1)}$

Since the rate of diffusion (or effusion) of a gas is directly proportional to its velocity, Graham's law is obtained:
$Rate_1/Rate_2 = \sqrt{(M_2/M_1)}$,
where M is molar mass.

(b) (i) At the ends of a horizontal glass tube, plugs of cotton wool soaked in concentrated ammonia solution and concentrated hydrochloric acid are inserted simultaneously. After a short time, a white ring of solid ammonium chloride forms at a certain point in the tube. If the distance between the inner surfaces of the cotton wool plugs is 50 cm, how far from the ammonia plug does the ammonium chloride ring form?

Ammonia and HCl gases diffuse and meet to form NH_4Cl. The ring forms closer to the slower gas, HCl, since NH_3 diffuses faster.
Rate $\propto 1/\sqrt{\text{Molar mass}}$

Molar masses:
$NH_3 = 17$, $HCl = 36.5$
Rate NH_3/Rate HCl $= \sqrt{(36.5/17)} = \sqrt{2.15} \approx 1.47$

So distance from NH_3 end = x, from HCl end = (50 − x)
$x / (50 - x) = 1.47$
Cross-multiplied: $x = 1.47(50 - x)$
$x = 73.5 - 1.47x$
$x + 1.47x = 73.5$
$2.47x = 73.5$
$x \approx 29.8$ cm

The ring forms approximately 29.8 cm from the ammonia plug.

(ii) What is the molar mass of gas Z, if it takes 54.4 seconds for 100 cm^3 of gas Z to effuse through an aperture and 36.5 seconds for 100 cm^3 of oxygen gas to effuse through the same aperture?

From Graham's law:
$Rate_1/Rate_2 = \sqrt{(M_2/M_1)}$
Let Z be gas 1, O_2 be gas 2
Rate $\propto$ 1/time, so:
$36.5 / 54.4 = \sqrt{(M\_Z / 32)}$
$0.671 = \sqrt{(M\_Z / 32)}$
Square both sides:
$0.450 = M\_Z / 32$
$M\_Z = 0.450 \times 32 = 14.4$ g/mol

The molar mass of gas Z is approximately 14.4 g/mol.

6. (a) (i) A dark brown color is produced when a dilute HCl is added to a solution containing potassium iodide and potassium iodate.

When HCl is added to a mixture of iodide (I^-) and iodate (IO_3^-) ions, the acidic conditions promote a redox reaction. Iodate is reduced and iodide is oxidized, forming iodine (I_2), which is brown in color.
$IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$
The iodine formed is responsible for the dark brown color observed.

(ii) Iodine is more soluble in aqueous solution of potassium iodide than in water.

Iodine (I_2) is nonpolar and has limited solubility in water. However, in the presence of iodide ions (I^-), it forms the triiodide ion (I_3^-), which is soluble in water.

$I_2 + I^- \rightarrow I_3^-$
This complex ion increases the solubility of iodine in potassium iodide solution.

(b) By using three specific examples, show that the solutions of salts formed from strong acids and weak bases are acidic.

When ammonium chloride (NH_4Cl), a salt of strong acid (HCl) and weak base (NH_3), dissolves in water, NH_4^+ ion hydrolyzes to produce H_3O^+ ions, making the solution acidic.
$NH_4^+ + H_2O \rightarrow NH_3 + H_3O^+$

Aluminium sulfate [$Al_2(SO_4)_3$] is another example. It originates from sulfuric acid (strong) and aluminium hydroxide (weak base). The Al^{3+} ion hydrolyzes to form acidic solution.
$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+$

Iron(III) chloride ($FeCl_3$) comes from hydrochloric acid and iron(III) hydroxide. Fe^{3+} ion undergoes hydrolysis in water to form acidic solution.
$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$

(c) (i) When a solution of barium hydroxide [$Ba(OH)_2$] is mixed with sulfuric acid, a white precipitate forms and conductivity drops.
Balanced equation:
$Ba(OH)_2 + H_2SO_4 \rightarrow BaSO_4\downarrow + 2H_2O$

(ii)
The decrease in electrical conductivity is due to the formation of an insoluble salt, barium sulfate ($BaSO_4$), which removes free ions from the solution. This reduces the total number of mobile charged species, lowering conductivity.

7. (a) Explain the applicability of the Hess's law of constant heat summation.

Hess's law states that the total enthalpy change for a chemical reaction is the same, regardless of the number of steps or the path taken, provided the initial and final conditions are the same. This law is applicable in determining enthalpy changes that are difficult to measure directly by allowing the use of known enthalpy changes for related reactions to find unknown ones. It also enables the calculation of standard enthalpy of formation, combustion, or neutralization by constructing thermochemical cycles based on known data.

(b) (i) Calculate the lattice energy (ΔH_LE) of a solid calcium chloride given the following data:
ΔH_sub (Ca) = +111 kJ/mol
ΔH_1st (Ca) = +33.5 kJ/mol
ΔH_2nd (Ca) = +65.2 kJ/mol
ΔH_diss (Cl_2) = +243 kJ/mol
ΔH_EA (Cl) = −349.6 kJ/mol (2 × −20.8 + 2 × −153.5)
ΔH_f ($CaCl_2$) = −854 kJ/mol

Use Born-Haber cycle:
$\Delta H\_f = \Delta H\_sub + \Delta H\_ionization + \Delta H\_dissociation + \Delta H\_electron\ affinity + \Delta H\_LE$

$\Delta H\_f = +111 + (33.5 + 65.2) + (½ \times 243) + (2 \times -20.8) + \Delta H\_LE$
$\Delta H\_f = +111 + 98.7 + 121.5 - 41.6 + \Delta H\_LE$
$-854 = 289.6 + \Delta H\_LE$
$\Delta H\_LE = -854 - 289.6 = -1143.6$ kJ/mol

Lattice energy = −1143.6 kJ/mol

(ii) If Ca^+ and Cl^- ions formed a hypothetical crystal CaCl(s), with lattice energy of −431 kJ/mol, and assuming ΔH_f (CaCl) is unknown, use Hess's law to determine its heat of formation.

$\Delta H\_f = \Delta H\_sub + \Delta H\_1st\ ionization + ½\ \Delta H\_diss + EA + Lattice\ energy$
$\Delta H\_f = 111 + 33.5 + 121.5 - 20.8 - 431$
$\Delta H\_f = 144.5 + 121.5 - 20.8 - 431 = -186$ kJ/mol

Heat of formation of CaCl(s) = −186 kJ/mol

(iii) Which of the two, CaCl(s) or $CaCl_2$(s), has a more stable crystal lattice? Briefly explain your answer.

$CaCl_2$(s) has a more stable crystal lattice because its lattice energy is much more negative (−1143.6 kJ/mol) compared to that of CaCl(s) (−431 kJ/mol). A more negative lattice energy indicates stronger ionic bonding and greater stability in the crystal structure.

8. (a) (i) What are colligative properties?

Colligative properties are physical properties of solutions that depend on the number of solute particles present in a given quantity of solvent, not on the type or nature of the particles. These properties include vapor pressure lowering, boiling point elevation, freezing point depression, and osmotic pressure.

(ii) Give two limitations of colligative properties.

Colligative properties assume ideal solution behavior, which may not hold true in concentrated solutions or in the presence of strong solute-solvent interactions. Additionally, for ionic solutes that dissociate in solution, the expected number of particles may not match the actual number due to ion pairing or incomplete dissociation.

(b) A sugar solution with concentration 2.5 g/dm³ gave an osmotic pressure of 8.3×10^{-4} atm at 25°C. Calculate the molecular mass of the solute.

Use formula: $\pi = cRT$
$c = n/V = (mass/Mr)$
So: $\pi = (w/M)RT \rightarrow M = wRT/\pi$

Given:
$w = 2.5$ g, $T = 298$ K, $R = 0.0821$ $dm^3\cdot atm/mol\cdot K$
$\pi = 8.3 \times 10^{-4}$ atm

$M = (2.5 \times 0.0821 \times 298) \div 8.3 \times 10^{-4} = (61.19) \div 8.3 \times 10^{-4} = 73723$ g/mol

Molecular mass ≈ 73.7 g/mol

(c) A solution of Urea (CON_2H_4) contains 1.75 g/dm^3 and is isotonic with a 10 g solution of a certain sugar in 1 dm^3 aqueous solution at the same temperature. Calculate the relative molecular mass of the sugar.

Since both are isotonic, they exert the same osmotic pressure, so:
$(n_{urea}) = (n_{sugar})$
$(1.75 / 60) = (10 / M)$
$M = (10 \times 60) / 1.75 = 600 / 1.75 = 342.9$ g/mol

Relative molecular mass of sugar ≈ 343 g/mol

9. (a) Describe briefly the following with reference to substitution reactions on benzene:
(i) Activators
(ii) Deactivators

Activators are substituents that increase the reactivity of the benzene ring toward electrophilic substitution. They donate electron density into the ring, either through resonance or inductive effect, making the ring more electron-rich and reactive. Examples include –OH, $–NH_2$, and $–CH_3$ groups.

Deactivators are substituents that decrease the reactivity of the benzene ring toward electrophilic substitution. They withdraw electron density from the ring, making it less reactive toward electrophiles. Examples include $–NO_2$, –COOH, and $–SO_3H$ groups.

(b) State with reasons the group which entered the benzene ring first in the following compounds:

(i) $–CH_3$ is an activating group, so it directs substitution to ortho/para positions.
(ii) $–NO_2$ is deactivating, so it entered the ring after $–CH_3$.
(iii) –OH is activating, entered before Cl.
(iv) –Cl is weakly deactivating but enters before $–NO_2$.
(v) $–SO_3H$ is strongly deactivating, entered after NO_2.
(vi) –COOH is deactivating, entered before –OH.

Group that entered first:
(i) $–CH_3$
(ii) $–CH_3$
(iii) –OH
(iv) –Cl

(v) –NO_2
(vi) –COOH

(c) Complete the following organic reactions by filling the missing structures and reagents designated by letters.

(i)
A → nitrobenzene → B + C → aniline

The first step (A to nitrobenzene) is nitration of benzene using concentrated nitric acid and sulfuric acid as the nitrating mixture.
So A is benzene, and the reagent is conc. HNO_3/H_2SO_4.

The second step (nitrobenzene to aniline) involves reduction using either tin and hydrochloric acid (Sn/HCl) or iron and hydrochloric acid (Fe/HCl).
So B is $SnCl_2$ and C is HCl.

(ii)
Toluene (CH_3-benzene) on chlorination under boiling with Cl_2 gives benzyl chloride ($C_6H_5CH_2Cl$), designated as X.

Then X undergoes hydrolysis with aqueous OH^- to give benzyl alcohol ($C_6H_5CH_2OH$), designated as Y.

10. (a) What do you understand by the following terms?

(i) Global warming is the gradual increase in Earth's average surface temperature due to the buildup of greenhouse gases like CO_2, CH_4, and N_2O in the atmosphere, which trap heat.

(ii) Ozone layer is a layer of ozone (O_3) molecules found in the Earth's stratosphere that absorbs most of the Sun's harmful ultraviolet (UV) radiation, protecting living organisms from DNA damage and harmful exposure.

(b) Suppose you got a job at the National Environmental Management Council (NEMC) of Tanzania, and in one of the occasions, you are required to address the residents of a certain area on environmental issues. Briefly, explain the following:

(i) Incineration is the process of burning waste materials at high temperatures to reduce their volume and convert them into ash, flue gases, and heat. It is a method used in waste management to dispose of hazardous, medical, and municipal waste.

(ii) Two advantages of incineration include volume reduction of waste by up to 90%, and the possibility of energy recovery in the form of heat or electricity. Two disadvantages include the emission of toxic gases and the high cost of equipment and maintenance.

(iii) Particulate pollutants cause respiratory diseases such as asthma and bronchitis when inhaled into the lungs. They reduce visibility in the atmosphere, contributing to smog. They also damage crops and soil when they settle, impacting agriculture and biodiversity.

(c) (i) If greenhouse gases were totally missing from Earth's atmosphere, the planet would lose most of its heat to space, resulting in extremely cold temperatures that would make life unsustainable. The natural greenhouse effect keeps the Earth's temperature within a habitable range, and without it, the Earth's average surface temperature would drop significantly.

(ii) Four damaging effects of acidic rainfall include the acidification of lakes and rivers, which harms aquatic life; the leaching of nutrients from soil, reducing crop productivity; corrosion of buildings and monuments, especially those made of limestone or marble; and damage to leaves and stems of plants, which interferes with photosynthesis and weakens their structure.