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: 2023**

Instructions

1. This paper consists of sections A and B with total of ten questions

2. Each question carries ten marks in section A and fifteen marks in section B.

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1. (a) A person swallowed a drop of liquid oxygen, $O_2(l)$, which has a density of 1.149 g/cm³. Assuming the drop has a volume of 0.050 cm³, calculate the volume of a gas that would be produced in the person's stomach at body temperature (37°C) and a pressure of one (1) atmosphere.

Solution:
Given data:
Density of liquid oxygen = 1.149 g/cm³
Volume of liquid oxygen = 0.050 cm³
Temperature of gas = 37°C = 310 K
Pressure of gas = 1 atm
Molar mass of O_2 = 32 g/mol
Gas constant R = 0.0821 L·atm/mol·K

Step 1: Calculate the mass of liquid oxygen:
mass = density × volume
mass = 1.149 g/cm³ × 0.050 cm³
mass = 0.05745 g

Step 2: Calculate the moles of oxygen gas produced:
moles of O_2 = mass / molar mass
moles of O_2 = 0.05745 g / 32 g/mol
moles of O_2 = 0.001795 mol

Step 3: Use the ideal gas equation to determine the volume of gas:
$PV = nRT$
$V = (nRT) / P$
V = (0.001795 mol × 0.0821 L·atm/mol·K × 310 K) / 1 atm
V = (0.0457) L
V ≈ 45.7 mL

Final answer: The volume of gas produced in the stomach is approximately 45.7 mL.

(b) A compound contains only nitrogen and hydrogen and is 87.4% nitrogen by mass. A gaseous sample of the compound has a density of 0.977 g/L at 710 mmHg and 100°C. Determine the molecular formula of the compound.

Solution:
Step 1: Assume 100 g of the compound.
Mass of nitrogen = 87.4 g
Mass of hydrogen = 100 - 87.4 = 12.6 g

Step 2: Determine the moles of each element:
Moles of nitrogen = 87.4 g / 14 g/mol = 6.243 mol

Moles of hydrogen = 12.6 g / 1 g/mol = 12.6 mol

Step 3: Find the simplest ratio:
Divide by the smallest value (6.243):
N = 6.243 / 6.243 = 1
H = 12.6 / 6.243 = 2

Empirical formula: NH_2

Step 4: Determine the molar mass using the given density:
$PV = nRT \rightarrow M = (dRT) / P$
Given data:
d = 0.977 g/L
P = 710 mmHg = 710/760 atm = 0.934 atm
T = 100°C = 373 K
R = 0.0821 L·atm/mol·K

$M = (0.977 \times 0.0821 \times 373) / 0.934$
M = 32 g/mol

Step 5: Compare the empirical formula mass with the molar mass:
Empirical formula mass (NH_2) = 14 + (2 × 1) = 16 g/mol
Molecular formula = (32 / 16) × NH_2 = N_2H_4

Final answer: The molecular formula of the compound is N_2H_4.

(c) A total volume of 2.50×10^2 cm^3 chlorine gas was collected over water at 20°C and a total pressure of 1 atm. Calculate the mass of chlorine collected at this temperature if the vapour pressure of water was 17.5 mmHg.

Solution:
Given data:
V = 2.50×10^2 cm^3 = 0.250 L
T = 20°C = 293 K
P_{total} = 1 atm
P_{H_2O} = 17.5 mmHg = 17.5/760 atm = 0.023 atm
$P_{Cl_2} = P_{total} - P_{H_2O}$ = 1 - 0.023 = 0.977 atm
R = 0.0821 L·atm/mol·K
Molar mass of Cl_2 = 71 g/mol

Step 1: Use PV = nRT to find moles of Cl_2:
n = (PV) / (RT)
$n = (0.977 \times 0.250) / (0.0821 \times 293)$

n = 0.0101 mol

Step 2: Calculate mass of Cl_2:
mass = n × molar mass
mass = 0.0101 × 71
mass = 0.717 g

Final answer: The mass of chlorine collected is approximately 0.717 g.

2. (a) Comment briefly on the following observations:

(i) Sodium chloride solution freezes at a lower temperature than that of pure water but boils at higher temperature than pure water.

Solution:
Adding sodium chloride to water lowers its freezing point due to colligative properties, as salt disrupts the formation of ice crystals. This is known as freezing point depression. Conversely, the boiling point increases because the presence of solute particles raises the boiling point, a phenomenon known as boiling point elevation.

(ii) A driver adds ethylene glycol to water in a car radiator during winter season.

Solution:
Ethylene glycol acts as an antifreeze. It lowers the freezing point of water, preventing the engine coolant from freezing in cold conditions. Additionally, it raises the boiling point, reducing the risk of overheating in summer.

(iii) The blood cells which are isotonic with 0.9% sodium chloride solution are placed in 1.2% sodium chloride solution.

Solution:
A 1.2% NaCl solution is hypertonic compared to blood cells. This causes water to move out of the cells by osmosis, leading to cell shrinkage (crenation), which can impair cell function.

(iv) When dehydrated fruits and vegetables are placed in water, they slowly swell and return to the original forms.

Solution:
Dehydrated fruits and vegetables absorb water through osmosis. Water moves from a region of higher concentration (external environment) to a region of lower concentration (dehydrated cells), restoring the original shape and texture.

(b) (i) Eighteen grams (18 g) of glucose, $C_6H_{12}O_6$ (molar mass = 180 g/mol) are dissolved in 1 kg of water in a sauce pan. At what temperature will this solution boil? Given the K_b for water = 0.52 K·kg/mol.

Solution:
Step 1: Calculate the moles of glucose:
moles = mass / molar mass
moles = 18 g / 180 g/mol
moles = 0.1 mol

Step 2: Calculate the boiling point elevation:
$\Delta T_b = i \times K_b \times m$
i = 1 (glucose does not ionize)
m = (0.1 mol) / (1 kg) = 0.1 m
$\Delta T_b = (1 \times 0.52 \times 0.1)$
$\Delta T_b = 0.052$ K

Step 3: Find the boiling point of solution:
$T_b = 100 + \Delta T_b$
$T_b = 100 + 0.052$
$T_b = 100.052$°C

Final answer: The solution will boil at approximately 100.05°C.

(ii) Calculate the elevation in boiling point that is expected for an alcohol when 5 g of urea (molar mass 60 g/mol) are dissolved in 75 g of it. Given the molal elevation constant for the alcohol = 1.15 K/m.

Solution:
Step 1: Calculate the moles of urea:
moles = mass / molar mass
moles = 5 g / 60 g/mol
moles = 0.0833 mol

Step 2: Calculate the molality:
m = (0.0833 mol) / (0.075 kg)
m = 1.11 m

Step 3: Calculate the boiling point elevation:
$\Delta T_b = i \times K_b \times m$
$\Delta T_b = (1 \times 1.15 \times 1.11)$
$\Delta T_b = 1.28$ K

Final answer: The expected elevation in boiling point is 1.28 K.

3. (a) What are the two conditions necessary for the formation of hydrogen bonding? Briefly explain.

Solution:

Hydrogen bonding is a special type of dipole-dipole interaction that occurs when hydrogen is bonded to highly electronegative elements. The two necessary conditions for hydrogen bonding are:

(i) The presence of a highly electronegative atom:
For hydrogen bonding to occur, hydrogen must be directly bonded to a highly electronegative atom such as fluorine (F), oxygen (O), or nitrogen (N). These atoms create a strong partial positive charge on hydrogen, making it highly polar.

(ii) The presence of a lone pair on a neighboring electronegative atom:
The partially positive hydrogen must interact with a lone pair of electrons on another electronegative atom in a nearby molecule. This lone pair stabilizes the interaction and allows the formation of hydrogen bonding.
Example: In water (H_2O), each oxygen atom has lone pairs and is highly electronegative. The hydrogen atoms from one water molecule form hydrogen bonds with the oxygen of another molecule, leading to strong intermolecular forces.

(b) Study the chemical structures of compounds I and II and answer the questions that follow while giving one reason in each case:

(i) What type of hydrogen bonding is exhibited in each compound?

Solution:
In compound I, the hydrogen bonding is intramolecular hydrogen bonding because the hydrogen bond forms within the same molecule due to the proximity of the hydroxyl (-OH) and nitro ($-NO_2$) groups.

In compound II, the hydrogen bonding is intermolecular hydrogen bonding because hydrogen bonds form between separate molecules, as the hydroxyl (-OH) group can interact with the nitrogen in the nitro ($-NO_2$) group of another molecule.

(ii) Which of the two compounds is expected to have a higher melting point than the other?

Solution:
Compound II is expected to have a higher melting point than compound I because it exhibits intermolecular hydrogen bonding, which strengthens the molecular interactions and requires more energy to break. In contrast, compound I has intramolecular hydrogen bonding, which does not contribute to strong intermolecular forces and results in a lower melting point.

(iii) Which compound is likely to be more soluble in a polar solvent?

Solution:
Compound II is more soluble in polar solvents like water because it exhibits intermolecular hydrogen bonding, allowing it to interact strongly with solvent molecules. Compound I, which has intramolecular hydrogen bonding, does not form strong interactions with the solvent, reducing its solubility.

(c) Indicate the types of bonds present in NH_4NO_3 and state the mode of hybridization of the N atom in the NO_3^- ion.

Solution:
NH_4NO_3 (ammonium nitrate) contains the following types of bonds:
- Ionic bonds between NH_4^+ (ammonium ion) and NO_3^- (nitrate ion).
- Covalent bonds within NH_4^+ and NO_3^-. The NH_4^+ ion has four N-H covalent bonds, and the NO_3^- ion has three N-O covalent bonds.
- Coordinate covalent bonds in NH_4^+, where nitrogen donates a lone pair to form a bond with H^+.

Mode of hybridization of the nitrogen atom in NO_3^-:
The nitrogen atom in NO_3^- undergoes sp^2 hybridization, resulting in a trigonal planar geometry with resonance structures that delocalize the negative charge over the oxygen atoms.

4. (a) All radiations are associated with wave nature and differ from one another in terms of wavelength, frequency, velocity, and energy. Give the relationship between the following:

(i) Frequency and wavelength

Solution:
The relationship between frequency (ν) and wavelength (λ) is given by the wave equation:

$$c = \nu\lambda$$

where c is the speed of light in a vacuum (3.00×10^8 m/s). This equation shows that frequency and wavelength are inversely proportional: as wavelength increases, frequency decreases, and vice versa.

(ii) Wavelength and wavenumber

Solution:
Wavenumber (k) is defined as the reciprocal of wavelength:

$$k = 1/\lambda$$

This indicates that wavenumber and wavelength are inversely proportional. A shorter wavelength corresponds to a higher wavenumber.

(iii) Energy and frequency

Solution:
The energy (E) of electromagnetic radiation is related to frequency by Planck's equation:

$E = h\nu$

where h is Planck's constant (6.626×10^{-34} J·s). This shows that energy and frequency are directly proportional: as frequency increases, energy also increases.

(iv) Energy and wavelength

Solution:
Using the wave equation ($c = \nu\lambda$) and Planck's equation ($E = h\nu$), we derive:

$E = hc / \lambda$

This equation shows that energy and wavelength are inversely proportional: as wavelength increases, energy decreases.

(b) Indicate whether the following electronic configurations are possible or impossible. For the impossible ones, specify the rules which have been violated.

(i) $1s^2\ 2s^2\ 2p^2$
Solution: Possible, as it follows the Aufbau principle and Hund's rule.

(ii) $1s^2\ 2s^0\ 2p^0\ 3s^1$
Solution: Impossible. The Aufbau principle is violated because 2s and 2p cannot be empty while 3s is occupied.

(iii) $1s^2\ 2s^2\ 2p^2\ 3s^1$
Solution: Possible, as it follows the correct order of filling orbitals.

(iv) $1s^2\ 2s^2\ 2p^4$
Solution: Possible, as it follows Hund's rule and the Aufbau principle.

(v) $1s^2\ 2s^2\ 2p^6\ 2d^1$
Solution: Impossible. The 2d orbital does not exist in the second energy level. Only s and p orbitals are allowed in n=2.

(c) How many orbitals are there in each of the following sub-shells?

(i) 2p
Solution: The p sub-shell has three orbitals (px, py, pz).

(ii) 3d
Solution: The d sub-shell has five orbitals (dxy, dxz, dyz, dx^2-y^2, dz^2).

5. (a) In the process of manufacturing chemicals, in one of the emerging chemical industries in Tanzania, a Chemist performed the following activities:

(i) Exposed sodium metal to air followed by addition of water.
(ii) Burned sodium metal in air followed by addition of water.

Briefly, explain the chemical processes that took place while supporting your answer with balanced chemical equations in each case.

Solution:

(i) When sodium metal is exposed to air, it reacts with oxygen to form sodium oxide. Upon addition of water, sodium oxide dissolves to form sodium hydroxide.

Reaction with oxygen:
$4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$

Reaction with water:
$Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$

Overall process: Sodium reacts with oxygen to form sodium oxide, which dissolves in water to produce a strongly basic solution of sodium hydroxide.

(ii) When sodium metal is burned in air, it reacts vigorously with oxygen to form sodium peroxide instead of sodium oxide. Upon addition of water, sodium peroxide hydrolyzes to form sodium hydroxide and hydrogen peroxide.

Reaction with oxygen:
$2Na(s) + O_2(g) \rightarrow Na_2O_2(s)$

Reaction with water:
$Na_2O_2(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2O_2(aq)$

Overall process: Sodium burns in air to form sodium peroxide, which reacts with water to form sodium hydroxide and hydrogen peroxide.

(b) Using balanced chemical equations, describe the reactions between the oxides of lead, aluminium and calcium with dilute:

(i) Sulphuric acid

(ii) Nitric acid

Solution:

(i) Reactions with sulphuric acid

Lead(II) oxide reacts with dilute sulphuric acid to form lead(II) sulphate and water:
$PbO(s) + H_2SO_4(aq) \rightarrow PbSO_4(s) + H_2O(l)$

Aluminium oxide reacts with dilute sulphuric acid to form aluminium sulphate and water:
$Al_2O_3(s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3H_2O(l)$

Calcium oxide reacts with dilute sulphuric acid to form calcium sulphate and water:
$CaO(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + H_2O(l)$

(ii) Reactions with nitric acid

Lead(II) oxide reacts with dilute nitric acid to form lead(II) nitrate and water:
$PbO(s) + 2HNO_3(aq) \rightarrow Pb(NO_3)_2(aq) + H_2O(l)$

Aluminium oxide reacts with dilute nitric acid to form aluminium nitrate and water:
$Al_2O_3(s) + 6HNO_3(aq) \rightarrow 2Al(NO_3)_3(aq) + 3H_2O(l)$

Calcium oxide reacts with dilute nitric acid to form calcium nitrate and water:
$CaO(s) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + H_2O(l)$

6. (a) Differentiate between the following terms:

(i) Born-Haber cycle and enthalpy of formation.
(ii) Heat of neutralization and heat of solution.

Solution:

(i) Born-Haber cycle is a thermodynamic cycle used to determine the lattice enthalpy of ionic compounds by combining different energy changes in the formation of an ionic solid from its constituent elements. It involves ionization energy, electron affinity, bond dissociation energy, and lattice energy.

Enthalpy of formation, on the other hand, is the heat change that occurs when one mole of a compound is formed from its elements in their standard states under standard conditions. It represents a direct enthalpy change, while the Born-Haber cycle is an indirect approach to determining lattice energy.

(ii) Heat of neutralization is the heat change that occurs when an acid reacts with a base to form one mole of water in a neutralization reaction. It is always exothermic.

Heat of solution is the heat change that occurs when one mole of a substance dissolves in a given amount of solvent to form a solution at constant pressure. It can be exothermic or endothermic depending on the solute-solvent interactions.

(b) You are given an equation representing the hydrogenation of ethene as
$C_2H_4(g) + H_2(g) \rightarrow CH_3CH_3(g)$. What would be the value for standard enthalpy of hydrogenation of ethene (in kJ) if the bond enthalpies were: C-H = 416; C=C = 612; C-C = 348 and H-H = 436?

Solution:

Step 1: Identify bonds broken and formed

Bonds broken:
- One C=C bond (612 kJ)
- One H-H bond (436 kJ)

Total energy required to break bonds = 612 + 436 = 1048 kJ

Bonds formed:
- Two C-H bonds (2 × 416 = 832 kJ)
- One C-C bond (348 kJ)

Total energy released in bond formation = 832 + 348 = 1180 kJ

Step 2: Calculate enthalpy change of reaction

ΔH = Bonds broken - Bonds formed
$\Delta H = 1048 - 1180$
$\Delta H = -132$ kJ

7. (a) Using one chemical test, distinguish the following organic compounds:

(i) $CH_2CH\text{-}CH_2$ and $CH_3CH_2CH_3$
(ii) $CH_3C{\equiv}CCH_3$ and $CH_3CH{=}C{=}CH$

Solution:

(i) Bromine water test:
$CH_2CH\text{-}CH_2$ (alkene) will decolorize bromine water due to the presence of a double bond. $CH_3CH_2CH_3$ (alkane) will not react with bromine water and remains brown.

(ii) Ammoniacal silver nitrate test (Tollens' reagent):

$CH_3C{\equiv}CCH_3$ (alkyne with no terminal hydrogen) will not react with Tollens' reagent. $CH_3CH{=}C{=}CH$ (allene) does not react either, as it lacks a terminal hydrogen, making this test ineffective. Instead, acidic $KMnO_4$ can be used, where the alkyne undergoes oxidative cleavage to form acids, while the allene does not react as readily.

(b) Predict the major product in each of the following organic reactions:

(i) $CH_3C{\equiv}CCH_3(g) + H_2O(g)$ -----> ($HgSO_4$, H_2SO_4)
The reaction follows Markovnikov's addition, forming 2-butanone ($CH_3COCH_2CH_3$).

(ii) CH_3CH_2Br + Na ----> (dry ether)
This is a Wurtz reaction, forming butane ($CH_3CH_2CH_2CH_3$).

(iii) CH_3CH_3 + Conc. HNO_3 -----> (heat)
The major product is nitroethane ($CH_3CH_2NO_2$).

(iv) $CH_3CH{=}CH_2 + Br_2$ -----> (UV light)
This leads to allylic bromination, forming 3-bromopropene ($CH_2Br\text{-}CH{=}CH_2$).

7. (c) A form six student wanted to arrange the following organic compounds in order of increasing acidity of their terminal hydrogen atoms.

$CH{\equiv}CH$; $CH_2{=}CH_2$; $(CH_3)_3C{\equiv}CH$; $ClC{=}CH$; $NO_2C{=}CH$

Suggest a correct sequence required by the student and give two reasons for your choice of arrangement.

Solution:

The correct sequence in increasing acidity is:

$(CH_3)_3C{\equiv}CH < CH_2{=}CH_2 < CH{\equiv}CH < ClC{=}CH < NO_2C{=}CH$

Reasons:

(i) The acidity of terminal hydrogen atoms in hydrocarbons follows the trend: alkane < alkene < alkyne, due to the increasing s-character of the hybridized carbon. Alkynes (sp hybridization) hold the hydrogen more tightly than alkenes (sp^2) and alkanes (sp^3), making them more acidic.

(ii) The presence of electronegative substituents like Cl and NO_2 increases acidity by stabilizing the conjugate base through the inductive and resonance effects. The nitro group ($-NO_2$) has a strong electron-withdrawing effect, making $NO_2C{=}CH$ the most acidic compound.

8. (a) (i) "A chemical system at equilibrium is dynamic." Explain briefly the meaning of this statement.

Solution:
A chemical system at equilibrium is dynamic because the forward and reverse reactions continue to occur at the same rate. Even though the macroscopic properties of the system (such as concentration and pressure) remain constant, there is a continuous exchange of reactants and products at the molecular level.

(ii) The equilibrium constant, Kp for the reaction $CCl_4(g)$ ---> $C(s) + 2Cl_2(g)$ is 0.76 atm at 978 K. Calculate the initial pressure of carbon tetrachloride that will produce a total equilibrium pressure of 1.2 atm at 978 K.

Solution:

Step 1: Define variables
Let P be the initial pressure of CCl_4.
At equilibrium, let x be the dissociated pressure of CCl_4.

Reaction: $CCl_4(g) \rightarrow C(s) + 2Cl_2(g)$

Initial pressure: P
Change: -x for CCl_4, +2x for Cl_2
Equilibrium pressure: (P - x) for CCl_4 and 2x for Cl_2

Total pressure at equilibrium:
$(P - x) + 2x = 1.2$ atm
$P + x = 1.2$

Step 2: Apply the equilibrium expression:
$Kp = (P\_Cl_2)^2 / P\_CCl_4$
$0.76 = (2x)^2 / (P - x)$

Step 3: Solve for x
Substituting $P = 1.2 - x$ into the Kp expression:
$0.76 = (4x^2) / (1.2 - x)$
$0.76(1.2 - x) = 4x^2$
$0.912 - 0.76x = 4x^2$
$4x^2 + 0.76x - 0.912 = 0$

Solving the quadratic equation for x, we get:
$x \approx 0.42$ atm

Step 4: Calculate initial pressure
$P = 1.2 - x$

P = 1.2 - 0.42
P = 0.78 atm

(b) (i) Why the solubility of CO_2 in soft drinks like Coca-Cola decreases with rise in temperature? Briefly explain.

Solution:
The solubility of CO_2 in liquids follows Henry's Law, which states that the solubility of a gas decreases as temperature increases. When temperature rises, gas molecules gain kinetic energy, making it easier for CO_2 to escape from the liquid into the atmosphere, reducing solubility.

(ii) What happens to equilibrium in a reversible reaction if a catalyst is added to it? Explain briefly.

Solution:
A catalyst does not affect the position of equilibrium. It only increases the rate of both the forward and reverse reactions equally, allowing equilibrium to be reached faster without altering the equilibrium composition.
(iii) What happens to equilibrium constant of an exothermic reaction if temperature is raised? Explain briefly.

Solution:
For an exothermic reaction, increasing temperature shifts the equilibrium position toward the reactants according to Le Chatelier's Principle. Since equilibrium constant (K) is related to temperature by the van't Hoff equation, K decreases as temperature increases.

(c) When a yellow solution of iron(III) chloride and a colorless solution of potassium thiocyanate (KSCN) are mixed in a test tube, a red color appears according to the following equilibrium:

$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons [Fe(SCN)]^{2+}(aq)$ (red solution)

(i) What would be the effect on Fe^{3+} ions upon addition of KSCN to the equilibrium?

Solution:
Adding KSCN increases the concentration of SCN^{-} ions. According to Le Chatelier's Principle, the equilibrium shifts to the right to reduce the stress, leading to a decrease in Fe^{3+} concentration as more $[Fe(SCN)]^{2+}$ complex forms, intensifying the red color.
(ii) What would happen to the equilibrium position when the pressure of the system was to be doubled? Briefly explain.

Solution:
Since all species in the reaction are in aqueous solution, pressure has no significant effect on the equilibrium position. Pressure changes primarily affect gaseous equilibria.

(iii) The red color faded when the test tube containing the equilibrium mixture was placed in an ice-water bath. Briefly explain whether the value of K for this reaction is high or low and whether the reaction is exothermic or endothermic.

Solution:
The red color fading in an ice-water bath suggests that the equilibrium shifted to the left, reducing the concentration of $[Fe(SCN)]^{2+}$. Since lowering the temperature favors the exothermic direction, it indicates that the reaction is endothermic in the forward direction.

The value of K is low because a significant portion of Fe^{3+} and SCN^- remains unreacted, meaning the complex formation is not highly favored.

9. (a) After a successful completion of your Secondary Education, some farmers in your area of residence invite you to give a talk as far as the concept of Soil Chemistry is concerned. Briefly, explain each of the following terms while citing one example in each case:

(i) Soil reaction
(ii) Soil colloids
(iii) Liming
(iv) Organic fertilizers
(v) Artificial fertilizers

Solution:

(i) Soil reaction refers to the acidity, alkalinity, or neutrality of soil, which is determined by measuring soil pH. It affects the availability of nutrients to plants and the activity of microorganisms. For example, acidic soils with a low pH can limit nutrient uptake and require treatment with lime.

(ii) Soil colloids are fine, microscopic particles in soil, including clay and humus, that have a large surface area and the ability to retain water and nutrients. These colloids carry electrical charges that help in cation exchange, making essential nutrients available for plant growth. For example, clay minerals such as montmorillonite are important soil colloids.

(iii) Liming is the process of applying calcium-containing compounds, such as calcium carbonate ($CaCO_3$), to acidic soils to increase pH and improve soil structure. Liming helps neutralize excess hydrogen ions and enhances nutrient availability. For example, agricultural lime ($CaCO_3$) is commonly used for liming acidic soils.

(iv) Organic fertilizers are natural substances derived from plant or animal matter that improve soil fertility by supplying essential nutrients and enhancing microbial activity. They release nutrients slowly and improve soil structure. For example, compost made from decomposed plant and animal waste is an organic fertilizer.

(v) Artificial fertilizers are chemically synthesized substances that provide specific nutrients in precise amounts to enhance plant growth. They are usually fast-acting and contain macronutrients like nitrogen, phosphorus, and potassium. For example, ammonium nitrate (NH_4NO_3) is an artificial fertilizer used to supply nitrogen to crops.

(b) Why is it necessary to measure soil pH? Briefly, explain by giving two reasons.

Solution:

(i) Soil pH affects nutrient availability: Different nutrients are available to plants at specific pH levels. For example, at low pH (acidic soils), essential nutrients like phosphorus and calcium become less available, whereas toxic elements like aluminum may become more soluble, harming plant growth.

(ii) Soil pH influences microbial activity: Beneficial soil microorganisms, such as nitrogen-fixing bacteria, thrive within a certain pH range (typically neutral to slightly acidic). Extreme pH levels can inhibit microbial activity, reducing organic matter decomposition and nutrient cycling.

(c) A farmer was advised to supply 200 kg of nitrogen on the paddy farm. What would be the mass of a fertilizer with 60% by mass $Ca(NO_3)_2$ which the farmer has to buy in order to meet the nitrogen requirements for the farm?

Solution:

Step 1: Determine the nitrogen content in $Ca(NO_3)_2$

Molar mass of $Ca(NO_3)_2 = 40 + (2 \times (14 + 3 \times 16))$
$= 40 + (2 \times 62)$
$= 164$ g/mol

Nitrogen content in $Ca(NO_3)_2 = (2 \times 14) / 164 \times 100\%$
$= 28 / 164 \times 100$
$= 17.07\%$

Step 2: Calculate the required mass of $Ca(NO_3)_2$ fertilizer

Let x be the mass of $Ca(NO_3)_2$ required to supply 200 kg of nitrogen:

17.07% of x = 200 kg
$0.1707x = 200$
$x = 200 / 0.1707$
$x \approx 1171$ kg

10. (a) (i) What are the two effects of substituent groups on the reactivity of benzene ring? Briefly, explain.

Solution:

Substituent groups on a benzene ring influence its reactivity in two main ways:

1. Electron donation or withdrawal:
- Electron-donating groups (EDGs) increase the electron density on the benzene ring, making it more reactive toward electrophilic substitution. Examples include -OH, $-NH_2$, and $-CH_3$.
- Electron-withdrawing groups (EWGs) decrease the electron density, making the ring less reactive toward electrophilic substitution. Examples include $-NO_2$, $-CF_3$, and -COOH.

2. Directing effects on electrophilic substitution.
- Electron-donating groups activate the benzene ring and direct incoming electrophiles to the ortho and para positions.
- Electron-withdrawing groups deactivate the benzene ring and direct incoming electrophiles to the meta position.

(ii) By giving one example in each case, briefly justify the statement "Despite the fact that both benzene and alkenes are unsaturated hydrocarbons, benzene undergoes electrophilic substitution reactions whereas alkenes undergo electrophilic addition reactions."

Solution:

Benzene undergoes electrophilic substitution rather than addition due to the delocalized π-electron system, which provides extra stability. Addition reactions would disrupt this stability by breaking the aromaticity.

Example of benzene electrophilic substitution: Nitration of benzene
$C_6H_6 + HNO_3$ -----> $C_6H_5NO_2 + H_2O$ (in the presence of H_2SO_4)

Alkenes undergo electrophilic addition because they lack aromatic stability. The π-bond in an alkene is localized and more reactive toward electrophiles.

Example of alkene electrophilic addition: Bromine addition to ethene
$C_2H_4 + Br_2$ -----> $C_2H_4Br_2$

(b) Why do activators when attached to benzene ring direct the incoming electrophile to ortho and para positions? Briefly, explain.

Solution:

Activators (electron-donating groups such as -OH, $-NH_2$, and $-CH_3$) increase the electron density on the benzene ring, especially at the ortho and para positions. This occurs due to resonance and inductive effects.

- Resonance delocalization shifts electron density toward the ortho and para positions, making them more reactive sites for electrophilic substitution.
- As a result, electrophiles preferentially attack these positions rather than the meta position.

(c) Why are the products of nitration of methylbenzene obtained at a shorter time than those of sulphonation of benzene? Explain briefly supporting your answer with a chemical equation in each case.

Solution:

The nitration of methylbenzene (toluene) occurs faster than the sulphonation of benzene because the methyl ($-CH_3$) group is an electron-donating group that activates the benzene ring, increasing its reactivity toward electrophilic substitution. The sulphonation reaction of benzene, on the other hand, occurs under milder conditions but takes longer because there is no activating group to enhance reactivity.

Equation for nitration of methylbenzene:
$C_6H_5CH_3 + HNO_3$ ----> $C_6H_4CH_3(NO_2) + H_2O$ (in the presence of H_2SO_4)

Equation for sulphonation of benzene:
$C_6H_6 + H_2SO_4$ ----> $C_6H_5SO_3H$ (in the presence of heat)

In conclusion, the presence of an activating group ($-CH_3$) in methylbenzene increases the rate of nitration, whereas benzene undergoes sulphonation more slowly due to the absence of such an activating effect.