CBSE Class 12 Chemistry Question Paper 2024 with Solution PDF-Set 56-5-2

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 contains **33 questions**. **All** questions are **compulsory**.

(ii) Question paper is divided into **FIVE** sections – **Section A, B, C, D and E**.

(iii) **Section A** – question number **1** to **16** are multiple choice type questions. Each question carries **1** mark.

(iv) **Section B** – question number **17** to **21** are very short answer type questions. Each question carries **2** marks.

(v) **Section C** – question number **22** to **28** are short answer type questions. Each question carries **3** marks.

(vi) **Section D** – question number **29** and **30** are case-based questions. Each question carries **4** marks.

(vii) **Section E** – question number **31** to **33** are long answer type questions. Each question carries **5** marks.

(viii) There is no overall choice given in the question paper. However, an internal choice has been provided in few questions in all the Sections except section **A**.

(ix) Kindly note that there is a separate question paper for Visually Impaired candidates.

(x) Use of calculator is NOT allowed.

Section A (16 marks)

Question No. 1 to 16 are Multiple Choice type Questions, carrying 1 mark each.

1. Which of the following species can act as the strongest base? [1 mark]

(A) OH^-

(B) $C_6H_5O^-$

(C) RO^-

(D) m-$O_2N-C_6H_4-O^-$

Correct Answer: (C) RO^-

Solution:

Concept:

- A base accepts a proton. Greater availability of the negative charge on oxygen generally increases basicity.
- An electron-releasing alkyl group has a positive inductive effect, whereas resonance delocalisation and electron-withdrawing groups stabilise an anion and reduce its basicity.

Step 1: Compare alkoxide with hydroxide In RO^-, the alkyl group R releases electron density towards oxygen through its positive inductive effect. The oxygen therefore accepts a proton more readily than the oxygen of OH^-, which has no electron-releasing alkyl group. Thus option (A) is less basic than option (C).

Step 2: Compare the aromatic anions In phenoxide, $C_6H_5O^-$, the negative charge is delocalised into the benzene ring by resonance, making it less available for protonation. The meta nitro group in option (D) additionally withdraws electrons by its negative inductive effect. Thus neither (B) nor (D) is stronger than the alkoxide ion.

Step 3: Conclusion The strongest base is $\boxed{RO^-}$. Hence, the correct option is (C).

Quick Tip to Solve: For these oxygen anions, look first for an alkyl group that increases electron density on oxygen; resonance-stabilised phenoxides are weaker bases.

2. Auto-oxidation of chloroform in air and light produces a poisonous gas known as [1 mark]

(A) Phosphine

(B) Mustard gas

(C) Phosgene

(D) Tear gas

Correct Answer: (C) Phosgene

Solution:

Concept:

- Chloroform, $CHCl_3$, undergoes slow oxidation by atmospheric oxygen in the presence of light.

Quick Tip to Solve: Link chloroform exposed to air and light with carbonyl chloride: the common name of $COCl_2$ is phosgene.

- Carbonyl chloride, $COCl_2$, is commonly called phosgene and is highly poisonous.

Step 1: Identify the oxidation product The balanced reaction is

$$2CHCl_3 + O_2 \xrightarrow{\text{light}} 2COCl_2 + 2HCl.$$

The oxygen-containing product has one carbonyl group and two chlorine atoms attached to the carbonyl carbon.

Step 2: Match the formula with the gas name $COCl_2$ is phosgene. Phosphine is PH_3, so it cannot form from chloroform and oxygen, which contain no phosphorus. Mustard gas is a sulfur-containing compound, whereas no sulfur is present here. Tear gas is not the name of the carbonyl chloride product in this reaction.

Step 3: Conclusion The poisonous gas produced is $\boxed{\text{phosgene}}$. Hence, the correct option is (C).

Quick Tip to Solve: Link chloroform exposed to air and light with carbonyl chloride: the common name of $COCl_2$ is phosgene.

3. Isotonic solutions have the same [1 mark]

(A) density

(B) refractive index

(C) osmotic pressure

(D) volume

Correct Answer: (C) osmotic pressure

Solution:

Concept:

- Osmotic pressure is the pressure required to stop solvent flow through a semipermeable membrane into a solution.
- For a dilute solution, $\pi = iCRT$, where i is the van't Hoff factor, C is molar concentration, R is the gas constant and T is absolute temperature.

Step 1: Apply the definition of isotonic solutions Two solutions are called isotonic when their osmotic pressures are equal at the same temperature. If separated by a membrane permeable only to the solvent, there is no net osmosis between them because neither side has a larger osmotic pressure.

Step 2: Check the other properties Equality of π requires equality of iC at a common temperature; it does not require identical solutes. Density and refractive index also depend on the chemical nature of the components, so (A) and (B) need not be equal. The total volume may be chosen independently of concentration, so equal volume in (D) is not required either.

Step 3: Conclusion Isotonic solutions have the same $\boxed{\text{osmotic pressure}}$ at a given temperature. Hence, the correct option is (C).

Quick Tip to Solve: Read isotonic as equal osmotic pressure at the same temperature; equal molarity alone works only when the van't Hoff factors also agree.

4. The specific sequence in which amino acids are arranged in a protein is called its [1 mark]

(A) Primary structure

(B) Secondary structure

(C) Tertiary structure

(D) Quaternary structure

Correct Answer: (A) Primary structure

Solution:

Concept:

- Amino acids are linked by peptide bonds to form a polypeptide chain. Their order along that chain is a definite sequence.
- Protein structure is described at primary, secondary, tertiary and quaternary levels, each referring to a different kind of organisation.

Step 1: Identify what the question describes The question asks for the specific sequence of amino acid residues, rather than the shape of the chain. This sequence is read from the amino-terminal end to the carboxyl-terminal end and specifies which amino acid occupies each position.

Step 2: Distinguish the remaining levels Secondary structure refers to local arrangements such as an α-helix or a β-pleated sheet. Tertiary structure describes the overall three-dimensional folding of one polypeptide. Quaternary structure describes how multiple polypeptide subunits associate. Thus (B), (C) and (D) describe folding or assembly, rather than the residue sequence asked for.

Step 3: Conclusion The specific amino acid sequence is the $\boxed{\text{primary structure}}$ of a protein. Hence, the correct option is (A).

Quick Tip to Solve: Associate sequence with primary structure, local folds with secondary structure, one chain's complete fold with tertiary structure, and subunit assembly with quaternary structure.

5. Transition metals are known to make interstitial compounds. Formation of interstitial compounds makes the transition metal [1 mark]

(A) more hard

(B) more soft

(C) more ductile

(D) more metallic

Correct Answer: (A) more hard

Solution:

Concept:

- Interstitial compounds form when small atoms, such as hydrogen, carbon or nitrogen, occupy vacant spaces within a metal lattice.
- These compounds commonly retain metallic conductivity but show increased hardness and high melting points.

Quick Tip to Solve: For an interstitial compound, imagine small atoms occupying the gaps and hindering layer movement; this points directly to increased hardness.

Step 1: Relate the occupied voids to hardness The small atoms fit into interstitial spaces between the transition-metal atoms. Their presence makes the relative movement of metal layers more difficult and strengthens the lattice against deformation. Consequently, a larger force is required to deform the material.

Step 2: Check the alternatives against this effect Increased resistance to deformation means increased hardness, which supports (A). Becoming softer in (B) would be the opposite effect. Increased ductility in (C) would mean easier drawing into wires, which is not the characteristic result of restricting lattice movement. Metallic conductivity is generally retained, but this does not mean that the metal becomes more metallic as asserted in (D).

Step 3: Conclusion Formation of interstitial compounds makes the transition metal $\boxed{\text{harder}}$. Hence, the correct option is (A).

Quick Tip to Solve: For an interstitial compound, imagine small atoms occupying the gaps and hindering layer movement; this points directly to increased hardness.

6. The correct name of the given reaction is

$$\mathrm{Ar{-}N_2^{+}\,X^{-}} \xrightarrow[\textbf{Cu powder}]{\mathrm{HBr}} \mathrm{Ar{-}Br + N_2}.$$

[1 mark]

(A) Hoffmann Bromamide degradation reaction.

(B) Gabriel Phthalimide synthesis

(C) Carbyl amine reaction

(D) Gatterman reaction

Correct Answer: (D) Gatterman reaction

Solution:

Concept:

- An arenediazonium group can be replaced by a halogen with liberation of nitrogen gas.
- Treatment of an arenediazonium salt with hydrochloric or hydrobromic acid in the presence of copper powder is called the Gattermann reaction.

Step 1: Identify the reacting group and the reagents In the printed reaction, $\mathrm{Ar{-}N_2^{+}}$ loses its diazonium group and gives $\mathrm{Ar{-}Br}$, with $\mathrm{N_2}$ released. The identifying reagent combination is hydrobromic acid with copper powder. This is the Gattermann method; the related Sandmeyer substitution instead uses a cuprous halide.

Step 2: Eliminate the other named reactions Hoffmann bromamide degradation converts a primary amide into an amine with one fewer carbon atom, so (A) does not fit. Gabriel phthalimide synthesis prepares primary amines from alkyl halides, excluding (B). The carbylamine reaction converts a primary amine into an isocyanide using chloroform and alcoholic alkali, excluding (C). None describes the diazonium-to-bromide substitution shown here.

Quick Tip to Solve: For diazonium substitution, distinguish copper powder plus HBr (Gattermann) from cuprous bromide (Sandmeyer).

Step 3: Conclusion The reaction is the Gattermann reaction, printed as Gatterman in option (D). Hence, the correct option is (D).

Quick Tip to Solve: For diazonium substitution, distinguish copper powder plus HBr (Gattermann) from cuprous bromide (Sandmeyer).

7. Visha took 4 test-tubes namely A, B, C & D containing $CH_3CH = CH_2$, $CH_3CH_2CH = CH_2$, $CH_3CH = CH–CH_3$ and $(CH_3)_2C = CH_2$ respectively and tried to convert them into tert-butylalcohol. She carried out acid catalysed hydration reaction on every alkene. Out of the four test-tubes, the one which will give desired result is [1 mark]

(A) A

(B) B

(C) C

(D) D

Correct Answer: (D) D

Solution:

Concept:

- Acid-catalysed hydration adds water across an alkene double bond according to Markovnikov's rule, through the more stable carbocation.
- tert-Butyl alcohol is $(CH_3)_3COH$, a tertiary alcohol with a branched four-carbon skeleton.

Step 1: Hydrate the branched alkene In test-tube D, the alkene is 2-methylpropene, $(CH_3)_2C{=}CH_2$. Proton addition to the terminal carbon forms the tertiary tert-butyl carbocation. Water attacks this ion and subsequent loss of a proton produces the alcohol:

$$(CH_3)_2C{=}CH_2 + H_2O \xrightarrow{H^+} (CH_3)_3COH.$$

Step 2: Check the other test-tubes Propene in A gives propan-2-ol and has only three carbon atoms. But-1-ene in B and but-2-ene in C give butan-2-ol on ordinary acid-catalysed hydration. Their straight-chain skeletons therefore do not give the required branched tertiary alcohol. Only the alkene in D directly forms the required tertiary carbocation.

Step 3: Conclusion Test-tube D gives tert-butyl alcohol. Hence, the correct option is (D).

Quick Tip to Solve: For tert-butyl alcohol, first identify the branched four-carbon alkene, then place the hydroxyl group on its more substituted carbon.

8. Van't Hoff factor for KCl solution assuming the complete dissociation is [1 mark]

(A) 1

(B) 2

(C) 0.5

(D) 1.5

Correct Answer: (B) 2

Solution:

Concept:

- The van't Hoff factor i is the ratio of the number of solute particles actually present to the number of formula units initially dissolved.
- For complete dissociation into n ions per formula unit, $i = n$. Association instead reduces the number of independent particles.

Step 1: Write the dissociation Potassium chloride is a 1:1 electrolyte and dissociates completely as stated:

$$\mathrm{KCl(aq)} \longrightarrow \mathrm{K^+(aq) + Cl^-(aq)}.$$

Thus, each formula unit produces one potassium ion and one chloride ion, giving two independently moving solute particles.

Step 2: Count the particles If one mole of KCl is dissolved, complete dissociation gives two moles of ions, so $i = 2/1 = 2$. The value 1 would describe no dissociation, 0.5 would imply association, and 1.5 would describe only partial dissociation of a 1:1 electrolyte. None matches the stated complete dissociation.

Step 3: Conclusion The van't Hoff factor is $i = 2$. Hence, the correct option is (B).

Quick Tip to Solve: Count both ionic species from one formula unit of KCl; complete dissociation means one cation plus one anion.

9. Dilution affects both molar conductivity as well as conductivity. Effect of dilution on both is [1 mark]

(A) molar conductivity decreases whereas conductivity increases on dilution

(B) molar conductivity increases whereas conductivity decreases on dilution

(C) both decrease with dilution

(D) both increase with dilution

Correct Answer: (B) molar conductivity increases whereas conductivity decreases on dilution

Solution:

Concept:

- Conductivity κ measures conduction by a solution of unit dimensions and depends on the number of charge carriers per unit volume.
- Molar conductivity is $\Lambda_m = 1000\kappa/c$ when concentration c is in mol $\mathrm{L^{-1}}$, κ in S $\mathrm{cm^{-1}}$, and Λ_m in

Quick Tip to Solve: Distinguish ions per unit volume from conduction per mole: dilution lowers the former but increases molar conductivity.

S cm^2 mol^{-1}.

Step 1: Examine conductivity on dilution Adding solvent increases the volume of the solution, lowering the number of ions per unit volume. Consequently, the conductivity κ decreases. This eliminates options (A) and (D), which claim that conductivity increases.

Step 2: Examine conduction per mole Molar conductivity refers to the conduction due to all the ions supplied by one mole of electrolyte. On dilution, interionic attractions decrease and ions move more freely. For a weak electrolyte, increased ionisation further increases the number of ions per mole. Hence Λ_m increases on dilution for both strong and weak electrolytes, excluding option (C). The increase is more pronounced for weak electrolytes.

Step 3: Conclusion Molar conductivity increases whereas conductivity decreases on dilution. Hence, the correct option is (B).

Quick Tip to Solve: Distinguish ions per unit volume from conduction per mole: dilution lowers the former but increases molar conductivity.

10. Which of the following cell is used in inverter? [1 mark]

(A) Fuel cell

(B) Mercury cell

(C) Lead storage cell

(D) Dry cell

Correct Answer: (C) Lead storage cell

Solution:

Concept:

- An inverter obtains electrical energy from a rechargeable battery during a power failure and converts its direct-current output into alternating current.
- The lead storage cell is a secondary cell: its discharge reaction can be reversed by supplying electrical energy during charging.

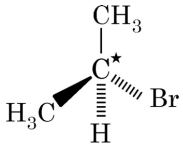
Step 1: Identify the required cell property An inverter battery must deliver substantial current repeatedly and be recharged when the mains supply returns. A lead storage cell has a lead negative electrode, a lead dioxide positive electrode and sulphuric acid electrolyte. Its reversible electrochemical reactions make it suitable for this repeated charge-discharge operation.

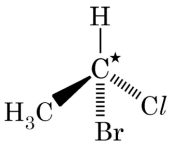
Step 2: Compare the given choices The lead storage cell is the conventional rechargeable cell used in inverters. Mercury cells and ordinary dry cells are primary cells and are not designed for repeated recharging. A fuel cell requires a continuous supply of fuel and oxidant, so it is not the storage battery intended here.

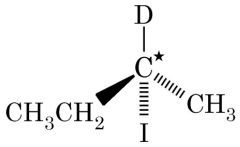
Step 3: Conclusion A lead storage cell is used in an inverter. Hence, the correct option is (C).

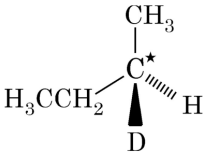
Quick Tip to Solve: Match an inverter's repeated charging requirement with the secondary cell among the options: the lead storage cell.

11. In which of the following molecules, C atom marked with asterisk is chiral? [1 mark]

(I) 

(II) 

(III) 

(IV) 

(A) I, II, III

(B) II, III, IV

(C) I, II, III, IV

(D) I, III, IV

Correct Answer: (B) II, III, IV

Solution:

Concept:

- A tetrahedral carbon is a chiral centre when it is bonded to four different atoms or groups.
- Isotopes count as different substituents: hydrogen H and deuterium D differ in isotopic mass, even though both are isotopes of hydrogen.

Step 1: Examine structures I and II In I, the marked carbon is attached to CH_3, CH_3, H and Br. Because two methyl groups are identical, this carbon is not chiral. In II, its substituents are CH_3, H, Br and Cl; all four differ, so the marked carbon is chiral.

Step 2: Examine structures III and IV In III, the marked carbon bears D, I, CH_3 and CH_2CH_3; these are four different substituents. In IV, the groups are CH_3, CH_2CH_3, H and D. The last two are distinct isotopes, so this carbon is also chiral. Every other answer choice includes I and must therefore be rejected.

Step 3: Conclusion The marked carbon is chiral in II, III and IV. Hence, the correct option is (B).

Quick Tip to Solve: List all four substituents at each starred carbon; reject identical methyl groups, but distinguish hydrogen from deuterium.

12. For the reaction A + 2B $\rightarrow$ C + D. The order of the reaction is [1 mark]

(A) 1 with respect to A

(B) 2 with respect to B

(C) can't be predicted as order is determined experimentally.

(D) 3

Correct Answer: (C) can't be predicted as order is determined experimentally.

Solution:

Concept:

- Reaction order is the sum of the exponents of reactant concentrations in the experimentally determined rate law.
- Stoichiometric coefficients describe the balanced overall reaction. They give rate-law exponents only when the reaction is specified to be a single elementary step.

Step 1: Write a general rate law For the given reaction, write $r = k[A]^m[B]^n$, where r is the rate, k the rate constant, and m, n the experimentally measured orders with respect to A and B. The overall order is $m + n$. No experimental concentration-rate data or elementary-step condition is supplied.

Step 2: Separate order from stoichiometry The coefficient 1 of A does not establish $m = 1$, and the coefficient 2 of B does not establish $n = 2$. Thus options (A) and (B) cannot be inferred. Adding these coefficients to claim order 3, as in (D), would make the same unsupported assumption. The overall equation alone cannot determine the rate law.

Step 3: Conclusion The order cannot be predicted from the equation; it is determined experimentally. Hence, the correct option is (C).

Quick Tip to Solve: Before using coefficients as rate-law powers, check whether the question explicitly identifies an elementary reaction.

For questions number 13 to 16, two statements are given, one labelled as Assertion (A) and the other labelled as Reason (R). Select the correct answer to these questions from the codes (A), (B), (C) and (D) as given below:

13. Assertion (A): p-methoxyphenol is a stronger acid than p-nitrophenol.
Reason (R): Methoxy group shows $+I$ effect whereas nitro group shows $-I$ effect. [1 mark]

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false, but Reason (R) is true.

Correct Answer: Both Assertion (A) and Reason (R) are false; none of the printed options is correct.

Solution:

Concept:

- A phenol is more acidic when its conjugate phenoxide ion is more stable. Electron-withdrawing substituents stabilise this anion.
- Inductive effects operate through sigma bonds, whereas resonance effects involve conjugated orbitals. The methoxy group has a $-I$ effect and a $+R$ effect.

Step 1: Evaluate Assertion (A) The para nitro group withdraws electrons by both inductive and resonance effects, stabilising the negative charge of the phenoxide ion. The para methoxy group donates by resonance and does not provide this stabilisation. Thus p-nitrophenol is the stronger acid and Assertion (A) is false.

Step 2: Evaluate Reason (R) In a methoxy substituent, oxygen is bonded directly to the ring and withdraws electron density inductively because of its electronegativity. Its inductive effect is $-I$, not the printed $+I$. Methoxy donates by resonance, $+R$, which is a different effect. Although the statement that nitro has a $-I$ effect is true, Reason (R) as a whole is false.

Step 3: Check the explanation and the codes A false reason cannot explain the false assertion. Codes (A), (B) and (C) require a true assertion, while code (D) requires a true reason. Hence none represents the actual combination of two false statements. Choosing (D) would incorrectly identify the printed methoxy inductive effect as true.

Step 4: Conclusion Both Assertion (A) and Reason (R) are false. None of the printed options (A)–(D) is scientifically correct.

Quick Tip to Solve: For methoxy, keep the effects separate: oxygen withdraws inductively ($-I$) but donates its lone pair by resonance ($+R$).

14. Assertion (A): Inversion of configuration is observed in S_N2 reaction.
Reason (R): The reaction proceeds with the formation of carbocation. [1 mark]

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false, but Reason (R) is true.

Correct Answer: (C) Assertion (A) is true, but Reason (R) is false.

Solution:

Concept:

- An S_N2 substitution occurs in one concerted step: bond formation with the nucleophile and bond breaking with the leaving group occur together.
- Backside attack at the reacting carbon reverses the spatial arrangement of its substituents, producing Walden inversion.

Step 1: Evaluate Assertion (A) The nucleophile attacks from the side opposite the leaving group. As the new bond forms and the old bond breaks, the other substituents turn over into the inverted arrangement. Thus inversion of configuration is characteristic of an S_N2 reaction and Assertion (A) is true.

Step 2: Evaluate Reason (R) The concerted reaction passes through a transition state with partially formed and partially broken bonds; it has no carbocation intermediate. Formation of a carbocation is characteristic of the two-step S_N1 mechanism. Therefore Reason (R) is false.

Step 3: Check the explanation and options Backside attack explains the inversion; carbocation formation does not. Options (A) and (B) fail because they call the reason true, and (D) also wrongly calls the assertion false. The code for a true assertion and a false reason is (C).

Step 4: Conclusion The assertion is true, but the reason is false. Hence, the correct option is (C).

Quick Tip to Solve: Associate S_N2 with one step, backside attack and inversion; reserve the carbocation intermediate for S_N1.

15. Assertion (A): The units of rate constant of a zero order reaction and rate of reaction are the same.

Reason (R): In zero order reaction, the rate of reaction is independent of the concentration of reactants. [1 mark]

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false, but Reason (R) is true.

Correct Answer: (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).

Solution:

Concept:

- For a zero-order reaction, the rate law is $r = k[C]^0 = k$, where r is the reaction rate, k is the rate constant and $[C]$ denotes reactant concentration.
- Reaction rate has dimensions concentration per unit time, commonly expressed in $\mathrm{mol\,L^{-1}\,s^{-1}}$.

Step 1: Evaluate Assertion (A) The zero-order rate law makes the rate equal to the rate constant. Their dimensions and units must therefore agree:

$$[k] = [r] = \mathrm{mol\,L^{-1}\,s^{-1}}.$$

Hence the assertion that both have the same units is true.

Step 2: Evaluate Reason (R) In the rate law, the concentration factor has exponent zero and equals unity. At a fixed temperature, changing the reactant concentration therefore does not change the rate within the range in which zero-order kinetics applies. Thus the reason is true.

Step 3: Test the explanatory link Independence from concentration gives $r = k$, so there is no concentration factor carrying extra units. This directly explains why k has the units of rate. Option (B) wrongly denies this link; (C) and (D) incorrectly reject one of the true statements.

Step 4: Conclusion Both statements are true, and the reason correctly explains the assertion. Hence, the correct option is (A).

Quick Tip to Solve: Set the order to zero in $r = k[C]^n$; the resulting equality $r = k$ gives the units immediately.

16. Assertion (A): Zr and Hf are of almost similar atomic radii.

Reason (R): This is due to the Lanthanoid contraction. [1 mark]

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false, but Reason (R) is true.

Correct Answer: (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).

Solution:

Concept:

- Lanthanoid contraction is the gradual decrease in atomic and ionic radii across the lanthanoid series as nuclear charge increases.
- The $4f$ electrons shield the increasing nuclear charge poorly, so the effective attraction on outer electrons increases and contracts the electron cloud.

Step 1: Evaluate Assertion (A) Zirconium (Zr) and hafnium (Hf) occupy the same group in the $4d$ and $5d$ transition series, respectively. Although hafnium has an additional principal shell, their atomic radii are nearly equal. Thus Assertion (A) is true.

Step 2: Evaluate Reason (R) The lanthanoid series occurs before hafnium and involves filling the $4f$ subshell. Because these electrons shield poorly, increasing nuclear charge causes a contraction that also affects hafnium. Lanthanoid contraction is therefore a real cause of its unexpectedly small radius, so Reason (R) is true.

Step 3: Establish the explanatory link The contraction largely offsets the normal increase in size expected on moving down from zirconium to hafnium. It consequently explains their almost equal radii. Option (B) wrongly denies this causal link; (C) and (D) each incorrectly classify a true statement as false.

Step 4: Conclusion Both statements are true, and lanthanoid contraction correctly explains the almost equal radii. Hence, the correct option is (A).

Quick Tip to Solve: When comparing Zr and Hf, account for the intervening $4f$ filling before applying the usual increase in radius down a group.

Section B (10 marks)

17. Define the following terms:

(a) Faraday's second law of electrolysis

(b) Corrosion [2 marks]

Solution:

Concept:

- During electrolysis, the amount of a substance deposited depends on the charge passed and its chemical equivalent mass.
- Corrosion is the gradual deterioration of a metal by chemical or electrochemical reaction with its surroundings.

Step 1: State Faraday's second law of electrolysis When the same quantity of electricity is passed through different electrolytes, the masses of substances deposited or liberated at their electrodes are directly proportional to their chemical equivalent masses. Thus,

$$\frac{m_1}{m_2} = \frac{E_1}{E_2} = \frac{M_1/n_1}{M_2/n_2}.$$

Here m is the deposited mass, $E = M/n$ is the equivalent mass, M is molar mass and n is the number of electrons exchanged per ion. The comparison requires equal charge, rather than merely equal current if the times differ.

Step 2: Define corrosion with an example Corrosion is the slow destruction of a metal due to attack by substances present in the environment, such as moisture, oxygen or acids. The metal is oxidised and converted into compounds. For example, iron rusts in the presence of oxygen and moisture, producing hydrated iron(III) oxide, $Fe_2O_3 \cdot xH_2O$. In electrochemical corrosion, oxidation at an anodic region of the metal is accompanied by reduction at a cathodic region.

Step 3: Conclusion (a) For equal charge, deposited masses are proportional to equivalent masses. (b) Corrosion is the gradual chemical or electrochemical deterioration of a metal by its environment.

Quick Tip to Solve: In Faraday's second law, state the equal-charge condition and use equivalent mass M/n, not molar mass alone.

18. Resistance of a conductivity cell filled with 0.2 mol L^{-1} KCl solution is $200\,\Omega$. If the resistance of the same cell when filled with 0.05 mol L^{-1} KCl solution is $620\,\Omega$, calculate the conductivity and molar conductivity of 0.05 mol L^{-1} KCl solution. The conductivity of 0.2 mol L^{-1} KCl solution is 0.0248 S cm^{-1}. [2 marks]

Solution:

Concept:

- Conductance is $G = 1/R$, where R is resistance. Conductivity is $\kappa = G(l/A)$, where l/A is the cell constant.

Quick Tip to Solve: For the same cell, use $\kappa_1 R_1 = \kappa_2 R_2$; insert the new concentration only when calculating molar conductivity.

- For concentration c in mol L^{-1} and conductivity in S cm^{-1}, molar conductivity is $\Lambda_m = 1000\kappa/c$. The factor 1000 converts litres to cubic centimetres.

Step 1: Determine the cell constant Calibrate the cell using the known conductivity and resistance of the 0.2 mol L^{-1} solution of KCl:

$$\frac{l}{A} = \kappa_1 R_1 = 0.0248 \times 200 = 4.96\,\text{cm}^{-1}.$$

The same cell has unchanged electrode area and separation, so this cell constant also applies to the dilute solution.

Step 2: Calculate conductivity and molar conductivity Use the resistance $620\,\Omega$ for the 0.05 mol L^{-1} solution:

$$\kappa_2 = \frac{l/A}{R_2} = \frac{4.96}{620} = 0.0080\,\text{S cm}^{-1}.$$

Now divide by the concentration in mol cm^{-3}, equivalently using the litre conversion factor:

$$\Lambda_m = \frac{1000 \times 0.0080}{0.05} = 160\,\text{S cm}^2\,\text{mol}^{-1}.$$

Step 3: Conclusion The conductivity is 8.0×10^{-3} S cm^{-1} and the molar conductivity is 160 S cm^2 mol^{-1}.

Quick Tip to Solve: For the same cell, use $\kappa_1 R_1 = \kappa_2 R_2$; insert the new concentration only when calculating molar conductivity.

19. Show that in case of a first order reaction, the time taken for completion of 99% reaction is twice the time required for 90% completion of the reaction. (log 10 = 1) [2 marks]

Solution:

Concept:

- The integrated first-order rate equation is $t = (2.303/k)\log([A]_0/[A]_t)$, where k is the rate constant and $[A]_0, [A]_t$ are initial and remaining reactant concentrations.
- A completion of $p\%$ leaves $(100 - p)\%$ of the initial reactant. Use the fraction remaining, rather than the fraction consumed, in the denominator of the logarithm.

Step 1: Find the time for 90 percent completion Let the initial concentration be a. At 90 percent completion, the remaining concentration is $0.10a$. Substitution in the first-order equation gives

$$t_{90} = \frac{2.303}{k}\log\frac{a}{0.10a} = \frac{2.303}{k}\log 10 = \frac{2.303}{k}.$$

The initial concentration cancels, which is a characteristic of a first-order reaction's fractional completion time.

Step 2: Find the time for 99 percent completion At 99 percent completion, only $0.01a$ remains. At

Quick Tip to Solve: For 90 percent and 99 percent completion, write the remaining fractions as 10^{-1} and 10^{-2}; their logarithms immediately give the time ratio $1 : 2$.

the same temperature, the rate constant is unchanged, so

$$t_{99} = \frac{2.303}{k} \log \frac{a}{0.01a} = \frac{2.303}{k} \log 100 = \frac{2(2.303)}{k}.$$

Here $\log 100 = \log(10^2) = 2 \log 10 = 2$. Thus reducing the amount remaining from one tenth to one hundredth requires a second equal time interval.

Step 3: Conclusion Taking the ratio gives $t_{99}/t_{90} = 2$; hence $\boxed{t_{99} = 2t_{90}}$, as required.

Quick Tip to Solve: For 90 percent and 99 percent completion, write the remaining fractions as 10^{-1} and 10^{-2}; their logarithms immediately give the time ratio $1 : 2$.

20(a)(i). Carry out the following conversions:

Nitrobenzene to Aniline [1 mark]

Solution:

Concept:

- Nitrobenzene, $C_6H_5NO_2$, is reduced to aniline, $C_6H_5NH_2$, by tin and hydrochloric acid, followed by treatment with alkali.
- Reduction changes the nitro group into an amino group while retaining the benzene ring. In acidic medium, aniline exists as its anilinium salt.

Step 1: Reduce the nitro group Heat nitrobenzene with Sn/HCl. The net reduction of the nitro group is

$$C_6H_5NO_2 + 6\,[H] \longrightarrow C_6H_5NH_2 + 2\,H_2O.$$

In the acidic reaction mixture, the amine is protonated and obtained as anilinium chloride, $C_6H_5NH_3Cl$.

Step 2: Liberate the free amine Add aqueous NaOH after reduction to release the free aniline from its salt:

$$C_6H_5NH_3Cl + NaOH \longrightarrow C_6H_5NH_2 + NaCl + H_2O.$$

The alkaline work-up is necessary because the acidic reduction mixture otherwise contains the protonated amine.

Step 3: Conclusion Convert nitrobenzene to aniline using Sn/HCl, followed by aqueous NaOH.

Quick Tip to Solve: When writing the Sn/HCl reduction of nitrobenzene, include the final alkali treatment to obtain free aniline.

20(a)(ii). Carry out the following conversions:

Aniline to Phenol [1 mark]

Solution:

Concept:

- A primary aromatic amine undergoes diazotisation with nitrous acid generated from $NaNO_2$ and HCl at 273–278 K.
- Aqueous benzenediazonium chloride gives phenol on warming with water, with evolution of nitrogen gas. This replaces the diazonium group by a hydroxyl group.

Step 1: Form the diazonium salt Treat aniline with $NaNO_2$ and dilute HCl, keeping the mixture at 273–278 K:

$$C_6H_5NH_2 + NaNO_2 + 2\,HCl \longrightarrow C_6H_5N_2Cl + NaCl + 2\,H_2O.$$

The low temperature preserves the benzenediazonium chloride intermediate.

Step 2: Hydrolyse the diazonium salt Warm the aqueous diazonium salt solution. Hydrolysis occurs with evolution of nitrogen:

$$C_6H_5N_2Cl + H_2O \xrightarrow{\Delta} C_6H_5OH + N_2 + HCl.$$

The hydroxyl group occupies the same ring position as the original amino group.

Step 3: Conclusion Aniline is converted to phenol by diazotisation with $NaNO_2$/HCl at 273–278 K, followed by warming with water.

Quick Tip to Solve: Keep diazotisation cold, then warm the aqueous diazonium salt to replace its diazonium group by $-OH$.

OR

20(b)(i). Write a chemical test to distinguish between Dimethyl amine and Ethanamine. [1 mark]

Solution:

Concept:

- The carbylamine test is given by primary amines on heating with chloroform and alcoholic potassium hydroxide; an offensive-smelling isocyanide is formed.
- Ethanamine, $C_2H_5NH_2$, is a primary amine, whereas dimethylamine, $(CH_3)_2NH$, is a secondary amine. Secondary amines do not give the carbylamine test.

Step 1: Apply the test to ethanamine Heat a small sample with $CHCl_3$ and alcoholic KOH. Ethanamine forms ethyl isocyanide with a highly offensive odour:

$$C_2H_5NH_2 + CHCl_3 + 3\,KOH \xrightarrow{\Delta} C_2H_5NC + 3\,KCl + 3\,H_2O.$$

This positive result identifies the primary amine.

Step 2: Compare with dimethylamine Treat a separate sample of dimethylamine with the same

Quick Tip to Solve: Count the alkyl groups attached to nitrogen: one in ethanamine permits the carbylamine test, while two in dimethylamine do not.

reagents under the same conditions. No isocyanide is formed and the characteristic offensive odour is absent, because its nitrogen is bonded to two methyl groups rather than one alkyl group.

Step 3: Conclusion Ethanamine gives a positive carbylamine test (offensive-smelling ethyl isocyanide), whereas dimethylamine gives a negative test.

Quick Tip to Solve: Count the alkyl groups attached to nitrogen: one in ethanamine permits the carbylamine test, while two in dimethylamine do not.

20(b)(ii). Write the product formed when benzene diazonium chloride is treated with KI. [1 mark]

Solution:

Concept:

- Arenediazonium salts undergo replacement of the diazonium group by a halogen, with liberation of nitrogen gas.
- Potassium iodide supplies iodide ions; iodine replaces the diazonium group directly, without a copper(I) salt.

Step 1: Identify the group being replaced Benzene diazonium chloride contains the $-N_2^+$ group bonded to the benzene ring. Treatment with KI replaces this group by iodine; the chloride counter-ion combines with potassium.

Step 2: Write the substitution reaction

$$C_6H_5N_2Cl + KI \longrightarrow C_6H_5I + N_2\uparrow + KCl$$

The evolution of stable nitrogen gas accompanies the substitution, and the benzene ring remains intact.

Step 3: Conclusion The organic product is **iodobenzene**, C_6H_5I.

Quick Tip to Solve: For a benzene diazonium salt with KI, replace the entire diazonium group by I and release nitrogen gas.

21. Classify the following sugars into monosaccharides and disaccharides:
Fructose, Lactose, Glucose, Maltose [2 marks]

Solution:

Concept:

- A monosaccharide is a carbohydrate that cannot be hydrolysed into simpler carbohydrate units.
- A disaccharide contains two monosaccharide residues joined by a glycosidic linkage and gives two monosaccharide molecules on hydrolysis.

Step 1: Identify the single sugar units Fructose and glucose are monosaccharides. Both have molecular formula $C_6H_{12}O_6$, but glucose is an aldohexose and fructose is a ketohexose. This difference in their

Quick Tip to Solve: Classify by the number of sugar units released on hydrolysis, not by whether the sugar has an aldehyde or ketone group.

functional groups does not alter their classification: neither contains a glycosidic linkage joining two sugar units.

Step 2: Identify the sugars containing two residues Lactose and maltose are disaccharides. Their classification is confirmed by their hydrolysis products:

$$\text{Lactose} + \text{H}_2\text{O} \longrightarrow \text{Glucose} + \text{Galactose},$$
$$\text{Maltose} + \text{H}_2\text{O} \longrightarrow 2\,\text{Glucose}.$$

In each case, cleavage of the glycosidic bond releases two monosaccharide molecules.

Step 3: Conclusion **Monosaccharides:** fructose and glucose.
Disaccharides: lactose and maltose.

Quick Tip to Solve: Classify by the number of sugar units released on hydrolysis, not by whether the sugar has an aldehyde or ketone group.

Section C (21 marks)

22. Give the structure of the major product expected from the following reactions: [3 marks]

22(a). Reaction of Ethanal with methyl-magnesium bromide followed by hydrolysis. [1 mark]

Solution:

Concept:

- A Grignard reagent supplies a nucleophilic alkyl group, which attacks the electrophilic carbonyl carbon of an aldehyde.
- Hydrolysis protonates the alkoxide intermediate to give an alcohol. An aldehyde other than methanal gives a secondary alcohol.

Step 1: Add the methyl group Ethanal, CH_3CHO, has a methyl group and a hydrogen attached to its carbonyl carbon. The methyl group from CH_3MgBr forms a new carbon-carbon bond at this carbon, producing the magnesium alkoxide:

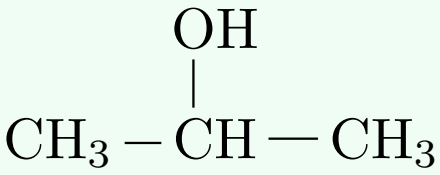
$$\text{CH}_3\text{CHO} + \text{CH}_3\text{MgBr} \longrightarrow \text{CH}_3\text{CH(OMgBr)CH}_3.$$

Step 2: Hydrolyse the alkoxide Water replaces the alkoxide's magnesium-containing group with hydrogen, giving an $-\text{OH}$ group without changing the carbon skeleton:

$$\text{CH}_3\text{CH(OMgBr)CH}_3 + \text{H}_2\text{O} \longrightarrow \text{CH}_3\text{CH(OH)CH}_3 + \text{Mg(OH)Br}.$$

The carbon bearing the hydroxyl group is now bonded to two methyl groups and one hydrogen, so the alcohol is secondary.

Quick Tip to Solve: Count the carbon atoms: ethanal contributes two and the Grignard methyl group contributes one, giving a three-carbon secondary alcohol.



Structure of propan-2-ol

Step 3: Conclusion The major product is propan-2-ol, $CH_3CH(OH)CH_3$, with the structure shown above.

Quick Tip to Solve: Count the carbon atoms: ethanal contributes two and the Grignard methyl group contributes one, giving a three-carbon secondary alcohol.

22(b). Hydration of But-1-ene in the presence of dilute sulphuric acid. [1 mark]

Solution:

Concept:

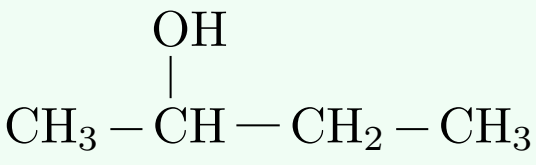
- Acid-catalysed hydration adds the elements of water across an alkene's double bond to form an alcohol.
- Markovnikov addition favours the pathway through the more stable carbocation: hydrogen adds to the double-bond carbon already bearing more hydrogen atoms.

Step 1: Form the more stable carbocation In but-1-ene, $CH_2{=}CHCH_2CH_3$, protonation at the terminal carbon produces a secondary carbocation at carbon 2. The alternative orientation would give a less stable primary carbocation, so it is disfavoured.

Step 2: Add water and remove a proton Water attacks carbon 2 of the secondary carbocation. Loss of a proton from the resulting oxonium ion regenerates the acid catalyst and leaves the hydroxyl group at carbon 2. The net hydration is

$$CH_2{=}CHCH_2CH_3 + H_2O \xrightarrow{H^+} CH_3CH(OH)CH_2CH_3.$$

The carbon chain retains four carbon atoms; the double bond becomes a single bond as hydrogen and hydroxyl are added across it.



Structure of butan-2-ol

Step 3: Conclusion The major product is butan-2-ol, $CH_3CH(OH)CH_2CH_3$, whose structure is shown above.

Quick Tip to Solve: For acid hydration of but-1-ene, place the hydroxyl group on carbon 2: this follows the secondary-carbocation pathway.

22(c). Reaction of phenol with bromine water. [1 mark]

Solution:

Concept:

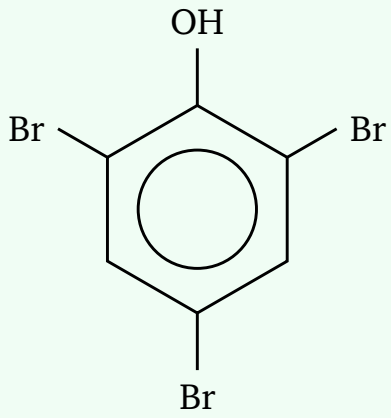
- The hydroxyl group strongly activates the benzene ring of phenol towards electrophilic substitution by donating an oxygen lone pair into the ring.
- The hydroxyl group directs incoming substituents to the ortho and para positions, numbered 2, 6 and 4 relative to the hydroxyl-bearing carbon 1.

Step 1: Identify the substituted positions With bromine water, phenol undergoes substitution at both ortho positions and the para position. Ring activation is sufficient for this reaction to occur readily without a Lewis acid catalyst. Three ring hydrogen atoms are replaced by bromine atoms, while the hydroxyl group remains attached.

Step 2: Write the balanced bromination reaction Each substitution consumes one molecule of bromine and releases one molecule of hydrogen bromide:

$$\mathrm{C_6H_5OH + 3\,Br_2 \longrightarrow C_6H_2Br_3OH + 3\,HBr.}$$

Bromine water is decolourised and a white precipitate forms. The aqueous reagent causes substitution at all three activated positions, rather than stopping at a single ortho or para substitution.



Structure of 2,4,6-tribromophenol

Step 3: Conclusion The major product is 2,4,6-tribromophenol, obtained as a white precipitate. Its structure is shown above, with bromine at both ortho positions and at the para position.

Quick Tip to Solve: For phenol with bromine water, put bromine at positions 2, 4 and 6; monobromination is associated with controlled bromination in a nonpolar solvent.

23. A compound 'X' with molecular formula C_3H_9N reacts with $C_6H_5SO_2Cl$ to give a solid, insoluble in alkali. Identify 'X' and give the IUPAC name of the product. Write the reaction involved. [3 marks]

Solution:

Concept:

- The Hinsberg reagent, benzenesulphonyl chloride, $C_6H_5SO_2Cl$, distinguishes primary, secondary and tertiary amines by their reaction products and solubility in alkali.
- A primary amine forms a sulphonamide with an acidic N–H bond, which dissolves in alkali. A secondary amine forms a sulphonamide without an N–H bond, which is insoluble in alkali.

Step 1: Infer the class of the amine Formation of a solid derivative proves that the compound reacts with the Hinsberg reagent. Its insolubility in alkali indicates a secondary amine: after sulphonylation, the nitrogen bears two carbon groups and no hydrogen. A primary amine would give an alkali-soluble derivative, while a tertiary amine lacks an N–H bond and does not form this sulphonamide.

Step 2: Use the molecular formula to identify X A secondary amine has the form R_2NH. The formula C_3H_9N provides three carbon atoms, so the two alkyl groups must be methyl and ethyl. Thus the structure is $CH_3CH_2NHCH_3$, whose IUPAC name is **N-methylethanamine**.

Step 3: Write the reaction and name the derivative The hydrogen on nitrogen is replaced by a benzenesulphonyl group:

$$C_6H_5SO_2Cl + CH_3CH_2NHCH_3 \longrightarrow C_6H_5SO_2N(CH_3)CH_2CH_3 + HCl.$$

In an alkaline reaction medium, the liberated acid is neutralised by the alkali. The solid product is **N-ethyl-N-methylbenzenesulphonamide**. It cannot form an alkali-soluble salt by loss of an N–H proton because no such bond remains.

Step 4: Conclusion X is **N-methylethanamine**, $CH_3CH_2NHCH_3$. The product is **N-ethyl-N-methylbenzenesulphonamide**, $C_6H_5SO_2N(CH_3)CH_2CH_3$.

Quick Tip to Solve: An alkali-insoluble Hinsberg derivative identifies a secondary amine; split its three carbon atoms into methyl and ethyl groups.

24. The rate constant of a reaction quadruples when the temperature changes from $300\,K$ to $320\,K$. Calculate the activation energy for this reaction.

[$\log 2 = 0.30,\ \log 4 = 0.60,\ 2.303R = 19.15\,J\,K^{-1}mol^{-1}$] [3 marks]

Solution:

Concept:

- The Arrhenius equation is $k = Ae^{-E_a/(RT)}$, where k is the rate constant, A the frequency factor, E_a the molar activation energy, R the gas constant and T the absolute temperature.
- For two temperatures, assuming the same A and E_a, elimination of A gives $\log(k_2/k_1) = \dfrac{E_a}{2.303R}(1/T_1 - 1/T_2)$. Here $\log$ denotes the common logarithm.

Quick Tip to Solve: For a rate-constant increase, put the larger rate constant in the numerator and pair it with $1/T_{low} - 1/T_{high}$; use 4, not 3, for quadrupling.

Step 1: Identify the two rate constants and temperatures Let k_1 be the rate constant at $T_1 = 300\,\text{K}$, and k_2 the rate constant at $T_2 = 320\,\text{K}$. Quadrupling means $k_2 = 4k_1$, so the ratio to use in the logarithm is $k_2/k_1 = 4$, not the increase $(k_2 - k_1)/k_1 = 3$. Both temperatures are already on the Kelvin scale.

Step 2: Substitute in the two-temperature Arrhenius equation Taking common logarithms of the Arrhenius equation and subtracting the equation at T_1 from that at T_2 gives

$$\log \frac{k_2}{k_1} = \frac{E_a}{2.303R}\frac{T_2 - T_1}{T_1 T_2}.$$

Use the supplied values $\log 4 = 0.60$ and $2.303R = 19.15\,\text{J K}^{-1}\text{mol}^{-1}$:

$$0.60 = \frac{E_a}{19.15}\left(\frac{320 - 300}{300 \times 320}\right).$$

Step 3: Rearrange and check the units Isolating E_a and evaluating with the supplied logarithm,

$$\begin{aligned} E_a &= 0.60 \times 19.15 \times \frac{300 \times 320}{20} \\ &= 55\,152\,\text{J mol}^{-1}. \end{aligned}$$

The temperature factor has units of kelvin, which cancel the inverse kelvin in $2.303R$. Since both $\log(k_2/k_1)$ and $1/T_1 - 1/T_2$ are positive, the calculated activation energy is positive, as expected.

Step 4: Conclusion The activation energy is $E_a = 55.152\,\text{kJ mol}^{-1}$, or approximately $\boxed{55.2\,\text{kJ mol}^{-1}}$, using the supplied constants.

Quick Tip to Solve: For a rate-constant increase, put the larger rate constant in the numerator and pair it with $1/T_{\text{low}} - 1/T_{\text{high}}$; use 4, not 3, for quadrupling.

25. Write IUPAC names of the following coordination compounds: (any three) [3 marks]

25(a). $K_3[Fe(CN)_6]$ [1 mark]

Solution:

Concept:

- Each cyanido ligand, CN^-, has charge -1; potassium is present as the cation K^+.
- An anionic iron complex is named ferrate, followed by the metal oxidation state in Roman numerals.

Step 1: Find the iron oxidation state Three K^+ ions in $K_3[Fe(CN)_6]$ make the complex charge -3. For iron oxidation state x:

$$x + 6(-1) = -3 \quad \Rightarrow \quad x = +3.$$

Six cyanido ligands give hexacyanido, and the negative complex requires ferrate(III). Name potassium first.

Step 2: Assemble the coordination name The six cyanido ligands give hexacyanido. Since the bracketed ion is negative, use ferrate(III), not iron(III). The potassium cation is named first, without a

Quick Tip to Solve: Find the bracket charge from three potassium ions before choosing ferrate and the Roman numeral.

numerical prefix.

Step 3: Conclusion Potassium hexacyanidoferrate(III).

Quick Tip to Solve: Find the bracket charge from three potassium ions before choosing ferrate and the Roman numeral.

25(b). $[Pt(en)_2Cl_2]^{2+}$ [1 mark]

Solution:

Concept:

- Ethane-1,2-diamine, abbreviated en, is a neutral bidentate ligand; chlorido has charge -1.
- Ligands are named alphabetically, ignoring multiplicative prefixes; two ethane-1,2-diamine ligands use bis.

Step 1: Find the platinum oxidation state In $[Pt(en)_2Cl_2]^{2+}$, both en ligands are neutral and each chlorido ligand is negative:

$$x + 2(0) + 2(-1) = +2 \quad \Rightarrow \quad x = +4.$$

Chlorido precedes ethane-1,2-diamine. The positive complex retains platinum(IV).

Step 2: Order the ligands and name the metal Chlorido comes before ethane-1,2-diamine alphabetically. Use dichlorido for the two chloride ligands and bis(ethane-1,2-diamine) for the two neutral chelating ligands. The complex is positive, so the metal retains the name platinum.

Step 3: Conclusion Dichloridobis(ethane-1,2-diamine)platinum(IV) ion.

Quick Tip to Solve: Treat en as neutral; two chlorido ligands make platinum(IV), despite the overall charge being $+2$.

25(c). $[Co(NH_3)_4Cl(ONO)]Cl$ [1 mark]

Solution:

Concept:

- Ammine is neutral, while chlorido and nitrito each carry charge -1. The external chloride ion fixes the complex charge.
- The notation ONO identifies an oxygen-bonded nitrito ligand, named nitrito-O. Name the cation before the chloride anion.

Step 1: Find the cobalt oxidation state The external Cl^- in $[Co(NH_3)_4Cl(ONO)]Cl$ makes the complex charge $+1$. Four ammines are neutral; chlorido and nitrito-O each contribute -1:

$$x + 4(0) - 1 - 1 = +1 \quad \Rightarrow \quad x = +3.$$

Order ligands as ammine, chlorido, nitrito-O; add chloride for the counter-ion.

Quick Tip to Solve: Use ONO to identify oxygen bonding and use the external chloride to obtain cobalt(III).

Step 2: Identify the donor atom and order the names The ligand sequence is ammine, chlorido, then nitrito-O. Four ammines give tetraammine. Since oxygen, rather than nitrogen, coordinates in ONO, retain the O donor designation. The counter-ion outside the brackets is named chloride.

Step 3: Conclusion Tetraamminechloridonitrito-O-cobalt(III) chloride.

Quick Tip to Solve: Use ONO to identify oxygen bonding and use the external chloride to obtain cobalt(III).

25(d). $[Zn(OH)_4]^{2-}$ [1 mark]

Solution:

Concept:

- Each hydroxido ligand, OH^-, carries charge -1. The sum of metal and ligand charges equals the charge on the complex.
- A negative zinc complex uses the metal name zincate; four identical hydroxido ligands take the prefix tetra.

Step 1: Find the zinc oxidation state In $[Zn(OH)_4]^{2-}$, the four hydroxido ligands contribute a total charge of -4:

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

Four hydroxido ligands give tetrahydroxido; the negative complex requires zincate(II).

Step 2: Assemble the anion name Four hydroxido ligands give tetrahydroxido. Because the whole complex is negatively charged, the metal name becomes zincate. Append the oxidation state II in parentheses; it specifies zinc and is distinct from the overall charge of the complex.

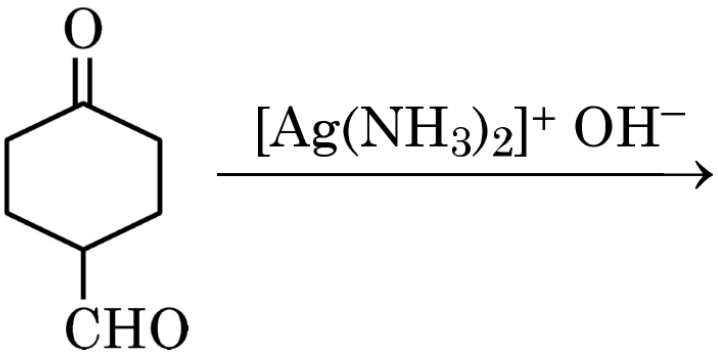
Step 3: Conclusion Tetrahydroxidozincate(II) ion.

Quick Tip to Solve: Keep the metal oxidation state separate from the ion charge: zinc is $+2$ although the complex is -2.

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26. Draw the structures of major product(s) in each of the following reactions: [3 marks]

26(a). [1 mark]



Solution:

Concept:

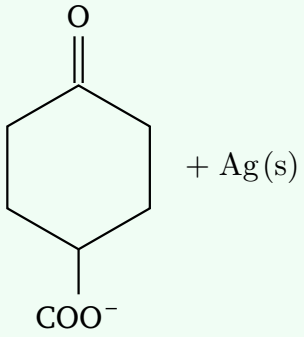
- Tollens' reagent oxidises an aldehyde group, $-\mathrm{CHO}$, to a carboxylate group, $-\mathrm{COO^-}$, in alkaline solution; an ordinary ketone group is unaffected.
- Oxidation changes $-\mathrm{CHO}$ into $-\mathrm{COO^-}$ without breaking its bond to the ring carbon. The printed medium is alkaline.

Step 1: Identify the oxidisable group The substrate contains a cyclic ketone and an aldehyde substituent at opposite ring positions. Tollens' reagent, $[\mathrm{Ag(NH_3)_2}]^+/\mathrm{OH^-}$, selectively oxidises the aldehyde, leaving the ketone unchanged.

Step 2: Oxidise only the aldehyde group The aldehyde becomes carboxylate in the printed alkaline medium. The balanced redox equation is

$$\mathrm{RCHO} + 2\,[\mathrm{Ag(NH_3)_2}]^+ + 3\,\mathrm{OH^-} \longrightarrow \mathrm{RCOO^-} + 2\,\mathrm{Ag} + 4\,\mathrm{NH_3} + 2\,\mathrm{H_2O}.$$

Here R is the ketone-containing cyclohexyl group. Acidification, if performed later, would convert the carboxylate into the carboxylic acid.

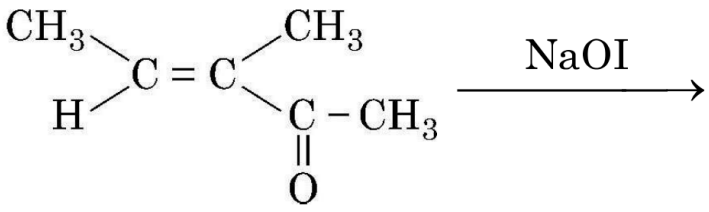


Carboxylate product; the ring ketone is retained.

Step 3: Conclusion The organic product is 4-oxocyclohexane-1-carboxylate, as drawn; silver is deposited. The ring ketone remains unchanged.

Quick Tip to Solve: With alkaline Tollens reagent, change only CHO to carboxylate; retain the ketone carbonyl and the ring.

26(b). [1 mark]



Solution:

Concept:

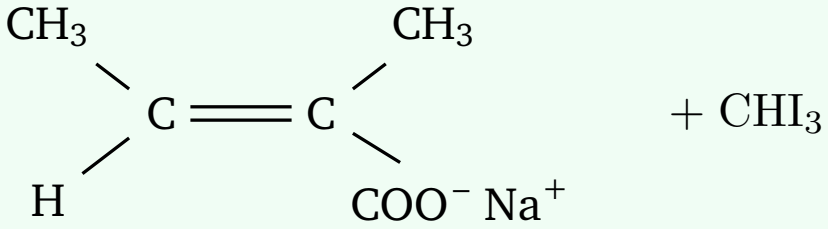
- A methyl ketone, $RCOCH_3$, undergoes the iodoform reaction with sodium hypoiodite to form RCOONa and yellow CHI_3.
- The methyl carbon of $-COCH_3$ becomes iodoform, whereas its carbonyl carbon remains in the carboxylate fragment.

Step 1: Locate the methyl ketone The right-hand side chain is $-COCH_3$. Sodium hypoiodite therefore causes the haloform reaction, with exhaustive iodination and cleavage of that methyl group. The alkene elsewhere in the molecule is retained in the standard product transformation.

Step 2: Cleave the methyl ketone group The side chain contains $-COCH_3$, so it gives the iodoform reaction. Replace this group by $-COO^- Na^+$; its methyl carbon becomes CHI_3. The carbon-carbon double bond and its substituent arrangement are retained:

$$CH_3CH{=}C(CH_3)COCH_3 \xrightarrow{NaOI} CH_3CH{=}C(CH_3)COONa + CHI_3.$$

This organic-product scheme gives sodium 2-methylbut-2-enoate and iodoform. It is not a Cannizzaro reaction: the reacting functional group here is a methyl ketone.

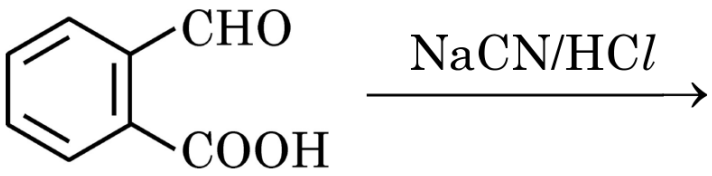


Sodium carboxylate and iodoform.

Step 3: Conclusion The products are sodium 2-methylbut-2-enoate and iodoform, CHI_3, with the alkene substituent arrangement retained as drawn.

Quick Tip to Solve: For NaOI, circle COCH3: its methyl carbon leaves as CHI3 and the carbonyl carbon becomes carboxylate.

26(c). [1 mark]



Solution:

Concept:

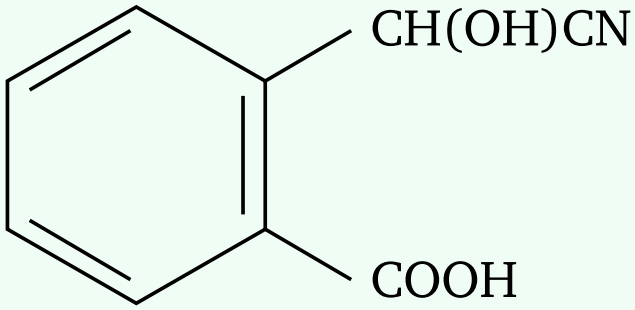
- Hydrogen cyanide, generated from NaCN/HCl, adds across an aldehyde carbonyl to form a cyanohydrin, RCH(OH)CN.
- Cyanide is a nucleophile: it forms a new carbon-carbon bond at the aldehyde carbonyl carbon, while the oxygen is protonated.

Step 1: Identify the addition site The benzene ring has adjacent $-$CHO and $-$COOH groups. The combination NaCN/HCl supplies HCN, which undergoes nucleophilic addition at the aldehyde group; the carboxylic acid group is not converted into a cyanohydrin.

Step 2: Add cyanide at the aldehyde carbonyl Cyanide attacks the electrophilic carbonyl carbon of $-$CHO. Protonation of the resulting alkoxide gives $-$CH(OH)CN. The neighbouring carboxylic acid group remains unchanged; the two substituents remain ortho on the benzene ring:

$$\text{o-HOOC}-\text{C}_6\text{H}_4-\text{CHO} + \text{HCN} \longrightarrow \text{o-HOOC}-\text{C}_6\text{H}_4-\text{CH(OH)CN}.$$

Addition creates a stereogenic carbon, so the cyanohydrin is obtained as a racemic mixture under these achiral conditions.



Cyanohydrin with the unchanged ortho carboxyl group.

Step 3: Conclusion The product is the cyanohydrin o-HOOC$-$C$_6$H$_4-$CH(OH)CN, with adjacent substituents on the ring as drawn.

Quick Tip to Solve: For HCN addition, replace CHO by CH(OH)CN and retain the ortho carboxylic acid group.

27. Calculate the emf of the following cell:

$Ni(s) + 2Ag^+(0.01\ M) \rightarrow Ni^{2+}(0.1\ M) + 2Ag(s)$

Given that $E^\circ_{cell} = 1.05$ V, log 10 = 1 [3 marks]

Solution:

Concept:

- The Nernst equation relates cell emf to concentrations: $E_{\text{cell}} = E^\circ_{\text{cell}} - \dfrac{0.0591}{n} \log Q$ at $298\,\text{K}$, where n is the number of electrons transferred and Q is the reaction quotient.
- Pure solids have unit activity and are omitted from Q. Dissolved species enter with powers equal to their stoichiometric coefficients; dilute-solution activities are approximated by molar concentrations relative to the standard concentration.

Step 1: Identify the electron transfer Nickel is oxidised at the anode and silver ions are reduced at the cathode:

$$\text{Ni}\,(\text{s}) \longrightarrow \text{Ni}^{2+}(\text{aq}) + 2\,\text{e}^-,$$
$$2\,\text{Ag}^+(\text{aq}) + 2\,\text{e}^- \longrightarrow 2\,\text{Ag}\,(\text{s}).$$

Therefore $n = 2$ for the cell reaction as written. The supplied standard cell potential is already for this complete reaction, so no additional electrode-potential subtraction is required.

Step 2: Form the reaction quotient The nickel-ion concentration is in the numerator, while the silver-ion concentration is squared in the denominator because its coefficient is two. Neither solid metal is included:

$$Q = \frac{[\text{Ni}^{2+}]}{[\text{Ag}^+]^2} = \frac{0.1}{(0.01)^2} = 10^3.$$

Thus $\log Q = 3 \log 10 = 3$. Squaring 0.01 gives 0.0001, not 0.02.

Step 3: Substitute in the Nernst equation Using the usual $298\,\text{K}$ form of the equation for this concentration-based emf calculation,

$$\begin{aligned} E_{\text{cell}} &= 1.05 - \frac{0.0591}{2} \log(10^3) \\ &= 1.05 - 0.08865 \\ &= 0.96135\,\text{V}. \end{aligned}$$

Since $Q > 1$, the logarithmic correction lowers the emf below its standard value; this agrees with the depletion of reactant silver ions relative to the standard state.

Step 4: Conclusion The cell emf is $\boxed{E_{\text{cell}} \simeq 0.961\,\text{V}}$, or approximately $0.96\,\text{V}$, at $298\,\text{K}$.

Quick Tip to Solve: For this cell, use n = 2 and square the silver-ion concentration in Q; Q = 1000 makes the Nernst correction a simple threefold factor.

28. Account for the following: [3 marks]

28(a). Haloalkanes react with NaCN to form both cyanides and isocyanides. [1 mark]

Solution:

Concept:

- An ambident nucleophile can form a bond through either of two alternative donor atoms. Cyanide ion, CN^-, can attack through carbon or nitrogen.
- In substitution of a haloalkane RX, R is an alkyl group and X is the halogen leaving group. The attack site determines the product connectivity.

Step 1: Explain the carbon-end attack NaCN is ionic and provides free cyanide ions. Attack through carbon gives an alkyl cyanide (nitrile):

$$\mathrm{RX} + \mathrm{CN}^- \longrightarrow \mathrm{RCN} + \mathrm{X}^-.$$

This pathway predominates with sodium cyanide.

Step 2: Explain the nitrogen-end attack Because cyanide is ambident, nitrogen can also form the new bond to the alkyl group, giving an isocyanide:

$$\mathrm{RX} + \mathrm{CN}^- \longrightarrow \mathrm{RNC} + \mathrm{X}^-.$$

This is the minor pathway with NaCN; the printed statement does not imply equal amounts of the two products.

Step 3: Conclusion Both products are possible because CN^- is ambident: RCN is the major product and RNC the minor product.

Quick Tip to Solve: Write the atom bonded directly to R: carbon gives RCN, whereas nitrogen gives RNC; NaCN favours the carbon connection.

28(b). Haloarenes do not undergo nucleophilic substitution reaction easily. [1 mark]

Solution:

Concept:

- Nucleophilic substitution requires breaking the carbon-halogen bond. A stronger bond is more difficult to cleave.
- In haloarenes, halogen is bonded directly to an sp^2-hybridised ring carbon, and its lone pair interacts with the aromatic π system.

Step 1: Explain the strength of the aryl-halogen bond Resonance delocalisation of a halogen lone pair into the benzene ring gives the aryl carbon-halogen bond partial double-bond character. The bond is consequently shorter and stronger than the corresponding bond in a haloalkane; attachment to an sp^2 carbon also contributes to its strength.

Step 2: Examine the substitution pathways The phenyl carbocation required for an ordinary S_N1 pathway is highly unstable. The usual backside attack of S_N2 is also difficult at the aromatic carbon

Quick Tip to Solve: First check that halogen is bonded directly to the aromatic ring; then invoke resonance strengthening of that bond.

because of the ring framework and its electron cloud. Thus haloarenes resist ordinary nucleophilic substitution under mild conditions.

Step 3: Conclusion Haloarenes are less reactive because their aryl carbon-halogen bond has partial double-bond character and ordinary S_N1 and S_N2 pathways are unfavourable.

Quick Tip to Solve: First check that halogen is bonded directly to the aromatic ring; then invoke resonance strengthening of that bond.

28(c). Benzyl chloride gives S_N1 reaction. [1 mark]

Solution:

Concept:

- An S_N1 reaction proceeds through a carbocation intermediate; stabilising that carbocation facilitates ionisation.
- A benzyl carbocation has its positively charged side-chain carbon directly adjacent to a benzene ring and is stabilised by resonance.

Step 1: Form the benzyl carbocation In benzyl chloride, chlorine is on the side chain rather than directly on the aromatic ring. Heterolytic bond cleavage gives

$$C_6H_5CH_2Cl \longrightarrow C_6H_5CH_2{}^+ + Cl^-.$$

This is the carbocation-forming step in the S_N1 pathway.

Step 2: Explain resonance stabilisation The vacant p orbital at the benzylic carbon overlaps with the aromatic system. The positive charge is delocalised over the benzylic carbon and the ortho and para ring positions in the resonance forms. This stabilises the carbocation intermediate, allowing a nucleophile to attack it in the subsequent step.

Step 3: Conclusion Benzyl chloride undergoes S_N1 substitution because ionisation produces a resonance-stabilised benzyl carbocation.

Quick Tip to Solve: Distinguish benzyl chloride from chlorobenzene: a CH2 group between the ring and Cl permits a stabilised benzyl carbocation.

Section D (8 marks)

The following questions are case-based questions. Read the case carefully and answer the questions that follow :

29(a). Certain organic compounds are required in small amounts in our diet but their deficiency causes specific disease. These compounds are called vitamins. Most of the vitamins cannot be synthesized in our body but plants can synthesize almost all of them. So they are considered as essential food factors. However, the bacteria of the gut can produce some of the vitamins required by us. All the vitamins are generally available in our diet. The term 'vitamin' was coined from the words vital + amine, since the earlier identified compounds had amino group. Vitamins are classified into two groups depending upon their solubility in water or fat namely – fat soluble vitamins and water soluble vitamins.

(a) What is the other name of vitamin B_6? [1 mark]

Solution:

Concept:

- Vitamins are essential dietary substances needed in small quantities; individual members of the vitamin B complex have distinct chemical names.
- Vitamin B_6 is a water-soluble vitamin known as pyridoxine in the standard vitamin-name classification.

Step 1: Identify the indicated member of the B complex The subscript in the question is 6, so use the name corresponding specifically to vitamin B_6. The general term B complex refers to several different vitamins and is not the requested other name.

Step 2: Match the vitamin to its chemical name The standard pairing is vitamin B_6–pyridoxine. Keep this separate from vitamin B_1, whose name is thiamine, and vitamin B_2, whose name is riboflavin; their subscripts identify different members of the group.

Step 3: Conclusion The other name of vitamin B_6 is **pyridoxine**.

Quick Tip to Solve: Check the subscript before recalling the name: B_1 is thiamine, but B_6 is pyridoxine.

29(b). Name the vitamin whose deficiency causes increased blood clotting time. [1 mark]

Solution:

Concept:

- Vitamin K is a fat-soluble vitamin required for normal blood coagulation.
- A deficiency disease can be identified by connecting the observed symptom with the physiological function of the missing vitamin.

Step 1: Interpret the change in clotting time Increased blood clotting time means that blood takes longer than normal to form a clot. This points to impaired coagulation rather than to a defect in vision or bone mineralisation.

Step 2: Connect coagulation with the required vitamin Vitamin K is needed for the formation of

Quick Tip to Solve: Link vitamin K with coagulation: a delay in clot formation points directly to vitamin K deficiency.

functional clotting proteins, including prothrombin, in the liver. When vitamin K is deficient, normal clot formation is delayed and bleeding may persist for longer. This explains the increased clotting time specified in the question.

Step 3: Conclusion Deficiency of **vitamin K** causes increased blood clotting time.

Quick Tip to Solve: Link vitamin K with coagulation: a delay in clot formation points directly to vitamin K deficiency.

29(c). Xerophthalmia is caused by the deficiency of which vitamin? Give two sources of this vitamin.

[2 marks]

Solution:

Concept:

- Vitamin A is a fat-soluble vitamin needed for normal vision and maintenance of the epithelial tissues of the eye.
- Xerophthalmia is a deficiency condition involving dryness of the eye; vitamin A deficiency may lead to hardening and damage of the cornea.

Step 1: Identify the deficient vitamin from the eye disorder Xerophthalmia is associated with a lack of vitamin A. This vitamin maintains healthy ocular surfaces, so its deficiency can cause abnormal drying of the conjunctiva and cornea. Vitamin A deficiency is also associated with night blindness, but xerophthalmia specifically concerns these dry-eye changes rather than merely difficulty seeing in dim light.

Step 2: Give two dietary sources Two sources are **carrots** and **fish liver oil**. Carrots supply carotenoids such as beta-carotene, which the body can convert into vitamin A. Fish liver oil supplies preformed vitamin A. Thus both are valid dietary sources, although one provides a precursor and the other the vitamin itself.

Step 3: Conclusion Xerophthalmia is caused by **vitamin A deficiency**. Two sources of vitamin A are **carrots and fish liver oil**.

Quick Tip to Solve: Pair xerophthalmia with vitamin A, then name one orange vegetable and one animal source: carrots and fish liver oil.

OR

29(c). Why can't vitamin C be stored in our body? Name the disease caused by the deficiency of this vitamin.

[2 marks]

Solution:

Concept:

- Vitamins are classified as water-soluble or fat-soluble according to their solubility. Vitamin C, also called ascorbic acid, is water-soluble.

Quick Tip to Solve: Link vitamin C to the pair "water-soluble, scurvy"; water solubility explains why a regular dietary supply is needed.

- The body does not maintain a substantial reserve of vitamin C; its excess is removed in urine. Deficiency therefore develops if an adequate supply is not maintained.

Step 1: Relate solubility to storage Vitamin C dissolves in the aqueous fluids of the body. Excess vitamin C is readily excreted through urine instead of being stored in body fat. Hence it cannot be stored as a long-term reserve and must be supplied regularly through the diet.

Step 2: Identify the deficiency disease Vitamin C is needed for the normal formation and maintenance of connective tissue. Its deficiency causes scurvy, whose characteristic features include bleeding gums and poor wound healing. This links the name of the disease to the tissue damage caused by inadequate vitamin C.

Step 3: Conclusion Vitamin C cannot be stored because it is water-soluble and excess amounts are excreted in urine. Its deficiency causes **scurvy**.

Quick Tip to Solve: Link vitamin C to the pair "water-soluble, scurvy"; water solubility explains why a regular dietary supply is needed.

30(a). Case: The oxidation number of the central atom in a complex is defined as the charge it would carry if all the ligands are removed along with the electron pairs that are shared with the central atom. Similarly the charge on the complex is the sum of the charges of the constituent parts i.e. the sum of the charges on the central metal ion and its surrounding ligands. Based on this, the complex is called neutral if the sum of the charges of the constituents is equal to zero. However, for an anion or cationic complex, the sum of the charges of the constituents is equal to the charge on the coordination sphere.

(a) Define ambidentate ligand with an example. [1 mark]

Solution:

Concept:

- A ligand donates a lone pair from a donor atom to a central metal ion to form a coordinate bond.
- An ambidentate ligand has two different possible donor atoms, but attaches through only one of them at a time to a given metal centre.

Step 1: Define the bonding choice An ambidentate ligand is a monodentate ligand capable of coordinating through either of two different donor atoms. The word does not mean that both atoms bind simultaneously, as in a bidentate ligand.

Step 2: Give a representative example The nitrite ion, NO_2^-, is ambidentate: it can coordinate through nitrogen or through oxygen. These alternative modes give nitro and nitrito bonding, respectively.

Step 3: Conclusion An ambidentate ligand can bind through either of two different donor atoms, one at a time; for example, NO_2^- binds through nitrogen or oxygen.

Quick Tip to Solve: For NO_2^-, name both possible donor atoms, N and O; do not describe ambidentate binding as simultaneous binding through both.

30(b). What type of isomerism is shown by $[Co(NH_3)_5Cl]SO_4$ and $[Co(NH_3)_5SO_4]Cl$? [1 mark]

Solution:

Concept:

- Ionisation isomers have the same overall composition but exchange a coordinated ligand with an ion outside the coordination sphere.
- The square brackets identify the coordination sphere. Counter-ions outside the brackets are released separately on dissolution.

Step 1: Compare the coordinated and free ions In $[Co(NH_3)_5Cl]SO_4$, chloride is coordinated to cobalt and sulfate is the counter-ion. In $[Co(NH_3)_5SO_4]Cl$, sulfate is coordinated and chloride is the counter-ion.

Step 2: Identify the structural change The two compounds therefore interchange Cl^- and SO_4^{2-} between the inside and outside of the coordination sphere. They furnish different free anions in solution: sulfate in the first case and chloride in the second.

Step 3: Conclusion The given pair exhibits **ionisation isomerism**.

Quick Tip to Solve: Compare what lies outside the brackets: exchange of a counter-ion with an inner-sphere ligand identifies ionisation isomerism.

30(c). Define Chelate effect. How does it affect the stability of complex? [2 marks]

Solution:

Concept:

- A chelating ligand contains two or more donor atoms that coordinate to the same metal ion, producing one or more rings containing the metal.
- The chelate effect is the enhanced stability of a complex containing chelating ligands compared with a corresponding complex containing comparable monodentate ligands.

Step 1: Explain chelate formation When a bidentate or polydentate ligand binds to a metal through several donor atoms, it forms a ring structure called a chelate. For example, ethane-1,2-diamine binds through its two nitrogen atoms to the same metal, forming a five-membered ring.

Step 2: Relate chelation to stability The ring-forming ligand is held at several points, so complete removal requires the loss of several metal-donor bonds. If one bond opens, the other donor remains attached and promotes re-formation of the ring. Chelation therefore increases the thermodynamic stability of the corresponding complex; for comparable ligands, its formation equilibrium is more favourable.

Step 3: Conclusion The chelate effect is the increased stability caused by coordination of a multidentate ligand through several donor atoms to form rings. Chelated complexes are more stable than comparable complexes with monodentate ligands.

Quick Tip to Solve: In a chelate-effect answer, state both the ring-forming attachment and the resulting increase in stability relative to comparable monodentate complexes.

OR

30(c). Find the coordination number and oxidation state of chromium in $Na_3[Cr(C_2O_4)_3]$. [2 marks]

Solution:

Concept:

- Coordination number is the number of donor atoms directly bonded to the central metal ion; a bidentate ligand contributes two donor atoms.
- The algebraic sum of the oxidation state of the metal and all ligand charges equals the charge on the coordination sphere. Oxalate, $C_2O_4^{2-}$, is a bidentate ligand of charge -2.

Step 1: Count the donor atoms The complex $[Cr(C_2O_4)_3]^{3-}$ contains three oxalate ligands. Each oxalate coordinates through two oxygen atoms to chromium. Count donor atoms rather than simply counting ligands:

$$\text{Coordination number} = 3 \times 2 = 6.$$

Step 2: Balance the charges The three sodium ions in $Na_3[Cr(C_2O_4)_3]$ contribute a total charge of $+3$, so the complex ion has charge -3. Let the oxidation state of chromium be x. Using the charge -2 of each oxalate ion,

$$\begin{aligned} x + 3(-2) &= -3, \\ x - 6 &= -3, \\ x &= +3. \end{aligned}$$

Sodium ions lie outside the coordination sphere and do not contribute to chromium's coordination number.

Step 3: Conclusion Chromium has **coordination number 6** and **oxidation state** $+3$ in $Na_3[Cr(C_2O_4)_3]$.

Quick Tip to Solve: Count oxalate twice for coordination number but use its charge of -2 for oxidation state; the three sodium ions determine the complex charge.

Section E (15 marks)

An organic compound (A) with the molecular formula $C_9H_{10}O$ forms 2,4-DNP derivative, reduces Fehling solution and undergoes Cannizzaro reaction. On vigorous oxidation, it gives 1,2-benzene dicarboxylic acid.

31(a)(i). Identify the compound (A) and write its IUPAC name. [2 marks]

Solution:

Concept:

- 2,4-DNP forms hydrazones with aldehydes and ketones. Cannizzaro disproportionation is shown by aldehydes without an α-hydrogen.
- Vigorous oxidation of oxidisable side chains on a benzene ring gives carboxyl groups at the original attachment positions.

Quick Tip to Solve: Use the adjacent dicarboxylic-acid product to place ethyl ortho to $-CHO$, and explicitly check the conflicting Fehling claim.

Step 1: Use the formula and oxidation product An aldehyde group $-CHO$ and an ethyl group $-CH_2CH_3$ on adjacent ring carbons give $C_6H_4(C_2H_5)CHO$, molecular formula $C_9H_{10}O$. Oxidation converts both side chains to $-COOH$, giving benzene-1,2-dicarboxylic acid. The aldehyde is attached directly to the ring and has no α-hydrogen, so Cannizzaro reaction is possible. These clues identify the candidate 2-ethylbenzaldehyde.

Step 2: Check the Fehling statement The printed statement that this compound reduces Fehling solution is inconsistent with the other identifying clues. An ordinary aromatic aldehyde such as 2-ethylbenzaldehyde does not give a positive Fehling test under the standard conditions. Therefore no compound can be asserted to satisfy all the stated tests in the usual CBSE treatment; the candidate must be stated with this qualification.

Step 3: Conclusion The formula, Cannizzaro reaction and oxidation product indicate 2-$C_2H_5C_6H_4CHO$, named 2-ethylbenzaldehyde. However, it does not reduce Fehling solution, so the printed clues are mutually inconsistent.

Quick Tip to Solve: Use the adjacent dicarboxylic-acid product to place ethyl ortho to $-CHO$, and explicitly check the conflicting Fehling claim.

Write the reaction of compound (A) with

31(a)(ii)(1). 2,4-Dinitrophenyl hydrazine [1 mark]

Solution:

Concept:

- Aldehydes react with 2,4-dinitrophenylhydrazine by condensation, eliminating water.
- The product contains the hydrazone linkage $C{=}N{-}NH$, and is usually a yellow or orange precipitate.

Step 1: Define the candidate and reagent groups The consistent structural clues in part (i) give 2-ethylbenzaldehyde. Write $R = 2\text{-}C_2H_5C_6H_4$ and $Ar = 2{,}4{-}(NO_2)_2C_6H_3$, so the aldehyde is RCHO and 2,4-DNP is H_2NNHAr. The separate Fehling claim remains inconsistent.

Step 2: Write the condensation

$$RCHO + H_2NNHAr \xrightarrow{H^+} RCH{=}NNHAr + H_2O$$

The aldehyde carbonyl group is converted into the corresponding 2,4-dinitrophenylhydrazone. This reaction confirms the presence of a carbonyl group but does not by itself distinguish an aldehyde from a ketone.

Step 3: Conclusion 2-Ethylbenzaldehyde forms its 2,4-dinitrophenylhydrazone, $RCH{=}NNHAr$, with elimination of one molecule of water.

Quick Tip to Solve: Keep the hydrazone linkage $CH{=}N{-}NHAr$; the carbonyl oxygen leaves as water in this condensation.

31(a)(ii)(2). Fehling solution [1 mark]

Solution:

Concept:

- Fehling solution is an alkaline copper(II)-tartrate reagent; a positive aldehyde test gives brick-red Cu_2O.
- Ordinary aromatic aldehydes do not reduce Fehling solution under standard test conditions.

Step 1: Check the proposed compound The formula, Cannizzaro behaviour and oxidation to benzene-1,2-dicarboxylic acid indicate 2-ethylbenzaldehyde, 2-$C_2H_5C_6H_4CHO$. Its $-CHO$ group is directly attached to an aromatic ring.

Step 2: Resolve the printed contradiction This aromatic aldehyde does not give the stated Fehling reduction. With Fehling solution, there is no brick-red Cu_2O precipitate under the standard test conditions. Thus no positive Fehling reaction equation can correctly be written for the candidate; writing one would contradict its known chemistry.

Step 3: Conclusion For 2-ethylbenzaldehyde, Fehling test is negative: no Cu_2O precipitate forms. The printed claim that compound (A) reduces Fehling solution is inconsistent with the remaining clues.

Quick Tip to Solve: Do not apply the generic aliphatic-aldehyde Fehling equation to an aromatic aldehyde attached directly to the ring.

31(a)(iii). Write the equation of compound (A) when it undergoes Cannizzaro reaction. [1 mark]

Solution:

Concept:

- An aldehyde without an α-hydrogen undergoes Cannizzaro disproportionation in concentrated alkali.
- One aldehyde molecule is reduced to an alcohol while another is oxidised to a carboxylate salt.

Step 1: Identify the reacting group For the 2-ethylbenzaldehyde candidate indicated by the consistent structural clues, define $R = 2\text{-}C_2H_5C_6H_4$. The aldehyde is RCHO; the ring carbon adjacent to $-CHO$ bears no hydrogen that can be removed as an α-hydrogen. The printed Fehling claim remains inconsistent.

Step 2: Write the balanced disproportionation

$$2\,RCHO + NaOH \xrightarrow{\text{conc.}} RCH_2OH + RCOONa$$

The products are (2-ethylphenyl)methanol and sodium 2-ethylbenzoate. The ring ethyl substituent is unchanged; only the two aldehyde groups undergo complementary reduction and oxidation.

Step 3: Conclusion Concentrated NaOH converts two molecules of 2-ethylbenzaldehyde into (2-ethylphenyl)methanol and sodium 2-ethylbenzoate in a 1:1 ratio.

Quick Tip to Solve: In Cannizzaro reaction, pair two $-CHO$ groups: one becomes $-CH_2OH$ and the other becomes $-COO^-$.

OR

Account for the following:

31(b)(i)(1). The alpha (α)-hydrogens of aldehydes and ketones are acidic in nature. [1 mark]

Solution:

Concept:

- An α-hydrogen is bonded to the carbon adjacent to a carbonyl carbon.
- Acidity increases when the conjugate base formed after loss of H^+ is stabilised.

Step 1: Remove an alpha hydrogen A base can remove an α-hydrogen from an aldehyde or ketone, leaving an enolate ion. The electron-withdrawing carbonyl group increases the tendency of this neighbouring C-H bond to release a proton.

Step 2: Show conjugate-base stabilisation For acetaldehyde, the enolate has resonance contributors

$$^{-}CH_2-CH=O \longleftrightarrow CH_2=CH-O^{-}.$$

The negative charge is delocalised between the α-carbon and the electronegative oxygen, rather than being localised solely on carbon. This resonance stabilisation favours deprotonation.

Step 3: Conclusion The α-hydrogens are acidic because their removal produces a resonance-stabilised enolate ion, assisted by the electron-withdrawing carbonyl group.

Quick Tip to Solve: To explain alpha-hydrogen acidity, draw the conjugate base and show how its charge can be delocalised onto oxygen.

31(b)(i)(2). Oxidation of aldehydes is easier than ketones. [1 mark]

Solution:

Concept:

- Aldehydes contain a hydrogen directly bonded to the carbonyl carbon; ketones have two carbon substituents there.
- The structural changes needed during oxidation determine how readily the reaction occurs.

Step 1: Examine aldehyde oxidation An aldehyde RCHO is readily oxidised to RCOOH. The hydrogen on the carbonyl carbon can be replaced by oxygen-containing functionality without breaking a carbon-carbon bond, so mild oxidants are sufficient.

Step 2: Compare the ketone requirement A ketone R–CO–R has no hydrogen on its carbonyl carbon. Oxidation normally requires cleavage of a carbon-carbon bond adjacent to the carbonyl group and therefore harsher conditions or stronger oxidising agents.

Step 3: Conclusion Aldehydes oxidise more easily because they form carboxylic acids without C-C bond cleavage; ketone oxidation generally requires breaking a C-C bond.

Quick Tip to Solve: Look for the hydrogen directly on the carbonyl carbon; do not confuse it with a hydrogen on the neighbouring alpha carbon.

Arrange the following in:

31(b)(ii)(1). Decreasing reactivity towards nucleophilic addition reaction propanal, acetone, benzaldehyde.

[1 mark]

Solution:

Concept:

- Nucleophiles attack the electrophilic carbonyl carbon; electron donation and steric hindrance reduce its reactivity.
- Aldehydes are generally more reactive than ketones, while aromatic conjugation lowers an aldehyde's reactivity relative to an aliphatic aldehyde.

Step 1: Compare the two aldehydes Propanal has an unconjugated aldehyde group. In benzaldehyde the carbonyl group is conjugated with the benzene ring, which reduces the positive character of the carbonyl carbon. Therefore propanal is more reactive than benzaldehyde.

Step 2: Place acetone in the sequence Acetone has two electron-donating methyl groups and greater crowding around its carbonyl carbon than the aldehydes. These electronic and steric effects make nucleophilic addition less favourable; in the standard comparison acetone is less reactive than benzaldehyde.

Step 3: Conclusion The decreasing order is

$$\text{Propanal} > \text{Benzaldehyde} > \text{Acetone}.$$

Quick Tip to Solve: Place the aliphatic aldehyde first, then the aromatic aldehyde; the ketone is last because of donation and crowding by two alkyl groups.

31(b)(ii)(2). Increasing order of boiling point: Propane, Ethanol, Dimethylether, Propanal. [1 mark]

Solution:

Concept:

- Boiling point increases with the strength of intermolecular attractions.
- Hydrogen bonding is stronger than ordinary dipole-dipole attractions, while nonpolar molecules mainly have dispersion forces.

Step 1: Compare propane, ether and aldehyde Propane is nonpolar and has only weak dispersion forces, so it boils first. Dimethyl ether is polar and has a higher boiling point. Propanal has a strongly polar carbonyl group and larger molecular mass, so its intermolecular attractions are stronger than those of dimethyl ether.

Step 2: Identify the hydrogen-bonded liquid Ethanol contains an O−H group and forms strong intermolecular hydrogen bonds. Neither dimethyl ether nor propanal has an O-H bond for comparable self-association, so ethanol has the highest boiling point of the four.

Quick Tip to Solve: Check for an O-H bond first: only ethanol can form an extensive hydrogen-bond network in its pure liquid.

Step 3: Conclusion The increasing order is

$$\text{Propane} < \text{Dimethyl ether} < \text{Propanal} < \text{Ethanol}.$$

Quick Tip to Solve: Check for an O-H bond first: only ethanol can form an extensive hydrogen-bond network in its pure liquid.

31(b)(iii). Give simple chemical test to distinguish between Benzoic acid and Benzaldehyde. [1 mark]

Solution:

Concept:

- Carboxylic acids react with sodium hydrogen carbonate to release carbon dioxide.
- Aldehydes do not have the acidic carboxyl proton required for this reaction.

Step 1: Add sodium hydrogen carbonate Treat separate small samples with aqueous $NaHCO_3$. Benzoic acid produces brisk effervescence of CO_2, while benzaldehyde produces no such effervescence under the same conditions.

Step 2: Write the distinguishing reaction

$$C_6H_5COOH + NaHCO_3 \longrightarrow C_6H_5COONa + H_2O + CO_2\uparrow$$

The gas can be confirmed as carbon dioxide by passing it through limewater, which turns milky. The absence of this acid-carbonate reaction identifies the benzaldehyde sample.

Step 3: Conclusion Use aqueous $NaHCO_3$: benzoic acid liberates CO_2 with brisk effervescence, whereas benzaldehyde does not.

Quick Tip to Solve: A bicarbonate test distinguishes $-COOH$ from $-CHO$ directly; look for carbon dioxide bubbles, not just dissolution.

32. Attempt any five of the following: [5 marks]

32(a). Ce(III) is easily oxidised to Ce(IV). Comment. [1 mark]

Solution:

Concept:

- Oxidation removes an electron and increases the oxidation state by one.
- A noble-gas electronic configuration can stabilise a higher oxidation state.

Step 1: Compare the ionic configurations Cerium has atomic number 58. Its ions have configurations $Ce^{3+} : [Xe]4f^1$ and $Ce^{4+} : [Xe]4f^0$. Thus the fourth electron is removed from the singly occupied $4f$ subshell.

Step 2: Explain the stabilisation The change $Ce^{3+} \longrightarrow Ce^{4+} + e^-$ produces the closed-shell xenon configuration. This extra stability explains why the $+4$ state is accessible for cerium, unlike most

Quick Tip to Solve: Write $4f^1$ for Ce^{3+} and $4f^0$ for Ce^{4+} to identify the closed-shell stabilisation.

lanthanoids which predominantly show +3.

Step 3: Conclusion Ce(III) can be oxidised to Ce(IV) because Ce^{4+} attains the stable noble-gas configuration $[Xe]$.

Quick Tip to Solve: Write $4f^1$ for Ce^{3+} and $4f^0$ for Ce^{4+} to identify the closed-shell stabilisation.

32(b). $E^\circ(Mn^{2+}/Mn)$ **is** $-1.18\,V$**. Why is this value highly negative in comparison to neighbouring d block elements?** [1 mark]

Solution:

Concept:

- A negative standard reduction potential indicates an unfavourable reduction relative to the standard hydrogen electrode.
- Half-filled d^5 subshells have extra exchange stability.

Step 1: Identify the stable ion Manganese has configuration $[Ar]3d^5 4s^2$. Loss of its two $4s$ electrons gives Mn^{2+} with the stable half-filled $[Ar]3d^5$ configuration.

Step 2: Relate stability to the reduction The electrode process is $Mn^{2+}(aq) + 2\,e^- \longrightarrow Mn\,(s)$. The exceptional stability of the aqueous divalent ion makes this reduction relatively difficult. Conversely, formation of Mn^{2+} from the metal is favoured.

Step 3: Conclusion The highly negative value, $-1.18\,V$, is associated with the extra stability of half-filled $3d^5$ Mn^{2+}, which resists reduction to Mn.

Quick Tip to Solve: Read the couple as a reduction: stable Mn^{2+} means difficult ion-to-metal reduction and a more negative potential.

32(c). Which element of 3d series has lowest enthalpy of atomisation and why? [1 mark]

Solution:

Concept:

- Enthalpy of atomisation is the energy required to form gaseous atoms from the elemental solid.
- Stronger metallic bonding gives a larger atomisation enthalpy.

Step 1: Examine the end of the 3d series Zinc has electronic configuration $[Ar]3d^{10}4s^2$. Its $3d$ subshell is completely filled, so it has no unpaired $3d$ electrons available to contribute strongly to metallic bonding.

Step 2: Compare the bond strength Compared with the other metals in the 3d series, zinc has weak metallic bonding. Consequently, less energy is needed to separate its solid lattice into individual gaseous atoms.

Step 3: Conclusion Zinc (Zn) has the lowest enthalpy of atomisation in the 3d series because its filled $3d^{10}$ subshell leads to weak metallic bonding.

Quick Tip to Solve: For atomisation, compare metallic bond strength; zinc has a filled d subshell and no unpaired d electrons.

32(d). What happens when sodium chromate is acidified? [1 mark]

Solution:

Concept:

- Chromate and dichromate ions interconvert in a pH-dependent equilibrium.
- Chromate is yellow, whereas dichromate is orange; chromium remains in oxidation state +6.

Step 1: Add hydrogen ions Acidification increases the concentration of H^+. These ions shift the chromate-dichromate equilibrium towards dichromate, consuming chromate ions.

Step 2: Write the balanced ionic equation

$$2\,{CrO_4}^{2-} + 2\,H^+ \rightleftharpoons {Cr_2O_7}^{2-} + H_2O$$

Both sides contain two chromium atoms, eight oxygen atoms and two hydrogen atoms, with net charge -2. The change is not a redox reaction.

Step 3: Conclusion On acidification, yellow sodium chromate solution changes to orange because dichromate ions are formed.

Quick Tip to Solve: Remember acid favours orange dichromate; adding alkali shifts the equilibrium back towards yellow chromate.

32(e). Zn, Cd and Hg are soft metals. Why? [1 mark]

Solution:

Concept:

- Metallic hardness depends on the strength of bonding between the metal atoms.
- Group 12 metals have filled $(n-1)d^{10}$ subshells and paired d electrons.

Step 1: Inspect the electronic structures Zn, Cd and Hg have valence configurations $(n-1)d^{10}ns^2$. Their filled d subshells lack unpaired electrons that would otherwise increase the strength of metallic bonding.

Step 2: Connect bonding with softness The relatively small d-electron contribution gives weak metallic bonding compared with many transition metals. Their atoms are held less strongly together, accounting for the low hardness; mercury is in fact liquid at ordinary room temperature.

Step 3: Conclusion Zn, Cd and Hg show weak metallic bonding because of their filled d^{10} configurations, accounting for their softness (and mercury being liquid at room temperature).

Quick Tip to Solve: Use the filled d subshell to explain weak metallic bonding; do not claim these metals lack all metallic bonding.

32(f). Why is permanganate titration not carried out in the presence of HCl? [1 mark]

Solution:

Concept:

- Acidified permanganate is a strong oxidising agent.
- The acid used in a redox titration must not itself consume the titrant.

Step 1: Identify the interfering ion Hydrochloric acid supplies chloride ions. Acidified MnO_4^- oxidises Cl^- to chlorine gas while itself being reduced to Mn^{2+}.

Step 2: Show why the titre is altered

$$2\,MnO_4^- + 16\,H^+ + 10\,Cl^- \longrightarrow 2\,Mn^{2+} + 8\,H_2O + 5\,Cl_2$$

This side reaction consumes additional permanganate, so its measured volume no longer represents only the substance being analysed. Dilute sulphuric acid is used instead.

Step 3: Conclusion HCl is unsuitable because permanganate oxidises its chloride ions to chlorine, consuming titrant and producing an erroneous titre.

Quick Tip to Solve: Choose dilute H_2SO_4 for permanganate titrations because chloride from HCl would also be oxidised.

32(g). The lower oxides of transition metals are basic whereas the highest are amphoteric/acidic. Give reason. [1 mark]

Solution:

Concept:

- As metal oxidation state increases, its polarising power and the covalent character of its oxides generally increase.
- Ionic metal oxides are usually basic; strongly covalent oxides in high oxidation states tend to be acidic.

Step 1: Explain the lower oxides In a low oxidation state the metal has relatively low polarising power. Its oxide is predominantly ionic, and the oxide ions react with acids. This gives basic behaviour, as illustrated by MnO.

Step 2: Explain the higher oxides At higher oxidation states, greater polarisation of oxygen increases covalent character. Intermediate oxides may be amphoteric, for example Cr_2O_3, while high oxidation-state oxides such as CrO_3 and Mn_2O_7 are acidic.

Step 3: Conclusion Lower oxides are basic because they are more ionic; increasing oxidation state increases covalent character, producing amphoteric or acidic oxides.

Quick Tip to Solve: Link increasing oxidation state to increasing polarisation, then to greater covalent character and acidity.

33(a)(i). Ishan's automobile radiator is filled with 1.0 kg of water. How many grams of ethylene glycol (Molar mass = $62\,\text{g mol}^{-1}$) must Ishan add to get the freezing point of the solution lowered to $-2.8\,^\circ\text{C}$. K_f for water is $1.86\,\text{K kg mol}^{-1}$. [3 marks]

Solution:

Concept:

- For a dilute solution, freezing-point depression is $\Delta T_f = iK_f m$, where K_f is the solvent freezing-point constant and m is molality.
- Ethylene glycol is a non-electrolyte, so $i = 1$. Molality is moles of solute per kilogram of solvent.

Step 1: Determine the required molality Pure water freezes at $0\,^\circ\text{C}$. The required lowering is a positive temperature difference:

$$\Delta T_f = 0 - (-2.8) = 2.8\,\text{K}.$$

With $K_f = 1.86\,\text{K kg mol}^{-1}$,

$$m = \frac{\Delta T_f}{K_f} = \frac{2.8}{1.86} = 1.5054\,\text{mol kg}^{-1}.$$

A Celsius temperature difference has the same numerical value as a kelvin difference.

Step 2: Convert moles to mass The solvent mass is $1.0\,\text{kg}$, so the required amount of glycol is

$$n = m \times 1.0\,\text{kg} = 1.5054\,\text{mol}.$$

Using its molar mass $M = 62\,\text{g mol}^{-1}$,

$$w = nM = 1.5054 \times 62 = 93.33\,\text{g}.$$

The denominator in molality is the initial mass of water, not the combined mass after adding glycol. Substitution gives $1.86(93.33/62)/1.0 \approx 2.8\,\text{K}$, confirming the desired depression.

Step 3: Conclusion Ishan must add approximately $93.3\,\text{g}$ of ethylene glycol to the $1.0\,\text{kg}$ of water.

Quick Tip to Solve: First use $0 - (-2.8) = 2.8\,\text{K}$; then multiply the calculated molality by solvent kilograms and the molar mass.

33(a)(ii). What type of deviation from Raoult's law is shown by ethanol and acetone mixture? Give reason. [2 marks]

Solution:

Concept:

- Raoult's law for an ideal mixture is $p_i = x_i p_i^\circ$, where x_i is mole fraction and p_i° is pure-component vapour pressure.
- Positive deviation occurs when escaping tendency is greater than in an ideal mixture because the unlike interactions are weaker overall.

Quick Tip to Solve: Disruption of ethanol hydrogen bonds increases escaping tendency: weaker overall attraction means positive vapour-pressure deviation.

Step 1: Compare the intermolecular attractions Pure ethanol molecules form an extensive intermolecular hydrogen-bond network through their –OH groups. Adding acetone disturbs this network and separates ethanol molecules. Ethanol-acetone attractions do occur, but they do not fully compensate for the disruption of the original attractions.

Step 2: Relate the change to vapour pressure The molecules escape into the vapour phase more readily than predicted for an ideal solution of the same composition. Consequently the measured total vapour pressure is greater than the Raoult-law value $x_{\text{ethanol}}p^{\circ}_{\text{ethanol}} + x_{\text{acetone}}p^{\circ}_{\text{acetone}}$. This behaviour is the criterion for a positive deviation.

Step 3: Conclusion The ethanol-acetone mixture shows positive deviation from Raoult's law because acetone disrupts ethanol-ethanol hydrogen bonding, weakening the overall intermolecular attractions.

Quick Tip to Solve: Disruption of ethanol hydrogen bonds increases escaping tendency: weaker overall attraction means positive vapour-pressure deviation.

OR

33(b)(i). Boiling point of water at 750 mm Hg pressure is $99.68\,^{\circ}\text{C}$. How much sucrose (Molar mass = $342\,\text{g mol}^{-1}$) is to be added to 500 g of water such that it boils at $100\,^{\circ}\text{C}$? (K_b for water = $0.52\,\text{K kg mol}^{-1}$.) [3 marks]

Solution:

Concept:

- Boiling-point elevation for a dilute solution is $\Delta T_b = iK_b m$, where m is solute moles per kilogram of solvent.
- Sucrose is a non-volatile non-electrolyte and does not dissociate, so its van't Hoff factor is $i = 1$.

Step 1: Calculate the elevation at the stated pressure At 750 mm Hg, the pure-water boiling point is $99.68\,^{\circ}\text{C}$. The required solution boiling point is $100\,^{\circ}\text{C}$ at this same pressure. Therefore

$$\Delta T_b = 100 - 99.68 = 0.32\,\text{K}.$$

The normal boiling point at a different pressure must not replace the given pure-solvent value. Addition of the non-volatile solute lowers the vapour pressure, requiring this increase in temperature to reach the external pressure.

Step 2: Find the amount of sucrose From $K_b = 0.52\,\text{K kg mol}^{-1}$,

$$m = \frac{0.32}{0.52} = 0.61538\,\text{mol kg}^{-1}.$$

The water mass is $500\,\text{g} = 0.500\,\text{kg}$; hence

$$n = 0.61538 \times 0.500 = 0.30769\,\text{mol}.$$

Quick Tip to Solve: Use the difference $100 - 99.68$, with both temperatures measured at 750 mm Hg, and convert solvent grams to kilograms.

Multiplying by $M = 342\,\text{g mol}^{-1}$,

$$w = 0.30769 \times 342 = 105.23\,\text{g}.$$

As a check, $0.52(105.23/342)/0.500 \approx 0.32\,\text{K}$, so the calculated boiling point is $99.68 + 0.32 = 100\,^\circ\text{C}$.

Step 3: Conclusion Approximately $105.2\,\text{g}$ of sucrose must be added to $500\,\text{g}$ of water.

Quick Tip to Solve: Use the difference $100 - 99.68$, with both temperatures measured at 750 mm Hg, and convert solvent grams to kilograms.

33(b)(ii). State Henry's law and write its any one application. [2 marks]

Solution:

Concept:

- Henry's law relates the partial pressure of a gas to its equilibrium solubility in a liquid at constant temperature.
- In the CBSE convention, $p = K_H x$, with p the gas partial pressure, x its mole fraction in solution and K_H Henry's law constant.

Step 1: State the law precisely At a fixed temperature, the partial pressure of a gas above a solution is proportional to its mole fraction dissolved in that solution:

$$p = K_H x.$$

Equivalently, for a given gas-solvent pair and temperature, $x = p/K_H$, so raising the gas pressure increases its dissolved concentration. The constant depends on the gas, solvent and temperature.

Step 2: Apply the pressure-solubility relation Soft drinks and soda water are bottled under high carbon dioxide pressure. The large CO_2 partial pressure increases the amount of gas dissolved in the drink. Opening the bottle reduces the pressure above the liquid, lowers the equilibrium solubility and allows excess CO_2 to escape as bubbles.

Step 3: Conclusion Henry's law is $p = K_H x$ at constant temperature; one application is dissolving CO_2 in soft drinks by bottling them under high pressure.

Quick Tip to Solve: Write partial pressure, constant temperature and $p = K_H x$; high-pressure carbonation gives a direct application.