

CBSE Class 12 Chemistry Question Paper 2020 with Solution PDF-Set 56-2-1

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)



Time Allowed: 3 hours

Maximum Marks: 70

General Instructions

- (i) This question paper comprises **four** Sections – **A, B, C** and **D**. There are **37** questions in the question paper. **All** questions are compulsory.
- (ii) **Section A** – Questions no. **1 to 20** are very short answer type questions carrying **1 mark** each. Answer these questions in one word or one sentence.
- (iii) **Section B** – Questions no. **21 to 27** are short answer type questions, carrying **2 marks** each.
- (iv) **Section C** – Questions no. **28 to 34** are long answer type-I questions, carrying **3 marks** each.
- (v) **Section D** – Questions no. **35 to 37** are long answer type-II questions, carrying **5 marks** each.
- (vi) There is no overall choice in the question paper. However, an internal choice has been provided in 2 questions of two marks, 2 questions of three marks and all the 3 questions of five marks. You have to attempt only one of the choices in such questions.
- (vii) In addition to this, separate instructions are given with each section and question, wherever necessary.
- (viii) Use of calculators and log tables is not permitted.

Section A (20 marks)

Read the given passage and answer the questions number 1 to 5 that follow : $1 \times 5 = 5$

1. Read the given passage and answer the question: Organic compounds containing amine as functional group are present in a vivid variety of compounds, namely amino acids, hormones, neurotransmitters, DNA, alkaloids, dyes, etc. Drugs including nicotine, morphine, codeine and heroin, etc. which have physiological effects on humans also contain amino group in one form or another. Amines are basic because of the presence of lone pair of electrons on nitrogen. Addition of nitrogen into an organic framework leads to the formation of two families of molecules, namely amines and amides. As chemistry students, we must appreciate the versatility of nitrogen.

What are amino acids?

[1 mark]

Solution:

Concept:

- Amino acids contain both an amino group, $-\text{NH}_2$, and a carboxyl group, $-\text{COOH}$, within the same molecule.
- In an α -amino acid, both groups are attached to the same carbon atom; R denotes its side chain.

Step 1: Identify the two functional groups The amino group is the nitrogen-containing basic group, while the carboxyl group is the acidic group. Their presence together distinguishes amino acids from ordinary amines, which need not contain a carboxyl group.

Step 2: Express the common structure The amino acids that form proteins are generally α -amino acids, represented as $\text{H}_2\text{N} - \text{CH}(\text{R}) - \text{COOH}$. For example, glycine has $R = \text{H}$, giving $\text{H}_2\text{N} - \text{CH}_2 - \text{COOH}$.

Step 3: Conclusion Amino acids are organic compounds containing both an amino group and a carboxyl group.

Quick Tip to Solve: In a definition, name both functional groups; an amino group alone defines an amine.

2. Why are amino acids amphoteric?

[1 mark]

Solution:

Concept:

- Amphoteric substances can behave as acids as well as bases.
- An amino acid contains an acidic $-\text{COOH}$ group and a basic $-\text{NH}_2$ group.

Step 1: Identify its acidic behaviour The carboxyl group can donate a proton to a base. Thus, in the presence of a base, the amino acid behaves as an acid and forms a carboxylate group, $-\text{COO}^-$.

Step 2: Identify its basic behaviour The lone pair on the amino nitrogen can accept a proton from an acid, forming $-\text{NH}_3^+$. In water, internal proton transfer commonly produces the zwitterion $^+\text{H}_3\text{N} - \text{CH}(\text{R}) - \text{COO}^-$, which contains both positive and negative charges.

Step 3: Conclusion Amino acids are amphoteric because their carboxyl group can donate a proton and their amino group can accept a proton.

Quick Tip to Solve: Link amphoteric behaviour to proton donation by COOH and proton acceptance by NH_2 .

3. Give one point of difference between acidic and basic amino acid.

[1 mark]

Solution:

Concept:

- Classification as acidic or basic depends on the relative numbers of carboxyl and amino groups.
- An extra carboxyl group gives acidic character, whereas an extra amino group gives basic character.

Step 1: Count groups in an acidic amino acid An acidic amino acid contains more carboxyl groups than amino groups. For example, glutamic acid has two carboxyl groups and one amino group; its side chain supplies the additional acidic group.

Step 2: Count groups in a basic amino acid A basic amino acid contains more amino groups than carboxyl groups in the standard CBSE classification. For example, lysine has two amino groups and one carboxyl group, so it provides a clear comparison with glutamic acid.

Step 3: Conclusion Acidic amino acids have more carboxyl groups than amino groups, whereas basic amino acids have more amino groups than carboxyl groups.

Quick Tip to Solve: Compare the numbers of COOH and amino groups; glutamic acid and lysine are clear examples.

4. What are essential amino acids?

[1 mark]

Solution:

Concept:

- Essential amino acids are required for normal growth and protein synthesis.
- The human body cannot synthesise these amino acids in adequate amounts, so they must be supplied through food.

Step 1: Identify the limitation of synthesis The word essential refers to dietary necessity. These amino acids cannot be made by the human body in the amounts required to meet its needs; it does not merely mean that they occur in proteins.

Step 2: State how the requirement is met They must therefore be obtained from the diet. Examples include valine, leucine and lysine. Amino acids that the body can synthesise sufficiently are termed non-essential, although they too are needed for normal biological functions.

Step 3: Conclusion Essential amino acids are those that the human body cannot synthesise adequately and must obtain from the diet.

Quick Tip to Solve: Use dietary necessity in the definition: essential amino acids must be obtained from food.

5. Name the linkage formed when carboxyl end of one amino acid condenses with amino end of other amino acid. [1 mark]

Solution:

Concept:

- A condensation reaction joins two molecules with elimination of a small molecule such as water.
- The linkage formed between amino acids is an amide unit, $-\text{CO} - \text{NH}-$, called a peptide linkage.

Step 1: Identify the reacting ends The carboxyl group of one amino acid reacts with the amino group of another. The hydroxyl part of the carboxyl group and a hydrogen from the amino group are eliminated as water.

Step 2: Identify the resulting bond The carbonyl carbon becomes bonded to the nitrogen, producing the $-\text{CO} - \text{NH}-$ unit. Joining two amino acids in this way gives a dipeptide; repeated formation of the same linkage produces a polypeptide chain.

Step 3: Conclusion The linkage formed is a peptide linkage, $-\text{CO} - \text{NH}-$.

Quick Tip to Solve: Spot COOH plus NH_2 with loss of water: the resulting CO-NH unit is a peptide linkage.

6. Name the process used for the benefaction of ores if the ore is soluble in some suitable solvent. [1 mark]

Solution:

Concept:

- Benefaction or beneficiation is concentration of an ore by removing unwanted gangue.
- Leaching relies on selective solubility of the ore in a suitable solvent while impurities remain insoluble.

Step 1: Recognise the separation property The question specifies that the ore dissolves in a suitable solvent. The solvent is selected so that the valuable ore component enters solution, while most of the unwanted insoluble material is left behind.

Step 2: Identify the concentration process The insoluble residue is separated, usually by filtration, and the dissolved valuable component is recovered from the solution. This selective dissolution method is called leaching; distillation instead uses differences in volatility.

Step 3: Conclusion Leaching.

Quick Tip to Solve: When concentration depends on selective dissolution in a solvent, answer leaching.

7. Give an example of a metal which can be purified by the process of distillation. [1 mark]

Solution:

Concept:

- Distillation separates a volatile metal from impurities that are less volatile.

Quick Tip to Solve: For distillation, choose a volatile metal such as zinc or mercury; impurities remain behind.

- The metal is vaporised and its vapour is cooled to obtain the purified metal.

Step 1: Choose a sufficiently volatile metal Zinc is a suitable example because it can be vaporised on heating while the less volatile impurities remain in the vessel. Mercury is another metal commonly purified by the same principle.

Step 2: Explain the purification The zinc vapour is collected and cooled in a condenser, where it changes back into liquid metal. Since the non-volatile impurities do not pass into the vapour to the same extent, the condensed zinc is purer than the starting sample.

Step 3: Conclusion Zinc.

Quick Tip to Solve: For distillation, choose a volatile metal such as zinc or mercury; impurities remain behind.

8. What type of isomerism is shown by the complex $[\text{Co}(\text{NH}_3)_5\text{NO}_2]\text{Cl}_2$?

[1 mark]

Solution:

Concept:

- Linkage isomerism occurs when an ambidentate ligand binds through different donor atoms.
- The nitrite ion, NO_2^- , can coordinate through nitrogen or oxygen.

Step 1: Identify the ligand The complex contains five ammonia ligands and one nitrite ligand. Ammonia has only the nitrogen donor atom for this purpose, whereas nitrite is ambidentate: both its nitrogen and oxygen atoms can attach to the central cobalt ion.

Step 2: Compare the two linkages Nitrogen coordination gives the nitro form, $[\text{Co}(\text{NH}_3)_5(\text{NO}_2)]\text{Cl}_2$. Oxygen coordination gives the nitrito form, $[\text{Co}(\text{NH}_3)_5(\text{ONO})]\text{Cl}_2$. The composition and oxidation state remain the same; only the ligand donor atom changes.

Step 3: Conclusion The complex shows linkage isomerism.

Quick Tip to Solve: Look for an ambidentate ligand such as nitrite before considering geometrical isomerism.

9. An organic compound is adsorbed on the surface of silica gel. Name the process of removing the organic compound from silica gel.

[1 mark]

Solution:

Concept:

- Adsorption is accumulation of a substance on the surface of an adsorbent.
- Desorption is removal of the adsorbed substance from that surface.

Step 1: Identify the roles Silica gel supplies the solid surface and is therefore the adsorbent. The organic compound attached to this surface is the adsorbate. Its accumulation is a surface process rather than uniform uptake throughout the bulk of silica gel.

Step 2: Name the reverse process Removing the organic compound releases the adsorbate from the adsorption sites. The reverse of adsorption is called desorption. It may be promoted by heating or by

Quick Tip to Solve: Remember the pair: adsorption attaches molecules to a surface; desorption releases them.

a suitable solvent, but the requested name refers to the release itself, irrespective of the method used.

Step 3: Conclusion The process is desorption.

Quick Tip to Solve: Remember the pair: adsorption attaches molecules to a surface; desorption releases them.

10. Calculate the overall order of the reaction whose rate law expression was predicted as:

$$\text{Rate} = k[\text{NO}]^{3/2}[\text{O}_2]^{1/2}.$$

[1 mark]

Solution:

Concept:

- For $r = k[A]^m[B]^n$, the overall order is $m + n$.
- Order is obtained from the given rate-law exponents, not from a balanced equation.

Step 1: Read the partial orders The printed rate law is $r = k[\text{NO}]^{3/2}[\text{O}_2]^{1/2}$. Thus the order with respect to nitric oxide is $3/2$, and the order with respect to oxygen is $1/2$. Fractional partial orders are permissible in an experimentally determined rate law.

Step 2: Add the exponents The overall order is the sum of the powers of all reactant concentrations:

$$n = \frac{3}{2} + \frac{1}{2} = \frac{4}{2} = 2.$$

The constant k is not a concentration factor and contributes nothing to this sum.

Step 3: Conclusion The overall order is 2: the reaction is second order.

Quick Tip to Solve: Copy every concentration exponent first, then add them; do not count reactant species.

11. 50 mL of an aqueous solution of glucose $\text{C}_6\text{H}_{12}\text{O}_6$ (Molar mass: 180 g/mol) contains 6.02×10^{22} molecules. The concentration of the solution will be

[1 mark]

- (A) 0.1 M
- (B) 0.2 M
- (C) 1.0 M
- (D) 2.0 M

Correct Answer: (D) 2.0 M

Solution:

Concept:

- Moles are $n = N/N_A$, where $N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$.
- Molarity is $M = n/V$, with solution volume V in litres.

Quick Tip to Solve: Convert millilitres to litres before dividing moles by volume.

Step 1: Convert molecules to moles The amount of glucose is

$$n = \frac{6.02 \times 10^{22}}{6.02 \times 10^{23}} = 0.10 \text{ mol.}$$

Molecular count directly supplies the amount, so the given molar mass need not be used. It would be required if the amount were supplied as a mass.

Step 2: Use the solution volume The solution volume is $50 \text{ mL} = 0.050 \text{ L}$. Therefore

$$M = \frac{0.10}{0.050} = 2.0 \text{ mol L}^{-1}.$$

Options (A), (B) and (C) are too small: even one litre would have a lower concentration than this small-volume solution containing the same amount.

Step 3: Conclusion The concentration is 2.0 M, option (D).

Quick Tip to Solve: Convert millilitres to litres before dividing moles by volume.

12. If the standard electrode potential of an electrode is greater than zero, then we can infer that its [1 mark]

- (A) reduced form is more stable compared to hydrogen gas.
- (B) oxidised form is more stable compared to hydrogen gas.
- (C) reduced and oxidised forms are equally stable.
- (D) reduced form is less stable than the hydrogen gas.

Correct Answer: (A) reduced form is more stable compared to hydrogen gas.

Solution:

Concept:

- Standard electrode potentials are reduction potentials relative to the standard hydrogen electrode.
- A positive reduction potential indicates a stronger tendency for reduction than the hydrogen reference.

Step 1: Interpret the positive sign For the reduction $\text{Ox} + ne^- \rightarrow \text{Red}$, a positive E° means reduction is favoured relative to the standard hydrogen electrode, whose potential is zero. The electrode acts as the cathode when coupled to that reference under standard conditions.

Step 2: Compare the stated alternatives The reduced form is consequently more stable in the comparison expressed by option (A). Option (B) reverses this inference, and option (D) likewise states the opposite tendency. Option (C) does not follow from a positive potential: the nonzero value specifies a preference relative to the hydrogen reference.

Step 3: Conclusion The reduced form is more stable compared to hydrogen gas: option (A).

Quick Tip to Solve: Treat a positive standard reduction potential as a greater tendency to gain electrons than hydrogen.

13. Total number of unpaired electrons present in Co^{3+} (Atomic number = 27) is

[1 mark]

- (A) 2
- (B) 7
- (C) 3
- (D) 5

Correct Answer: The printed Co^{3+} free ion has four unpaired electrons, which is absent from the options.

Solution:

Concept:

- Cobalt has configuration $[\text{Ar}]3d^7 4s^2$; ionisation removes $4s$ electrons first.
- Hund's rule places electrons singly in degenerate orbitals before pairing.

Step 1: Form the printed ion The printed ion is Co^{3+} . Remove both $4s$ electrons and then one $3d$ electron from neutral cobalt. Its configuration is therefore $[\text{Ar}]3d^6$, not the $3d^7$ configuration of Co^{2+} .

Step 2: Count the unpaired electrons For the free ion, the first five d electrons occupy the five orbitals singly, and the sixth pairs with one of them. The occupancies are (2, 1, 1, 1, 1), giving four unpaired electrons. None of the printed options, 2, 7, 3 or 5, equals this count; no ligand field is specified that would justify a different arrangement.

Step 3: Conclusion 4 unpaired electrons. None of the printed options is correct.

Quick Tip to Solve: Check the ionic charge carefully: free-ion cobalt(III) is d^6 , whereas cobalt(II) is d^7 .

14. The incorrect statement about interstitial compounds is

[1 mark]

- (A) They are chemically reactive.
- (B) They are very hard.
- (C) They retain metallic conductivity.
- (D) They have high melting point.

Correct Answer: (A) They are chemically reactive.

Solution:

Concept:

- Interstitial compounds form when small atoms occupy spaces in a metal lattice.
- They are typically hard, have high melting points, retain metallic conductivity and are chemically inert.

Step 1: Recall the physical properties Small atoms such as hydrogen, carbon or nitrogen fit into interstitial spaces in transition-metal lattices. Their presence makes these compounds very hard and generally raises their melting points. The metal framework remains, so metallic electrical conductivity is retained. Thus options (B), (C) and (D) describe accepted properties.

Step 2: Select the incorrect statement Interstitial compounds are generally chemically inert, rather than chemically reactive. Therefore option (A) contradicts their usual chemical behaviour. Because

Quick Tip to Solve: Underline "incorrect" and recall that interstitial compounds retain metallic conductivity but are inert.

the question asks for the incorrect statement, select this contradiction rather than one of the true physical properties.

Step 3: Conclusion The incorrect statement is "They are chemically reactive", option (A).

Quick Tip to Solve: Underline "incorrect" and recall that interstitial compounds retain metallic conductivity but are inert.

15. The correct IUPAC name of $\text{CH}_3\text{-C}(\text{CH}_3)(\text{OH})\text{-CH}_2\text{CH}_3$ is

[1 mark]

- (A) tert-butyl alcohol
- (B) 2,2-Dimethylpropanol
- (C) 2-Methylbutan-2-ol
- (D) 3-Methylbutan-3-ol

Correct Answer: (C) 2-Methylbutan-2-ol

Solution:

Concept:

- The parent chain must contain the carbon bearing the hydroxyl group; use the suffix -ol.
- Number the parent chain from the end nearer the hydroxyl group; substituents receive their corresponding locants.

Step 1: Select the parent chain The longest continuous chain containing the carbon attached to OH has four carbon atoms: $\text{CH}_3 - \text{C}(\text{OH}) - \text{CH}_2 - \text{CH}_3$. Therefore, the parent is butane, not propane. The remaining CH_3 group is a methyl substituent.

Step 2: Number and name the structure Numbering from the nearer end places both the hydroxyl group and the methyl substituent at carbon 2. Numbering from the other end would give carbon 3 and violates the lowest-locant rule for the hydroxyl group. The tert-butyl-alcohol name describes a different, four-carbon compound, while option (B) also has the wrong parent chain.

Step 3: Conclusion The correct IUPAC name is 2-methylbutan-2-ol, option (C).

Quick Tip to Solve: Choose the longest chain containing OH before counting the methyl branches.

16. Assertion (A): Boiling points of alkyl halides decrease in the order $R-I > R-Br > R-Cl > R-F$.

Reason (R): Van der Waals forces decrease with increase in the size of halogen atom.

Select the correct answer from the codes:

- (i) Both (A) and (R) are correct, and (R) is the correct explanation of (A).
- (ii) Both (A) and (R) are correct, but (R) is not the correct explanation of (A).
- (iii) (A) is correct, but (R) is incorrect.
- (iv) (A) is incorrect, but (R) is correct.

[1 mark]

Solution:

Concept:

- For the same alkyl group R, increasing halogen size increases polarizability and London dispersion forces.
- A higher intermolecular attraction generally requires more energy for vaporisation and raises the boiling point.

Step 1: Evaluate assertion (A) For comparable alkyl halides with the same R, the boiling-point order is $RI > RBr > RCl > RF$. The heavier, larger halogen atoms have more easily distorted electron clouds, so their compounds have stronger dispersion forces. Thus assertion (A) is correct.

Step 2: Evaluate reason (R) Reason (R) says van der Waals forces decrease as halogen size increases. This reverses the actual trend: polarizability and dispersion attractions increase from fluorine to iodine. Hence reason (R) is incorrect.

Step 3: Select the relationship Since the reason is false, it cannot explain the true assertion. Codes (i) and (ii) require two true statements, and code (iv) requires a false assertion; none applies here.

Step 4: Conclusion Assertion (A) is correct, but reason (R) is incorrect. The correct code is (iii).

Quick Tip to Solve: For a fixed alkyl group, relate the larger halogen to greater polarizability, not weaker attraction.

17. Assertion (A): Low spin tetrahedral complexes are rarely observed.

Reason (R): The orbital splitting energies are not sufficiently large to forcing pairing.

Select the correct answer from the codes (i)-(iv) as defined above.

[1 mark]

Solution:

Concept:

- In a tetrahedral field, the splitting Δ_t is small; approximately $\Delta_t = \frac{4}{9}\Delta_o$ for comparable complexes.
- Electrons pair preferentially only when the energy saved by occupying lower orbitals exceeds pairing energy P .

Step 1: Evaluate assertion (A) Tetrahedral complexes generally have small crystal-field splitting. When $\Delta_t < P$, electrons occupy higher-energy orbitals singly before pairing in lower orbitals, giving a high-spin arrangement. Low-spin tetrahedral complexes are therefore rarely observed, so assertion (A) is correct.

Quick Tip to Solve: Compare tetrahedral splitting with pairing energy: small splitting favours unpaired electrons.

Step 2: Evaluate reason (R) The stated orbital splitting energies are generally not sufficiently large to force electron pairing. Pairing costs energy, and tetrahedral splitting usually cannot compensate for that cost. Thus reason (R) is correct.

Step 3: Connect the two statements The small splitting described in reason (R) directly explains the predominance of high-spin tetrahedral complexes and the rarity of low-spin ones. Code (ii) fails because the reason does explain the assertion; codes (iii) and (iv) each falsely reject one true statement.

Step 4: Conclusion Both statements are correct, and reason (R) correctly explains assertion (A). The correct code is .

Quick Tip to Solve: Compare tetrahedral splitting with pairing energy: small splitting favours unpaired electrons.

18. Assertion (A): Albumin is a globular protein.

Reason (R): Polypeptide chain coils around to give a straight chain.

Select the correct answer from the codes (i)-(iv) as defined above.

[1 mark]

Solution:

Concept:

- Globular proteins have polypeptide chains folded into compact, approximately spherical structures.
- Protein shape depends on folding and interactions between amino-acid residues; globular proteins are generally water-soluble.

Step 1: Evaluate assertion (A) Albumin is a globular protein. Its polypeptide chain folds into a compact three-dimensional shape, consistent with its solubility and its role as a soluble protein. Therefore assertion (A) is correct.

Step 2: Evaluate reason (R) Coiling and folding of a globular protein produce a compact, roughly spherical shape, not a straight chain. The reason describes the resulting shape incorrectly, so reason (R) is false. Elongated structures instead characterise fibrous proteins.

Step 3: Choose the applicable code The false reason cannot explain albumin being globular. Codes (i) and (ii) wrongly treat the reason as true, while code (iv) wrongly treats the assertion as false. The true-assertion, false-reason combination selects code (iii).

Step 4: Conclusion Assertion (A) is correct, but reason (R) is incorrect. The correct code is .

Quick Tip to Solve: Associate albumin with a compact globular shape; folding does not yield a straight chain.

19. Assertion (A): Bakelite is a thermosetting polymer.

Reason (R): On heating, polymeric chain becomes a long and straight chain.

Select the correct answer from the codes (i)-(iv) as defined above.

[1 mark]

Solution:

Concept:

- Thermosetting polymers form extensively cross-linked networks that set irreversibly on heating.
- Bakelite is a phenol-formaldehyde resin with a rigid three-dimensional network.

Step 1: Evaluate assertion (A) Bakelite is a thermosetting polymer. During curing, cross-links form between its polymer chains, producing a hard, rigid network. Once set, it cannot be softened and remoulded repeatedly by heating, so assertion (A) is correct.

Step 2: Evaluate reason (R) Heating during curing does not convert Bakelite into a long, straight chain. It promotes cross-linking and formation of a three-dimensional network. The stated reason therefore gives the wrong structural change and is incorrect.

Step 3: Determine the relationship The correct explanation of the thermosetting behaviour is irreversible network formation, not straightening of chains. Codes (i) and (ii) would require a true reason, and code (iv) would require a false assertion; these are excluded.

Step 4: Conclusion Assertion (A) is correct, but reason (R) is incorrect. The correct code is (iii).

Quick Tip to Solve: For Bakelite, look for permanent cross-links and a three-dimensional network during curing.

20. Assertion (A): *o*-nitrophenol is a weaker acid than *p*-nitrophenol.

Reason (R): Intramolecular hydrogen bonding makes ortho isomer weaker than para isomer.

Select the correct answer from the codes (i)-(iv) as defined above.

[1 mark]

Solution:

Concept:

- Acid strength depends on the ease of proton loss and the relative stabilisation of the acid and its conjugate base.
- Intramolecular hydrogen bonding in *o*-nitrophenol stabilises its neutral molecule; aqueous solvation also affects ionisation.

Step 1: Evaluate assertion (A) In aqueous solution, *o*-nitrophenol is a weaker acid than *p*-nitrophenol. Although the nitro group withdraws electron density in both isomers, the ortho arrangement introduces an additional intramolecular interaction. Thus assertion (A) is correct.

Step 2: Evaluate reason (R) In the ortho isomer, the phenolic O – H group forms an intramolecular hydrogen bond with an oxygen of the neighbouring nitro group. This stabilises the undissociated molecule and makes proton release less favourable. The para arrangement cannot form this intramolecular hydrogen bond. Reason (R) is therefore correct.

Step 3: Check the explanatory link The intramolecular hydrogen bond accounts for the lower acidity of the ortho isomer relative to the para isomer in the comparison asked. The reason directly explains

Quick Tip to Solve: For the ortho isomer, identify the internal O-H...O bond that stabilises the neutral acid.

the assertion, so code (ii) is excluded; codes (iii) and (iv) incorrectly reject one of the true statements.

Step 4: Conclusion Both statements are correct, and reason (R) correctly explains assertion (A). The correct code is (i).

Quick Tip to Solve: For the ortho isomer, identify the internal O-H...O bond that stabilises the neutral acid.

Section B (14 marks)

21(a). Give one point of difference between the following:

(a) Tranquilizers and Analgesics

(b) Antiseptics and Disinfectants

[2 marks]

Solution:

Concept:

- Tranquilizers and analgesics are classified by their therapeutic action: reducing anxiety and relieving pain, respectively.
- Antiseptics and disinfectants control microorganisms; their suitability for living tissue distinguishes their usual use.

Step 1: Compare tranquilizers and analgesics Tranquilizers act on the central nervous system to reduce anxiety, stress and mental tension, producing a calming effect. Analgesics relieve or reduce pain. Thus the distinction is their principal therapeutic purpose: tranquilizers treat anxiety or tension, whereas analgesics treat pain.

Step 2: Compare antiseptics and disinfectants Antiseptics are applied to living tissues, such as skin, cuts and wounds, to kill microorganisms or inhibit their growth without damaging the tissue at the prescribed concentration. Disinfectants are used on non-living objects, such as floors, drains and instruments, and are generally unsuitable for direct application to living tissue. The concentration can determine the use of some substances.

Step 3: Conclusion Tranquilizers reduce anxiety and mental tension; analgesics relieve pain. Antiseptics are used on living tissues, whereas disinfectants are used on non-living objects.

Quick Tip to Solve: Compare each pair by its intended use: anxiety versus pain, and living tissue versus non-living surfaces.

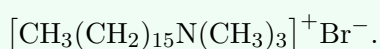
21(b). Differentiate on the basis of chemical composition between cationic and anionic detergents. Also give one example of each category. [2 marks]

Solution:

Concept:

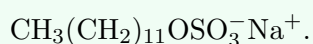
- Detergents contain a long hydrophobic hydrocarbon chain and an ionic hydrophilic head.
- The charge on the surface-active organic ion determines whether a detergent is cationic or anionic; the counter-ion does not determine this classification.

Step 1: Cationic detergents: composition and example Cationic detergents are generally quaternary ammonium salts containing one or more long hydrocarbon chains. The organic ion responsible for detergent action is positively charged. An example is cetyltrimethylammonium bromide (CTAB):



Its long-chain ammonium cation is the surface-active component.

Step 2: Anionic detergents: composition and example Anionic detergents are commonly sodium salts of long-chain alkyl sulfates or alkylbenzene sulfonates. Their surface-active organic ion is negatively charged. An example is sodium lauryl sulfate (sodium dodecyl sulfate):



Here the long-chain alkyl sulfate anion is responsible for detergent action; sodium is the counter-ion.

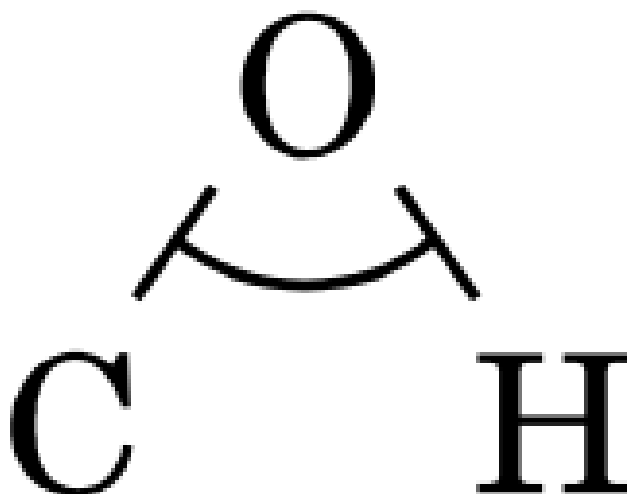
Step 3: Conclusion Cationic detergents have a positively charged organic head, e.g. cetyltrimethylammonium bromide. Anionic detergents have a negatively charged organic head, e.g. sodium lauryl sulfate.

Quick Tip to Solve: Identify the charge on the long-chain organic ion, ignoring the charge on its small counter-ion.

22. Give reasons for the following:

- (a) Bond angle C-O-H in alcohol is slightly less than the tetrahedral angle.
(b) C-OH bond length in CH_3OH is slightly more than the C-OH bond length in phenol.

[2 marks]



Solution:

Concept:

- An alcohol oxygen has two bond pairs and two lone pairs; its electron-pair arrangement is approximately tetrahedral.
- Lone-pair repulsion changes bond angles, whereas resonance and the hybridisation of the attached carbon affect carbon-oxygen bond lengths.

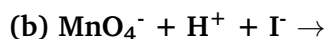
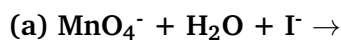
Step 1: Explain the smaller C-O-H angle The oxygen atom in an alcohol is approximately sp^3 -hybridised. It has two bonding pairs, in the C-O and O-H bonds, and two lone pairs. Lone pairs occupy more space and repel bonding pairs more strongly than bonding pairs repel one another. This greater lone-pair-bond-pair repulsion compresses the C-O-H bond angle below the ideal tetrahedral angle of 109.5° .

Step 2: Explain the shorter carbon-oxygen bond in phenol In methanol, CH_3OH , the C-O bond is an ordinary single bond involving an sp^3 -hybridised carbon. In phenol, a lone pair on oxygen is delocalised into the benzene ring by resonance. Consequently, the bond between the ring carbon and oxygen acquires partial double-bond character and becomes shorter. The ring carbon is also sp^2 -hybridised, which favours a shorter bond than the corresponding bond to an sp^3 carbon.

Step 3: Conclusion (a) Stronger repulsion by the two oxygen lone pairs compresses the C-O-H angle. (b) Resonance gives the C-O bond in phenol partial double-bond character, making it shorter than the C-O bond in methanol.

Quick Tip to Solve: For the angle, count oxygen lone pairs; for the bond length, check whether resonance gives partial double-bond character.

23. Complete and balance the following chemical equations:



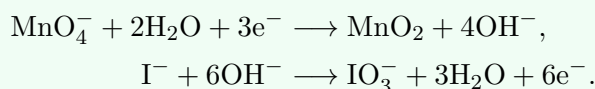
[2 marks]

Solution:

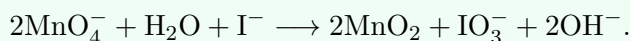
Concept:

- Permanganate is an oxidising agent. Its reduction product and the oxidation product of iodide depend on the reaction medium.
- Balance redox equations by conserving atoms and charge: electrons lost in oxidation must equal electrons gained in reduction.

Step 1: Balance the equation with water (neutral or alkaline medium) Permanganate is reduced from Mn(+7) to Mn(+4) in MnO_2 , while iodide is oxidised from I(-1) to I(+5) in iodate. The half-reactions are

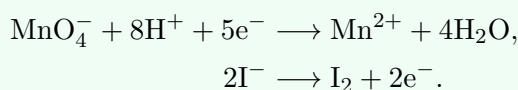


Multiply the manganese half-reaction by two and cancel electrons, water and hydroxide ions:

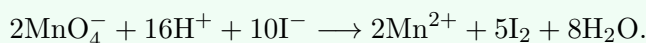


Both sides have total charge -3 , and each element is balanced.

Step 2: Balance the equation in acidic medium In acid, permanganate is reduced to Mn^{2+} , while iodide is oxidised to iodine. The half-reactions are

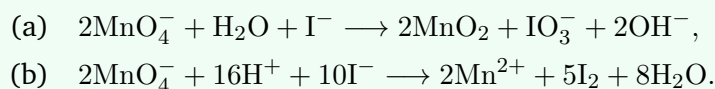


Multiply the first half-reaction by two and the second by five, then add:



Both sides have charge $+4$; the manganese, iodine, oxygen and hydrogen atoms are also conserved.

Step 3: Conclusion The balanced equations are:



Quick Tip to Solve: Choose products from the medium first: water gives manganese dioxide and iodate; acid gives manganese(II) and iodine.

24(a). Define adsorption isotherm. Give the empirical relationship between the quantity of gas adsorbed by unit mass of solid adsorbent and pressure at a particular temperature. [2 marks]

Solution:

Concept:

- Adsorption is the accumulation of a substance at the surface of an adsorbent. The uptake per unit mass is x/m , where x is the mass of gas adsorbed and m is the mass of solid adsorbent.
- At fixed temperature, Freundlich's empirical isotherm relates surface uptake to equilibrium gas pressure p . Its constants depend on the gas, adsorbent and temperature.

Step 1: Define the isotherm An adsorption isotherm is the relationship between the quantity of gas adsorbed per unit mass of a solid adsorbent and the equilibrium pressure of that gas at a constant temperature. The temperature must remain fixed because changing it changes the extent of adsorption.

Step 2: Write the empirical relationship Freundlich's adsorption isotherm is

$$\frac{x}{m} = kp^{1/n}, \quad k > 0, \quad 0 < \frac{1}{n} < 1.$$

Here k and n are empirical constants for the given system at the specified temperature. Equivalently, $\log(x/m) = \log k + (1/n) \log p$. It describes the increase of adsorption with pressure over its applicable pressure range.

Step 3: Conclusion An adsorption isotherm relates x/m to pressure at constant temperature; the required empirical relation is $x/m = kp^{1/n}$.

Quick Tip to Solve: Keep temperature fixed in the definition and define both masses before writing the Freundlich equation.

OR

24(b). Define shape-selective catalysis. Name the process by which alcohols convert directly into gasoline and give a variety of hydrocarbons. [2 marks]

Solution:

Concept:

- Shape-selective catalysis depends on the pore structure of the catalyst and the sizes and shapes of the reactant and product molecules.
- Zeolites are porous aluminosilicates whose molecular-sized channels admit only molecules of suitable dimensions. ZSM-5 is used for conversion of alcohol feedstocks into gasoline-range hydrocarbons.

Step 1: Define shape-selective catalysis Shape-selective catalysis is catalysis in which the catalyst's pore structure and the sizes and shapes of reactant and product molecules determine which reactions occur. Molecules that fit the pores can reach the active sites, while bulky molecules may be excluded.

Quick Tip to Solve: Associate ZSM-5 with the Mobil or MTG process and mention pore size when defining shape selectivity.

Thus the molecular dimensions control catalytic selectivity.

Step 2: Identify the alcohol-to-gasoline process The process is the Mobil process, also called the methanol-to-gasoline (MTG) process. The zeolite catalyst ZSM-5 converts alcohols, particularly methanol, into a mixture of hydrocarbons in the gasoline range. Its characteristic pore structure makes this conversion an example of shape-selective catalysis; gasoline is a mixture rather than a single compound.

Step 3: Conclusion The required process is the Mobil (MTG) process using ZSM-5; shape selectivity arises from the matching of molecular sizes and shapes to catalyst pores.

Quick Tip to Solve: Associate ZSM-5 with the Mobil or MTG process and mention pore size when defining shape selectivity.

25. A reaction is first order w.r.t. reactant A as well as w.r.t. reactant B. Give the rate law. Also give one point of difference between average rate and instantaneous rate. [2 marks]

Solution:

Concept:

- For $r = k[A]^a[B]^b$, the powers a and b are the individual orders with respect to A and B; their sum is the overall order.
- Average rate uses a finite concentration change over a time interval. Instantaneous rate is the limiting rate at one particular instant, expressed by a derivative.

Step 1: Use the given individual orders The reaction is first order in each reactant, so $a = 1$ and $b = 1$. Hence

$$r = k[A][B].$$

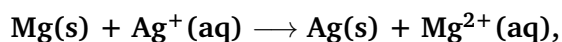
Here k is the rate constant and $[A]$, $[B]$ are reactant concentrations at the time considered. The total order is $1 + 1 = 2$; being first order in each reactant does not make the reaction first order overall.

Step 2: Distinguish the two rates For a reactant concentration $[A]$, the average disappearance rate during a finite interval is $-\Delta[A]/\Delta t$. The instantaneous disappearance rate at a particular time is $-d[A]/dt$, obtained as Δt approaches zero. On a concentration-time plot, these correspond respectively to the magnitude of a secant slope and a tangent slope. The minus sign makes the rate positive as reactant concentration falls.

Step 3: Conclusion $r = k[A][B]$. Average rate refers to a finite time interval; instantaneous rate refers to a particular instant.

Quick Tip to Solve: Add the concentration exponents to find overall order; use a finite difference for average rate and a derivative for instantaneous rate.

26. For an electrochemical cell



give the cell representation. Also write the Nernst equation for the above cell at 25°C.

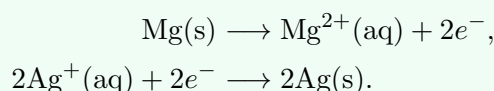
[2 marks]

Solution:

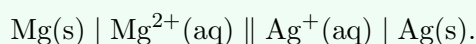
Concept:

- In galvanic-cell notation, the oxidation half-cell is written on the left and the reduction half-cell on the right. A single vertical line denotes a phase boundary and a double line denotes the salt bridge.
- The Nernst equation is $E_{\text{cell}} = E_{\text{cell}}^{\circ} - (RT/nF) \ln Q$. At 25°C, it becomes $E_{\text{cell}} = E_{\text{cell}}^{\circ} - (0.0591/n) \log_{10} Q$, with potential in volts.

Step 1: Identify the electrodes and write the cell The half-reactions are



Magnesium is the anode and silver is the cathode. The cell representation is



Two electrons are transferred per balanced cell reaction, so $n = 2$.

Step 2: Form the reaction quotient and substitute Pure solid magnesium and silver have unit activity and are omitted from the reaction quotient. The aqueous species give $Q = [\text{Mg}^{2+}]/[\text{Ag}^+]^2$, using the usual dilute-solution concentration approximation. Thus at 25°C,

$$E_{\text{cell}} = E_{\text{cell}}^{\circ} - \frac{0.0591}{2} \log_{10} \left(\frac{[\text{Mg}^{2+}]}{[\text{Ag}^+]^2} \right).$$

The exponent 2 comes from the coefficient of silver ions in the balanced reaction.

Step 3: Conclusion The cell is $\text{Mg} \mid \text{Mg}^{2+} \parallel \text{Ag}^+ \mid \text{Ag}$. Its potential in volts is

$$E_{\text{cell}} = E_{\text{cell}}^{\circ} - 0.02955 \log_{10} \left(\frac{[\text{Mg}^{2+}]}{[\text{Ag}^+]^2} \right).$$

Quick Tip to Solve: Omit pure solids from Q , retain the squared silver-ion concentration, and use $n = 2$ for this balanced cell reaction.

27. Predict the state of the solute in the solution in the following situations:

(a) When 'i' is found to be more than one.

(b) When 'i' is found to be less than one.

[2 marks]

Solution:

Concept:

- The van't Hoff factor is $i = \frac{\text{actual number of solute particles in solution}}{\text{number of particles expected without association or dissociation}}$.
- Colligative properties depend on the number of solute particles: dissociation increases this number, whereas association decreases it.

Step 1: Interpret a factor greater than one For $i > 1$, the observed number of solute particles is greater than the number introduced. Thus the solute undergoes dissociation into two or more smaller particles, usually ions. For example, $\text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^-$ produces more particles than undissociated sodium chloride. This raises the colligative effect relative to the value calculated for intact solute units.

Step 2: Interpret a factor less than one For $i < 1$, the observed number of independent particles is smaller than expected. Thus the solute undergoes association: two or more solute molecules combine to form a larger unit. For example, benzoic acid molecules associate as dimers in benzene through hydrogen bonding. Two molecules then behave as one particle, decreasing the colligative effect.

Step 3: Conclusion (a) $i > 1$: the solute is dissociated. (b) $i < 1$: the solute is associated.

Quick Tip to Solve: Compare particle counts: splitting gives $i > 1$, while joining gives $i < 1$.

Section C (21 marks)

28(a). Give the structures of the monomers of the following polymers:

(a) Teflon

(b) Glyptal

(c) Nylon-6

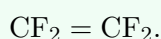
[3 marks]

Solution:

Concept:

- A monomer is the small molecule from which a polymer is formed. Addition polymerisation joins unsaturated monomers; condensation joins functional groups with elimination of small molecules.
- Teflon is an addition polymer, glyptal is a polyester, and nylon-6 is a polyamide obtained by opening the ring of a lactam.

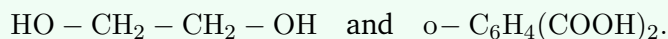
Step 1: Monomer of Teflon Teflon is formed from tetrafluoroethene (tetrafluoroethylene). Its structural formula is



The carbon-carbon double bond opens during addition polymerisation, yielding the repeating unit $[-\text{CF}_2 - \text{CF}_2-]_n$. Each carbon therefore retains two fluorine atoms.

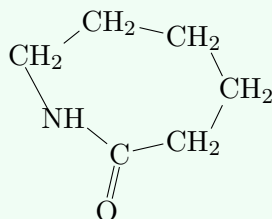
Quick Tip to Solve: For nylon-6, count the carbonyl carbon too: caprolactam has six carbon atoms and one ring nitrogen.

Step 2: Monomers of glyptal Glyptal is obtained by condensation of ethane-1,2-diol (ethylene glycol) with benzene-1,2-dicarboxylic acid (phthalic acid). Their structures are



The prefix *o* specifies that the two carboxyl groups occupy adjacent positions on the benzene ring. The hydroxyl and carboxyl groups form ester linkages with elimination of water.

Step 3: Monomer of nylon-6 The monomer is caprolactam, a seven-membered cyclic amide. Its condensed ring structure is



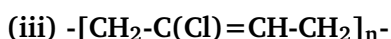
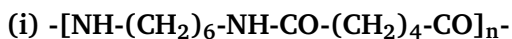
The bond from the carbonyl carbon back to nitrogen closes the seven-membered ring: five methylene carbons, one carbonyl carbon and one nitrogen. Ring opening produces the nylon-6 repeat unit $[-\text{NH} - (\text{CH}_2)_5 - \text{CO}-]_n$.

Step 4: Conclusion Teflon: $\text{CF}_2 = \text{CF}_2$. Glyptal: $\text{HOCH}_2\text{CH}_2\text{OH}$ and $\text{o} - \text{C}_6\text{H}_4(\text{COOH})_2$. Nylon-6: cyclic caprolactam, $\text{NH} - (\text{CH}_2)_5 - \text{C}(=\text{O})$, with the ends joined.

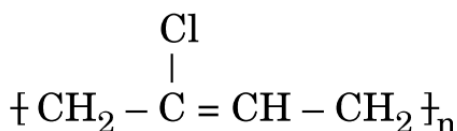
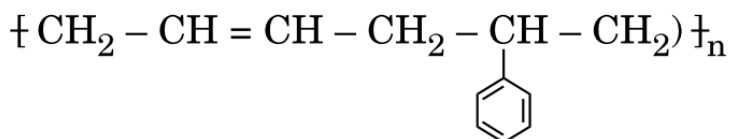
Quick Tip to Solve: For nylon-6, count the carbonyl carbon too: caprolactam has six carbon atoms and one ring nitrogen.

OR

28(b). Write the names of monomers of the following polymers:



[3 marks]



Solution:

Concept:

- Identify a condensation polymer by its functional linkage and split that linkage to recover the monomers.

Quick Tip to Solve: Read the side group: phenyl indicates styrene in Buna-S; chlorine on a diene indicates chloroprene.

- In diene addition polymers, a double bond remains in the repeat unit. A phenyl substituent identifies styrene, while a chlorine substituent identifies chloroprene.

Step 1: Identify the polyamide in (i) The repeat unit $[-\text{NH} - (\text{CH}_2)_6 - \text{NH} - \text{CO} - (\text{CH}_2)_4 - \text{CO}-]_n$ is nylon-6,6. Splitting its amide linkages restores an amino group at each end of the six-carbon diamine segment and a carboxyl group at each end of the acid segment. Its monomers are hexamethylenediamine (hexane-1,6-diamine), $\text{H}_2\text{N} - (\text{CH}_2)_6 - \text{NH}_2$, and adipic acid (hexanedioic acid), $\text{HOOC} - (\text{CH}_2)_4 - \text{COOH}$.

Step 2: Identify the copolymer in (ii) The segment $-\text{CH}_2 - \text{CH} = \text{CH} - \text{CH}_2-$ comes from the conjugated diene buta-1,3-diene, $\text{CH}_2 = \text{CH} - \text{CH} = \text{CH}_2$. The phenyl-bearing segment $-\text{CH}(\text{C}_6\text{H}_5) - \text{CH}_2-$ comes from styrene (phenylethene), $\text{C}_6\text{H}_5 - \text{CH} = \text{CH}_2$. Thus the printed polymer is Buna-S, formed from buta-1,3-diene and styrene.

Step 3: Identify the chlorinated polymer in (iii) The repeat unit $[-\text{CH}_2 - \text{C}(\text{Cl}) = \text{CH} - \text{CH}_2-]_n$ is neoprene. It is formed by addition polymerisation of chloroprene, whose systematic name is 2-chlorobuta-1,3-diene. The monomer structure is $\text{CH}_2 = \text{C}(\text{Cl}) - \text{CH} = \text{CH}_2$; the chlorine remains attached to the second carbon after polymerisation.

Step 4: Conclusion (i) Hexamethylenediamine and adipic acid. (ii) Buta-1,3-diene and styrene. (iii) Chloroprene (2-chlorobuta-1,3-diene).

Quick Tip to Solve: Read the side group: phenyl indicates styrene in Buna-S; chlorine on a diene indicates chloroprene.

29. Account for the following:

(a) Aniline is a weaker base compared to ethanamine.

(b) Aniline does not undergo Friedel-Crafts reaction.

(c) Only aliphatic primary amines can be prepared by Gabriel Phthalimide synthesis.

[3 marks]

Solution:

Concept:

- Basicity depends on the availability of the nitrogen lone pair for accepting a proton. Resonance delocalisation reduces its availability, whereas the positive inductive effect of an alkyl group increases electron density on nitrogen.
- Friedel-Crafts reactions use a Lewis acid catalyst such as AlCl_3 . Gabriel synthesis forms a carbon-nitrogen bond by nucleophilic substitution using the phthalimide anion.

Step 1: (a) Compare the availability of the nitrogen lone pair In aniline, $\text{C}_6\text{H}_5\text{NH}_2$, the nitrogen lone pair is delocalised into the benzene ring by resonance. It is therefore less available to combine with H^+ . In ethanamine, $\text{C}_2\text{H}_5\text{NH}_2$, the lone pair is localised on nitrogen and the ethyl group exerts a $+I$ effect, increasing electron density on nitrogen. Thus proton acceptance is easier for ethanamine than for aniline.

Step 2: (b) Examine the interaction with the Friedel-Crafts catalyst The amino group of aniline is basic and its lone pair coordinates strongly with the Lewis acid AlCl_3 . Formation of this Lewis acid-base

Quick Tip to Solve: For each explanation, connect the nitrogen lone pair to the process: proton acceptance, catalyst binding, or nucleophilic substitution.

complex gives nitrogen a positive character and strongly deactivates the ring towards electrophilic substitution. It also binds the catalyst. Consequently aniline does not undergo the usual Friedel-Crafts alkylation or acylation under these conditions.

Step 3: (c) Identify the substitution required in Gabriel synthesis Potassium phthalimide reacts with an alkyl halide by nucleophilic substitution to give an N-alkylphthalimide, which on hydrolysis releases RNH_2 . Aryl halides do not undergo the required substitution under these conditions: their aryl carbon-halogen bond has partial double-bond character through resonance, and attack at the sp^2 carbon is unfavourable. Therefore the method prepares aliphatic primary amines, but cannot prepare aromatic primary amines such as aniline. Only one organic group is introduced on the phthalimide nitrogen, so secondary and tertiary amines are not obtained.

Step 4: Conclusion (a) Resonance makes aniline less basic than ethanamine. (b) Aniline binds AlCl_3 , deactivating its ring. (c) Gabriel synthesis uses alkyl-halide substitution and yields only aliphatic primary amines.

Quick Tip to Solve: For each explanation, connect the nitrogen lone pair to the process: proton acceptance, catalyst binding, or nucleophilic substitution.

30. Justify and arrange the following compounds of each set in increasing order of reactivity towards the asked displacement:

(a) 1-Bromobutane, 2-Bromobutane, 2-Bromo-2-Methylpropane ($\text{S}_{\text{N}}1$ reaction)

(b) 1-Bromobutane, 2-Bromobutane, 2-Bromo-2-Methylpropane ($\text{S}_{\text{N}}2$ reaction)

[3 marks]

Solution:

Concept:

- In an $\text{S}_{\text{N}}1$ reaction, the slow step is ionisation of the carbon-bromine bond to form a carbocation. Greater carbocation stability gives a faster reaction.
- In an $\text{S}_{\text{N}}2$ reaction, the nucleophile attacks from the back as bromide leaves in a single step. Increasing crowding around the carbon bonded to bromine obstructs this attack.

Step 1: Identify the degree of each haloalkane In 1-bromobutane, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$, the carbon carrying bromine is primary. In 2-bromobutane, $\text{CH}_3\text{CH}(\text{Br})\text{CH}_2\text{CH}_3$, it is secondary. In 2-bromo-2-methylpropane, $(\text{CH}_3)_3\text{CBr}$, it is tertiary. Since all three have bromide as the leaving group, the main comparison is the alkyl substitution at the reacting carbon under the respective reaction conditions.

Step 2: (a) Compare carbocation formation for the $\text{S}_{\text{N}}1$ reaction Ionisation would produce a primary butyl carbocation, a secondary butyl carbocation and a tertiary tert-butyl carbocation, respectively. Alkyl groups stabilise a positive charge by the positive inductive effect and hyperconjugation, giving the stability order $1^\circ < 2^\circ < 3^\circ$. The tertiary carbocation forms most readily, so the tertiary bromide reacts fastest in $\text{S}_{\text{N}}1$. The primary bromide is least reactive because formation of its unstable primary carbocation is difficult.

Step 3: (b) Compare access for the $\text{S}_{\text{N}}2$ reaction Backside approach is least hindered at the primary carbon of 1-bromobutane. Two alkyl groups around the secondary carbon of 2-bromobutane make the attack more difficult. Three alkyl groups around the tertiary carbon of 2-bromo-2-methylpropane

Quick Tip to Solve: First label the bromine-bearing carbon primary, secondary or tertiary; use carbocation stability for $\text{S}_{\text{N}}1$ and backside crowding for $\text{S}_{\text{N}}2$.

block the approach most strongly; its normal S_N2 reaction is negligible. Thus steric hindrance gives the reverse order to the S_N1 comparison. Carbocation stability is not the controlling factor here because no carbocation intermediate forms in S_N2 .

Step 4: Conclusion Increasing reactivity:

S_N1 : 1-bromobutane < 2-bromobutane
< 2-bromo-2-methylpropane.

S_N2 : 2-bromo-2-methylpropane < 2-bromobutane
< 1-bromobutane.

Quick Tip to Solve: First label the bromine-bearing carbon primary, secondary or tertiary; use carbocation stability for S_N1 and backside crowding for S_N2 .

31(a). Give the IUPAC name and electronic configuration of central metal atom in terms of t_{2g} and e_g of $K_4[Mn(CN)_6]$.

(b) What is meant by 'Chelate effect'? Give an example.

[3 marks]

Solution:

Concept:

- The oxidation state of the metal follows from charge balance. In an octahedral field, the five d orbitals split into lower-energy t_{2g} and higher-energy e_g sets.
- Cyanide is a strong-field ligand and favours pairing in the lower-energy orbitals. A chelating ligand binds a metal through two or more donor atoms, forming a ring.

Step 1: (a) Determine the oxidation state and name the complex The four potassium ions give a total charge of +4, so the complex ion has charge -4. Each cyanide ligand carries charge -1. If the oxidation state of manganese is x ,

$$x + 6(-1) = -4 \Rightarrow x = +2.$$

There are six cyanido ligands, giving the prefix hexacyanido. Because the coordination entity is an anion, manganese is named manganate, followed by its oxidation state in Roman numerals. The name of the salt is therefore potassium hexacyanidomanganate(II).

Step 2: (a) Fill the octahedral d orbitals Manganese has atomic number 25 and ground-state configuration $[Ar] 3d^5 4s^2$. Removal of the two 4s electrons gives Mn^{2+} the configuration $[Ar] 3d^5$. The six cyanide ligands produce an octahedral field. Since CN^- is a strong-field ligand, the five d electrons occupy the lower t_{2g} orbitals with pairing before the higher e_g orbitals are occupied. The required configuration is $t_{2g}^5 e_g^0$, with one unpaired electron.

Step 3: (b) Explain the chelate effect and give an example The chelate effect is the enhanced stability of a complex containing a multidentate ligand compared with a corresponding complex containing similar monodentate donor ligands. A multidentate ligand attaches at several sites and forms one

Quick Tip to Solve: Calculate the metal oxidation state before counting d electrons; a strong-field ligand pairs the d5 electrons into t_{2g} before e_g is occupied.

or more rings with the metal. For example, ethane-1,2-diamine, abbreviated en, binds through both nitrogen atoms. The complex $[\text{Ni}(\text{en})_3]^{2+}$ contains three bidentate en ligands forming chelate rings and is more stable than the corresponding ammine complex $[\text{Ni}(\text{NH}_3)_6]^{2+}$, whose ammonia ligands are monodentate.

Step 4: Conclusion (a) Potassium hexacyanidomanganate(II), with $\text{Mn}^{2+} : t_{2g}^5 e_g^0$. (b) Chelation increases complex stability; $[\text{Ni}(\text{en})_3]^{2+}$ is an example.

Quick Tip to Solve: Calculate the metal oxidation state before counting d electrons; a strong-field ligand pairs the d5 electrons into t2g before eg is occupied.

OR

31(b). Write the hybridisation and magnetic characters of the following complexes:

(i) $[\text{Fe}(\text{CN})_6]^{4-}$

(ii) $[\text{CoF}_6]^{3-}$

(iii) $[\text{Ni}(\text{CO})_4]$

[Atomic number: Fe = 26, Co = 27, Ni = 28]

[3 marks]

Solution:

Concept:

- The oxidation state of the central metal is obtained by balancing the ligand charges with the overall complex charge. Cyanide and fluoride each have charge -1 , whereas carbon monoxide is neutral.
- In valence bond theory, an inner-orbital octahedral complex uses d^2sp^3 hybridisation and an outer-orbital octahedral complex uses sp^3d^2 . A tetrahedral complex uses sp^3 hybridisation.
- A complex with no unpaired electrons is diamagnetic; the presence of one or more unpaired electrons makes it paramagnetic. Strong-field ligands favour pairing, whereas weak-field ligands do not force pairing.

Step 1: (i) Hexacyanidoferrate(II) For $[\text{Fe}(\text{CN})_6]^{4-}$, let the oxidation state of iron be x . Then $x - 6 = -4$, so $x = +2$. Iron has configuration $[\text{Ar}]3d^6 4s^2$; therefore Fe^{2+} is $3d^6$. The strong-field ligand CN^- pairs the six $3d$ electrons in three orbitals, leaving two $3d$ orbitals vacant. These two orbitals, one $4s$ and three $4p$ orbitals form six d^2sp^3 hybrid orbitals. The octahedral configuration is $t_{2g}^6 e_g^0$, with zero unpaired electrons; hence it is diamagnetic.

Step 2: (ii) Hexafluoridocobaltate(III) For $[\text{CoF}_6]^{3-}$, $x - 6 = -3$ gives $x = +3$. Cobalt is $[\text{Ar}]3d^7 4s^2$, so Co^{3+} is $3d^6$. Fluoride is a weak-field ligand and does not cause the additional pairing needed to free two inner $3d$ orbitals. The complex therefore uses the outer $4d$ orbitals along with $4s$ and $4p$ orbitals, giving sp^3d^2 hybridisation. Its high-spin octahedral configuration is $t_{2g}^4 e_g^2$, which has four unpaired electrons; hence it is paramagnetic.

Step 3: (iii) Tetracarbonylnickel(0) In $[\text{Ni}(\text{CO})_4]$, all four CO ligands are neutral, so nickel has oxidation state zero. The strong-field CO ligands cause rearrangement and pairing of the valence electrons of nickel to give a filled $3d^{10}$ set. One $4s$ and three $4p$ orbitals form four sp^3 hybrid orbitals to accept the ligand electron pairs. The complex is tetrahedral, and all electrons are paired; hence it is

Quick Tip to Solve: First find the metal oxidation state; then use ligand strength to decide pairing before assigning hybridisation.

diamagnetic.

Step 4: Conclusion $[\text{Fe}(\text{CN})_6]^{4-}$: d^2sp^3 , diamagnetic; $[\text{CoF}_6]^{3-}$: sp^3d^2 , paramagnetic with four unpaired electrons; $[\text{Ni}(\text{CO})_4]$: sp^3 , diamagnetic.

Quick Tip to Solve: First find the metal oxidation state; then use ligand strength to decide pairing before assigning hybridisation.

32. Give the chemical reactions involved in the leaching of alumina from bauxite.

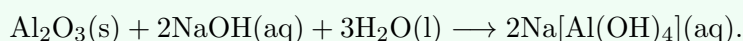
[3 marks]

Solution:

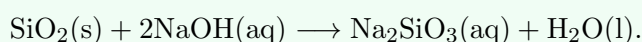
Concept:

- Leaching selectively dissolves alumina from bauxite in concentrated sodium hydroxide. Alumina is amphoteric and reacts with alkali to form soluble sodium aluminate.
- The soluble aluminate is converted to hydrated alumina by passing carbon dioxide through the solution. Heating the separated precipitate removes water and yields pure alumina.

Step 1: Dissolve alumina in sodium hydroxide Powdered bauxite is digested with concentrated NaOH at about 473–523 K under a pressure of about 35–36 bar. Alumina passes into solution as sodium aluminate:

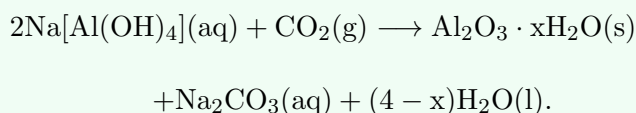


Silica impurity also dissolves as sodium silicate:



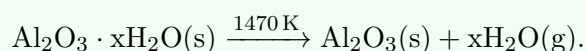
The insoluble iron oxide and other insoluble impurities are removed by filtration.

Step 2: Precipitate hydrated alumina The filtered sodium aluminate solution is neutralised by passing CO_2 through it. Seeding with freshly prepared hydrated alumina promotes precipitation:



Here x denotes the water of hydration. Sodium silicate remains in solution, allowing hydrated alumina to be separated by filtration.

Step 3: Obtain pure alumina by heating The separated hydrated alumina is heated at about 1470 K. Water is driven off, giving pure alumina:



Thus the process first transfers aluminium into a soluble aluminate, then isolates it as hydrated alumina and finally removes the hydration water.

Step 4: Conclusion The leaching sequence is $\text{Al}_2\text{O}_3 \rightarrow \text{Na}[\text{Al}(\text{OH})_4] \rightarrow \text{Al}_2\text{O}_3 \cdot x\text{H}_2\text{O} \rightarrow \text{Al}_2\text{O}_3$, using concentrated NaOH, carbon dioxide and heating, respectively.

Quick Tip to Solve: Remember the three operations in order: dissolve with NaOH, precipitate with carbon dioxide, and heat to remove water.

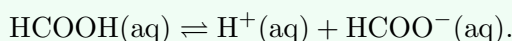
33. Conductivity of 2×10^{-3} M methanoic acid is $8 \times 10^{-5} \text{ S cm}^{-1}$. Calculate its molar conductivity and degree of dissociation if Λ_m^0 for methanoic acid is $404 \text{ S cm}^2 \text{ mol}^{-1}$. [3 marks]

Solution:

Concept:

- Molar conductivity is $\Lambda_m = 1000\kappa/c$ when conductivity κ is expressed in S cm^{-1} and concentration c in mol L^{-1} . The factor 1000 converts litres to cubic centimetres.
- For a weak electrolyte, the degree of dissociation is $\alpha = \Lambda_m/\Lambda_m^0$, where Λ_m^0 is the molar conductivity at infinite dilution, corresponding to complete dissociation.

Step 1: Identify the given quantities and unit convention Methanoic acid is a weak electrolyte:



The given values are $c = 2 \times 10^{-3} \text{ mol L}^{-1}$, $\kappa = 8 \times 10^{-5} \text{ S cm}^{-1}$, and $\Lambda_m^0 = 404 \text{ S cm}^2 \text{ mol}^{-1}$. Because conductivity is expressed per centimetre, the concentration in mol per litre requires the factor 1000 in the molar-conductivity formula.

Step 2: Calculate the molar conductivity Substituting the values gives

$$\begin{aligned}\Lambda_m &= \frac{1000\kappa}{c} \\ &= \frac{1000 \times 8 \times 10^{-5}}{2 \times 10^{-3}} \\ &= 40 \text{ S cm}^2 \text{ mol}^{-1}.\end{aligned}$$

Equivalently, the concentration is $2 \times 10^{-6} \text{ mol cm}^{-3}$, and dividing conductivity by this concentration gives the same result.

Step 3: Calculate the degree of dissociation For this weak acid, the ratio of its molar conductivity to the limiting value measures the fraction dissociated:

$$\alpha = \frac{\Lambda_m}{\Lambda_m^0} = \frac{40}{404} = 0.09901.$$

The degree of dissociation is dimensionless. In percentage form, $100\alpha = 9.901\%$. The value is less than unity, consistent with the acid being only partially ionised at the stated concentration.

Step 4: Conclusion The molar conductivity is $40 \text{ S cm}^2 \text{ mol}^{-1}$, and the degree of dissociation is $\alpha \approx 0.0990$, or approximately 9.90% .

Quick Tip to Solve: Keep the factor 1000 when concentration is in mol per litre and conductivity is in S per centimetre; divide the result by 404.

34. An antifreeze solution is prepared by dissolving 31 g of ethylene glycol (Molar mass = 62 g mol⁻¹) in 600 g of water. Calculate the freezing point of the solution. (K_f for water = 1.86 K kg mol⁻¹) [3 marks]

Solution:

Concept:

- Depression of freezing point is a colligative property: $\Delta T_f = iK_f m$, where m is the molality of solute and i is the van't Hoff factor.
- Ethylene glycol is a molecular non-electrolyte, so it neither dissociates nor ionises in water and $i = 1$. Molality uses kilograms of solvent, not the mass of the whole solution.

Step 1: Calculate the amount of ethylene glycol The molar mass is 62 g mol⁻¹. Thus the amount of dissolved solute is

$$n = \frac{31 \text{ g}}{62 \text{ g mol}^{-1}} = 0.500 \text{ mol.}$$

The solvent is water; its given mass is 600 g = 0.600 kg. The solute mass must not be added to the denominator when calculating molality.

Step 2: Find molality and freezing-point depression The molality and corresponding depression are

$$m = \frac{0.500}{0.600} = 0.8333 \text{ mol kg}^{-1},$$
$$\Delta T_f = 1 \times 1.86 \times 0.8333 = 1.55 \text{ K.}$$

A temperature interval of 1.55 K is also an interval of 1.55 °C. The dissolved glycol lowers the freezing point below that of pure water.

Step 3: Apply the depression to pure water Pure water freezes at 0 °C. By definition, $\Delta T_f = T_f^0 - T_f$, so

$$T_f = 0 - 1.55 = -1.55 \text{ °C.}$$

Equivalently, using 273.15 K for pure water, the solution freezes at 271.60 K. The negative Celsius sign is essential because the quantity calculated from $K_f m$ is a depression, not the final temperature.

Step 4: Conclusion The freezing point of the antifreeze solution is -1.55 °C, or 271.60 K.

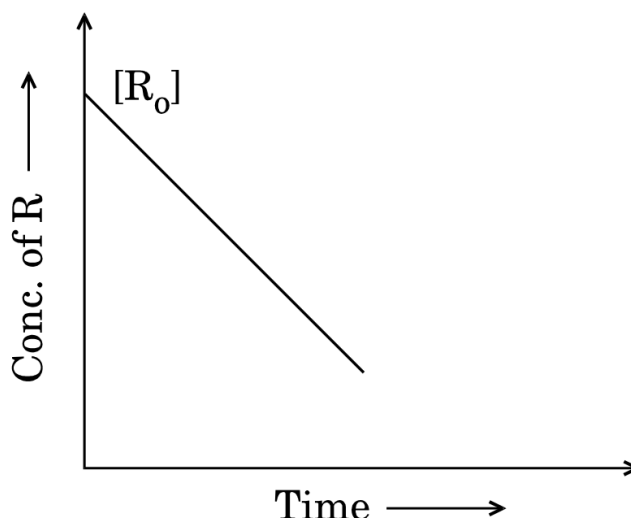
Quick Tip to Solve: Convert the water mass to kilograms before finding molality, then subtract the positive depression from zero degrees Celsius.

Section D (15 marks)

35(a). Visha plotted a graph between concentration of R and time for a reaction $R \rightarrow P$. On the basis of this graph, answer the following questions:

- (i) Predict the order of reaction.
- (ii) What does the slope of the line indicate?
- (iii) What are the units of rate constant?

[3 marks]



Solution:

Concept:

- For a zero-order reaction the rate is independent of reactant concentration: $-d[R]/dt = k$, where $[R]$ is the concentration of reactant and k is the rate constant.
- Integrating gives $[R] = [R]_0 - kt$. This has the straight-line form $y = c + sx$, with intercept $[R]_0$ and slope $s = -k$.

Step 1: (i) Identify the reaction order The printed graph plots the concentration $[R]$ directly against time and shows a straight line decreasing from the initial value $[R]_0$. A linear decrease means equal amounts of reactant are consumed in equal time intervals, so the rate remains constant even as the reactant concentration falls. This is the behaviour described by the zero-order integrated rate equation $[R] = [R]_0 - kt$. A first-order reaction would instead give a straight line for $\ln[R]$ against time, while its untransformed concentration-time plot would be curved.

Step 2: (ii) Interpret the slope Comparing $[R] = [R]_0 - kt$ with the equation of a straight line shows

$$\text{slope} = \frac{\Delta[R]}{\Delta t} = -k.$$

The negative slope describes the decrease in reactant concentration. Its magnitude gives the positive rate constant k , which also equals the constant rate of disappearance of R . The slope itself is not $+k$; its sign records that reactant is being consumed.

Quick Tip to Solve: Check the vertical axis first: a straight line for concentration itself against time identifies zero order, with slope minus k .

Step 3: (iii) Obtain the units of the rate constant Since $k = -\Delta[R]/\Delta t$, its units are concentration divided by time. With concentration in mol L^{-1} and time in seconds,

$$[k] = \text{mol L}^{-1}\text{s}^{-1}.$$

If the time axis is measured in minutes, the corresponding unit is $\text{mol L}^{-1}\text{min}^{-1}$. The graph does not specify a time unit, so the general dimensional form is concentration per unit time.

Step 4: Conclusion (i) The reaction is zero order. (ii) Its slope is $-k$. (iii) The standard units of k are $\text{mol L}^{-1}\text{s}^{-1}$.

Quick Tip to Solve: Check the vertical axis first: a straight line for concentration itself against time identifies zero order, with slope minus k .

35(b). A first order reaction takes 25 minutes for 25% decomposition. Calculate $t_{1/2}$.

[Given: $\log 2 = 0.3010$, $\log 3 = 0.4771$, $\log 4 = 0.6021$]

[2 marks]

Solution:

Concept:

- A first-order reaction obeys $k = (2.303/t) \log([R]_0/[R]_t)$, where $[R]_0$ and $[R]_t$ are initial and remaining reactant concentrations.
- The first-order half-life is $t_{1/2} = 2.303 \log 2/k$, independent of the initial concentration.

Step 1: Use the fraction remaining to calculate k After 25 min, 25% has decomposed, so 75% remains. Therefore $[R]_t = 0.75[R]_0$ and the concentration ratio is $4/3$, rather than 4.

$$\begin{aligned} k &= \frac{2.303}{25} \log \frac{4}{3} \\ &= \frac{2.303}{25} (0.6021 - 0.4771) \\ &= 0.011515 \text{ min}^{-1}. \end{aligned}$$

The given decomposition time is not a quarter of the half-life because first-order decay is exponential, not linear.

Step 2: Calculate the half-life At the half-life, half the initial reactant remains, giving a concentration ratio of 2. Hence

$$t_{1/2} = \frac{2.303(0.3010)}{0.011515} = 60.2 \text{ min}.$$

Equivalently, eliminating k gives $t_{1/2} = 25 \log 2 / \log(4/3) = 25(0.3010)/0.1250$. This produces the same result and keeps the time unit in minutes.

Step 3: Conclusion The half-life of the reaction is $t_{1/2} = 60.2 \text{ min}$.

Quick Tip to Solve: For a percentage decomposed, use the percentage remaining inside the logarithm; here the ratio is $100/75$, not $100/25$.

35(a). The rate constant for a first order reaction is 60 s^{-1} . How much time will it take to reduce the initial concentration of the reactant to its $1/16^{\text{th}}$ value? [3 marks]

Solution:

Concept:

- For a first order reaction, $\ln([R]_0/[R]_t) = kt$, where $[R]_0$ and $[R]_t$ are initial and remaining concentrations, k is the rate constant and t is time.
- The half-life is $t_{1/2} = \ln 2/k$, independent of the initial concentration.

Step 1: Identify the concentration ratio The final concentration is $[R]_t = [R]_0/16$; hence $[R]_0/[R]_t = 16$. The given rate constant is 60 s^{-1} , so the calculated time will be in seconds. No numerical value of the initial concentration is needed because it cancels from the ratio.

Step 2: Apply the integrated rate law Substitute the concentration ratio in the first order law:

$$t = \frac{1}{k} \ln \frac{[R]_0}{[R]_t} = \frac{\ln 16}{60} = \frac{4 \ln 2}{60} = \frac{2.7726}{60} = 0.04621 \text{ s.}$$

Equivalently, using common logarithms, $t = (2.303/60) \log 16$. The logarithm operates on a dimensionless ratio.

Step 3: Check using successive half-lives Reduction to $1/16$ corresponds to four successive halvings: $1 \rightarrow 1/2 \rightarrow 1/4 \rightarrow 1/8 \rightarrow 1/16$. Each takes $t_{1/2} = 0.6931/60 = 0.01155 \text{ s}$. Thus four half-lives give $4(0.01155) = 0.0462 \text{ s}$, confirming the integrated-law calculation. The small time is consistent with the large value of the rate constant.

Step 4: Conclusion The required time is $4.62 \times 10^{-2} \text{ s}$, or approximately 46.2 ms.

Quick Tip to Solve: Recognise $1/16 = (1/2)^4$: multiply the first order half-life by four.

35(b). Write two factors that affect the rate of a chemical reaction. [1 mark]

Solution:

Concept:

- Reaction rate depends on how often reactant particles collide and what fraction of those collisions is effective.
- Concentration and temperature can change these collision properties.

Step 1: State the concentration factor The concentration of reactants affects the rate. Increasing concentration generally increases the number of reactant particles per unit volume and therefore their collision frequency. The exact dependence is specified by the reaction rate law.

Step 2: State the temperature factor Temperature affects the rate. Raising temperature usually increases the rate constant because a larger fraction of molecules has sufficient energy to cross the activation-energy barrier. These are two distinct factors affecting reaction rate.

Quick Tip to Solve: Give two distinct controllable factors: concentration affects collisions; temperature affects their energy.

Step 3: Conclusion Two factors are reactant concentration and temperature.

Quick Tip to Solve: Give two distinct controllable factors: concentration affects collisions; temperature affects their energy.

35(c). Write two conditions for the collisions to be effective collisions.

[1 mark]

Solution:

Concept:

- Only effective collisions between reacting particles lead to the formation of products.
- Collision theory requires sufficient energy and a favourable molecular orientation.

Step 1: Specify the energy requirement The colliding particles must possess enough kinetic energy to reach the activated complex: their collision energy must be at least the threshold energy. This allows the reactants to overcome the activation-energy barrier.

Step 2: Specify the orientation requirement The particles must collide with the proper orientation so that the reacting sites meet in a way that allows the required bonds to break and new bonds to form. Even an energetic collision can be ineffective when the orientation is unsuitable.

Step 3: Conclusion Effective collisions require sufficient collision energy and proper orientation.

Quick Tip to Solve: Remember both requirements together: an energetic collision alone does not guarantee reaction.

36(a). An amorphous solid 'A' which has a crown shaped structure, burns in air to form a gas 'B' which turns lime water milky. 'B' is also produced by roasting of sulphide ores. 'B' undergoes oxidation in the presence of V_2O_5 to give 'C' and to carry out this oxidation low temperature and high pressure is mandatory to get a good yield of 'C'. 'C' is then absorbed in H_2SO_4 to give 'D'. 'D' is then diluted to give a very important compound 'E'. 'E' is largely responsible for the manufacture of variety of compounds in industry. 'E' in concentrated form, when combined with Cu metal, gives compound 'F'. From this description

Elucidate the structure of 'A' to 'F'.

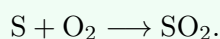
[3 marks]

Solution:

Concept:

- Sulphur exists as a puckered eight-membered S_8 ring with a crown-like shape.
- The contact-process sequence is $SO_2 \rightarrow SO_3 \rightarrow H_2S_2O_7 \rightarrow H_2SO_4$; concentrated sulphuric acid oxidises copper.

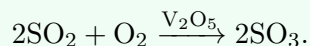
Step 1: Identify A and B A is sulphur, S_8 : eight sulphur atoms are joined by S–S single bonds in a non-planar, crown-shaped ring. Burning sulphur gives B, sulphur dioxide, SO_2 , a bent molecule.



Quick Tip to Solve: Trace the contact process through oleum; concentrated acid oxidises copper to copper(II) sulphate.

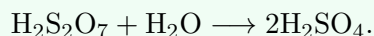
Its reaction with lime water produces insoluble calcium sulphite: $\text{SO}_2 + \text{Ca}(\text{OH})_2 \rightarrow \text{CaSO}_3 \downarrow + \text{H}_2\text{O}$.

Step 2: Identify C and D Catalytic oxidation gives *C*, sulphur trioxide, SO_3 , whose monomer has trigonal planar geometry:



Absorption in sulphuric acid yields *D*, oleum or pyrosulphuric acid, $\text{H}_2\text{S}_2\text{O}_7$: $\text{SO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{H}_2\text{S}_2\text{O}_7$. Its structural formula is $\text{HO} - \text{S}(=\text{O})_2 - \text{O} - \text{S}(=\text{O})_2 - \text{OH}$, with an oxygen bridge joining the two sulphur centres.

Step 3: Identify E and F Dilution of oleum gives *E*, sulphuric acid:



Its structural formula is $\text{HO} - \text{S}(=\text{O})_2 - \text{OH}$, with approximately tetrahedral arrangement of oxygen atoms around sulphur. Concentrated sulphuric acid reacts with copper to form *F*, copper(II) sulphate, CuSO_4 . This ionic compound contains Cu^{2+} and tetrahedral SO_4^{2-} ions; sulphur dioxide and water are also produced.

Step 4: Conclusion $A = \text{S}_8$, $B = \text{SO}_2$, $C = \text{SO}_3$, $D = \text{H}_2\text{S}_2\text{O}_7$, $E = \text{H}_2\text{SO}_4$, $F = \text{CuSO}_4$.

Quick Tip to Solve: Trace the contact process through oleum; concentrated acid oxidises copper to copper(II) sulphate.

36(b). An amorphous solid 'A' which has a crown shaped structure, burns in air to form a gas 'B' which turns lime water milky. 'B' is also produced by roasting of sulphide ores. 'B' undergoes oxidation in the presence of V_2O_5 to give 'C' and to carry out this oxidation low temperature and high pressure is mandatory to get a good yield of 'C'. 'C' is then absorbed in H_2SO_4 to give 'D'. 'D' is then diluted to give a very important compound 'E'. 'E' is largely responsible for the manufacture of variety of compounds in industry. 'E' in concentrated form, when combined with Cu metal, gives compound 'F'. From this description

Give a balanced chemical equation for the conversion of 'E' to 'F'.

[1 mark]

Solution:

Concept:

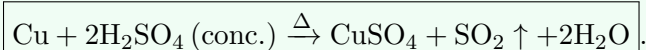
- *E* is sulphuric acid, H_2SO_4 , and *F* is copper(II) sulphate, CuSO_4 .
- Hot concentrated sulphuric acid acts as an oxidising agent and is reduced to sulphur dioxide.

Step 1: Identify the redox changes Copper is oxidised from oxidation state 0 to +2. Sulphur in the acid is reduced from +6 to +4 in SO_2 . Thus copper sulphate, sulphur dioxide and water are the reaction products.

Step 2: Balance the products and reactants Use two sulphuric acid molecules: one sulphate forms copper sulphate, while the other sulphur atom forms sulphur dioxide. Four hydrogen atoms give two water molecules. Both sides then contain one Cu atom, two S atoms, four H atoms and eight O atoms.

Quick Tip to Solve: Use two acid molecules: one supplies sulphate and the other is reduced to sulphur dioxide.

Step 3: Conclusion



Quick Tip to Solve: Use two acid molecules: one supplies sulphate and the other is reduced to sulphur dioxide.

36(c). An amorphous solid 'A' which has a crown shaped structure, burns in air to form a gas 'B' which turns lime water milky. 'B' is also produced by roasting of sulphide ores. 'B' undergoes oxidation in the presence of V_2O_5 to give 'C' and to carry out this oxidation low temperature and high pressure is mandatory to get a good yield of 'C'. 'C' is then absorbed in H_2SO_4 to give 'D'. 'D' is then diluted to give a very important compound 'E'. 'E' is largely responsible for the manufacture of variety of compounds in industry. 'E' in concentrated form, when combined with Cu metal, gives compound 'F'. From this description

Give two important functions of 'E' in the chemical industry.

[1 mark]

Solution:

Concept:

- Sulphur trioxide is absorbed in sulphuric acid to form oleum; dilution of oleum gives sulphuric acid, so $E = \text{H}_2\text{SO}_4$.
- Sulphuric acid is an important industrial acid used in bulk chemical manufacture.

Step 1: Identify the industrial acid The contact-process sequence is $\text{SO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{H}_2\text{S}_2\text{O}_7$, followed by $\text{H}_2\text{S}_2\text{O}_7 + \text{H}_2\text{O} \rightarrow 2\text{H}_2\text{SO}_4$. Thus the substance whose uses are required is sulphuric acid.

Step 2: State two important functions Sulphuric acid is used in the manufacture of fertilisers, such as ammonium sulphate and superphosphate of lime. It is also used in petroleum refining, where acid treatment helps remove undesirable impurities from petroleum products.

Step 3: Conclusion Two important industrial uses of E , sulphuric acid, are the manufacture of fertilisers and petroleum refining.

Quick Tip to Solve: Follow the oleum dilution step to identify sulphuric acid before listing its industrial uses.

OR

36(a). Give reasons for the following observations:

(i) Halogens are strong oxidising agents.

(ii) Noble gases have very low boiling points.

(iii) O and Cl have nearly same electronegativity, yet oxygen forms H bond while Cl doesn't. [3 marks]

Solution:

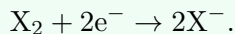
Concept:

- Oxidising agents accept electrons and are themselves reduced.

Quick Tip to Solve: For hydrogen bonding, compare atomic size as well as electronegativity; for boiling points, identify the attractive force.

- Noble gas atoms attract one another through weak London dispersion forces.
- Hydrogen bonding is strongest when hydrogen is bonded to a small, highly electronegative atom such as O, N or F.

Step 1: Explain the oxidising action of halogens Halogen atoms have the valence-shell configuration ns^2np^5 , so each requires one electron to attain a stable noble-gas configuration. A halogen molecule therefore accepts two electrons:



Their high electronegativity and favourable tendency to gain electrons make halogens strong oxidising agents; the species donating electrons to them is oxidised.

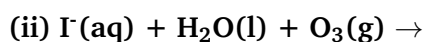
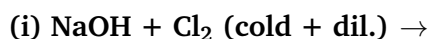
Step 2: Explain the low boiling points of noble gases Noble gases exist as individual, neutral atoms with completely filled valence shells. They have no permanent molecular dipoles, so the interatomic attractions are weak London dispersion forces. Only a small amount of thermal energy is needed to overcome these attractions and separate the atoms into the gaseous state. Consequently their boiling points are very low.

Step 3: Compare hydrogen bonding by oxygen and chlorine Electronegativity alone does not determine hydrogen-bond strength; atomic size is also important. Oxygen is much smaller than chlorine, and its lone-pair electron density is concentrated in a small volume. The small oxygen atom in an O–H bond permits a strong attraction between the partially positive hydrogen and a neighbouring oxygen lone pair. Chlorine is larger and its electron cloud is more diffuse, so the corresponding attraction is too weak to give the appreciable hydrogen bonding observed with oxygen in the usual CBSE comparison.

Step 4: Conclusion Halogens readily accept electrons; noble gases have only weak interatomic dispersion forces; and the smaller size and concentrated lone-pair density of oxygen favour hydrogen bonding compared with chlorine.

Quick Tip to Solve: For hydrogen bonding, compare atomic size as well as electronegativity; for boiling points, identify the attractive force.

36(b). Complete and balance the following chemical equations:



[2 marks]

Solution:

Concept:

- Chlorine disproportionates in cold dilute alkali: its oxidation state changes from zero to -1 in chloride and $+1$ in hypochlorite.
- Ozone oxidises iodide ions to iodine and is reduced to oxygen in aqueous solution.

Step 1: Balance chlorine with cold dilute sodium hydroxide The products are sodium chloride,

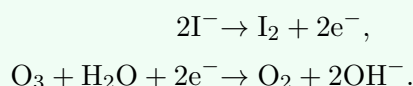
Quick Tip to Solve: Cold dilute alkali gives hypochlorite; in the ozone equation, check charge as well as atom balance.

sodium hypochlorite and water:

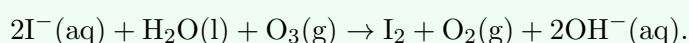


This is the reaction in cold, dilute alkali. Both chlorine atoms are accounted for, and each side contains two sodium atoms, two oxygen atoms and two hydrogen atoms. The stated conditions select hypochlorite as the oxidised chlorine product.

Step 2: Balance oxidation of iodide by ozone Two iodide ions lose two electrons to give iodine. The balancing half-reactions in the resulting alkaline medium are



Adding them cancels the electrons and gives



Both sides have total charge -2 ; hydrogen and oxygen atoms are balanced.

Step 3: Conclusion $\text{Cl}_2 + 2\text{NaOH} \rightarrow \text{NaCl} + \text{NaOCl} + \text{H}_2\text{O}$; $2\text{I}^- + \text{H}_2\text{O} + \text{O}_3 \rightarrow \text{I}_2 + \text{O}_2 + 2\text{OH}^-$.

Quick Tip to Solve: Cold dilute alkali gives hypochlorite; in the ozone equation, check charge as well as atom balance.

37(a). An organic compound 'A' having molecular formula $\text{C}_5\text{H}_{10}\text{O}$ gives negative Tollens' test, forms n-pentane on Clemmensen reduction but doesn't give iodoform test. Identify 'A' and give all the reactions involved. [2 marks]

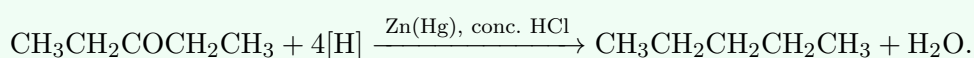
Solution:

Concept:

- Ordinary ketones do not reduce Tollens' reagent; aldehydes normally give a silver mirror.
- Clemmensen reduction, using $\text{Zn(Hg)}/\text{conc. HCl}$, converts a carbonyl group into $-\text{CH}_2-$ without changing the carbon skeleton.
- The iodoform test detects the methyl ketone group $\text{CH}_3\text{CO}-$.

Step 1: Use the tests to identify the ketone The negative Tollens' test indicates a ketone rather than an aldehyde. Formation of n-pentane on Clemmensen reduction establishes an unbranched five-carbon skeleton. The possible unbranched ketones are pentan-2-one and pentan-3-one. Pentan-2-one contains $\text{CH}_3\text{CO}-$ and gives an iodoform test, so it is excluded. Pentan-3-one lacks that group and fits all the observations.

Step 2: Write the reduction and test reactions For $A = \text{CH}_3\text{CH}_2\text{COCH}_2\text{CH}_3$, the Clemmensen reaction is



Quick Tip to Solve: First fix the straight-chain skeleton with Clemmensen reduction, then exclude the ketone bearing a methyl carbonyl group.

Pentan-3-one with Tollens' reagent gives no reaction and no silver mirror. With $I_2/NaOH$, it gives a negative iodoform test: no yellow precipitate of CHI_3 forms. These negative tests are reported as observations, since there is no corresponding positive-test equation to write.

Step 3: Conclusion A is pentan-3-one, $CH_3CH_2COCH_2CH_3$. It reduces to n-pentane and gives neither a silver mirror nor an iodoform precipitate.

Quick Tip to Solve: First fix the straight-chain skeleton with Clemmensen reduction, then exclude the ketone bearing a methyl carbonyl group.

37(b). Carry out the following conversions:

(i) Propanoic acid to 2-Bromopropanoic acid

(ii) Benzoyl chloride to benzaldehyde

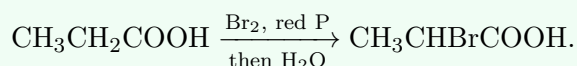
[2 marks]

Solution:

Concept:

- The Hell–Volhard–Zelinsky reaction replaces an alpha hydrogen of a carboxylic acid by bromine using bromine and red phosphorus.
- Rosenmund reduction converts an acid chloride into an aldehyde with hydrogen over poisoned palladium supported on barium sulphate.

Step 1: (i) Brominate the alpha carbon Propanoic acid has an alpha hydrogen on the carbon next to the carboxyl group. Treat it with Br_2 in the presence of red phosphorus, followed by hydrolysis. The Hell–Volhard–Zelinsky reaction gives



The carbon bearing bromine is carbon 2 when numbered from the carboxyl carbon.

Step 2: (ii) Reduce the acid chloride selectively Pass hydrogen over benzoyl chloride in the presence of poisoned $Pd/BaSO_4$. This is Rosenmund reduction:



The poisoned catalyst limits further reduction of the aldehyde, allowing benzaldehyde to be isolated.

Step 3: Conclusion The required products are $CH_3CHBrCOOH$ by HVZ bromination and C_6H_5CHO by Rosenmund reduction.

Quick Tip to Solve: For alpha bromination use $Br_2/red\ P$; for acid chloride to aldehyde use H_2 with poisoned $Pd/BaSO_4$.

37(c). How will you distinguish between benzaldehyde and acetaldehyde?

[1 mark]

Solution:

Concept:

- Fehling's solution is reduced by aliphatic aldehydes to brick-red copper(I) oxide.
- Aromatic aldehydes such as benzaldehyde do not give this precipitate under the usual test conditions.

Step 1: Perform the test Warm separate samples with freshly mixed Fehling's solution in a water bath. Acetaldehyde reduces the blue copper(II) complex and gives a brick-red precipitate of Cu_2O .

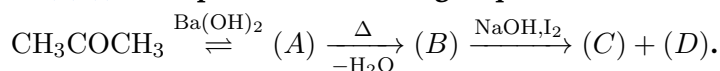
Step 2: Compare the observations Benzaldehyde gives no brick-red precipitate. Thus the sample producing the precipitate is acetaldehyde, while the sample showing no reaction is benzaldehyde. Tollens' test is unsuitable for distinguishing this pair because both are aldehydes and give a silver mirror.

Step 3: Conclusion Fehling's test distinguishes them: acetaldehyde gives brick-red Cu_2O ; benzaldehyde does not.

Quick Tip to Solve: Choose Fehling's reagent for aliphatic versus aromatic aldehydes; Tollens' reagent reacts with both.

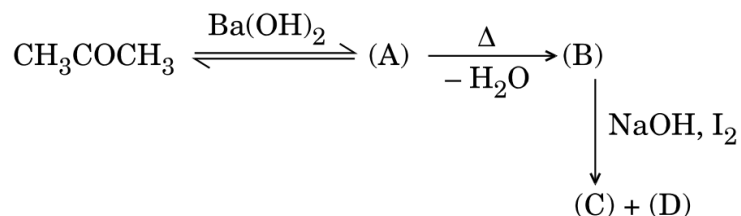
OR

37(a)(i). Complete the following sequence of reactions:



Identify (A) to (D).

[2 marks]

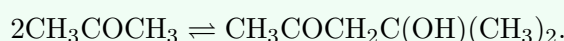


Solution:

Concept:

- Acetone undergoes aldol addition because it has alpha hydrogens; its aldol product is a beta-hydroxy ketone.
- Heating eliminates water to form an unsaturated methyl ketone. The methyl ketone group then gives iodoform with iodine and alkali.

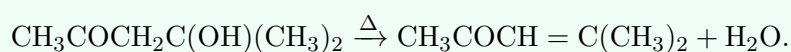
Step 1: Identify the aldol addition product A Two acetone molecules combine in the presence of $\text{Ba}(\text{OH})_2$. The carbonyl group of one molecule becomes the hydroxyl group:



Quick Tip to Solve: In the iodoform step replace the COCH_3 group by COONa and record CHI_3 as the second product.

Thus A is diacetone alcohol, whose structure retains one ketone group and contains a hydroxyl group on the beta carbon.

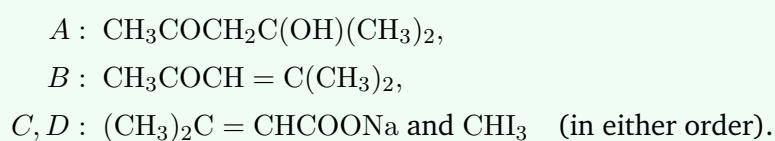
Step 2: Identify the dehydration product B On heating, A loses water from its hydroxyl group and an adjacent hydrogen:



B is mesityl oxide, an unsaturated methyl ketone.

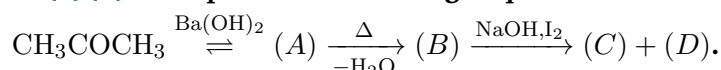
Step 3: Identify the iodoform products C and D For a methyl ketone RCOCH_3 , iodine and sodium hydroxide give RCOONa and CHI_3 . Here $\text{R} = \text{CH}=\text{C}(\text{CH}_3)_2$, so the products are sodium 3-methylbut-2-enoate, $(\text{CH}_3)_2\text{C}=\text{CHCOONa}$, and yellow iodoform, CHI_3 . The order of C and D can be interchanged because both are shown as products without further identifying information.

Step 4: Conclusion The identified compounds are



Quick Tip to Solve: In the iodoform step replace the COCH_3 group by COONa and record CHI_3 as the second product.

37(a)(ii). Complete the following sequence of reactions:



Give the IUPAC name of (A).

[1 mark]

Solution:

Concept:

- Acetone undergoes aldol addition to form $\text{CH}_3\text{COCH}_2\text{C}(\text{OH})(\text{CH}_3)_2$.
- For IUPAC naming, the ketone takes the suffix; the hydroxyl group is named by the prefix hydroxy.

Step 1: Choose and number the parent chain The longest chain containing the ketone carbon has five carbon atoms. Number it from the end nearer the carbonyl group, placing the ketone at carbon 2. The parent is therefore pentan-2-one.

Step 2: Locate the substituents Carbon 4 carries both a hydroxyl group and a methyl group. Use the prefixes 4-hydroxy and 4-methyl, in alphabetical order, before the parent name. The hydroxyl group is a prefix because the ketone has naming priority.

Step 3: Conclusion The IUPAC name of A is 4-hydroxy-4-methylpentan-2-one.

Quick Tip to Solve: Number from the carbonyl end and use hydroxy as a prefix when an alcohol group accompanies a ketone.

37(b). How can you distinguish between:

(i) Ethanol and Propanone, and

(ii) Benzoic acid and Phenol?

[2 marks]

Solution:

Concept:

- 2,4-Dinitrophenylhydrazine (2,4-DNP) gives a coloured hydrazone precipitate with aldehydes and ketones.
- Carboxylic acids liberate carbon dioxide from sodium hydrogen carbonate, whereas phenol is too weak an acid to do so.

Step 1: (i) Test ethanol and propanone with 2,4-DNP Add 2,4-dinitrophenylhydrazine reagent to separate samples. Propanone gives a yellow to orange precipitate of its 2,4-dinitrophenylhydrazone because it contains a carbonyl group. Ethanol gives no precipitate because its functional group is an alcohol. Iodoform is not a suitable distinguishing test here: both ethanol and propanone give that test.

Step 2: (ii) Test benzoic acid and phenol with sodium hydrogen carbonate Add aqueous NaHCO_3 separately to the samples. Benzoic acid gives brisk effervescence of carbon dioxide:



Phenol produces no effervescence because it cannot displace carbonic acid from hydrogen carbonate. The gas can be confirmed by its turning limewater milky.

Step 3: Conclusion Propanone gives a coloured precipitate with 2,4-DNP while ethanol does not. Benzoic acid releases CO_2 with NaHCO_3 while phenol does not.

Quick Tip to Solve: Avoid iodoform for ethanol versus propanone: both react. Use 2,4-DNP for the ketone and NaHCO_3 for the carboxylic acid.