UP Board Class 12 Chemistry 2026 Set 347 EB Question Paper with Solutions

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General Instructions

(i) This booklet contains 26 questions, each provided with a complete, step-by-step solution.

(ii) It comprises 6 single-correct multiple-choice questions.

(iii) Attempt each question on your own before reviewing the given solution.

1. The unit of rate and rate constant is same for which order of reaction?

(A) First

(B) Second

(C) Third

(D) Zero

Correct Answer: (D) Zero

Solution:

Step 1: The rate of a reaction is measured as change in concentration per unit time, so its unit is always $mol\,L^{-1}\,s^{-1}$.

Step 2: For a reaction of order n, rate $= k[A]^n$, so $k = \dfrac{\text{rate}}{[A]^n}$ and the unit of k is $\dfrac{mol\,L^{-1}\,s^{-1}}{(mol\,L^{-1})^n} = mol^{1-n}\,L^{n-1}\,s^{-1}$.

Step 3: The unit of k equals the unit of rate only when $1 - n = 1$, i.e. $n = 0$.

Step 4: For a zero order reaction, rate $= k[A]^0 = k$, so k carries the same unit $mol\,L^{-1}\,s^{-1}$ as the rate. (First order k is s^{-1}; second order L

$mol^{-1}\,s^{-1}$; third order $L^2\,mol^{-2}\,s^{-1}$, all different from the rate unit.)

Answer: Zero order.

Quick Tip: Unit of k is $mol^{1-n}L^{n-1}s^{-1}$; set it equal to the rate unit $molL^{-1}s^{-1}$.

2. Which of the following is the mathematical form of Raoult's law?

(A) $\frac{P^0 - P}{P^0} = \frac{n}{n+N}$

(B) $\frac{P^0 - P}{P^0} = \frac{N}{n+N}$

(C) $\frac{P^0 - P}{P} = \frac{n}{N+n}$

(D) $\frac{P - P^0}{P^0} = \frac{n}{n+N}$

Correct Answer: (A) $\frac{P^0 - P}{P^0} = \frac{n}{n+N}$

Solution:

Step 1: For a solution of a non-volatile solute, Raoult's law states that the relative lowering of vapour pressure equals the mole fraction of the solute.

Step 2: If P^0 is the vapour pressure of pure solvent and P that of the solution, then $\frac{P^0 - P}{P^0} = x_{solute} = \frac{n}{n+N}$, where n = moles of solute and N = moles of solvent.

Step 3: This is exactly option (i), so option 1 is correct.

Step 4: Why the others are wrong: option (ii) uses N (solvent) in the numerator, which is the mole fraction of solvent; option (iii) divides by P instead of P^0; option (iv) reverses the sign giving a negative

value.

Answer: $\frac{P^0 - P}{P^0} = \frac{n}{n+N}$.

Quick Tip: Relative lowering of vapour pressure equals the mole fraction of the solute, $n/(n+N)$.

3. The number of unpaired electrons in Cu^{2+} is

(A) 2

(B) 3

(C) 1

(D) 4

Correct Answer: (C) 1

Solution:

Step 1: Copper has atomic number 29, so its ground-state configuration is $[Ar]3d^{10}4s^1$.

Step 2: To form Cu^{2+}, two electrons are removed. The 4s electron leaves first, then one 3d electron, giving $Cu^{2+} = [Ar]3d^9$.

Step 3: In $3d^9$ the five d-orbitals hold 9 electrons: four orbitals are fully paired (8 electrons) and one orbital has a single electron.

Step 4: Hence there is exactly 1 unpaired electron.

Answer: 1.

Quick Tip: Cu^{2+} is $3d^9$; count the unpaired electrons in a d^9 set.

4. Chloroform is oxidised in the presence of sunlight to form

(A) CCl_4

(B) $COCl_2$

(C) CH_2Cl_2

(D) $CHCl_3$

Correct Answer: (B) $COCl_2$

Solution:

Step 1: Chloroform ($CHCl_3$) slowly reacts with atmospheric oxygen in the presence of sunlight (air and light oxidation).
Step 2: The product is the poisonous gas carbonyl chloride, also called phosgene, $COCl_2$.
Step 3: The reaction is

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

Step 4: This is why chloroform is stored in dark, well-filled bottles with a little ethanol added, which destroys any phosgene formed.
Hence the answer is $COCl_2$.

Quick Tip: Chloroform + air + light gives a toxic gas; think phosgene.

5. Glucose does not react with which of the following?

(A) Bromine water

(B) $NaHSO_3$

(C) $C_6H_5NHNH_2$

(D) $(CH_3CO)_2O$

Correct Answer: (B) $NaHSO_3$

Solution:

Step 1: Test each reagent against the known reactions of glucose.
Step 2: Bromine water oxidises the $-CHO$ group of glucose to gluconic acid, so a reaction occurs.
Step 3: Phenylhydrazine ($C_6H_5NHNH_2$) reacts with glucose to give the yellow crystalline osazone, so a reaction occurs.
Step 4: Acetic anhydride $(CH_3CO)_2O$ acetylates the five $-OH$ groups to give glucose pentaacetate, so a reaction occurs.
Step 5: Glucose does NOT form the aldehyde-bisulphite addition product with $NaHSO_3$. This failure shows that the free $-CHO$ group is largely absent because glucose exists mainly as a cyclic hemiacetal.
Answer: $NaHSO_3$.

Quick Tip: Which classic reagent fails because glucose has no free aldehyde group (cyclic hemiacetal)?

6. Formaldehyde reacts with KOH to give methanol and potassium formate. What is the name of the reaction?

(A) Perkin reaction

(B) Wittig reaction

(C) Cannizzaro reaction

(D) Reimer-Tiemann reaction

Correct Answer: (C) Cannizzaro reaction

Solution:

Step 1: Formaldehyde ($HCHO$) has no α-hydrogen atom.
Step 2: Aldehydes lacking an α-hydrogen, when warmed with concentrated alkali, undergo self oxidation-reduction (disproportionation).
Step 3: One molecule is reduced to an alcohol (methanol) while another is oxidised to the salt of the acid (potassium formate):

$$2HCHO + KOH \rightarrow CH_3OH + HCOOK$$

Step 4: This disproportionation of an aldehyde without α-H is called the Cannizzaro reaction. (Perkin uses anhydrides, Wittig uses ylides, Reimer-Tiemann is phenol formylation, so they do not apply.)
Answer: Cannizzaro reaction.

Quick Tip: An aldehyde with no α-hydrogen disproportionates with strong base; name that reaction.

7. The rate constant for a first order reaction is 60 sec^{-1}. How much time will it take for the reactant to reduce to 1/16th of its initial concentration?

Correct Answer: —

Solution:

Step 1 (Formula): For a first order reaction,

$$t = \frac{2.303}{k} \log \frac{[A]_0}{[A]}$$

Step 2 (Given): $k = 60\ s^{-1}$; the reactant reduces to 1/16 of its initial value, so $\frac{[A]_0}{[A]} = 16$.

Step 3 (Substitution):

$$t = \frac{2.303}{60} \log 16$$

Step 4 (Arithmetic): $\log 16 = 1.204$, so $t = \frac{2.303 \times 1.204}{60} = \frac{2.773}{60}$.

Step 5: $t = 0.0462\ s$.

$$\boxed{t \approx 0.046\ \text{s}}$$

Quick Tip: Use $t = \frac{2.303}{k} \log \frac{[A]_0}{[A]}$ with ratio 16, or note that 1/16 is four half-lives.

8. The freezing point decreases by 0.40 K, when 1.00 g non-electrolyte is dissolved in 50 g benzene. The value of K_f for benzene is 5.12 K kg mol^{-1}. Calculate the molar mass of the solute.

Correct Answer: —

Solution:

Step 1 (Formula): Depression in freezing point is a colligative property,

$$\Delta T_f = K_f \times m = K_f \times \frac{w \times 1000}{M \times W}$$

where w = mass of solute, W = mass of solvent in grams, M = molar mass of solute.

Step 2 (Rearrange for M):

$$M = \frac{K_f \times w \times 1000}{\Delta T_f \times W}$$

Step 3 (Given): $K_f = 5.12$, $w = 1.00\ g$, $W = 50\ g$, $\Delta T_f = 0.40\ K$.

Step 4 (Substitution):

$$M = \frac{5.12 \times 1.00 \times 1000}{0.40 \times 50}$$

Step 5 (Arithmetic): Numerator $= 5120$; denominator $= 20$; $M = 5120/20 = 256$.

$$\boxed{M = 256\ \text{g mol}^{-1}}$$

Quick Tip: Use $M = \frac{K_f\, w\, 1000}{\Delta T_f\, W}$ with $w = 1$ g, $W = 50$ g.

9. What is meant by the chelate effect? Give example also.

Correct Answer: —

Solution:

Step 1 (Definition): When a bidentate or polydentate ligand binds to a central metal ion through two or more donor atoms, it forms a ring structure called a chelate.
Step 2 (Chelate effect): The chelate effect is the extra stability shown by a complex containing chelate (ring-forming) ligands compared with a similar complex containing an equal number of monodentate ligands.
Step 3 (Reason): Ring formation greatly increases the stability, mainly because breaking a chelate needs several bonds to snap at once, and the process is favoured by a positive entropy change (more free particles are released into solution).
Step 4 (Example): $[Ni(en)_3]^{2+}$ (en = ethylenediamine, a bidentate ligand) is far more stable than $[Ni(NH_3)_6]^{2+}$, even though both have six $Ni-N$ bonds. This greater stability is due to the chelate effect.

Quick Tip: Extra stability from ring-forming polydentate ligands; compare en versus ammonia complexes.

10. The resistance of a conductivity cell filled with 0.1 mol L^{-1} KCl solution is 100 Ω. If the resistance of the same cell when filled with 0.02 mol L^{-1} KCl solution is 520 Ω, find the conductivity and molar conductivity of the 0.02 mol L^{-1} KCl solution. The conductivity of a 0.1 mol L^{-1} KCl solution is 1.29 S/m.

Correct Answer: —

Solution:

Step 1 (Cell constant): Cell constant $G^* = \kappa \times R$. Using the 0.1 mol L^{-1} data:

$$G^* = 1.29\ \text{S m}^{-1} \times 100\ \Omega = 129\ \text{m}^{-1}$$

Step 2 (Conductivity of 0.02 mol L^{-1}): $\kappa = \dfrac{G^*}{R} = \dfrac{129}{520}$.

Step 3 (Arithmetic):

$$\kappa = 0.248\ \text{S m}^{-1}$$

Step 4 (Molar conductivity formula):

$$\Lambda_m = \frac{\kappa \times 1000}{c}$$

with κ in S cm^{-1} and c in mol L^{-1}. Convert $\kappa = 0.248\ \text{S m}^{-1}$ $= 0.00248\ \text{S cm}^{-1}$.

Step 5 (Substitution):

$$\Lambda_m = \frac{0.00248 \times 1000}{0.02} = \frac{2.48}{0.02}$$

Step 6:

$$\boxed{\kappa = 0.248\ \text{S m}^{-1}, \quad \Lambda_m = 124\ \text{S cm}^2\ \text{mol}^{-1}}$$

Quick Tip: Find the cell constant κR from the 0.1 M data, reuse it for the 0.02 M cell, then $\Lambda_m = \kappa/c$.

11. What are the characteristics of transition metals? Why are they called transition metals?

Correct Answer: —

Solution:

Step 1 (Characteristics of transition metals):

1. They show variable oxidation states (for example Fe as +2 and +3, Mn from +2 to +7).
2. Their ions and compounds are usually coloured because of d-d electronic transitions.
3. Many are paramagnetic due to the presence of unpaired d-electrons.
4. They and their compounds often act as good catalysts (for example Fe in the Haber process, V_2O_5 in the contact process).
5. They readily form complex (coordination) compounds because of small size and high charge.
6. They form alloys and interstitial compounds, and have high melting and boiling points, high density and good hardness (strong metallic bonding using d-electrons).

Step 2 (Why they are called transition metals): They are placed in the middle of the periodic table between the strongly electropositive s-block metals on the left and the p-block elements on the right. They represent a gradual transition (change) in properties from the highly reactive s-block to the less metallic p-block.

Step 3: They are formally defined as elements whose atoms or stable ions have partly filled d-orbitals, which is the source of all the above properties.

Quick Tip: List variable oxidation states, colour, paramagnetism, catalysis, complex formation; the name reflects their bridging position with partly filled d-orbitals.

12. Write two reactions of phenol that demonstrate its acidic nature.

Correct Answer: —

Solution:

Step 1 (Why phenol is acidic): Phenol can lose the hydrogen of its $-OH$ group as H^+. The resulting phenoxide ion is stabilised by resonance with the benzene ring, so phenol behaves as a weak acid.
Step 2 (Reaction 1 with a strong base): Phenol reacts with sodium hydroxide to form sodium phenoxide and water:

$$C_6H_5OH + NaOH \rightarrow C_6H_5ONa + H_2O$$

Neutralising a base is proof of acidic character.
Step 3 (Reaction 2 with an active metal): Phenol reacts with sodium metal, liberating hydrogen gas:

$$2C_6H_5OH + 2Na \rightarrow 2C_6H_5ONa + H_2 \uparrow$$

Displacement of hydrogen by a metal again confirms its acidic nature.
Step 4: Both reactions show phenol donating the $O-H$ proton, which demonstrates its acidic behaviour.

Quick Tip: Show phenol forming a salt with NaOH and releasing H_2 with sodium metal.

13. Explain Aldol condensation with a chemical reaction.

Correct Answer: —

Solution:

Step 1: Definition. Aldol condensation is a reaction in which two molecules of an aldehyde or ketone that contain at least one α-hydrogen atom combine in the presence of a dilute base (dilute NaOH or KOH) to form a β-hydroxy aldehyde (called an aldol) or a β-hydroxy ketone (called a ketol).
Step 2: Why an α-hydrogen is needed. The base removes an acidic α-hydrogen to form a carbanion (enolate ion). This carbanion acts as the nucleophile and attacks the carbonyl carbon of a second molecule.
Step 3: Aldol formation (example with acetaldehyde).

$$2\,CH_3CHO \xrightarrow{dil.\,NaOH} CH_3CH(OH)CH_2CHO$$

The product is 3-hydroxybutanal (the aldol).
Step 4: Condensation (loss of water). On warming, the aldol loses a water molecule to give an α,β-unsaturated aldehyde.

$$CH_3CH(OH)CH_2CHO \xrightarrow{\Delta,\,-H_2O} CH_3CH=CHCHO$$

The final product is but-2-enal (crotonaldehyde).
Result: Acetaldehyde undergoes aldol condensation to finally give but-2-enal.

Quick Tip: Two carbonyl molecules that have an α-hydrogen combine in dilute base to give a β-hydroxy carbonyl (aldol), which on heating loses water. Try acetaldehyde.

14. What is an isotonic solution? Explain with an example.

Correct Answer: —

Solution:

Step 1: Definition. Two solutions that have the **same osmotic pressure** at a given temperature are called isotonic (or iso-osmotic) solutions.

Step 2: Consequence. Since osmotic pressure depends on molar concentration ($\pi = CRT$), isotonic solutions have the **same molar concentration** of solute particles. When they are separated by a semipermeable membrane there is **no net osmosis** (no flow of solvent) between them.

Step 3: Example. A 0.9% (mass/volume) solution of NaCl, called normal saline, is isotonic with the fluid inside human red blood cells. That is why 0.9% NaCl is used for intravenous injections: the blood cells neither swell nor shrink in it.

Step 4: Comparison. If a cell is placed in a hypertonic solution (higher osmotic pressure) it shrinks, and in a hypotonic solution (lower osmotic pressure) it swells and may burst. Only in an isotonic solution does it stay unchanged.

Quick Tip: Same osmotic pressure at the same temperature means the same molar concentration, so no osmosis occurs. Think of 0.9% NaCl and blood cells.

15. Write the uses of freon. What is its impact on the environment?

Correct Answer: —

Solution:

Step 1: What freons are. Freons are chlorofluorocarbons (CFCs), i.e. compounds of carbon containing both chlorine and fluorine. The most

common is Freon-12, dichlorodifluoromethane, CCl_2F_2.

Step 2: Uses.

• As refrigerants in refrigerators and air conditioners.

• As propellants in aerosol sprays (perfumes, deodorants, insecticides).

• As blowing agents for making plastic foams and as cleaning solvents for electronic parts.

Step 3: Environmental impact. CFCs are very stable, so they slowly rise into the stratosphere. There, high-energy UV radiation breaks the C-Cl bond and produces chlorine free radicals:

$$CF_2Cl_2 \xrightarrow{UV} Cl^{\bullet} + CF_2Cl^{\bullet}$$

Step 4: Ozone destruction. The chlorine radical attacks ozone and destroys it in a chain (catalytic) manner:

$$Cl^{\bullet} + O_3 \rightarrow ClO^{\bullet} + O_2$$

$$ClO^{\bullet} + O \rightarrow Cl^{\bullet} + O_2$$

The Cl radical is regenerated, so one radical destroys thousands of ozone molecules, creating the ozone hole.

Step 5: Effect. Ozone depletion lets more harmful UV-B radiation reach the earth, causing skin cancer, cataracts, ageing of skin, and damage to plants and aquatic life.

Quick Tip: Freons are CFCs such as CCl_2F_2, used as refrigerants and propellants; in the stratosphere they release Cl radicals that deplete the ozone

layer.

16. (i) Write the electronic configuration of the following ions: (a) Cr^{3+} (b) Cu^{2+}.
(ii) Write the formula of chromate and dichromate ions.

Correct Answer: —

Solution:

Step 1: Rule for writing ion configurations. First write the configuration of the neutral atom, then remove electrons for a cation. For d-block ions, electrons are removed from the outer **4s** orbital first and then from 3d.

Step 2: Cr^{3+} $(Z = 24)$. Neutral chromium: [Ar] $3d^5\ 4s^1$. Removing 3 electrons (first the 4s electron, then two 3d electrons) gives:
Cr^{3+}: [Ar] $3d^3$, i.e. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^3$.

Step 3: Cu^{2+} $(Z = 29)$. Neutral copper: [Ar] $3d^{10}\ 4s^1$. Removing 2 electrons (first 4s, then one 3d) gives:
Cu^{2+}: [Ar] $3d^9$, i.e. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9$.

Step 4: Formulae of the ions.

Chromate ion: $CrO_4^{2−}$

Dichromate ion: $Cr_2O_7^{2−}$

Quick Tip: Remove 4s before 3d: Cr^{3+} is $[Ar]3d^3$ and Cu^{2+} is $[Ar]3d^9$. Chromate is $CrO_4^{2−}$, dichromate is $Cr_2O_7^{2−}$.

17. State Henry's law and its important applications.

Correct Answer: —

Solution:

Step 1: Statement of Henry's law. At a constant temperature the solubility of a gas in a liquid is directly proportional to the pressure of the gas above the liquid. In other words, the partial pressure of the gas (p) in the vapour phase is proportional to its mole fraction (x) in the solution.

Step 2: Mathematical form.

$$p = K_H\, x$$

where K_H is the Henry's law constant. A higher value of K_H means lower solubility of the gas.

Step 3: Applications.

• **Soft drinks and soda water:** to dissolve more CO_2, the bottles are sealed under high pressure of carbon dioxide.

• **Deep-sea (scuba) diving:** at depth the high pressure increases the solubility of nitrogen in blood; while coming up it bubbles out and causes 'bends', so divers use air diluted with helium, which is less soluble.

• **High altitudes:** the partial pressure of oxygen is low, so less oxygen dissolves in a climber's blood, causing weakness and poor thinking (anoxia).

Quick Tip: Henry's law: the partial pressure of a gas is proportional to its mole fraction in solution, $p = K_H x$. Think of soda bottles, scuba diving and high-altitude anoxia.

18. (i) Explain reduction of nitriles, with chemical reaction.
(ii) Write only the chemical equation for the reaction that occurs when aniline is heated with chloroform in the presence of alcoholic KOH.

Correct Answer: —

Solution:

Part (i): Reduction of nitriles.

Step 1: What happens. Nitriles ($R\text{-}C \equiv N$) contain a carbon-nitrogen triple bond. On reduction (addition of hydrogen) this triple bond is converted to a single bond, giving a primary amine. Suitable reducing agents are H_2 with a Ni / Pt / Pd catalyst, or $LiAlH_4$, or sodium in alcohol (Mendius reduction).

Step 2: Equation.

$$R\text{-}C \equiv N + 2H_2 \xrightarrow{Ni} R\text{-}CH_2\text{-}NH_2$$

For example, methyl cyanide gives ethylamine:

$$CH_3CN + 2H_2 \xrightarrow{Ni} CH_3CH_2NH_2$$

The product is a primary amine having one more carbon than the parent alkyl group.

Part (ii): Carbylamine (isocyanide) reaction of aniline.

Step 3: Aniline, a primary amine, on heating with chloroform and alcoholic KOH gives foul-smelling phenyl isocyanide (carbylamine):

$$C_6H_5NH_2 + CHCl_3 + 3KOH \xrightarrow{\Delta} C_6H_5NC + 3KCl + 3H_2O$$

Quick Tip: Nitriles are reduced (H_2/Ni or $LiAlH_4$) to primary amines; aniline with $CHCl_3$ and alcoholic KOH is the carbylamine reaction that gives phenyl isocyanide.

19. The rate constants of a certain reaction at 500 K and 700 K are 0.02 sec^{-1} and 0.07 sec^{-1} respectively. Calculate E_a and A. (2+2)

Correct Answer: —

Solution:

Given: $k_1 = 0.02\ s^{-1}$ at $T_1 = 500\ K$; $k_2 = 0.07\ s^{-1}$ at $T_2 = 700\ K$; $R = 8.314\ J\ K^{-1}mol^{-1}$.

Step 1 (Concept): The temperature dependence of the rate constant is given by the two-temperature form of the Arrhenius equation:

$$\ln \frac{k_2}{k_1} = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

Step 2 (Ratio of rate constants):

$$\frac{k_2}{k_1} = \frac{0.07}{0.02} = 3.5, \qquad \ln 3.5 = 1.2528$$

Step 3 (Temperature term):

$$\frac{1}{T_1} - \frac{1}{T_2} = \frac{1}{500} - \frac{1}{700} = 0.002 - 0.0014286 = 5.714 \times 10^{-4}\ K^{-1}$$

Step 4 (Solve for the activation energy):

$$E_a = \frac{R \ln(k_2/k_1)}{\left(\frac{1}{T_1} - \frac{1}{T_2}\right)} = \frac{8.314 \times 1.2528}{5.714 \times 10^{-4}} = \frac{10.416}{5.714 \times 10^{-4}} \approx 18230 \text{ J mol}^{-1}$$

$$\boxed{E_a \approx 18.23 \text{ kJ mol}^{-1}}$$

Step 5 (Frequency factor A): From $k = A\,e^{-E_a/RT}$, so $A = k_1\,e^{E_a/RT_1}$.

$$\frac{E_a}{RT_1} = \frac{18230}{8.314 \times 500} = \frac{18230}{4157} = 4.385$$

$$A = 0.02 \times e^{4.385} = 0.02 \times 80.2 \approx 1.60 \text{ s}^{-1}$$

$$\boxed{A \approx 1.60 \text{ s}^{-1}}$$

Check: Using T_2: $E_a/RT_2 = 18230/5820 = 3.132$, $A = 0.07 \times e^{3.132}$ $= 0.07 \times 22.9 \approx 1.60 \text{ s}^{-1}$; both temperatures give the same A, confirming the answer.

Quick Tip: Use the two-temperature Arrhenius equation $\ln(k_2/k_1) = \frac{E_a}{R}(\frac{1}{T_1} - \frac{1}{T_2})$ to get E_a, then substitute back into $k = Ae^{-E_a/RT}$ to find A.

20. (i) What is meant by ambidentate ligand? Give examples also. (2)

(ii) Write the IUPAC names of following compounds:

a) $[Co(Br)_2(en)_2]^+$

b) $K_3[Fe(C_2O_4)_3]$ (1+1)

Correct Answer: —

Solution:

Part (i): Ambidentate ligand

Step 1 (Definition): A ligand that has two (or more) different donor atoms and can coordinate to the central metal atom through either one of them (but only one at a time) is called an ambidentate ligand.

Step 2 (Examples):

• Nitrite ion, NO_2^-: bonds through nitrogen (nitrito-N, written -NO_2) or through oxygen (nitrito-O, written -ONO).

• Thiocyanate ion, SCN^-: bonds through sulphur (thiocyanato-S, -SCN) or through nitrogen (isothiocyanato, -NCS).

• Cyanide ion, CN^-: bonds through carbon (cyano, -CN) or through nitrogen (isocyano, -NC).

Part (ii): IUPAC names

a) $[Co(Br)_2(en)_2]^+$

Step 1 (Oxidation state): en (ethane-1,2-diamine) is neutral; each Br is -1, so 2 Br give -2. Overall charge is +1, therefore $x - 2 = +1 \Rightarrow x = +3$; Co is in the +3 state.

Step 2 (Naming rules): Ligands are named alphabetically: bromido (b) before ethane-1,2-diamine (e). The prefix bis is used for the chelating en to avoid confusion with di.

Name: Dibromidobis(ethane-1,2-diamine)cobalt(III) ion.

b) $K_3[Fe(C_2O_4)_3]$

Step 1 (Oxidation state): Three K^+ give +3, so the complex ion carries -3. Each oxalate $C_2O_4^{2-}$ is -2, and three give -6. Thus $x - 6 = -3 \Rightarrow x = +3$; Fe is in the +3 state.

Step 2 (Naming rules): It is an anionic complex, so the metal ends in -ate: ferrate. The chelating oxalato ligand takes the prefix tris.
Name: Potassium tris(oxalato)ferrate(III).

Quick Tip: Ambidentate = one ligand, two possible donor atoms (e.g. NO_2^-, SCN^-). For naming, work out the metal oxidation state from the overall charge, list ligands alphabetically, and add -ate to the metal only when the complex is an anion.

21. (i) How would you obtain chlorobenzene from diazonium salt and aniline from chlorobenzene? (Write only chemical equation.) (2)
(ii) Write the increasing order of basicity of the following compounds: NH_3, $(CH_3)_3N$, CH_3NH_2, $(CH_3)_2NH$. (1)
(iii) What are the main sources of protein? (1)

Correct Answer: —

Solution:

Part (i): Chemical equations
Step 1 (Chlorobenzene from a diazonium salt - Sandmeyer reaction): Benzene diazonium chloride is warmed with cuprous chloride dissolved in HCl; the $-N_2^+$ group is replaced by -Cl and nitrogen gas escapes.

$$C_6H_5N_2^+Cl^- \xrightarrow{Cu_2Cl_2/HCl} C_6H_5Cl + N_2$$

Step 2 (Aniline from chlorobenzene): Chlorobenzene is heated with ammonia at high temperature and pressure using a cuprous oxide catalyst; the chlorine is replaced by the $-NH_2$ group.

$$C_6H_5Cl + 2NH_3 \xrightarrow[475\ K,\ high\ pressure]{Cu_2O} C_6H_5NH_2 + NH_4Cl$$

Part (ii): Increasing order of basicity

Step 1 (Concept): In aqueous solution the basic strength of amines depends on the combined effect of the electron-releasing (+I) effect of alkyl groups, solvation (stabilisation of the protonated cation by water) and steric hindrance. Adding methyl groups increases +I but reduces solvation and adds crowding, so the trend is not simply increasing.

Step 2 (Order): For methylamines in water the observed order of basic strength is $(CH_3)_2NH > CH_3NH_2 > (CH_3)_3N > NH_3$. Hence in increasing order:

$$\mathbf{NH_3 < (CH_3)_3N < CH_3NH_2 < (CH_3)_2NH}$$

Part (iii): Main sources of protein

Step 1: Proteins come from both animal and plant foods.

- Animal sources: milk, eggs, cheese, meat and fish.
- Plant sources: pulses and legumes (gram, beans, peas), soybean and nuts.

Quick Tip: Chlorobenzene from a diazonium salt is the Sandmeyer reaction (Cu_2Cl_2/HCl); aniline from chlorobenzene needs NH_3 with Cu_2O at high T and P. Remember the aqueous basicity order $(CH_3)_2NH > CH_3NH_2 > (CH_3)_3N > NH_3$.

22. What is Kohlrausch's law? If λ°_m for NaCl, HCl and NaAc are 126.4, 425.9 and 91.0 S cm^2 mol^{-1} respectively, find the value of λ°_m for HAc. (2+2)

Correct Answer: —

Solution:

Part 1: Kohlrausch's law

Statement: Kohlrausch's law of independent migration of ions states that, at infinite dilution (when dissociation is complete), the limiting molar conductivity of an electrolyte is the sum of the individual contributions of its cation and anion, each ion migrating independently of the other.

$$\lambda^\circ_m = \nu_+ \lambda^\circ_+ + \nu_- \lambda^\circ_-$$

where ν_+ and ν_- are the numbers of cations and anions per formula unit, and λ°_+, λ°_- are their limiting ionic molar conductivities.

Part 2: Calculation for HAc (acetic acid)

Step 1 (Set up the ion balance): Write each salt as its ions.

$$\lambda^\circ_m(\text{HCl}) = \lambda^\circ_{H^+} + \lambda^\circ_{Cl^-}$$

$$\lambda^\circ_m(\text{NaAc}) = \lambda^\circ_{Na^+} + \lambda^\circ_{Ac^-}$$

$$\lambda^\circ_m(\text{NaCl}) = \lambda^\circ_{Na^+} + \lambda^\circ_{Cl^-}$$

Step 2 (Combine to eliminate the spectator ions): Add HCl and NaAc, then subtract NaCl. The Na^+ and Cl^- cancel, leaving H^+ and Ac^-, which is exactly HAc:

$$\lambda_m^\circ(\text{HAc}) = \lambda_m^\circ(\text{HCl}) + \lambda_m^\circ(\text{NaAc}) - \lambda_m^\circ(\text{NaCl})$$

Step 3 (Substitute the data):

$$\lambda_m^\circ(\text{HAc}) = 425.9 + 91.0 - 126.4$$

Step 4 (Arithmetic):

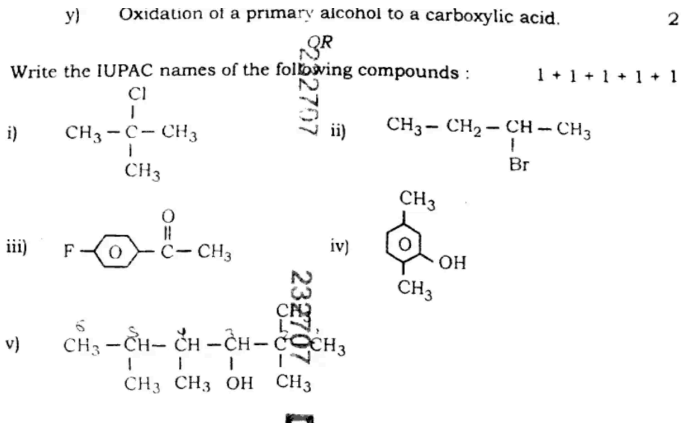
$$= 516.9 - 126.4 = 390.5 \text{ S cm}^2\text{mol}^{-1}$$

$$\boxed{\lambda_m^\circ(\text{HAc}) = 390.5 \text{ S cm}^2\text{mol}^{-1}}$$

This value is found indirectly because acetic acid is a weak electrolyte and its λ_m° cannot be obtained by direct extrapolation.

Quick Tip: Kohlrausch's law: at infinite dilution λ_m° is the sum of independent ionic conductivities. Combine the salts as $\lambda_m^\circ(\text{HAc}) = \lambda_m^\circ(\text{HCl}) + \lambda_m^\circ(\text{NaAc}) - \lambda_m^\circ(\text{NaCl})$.

23.



(i) Explain the mechanism of the Bimolecular Nucleophilic Substitution reaction (S_N2) in a haloalkane and give the order of reactivity of the alkyl halides based on S_N2. (3)

(ii) Name the reagent used in the following reactions: (x) Oxidation of a primary alcohol to an aldehyde. (y) Oxidation of a primary alcohol to a carboxylic acid. (2)

OR

Write the IUPAC names of the following compounds (1+1+1+1+1):

(i) $(CH_3)_3C$–Cl

(ii) CH_3–CH_2–CH(Br)–CH_3

(iii) 4-F–C_6H_4–$COCH_3$

(iv) a benzene ring bearing two CH_3 groups and one OH group

(v)

CH_3–$CH(CH_3)$–$CH(CH_3)$–CH(OH)–$C(CH_3)_3$

Correct Answer: —

Solution:

Option 1

Part (i): S_N2 mechanism and reactivity order

Step 1 (What S_N2 means): S_N2 stands for Substitution, Nucleophilic, Bimolecular. It is a one-step (concerted) reaction whose rate depends on the concentration of BOTH the alkyl halide and the nucleophile, so it follows second order kinetics: Rate = $k[RX][Nu^-]$.

Step 2 (How it happens): The nucleophile attacks the carbon atom carrying the halogen from the side exactly opposite (back side) to the leaving halogen. In the transition state this carbon is partly bonded to both the incoming nucleophile and the outgoing halogen; the three other groups lie in a plane (trigonal bipyramidal transition state). As the new bond forms, the C–X bond breaks, and the halide leaves.

Step 3 (Result): The reaction goes through a single transition state with no intermediate, and the configuration at carbon is turned inside-out (inversion of configuration, called Walden inversion). Example: $CH_3Br + OH^- \rightarrow CH_3OH + Br^-$.

Step 4 (Reactivity order): Because the nucleophile must reach the carbon from the back, bulky alkyl groups block the attack (steric hindrance). Fewer alkyl groups mean an easier attack, so the S_N2 reactivity order is: CH_3X > primary (1°) > secondary (2°) > tertiary (3°) halide. Methyl halide reacts fastest and the tertiary halide is essentially unreactive by S_N2.

Part (ii): Reagents

(x) To stop at the aldehyde and avoid over-oxidation, a mild oxidising agent is used: **PCC (Pyridinium Chlorochromate)** in dichloromethane (Collins reagent also works). $RCH_2OH \xrightarrow{PCC} RCHO$.

(y) To go all the way to the carboxylic acid, a strong oxidising agent is used: **acidified $KMnO_4$** (or $K_2Cr_2O_7/H_2SO_4$).

$RCH_2OH \xrightarrow{KMnO_4/H^+} RCOOH$.

Option 2 (OR): IUPAC names

Step 1 (i): $(CH_3)_3C$–Cl has a central carbon bonded to three methyl groups and one Cl. The longest chain is propane; the central C2 carries a methyl and a chlorine. Name: **2-chloro-2-methylpropane**.

Step 2 (ii): $CH_3CH_2CH(Br)CH_3$ is a four-carbon chain (butane) with Br on C2 (lowest locant). Name: **2-bromobutane**.

Step 3 (iii): A benzene ring carries a –$COCH_3$ (acetyl, the parent ketone is acetophenone = 1-phenylethan-1-one) and an F at the para (4) position. Name: **1-(4-fluorophenyl)ethan-1-one** (para-fluoroacetophenone).

Step 4 (iv): The –OH on a benzene ring makes it a phenol, so OH gets C1. Two methyl groups on the ring give a dimethylphenol (xylenol); for the shown structure the name is **3,5-dimethylphenol** (the two methyls occupy positions 3 and 5).

Step 5 (v):

CH_3–$CH(CH_3)$–$CH(CH_3)$–CH(OH)–$C(CH_3)_3$.

The longest chain that includes the –OH carbon is six carbons (hexane). Numbering from the tert-butyl end gives OH the lowest locant (C3): C2 carries two methyls, C4 and C5 each carry one methyl. Name: **2,2,4,5-tetramethylhexan-3-ol**.

2-chloro-2-methylpropane; 2-bromobutane; 1-(4-fluorophenyl)ethan-1-one; 3,5-dimethylphenol; 2,2,4,5-tetramethylhexan-3-ol

Quick Tip: S_N2 is a one-step back-side attack with inversion; reactivity is $CH_3X > 1° > 2° > 3°$. For oxidation use PCC (to aldehyde) and $KMnO_4$ (to acid). For the OR part, pick the longest chain and give OH/Cl/Br the lowest locant.

24. What happens when (give only the chemical equations):

(i) Methyl phenyl ketone is treated with iodine in the presence of NaOH?

(ii) Ethyl bromide is heated with aqueous KOH?

(iii) Phenol reacts with chloroform in the presence of aqueous NaOH?

(iv) Acetaldehyde is treated with Tollen's reagent?

(v) Benzoic acid is heated with ammonia? (1+1+1+1+1)

OR

How would you obtain (write chemical equations only):

(i) Formic acid from formaldehyde?

(ii) Propane-2-ol from propene?

(iii) Benzene from phenol?

(iv) m-bromobenzoic acid from benzoic acid?

(v) Ethyl acetate from acetic acid? (1+1+1+1+1)

Correct Answer: —

Solution:

Option 1: What happens when

Step (i) Iodoform reaction: Methyl phenyl ketone (acetophenone) has a CH_3CO– group, so it gives the iodoform test. Iodine and NaOH replace the three methyl hydrogens by iodine and then cleave the bond, forming yellow iodoform.

$$C_6H_5COCH_3 + 3I_2 + 4NaOH \rightarrow CHI_3 \downarrow + C_6H_5COONa + 3NaI + 3H_2O$$

Step (ii) Nucleophilic substitution: Aqueous KOH supplies OH^{-}, which replaces bromine to give ethanol.

$$C_2H_5Br + KOH_{(aq)} \rightarrow C_2H_5OH + KBr$$

Step (iii) Reimer-Tiemann reaction: Phenol with chloroform and aqueous NaOH, followed by acidification, gives salicylaldehyde (2-

hydroxybenzaldehyde). The –CHO enters mainly at the ortho position.

$$C_6H_5OH + CHCl_3 + 3NaOH \rightarrow o\text{-}HOC_6H_4CHO + 3NaCl + 2H_2O$$

Step (iv) Tollen's test: Tollen's reagent (ammoniacal silver nitrate) oxidises acetaldehyde to acetate ion and deposits a silver mirror.

$$CH_3CHO + 2[Ag(NH_3)_2]^+ + 3OH^- \rightarrow CH_3COO^- + 2Ag \downarrow + 4NH_3 + 2H_2O$$

Step (v) Amide formation: Benzoic acid first forms ammonium benzoate, which loses water on strong heating to give benzamide.

$$C_6H_5COOH + NH_3 \rightarrow C_6H_5COONH_4 \xrightarrow{\Delta} C_6H_5CONH_2 + H_2O$$

Option 2 (OR): How would you obtain

Step (i) Formic acid from formaldehyde: Mild oxidation of formaldehyde gives formic acid.

$$HCHO + [O] \xrightarrow{K_2Cr_2O_7/H^+} HCOOH$$

Step (ii) Propane-2-ol from propene: Acid-catalysed hydration adds water across the double bond following Markovnikov's rule, so OH goes to the middle carbon.

$$CH_3CH = CH_2 + H_2O \xrightarrow{H_2SO_4} CH_3CH(OH)CH_3$$

Step (iii) Benzene from phenol: Heating phenol vapours with zinc dust reduces it to benzene.

$$C_6H_5OH + Zn \xrightarrow{\Delta} C_6H_6 + ZnO$$

Step (iv) m-Bromobenzoic acid from benzoic acid: –COOH is a meta-directing, deactivating group, so bromination with Br_2 and

$FeBr_3$ gives the meta product.

$$C_6H_5COOH + Br_2 \xrightarrow{FeBr_3} m\text{-}BrC_6H_4COOH + HBr$$

Step (v) Ethyl acetate from acetic acid: Fischer esterification of acetic acid with ethanol using concentrated H_2SO_4 gives ethyl acetate.

$$CH_3COOH + C_2H_5OH \xrightarrow{conc.\ H_2SO_4} CH_3COOC_2H_5 + H_2O$$

All ten equations shown above

Quick Tip: Look for name reactions: iodoform (methyl ketone), aqueous KOH substitution, Reimer-Tiemann (salicylaldehyde), Tollen's oxidation, and amide formation. For the OR part, think oxidation, Markovnikov hydration, Zn-dust reduction, meta bromination and Fischer esterification.

25. Discuss the structure of glucose in detail. (5)

OR

i) What do you understand by mono, di and polysaccharides? Explain with examples. (3)

ii) What are peptide bonds and glycosidic bonds? (2)

Correct Answer: —

Solution:

Option 1: Structure of glucose

Step 1: Molecular formula. Elemental analysis and molar mass determination show glucose is $C_6H_{12}O_6$ (molar mass 180 g/mol).

Step 2: A straight chain of six carbons. On prolonged heating with HI,

glucose gives n-hexane. This proves all six carbon atoms are joined in a straight (unbranched) chain.

Step 3: Presence of a carbonyl group. Glucose reacts with hydroxylamine (NH_2OH) to form an oxime and adds one molecule of HCN to form a cyanohydrin. Both reactions confirm a carbonyl (>C=O) group.

Step 4: The carbonyl is an aldehyde. On mild oxidation with bromine water, glucose gives gluconic acid, a six-carbon monocarboxylic acid. Since a weak oxidant converts the carbonyl to a –COOH, the group must be a terminal aldehyde (–CHO).

Step 5: Five hydroxyl groups. Glucose reacts with acetic anhydride to form glucose pentaacetate. Formation of five acetate groups shows glucose contains five –OH groups, one each on five different carbon atoms (two OH on the same carbon would be unstable).

Step 6: A primary alcohol group. On oxidation with nitric acid, glucose gives saccharic acid, a dicarboxylic acid. This shows a primary alcohol group (–CH_2OH) at the end of the chain, which is oxidised to a second –COOH.

Step 7: Open-chain structure. Combining all the evidence, the open-chain structure is CHO–CHOH–CHOH–CHOH–CHOH–CH_2OH, i.e. an aldohexose. Its natural spatial arrangement is that of D-(+)-glucose.

Step 8: Cyclic (pyranose) structure. The open chain could not explain

that glucose does not give the Schiff test, does not react with $NaHSO_3$, and exists as two forms (alpha and beta) that show mutarotation. These facts are explained by a cyclic hemiacetal formed when the –OH on C-5 adds to the –CHO on C-1. This gives a six-membered pyranose ring and a new –OH at C-1 (the anomeric carbon). The two positions of this OH give alpha-D-glucose and beta-D-glucose, drawn as Haworth projections.

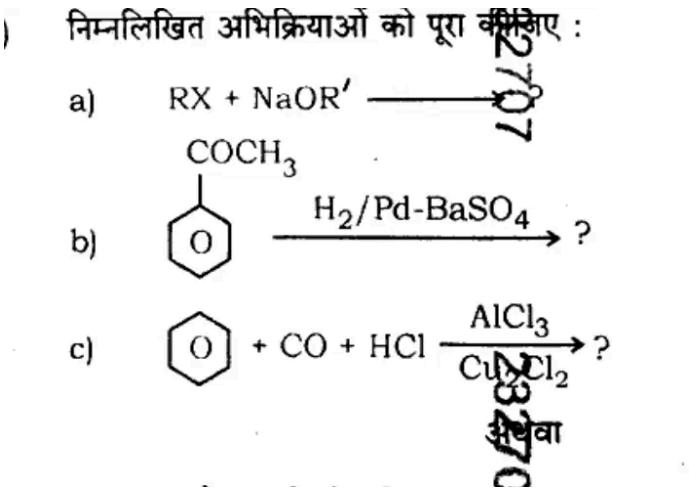
Option 2:

i) Mono, di and polysaccharides.
Monosaccharides: the simplest carbohydrates that cannot be hydrolysed into smaller carbohydrate units. Examples: glucose, fructose, ribose.
Disaccharides: carbohydrates that on hydrolysis give two monosaccharide units. Examples: sucrose (gives glucose + fructose), maltose (gives two glucose), lactose (gives glucose + galactose).
Polysaccharides: carbohydrates that on hydrolysis give a large number of monosaccharide units. Examples: starch, cellulose, glycogen.

ii) Peptide bond and glycosidic bond.
A **peptide bond** is the amide linkage (–CO–NH–) formed between the –COOH group of one amino acid and the –NH_2 group of another amino acid, with the loss of a water molecule.
A **glycosidic bond** is the C–O–C linkage formed between two monosaccharide units when they join together with the loss of a water molecule (for example, the linkage between glucose and fructose in sucrose).

Quick Tip: For the structure, recall the six pieces of evidence (n-hexane on HI, oxime and cyanohydrin, gluconic acid with bromine water, pentaacetate, saccharic acid with HNO_3) and then the cyclic pyranose form (anomers, mutarotation). For the OR part, classify sugars by the number of units released on hydrolysis.

26.



i) Define standard electrode potential. (1)

ii) Define bidentate ligand. (1)

iii) Complete the following reactions (1+1+1):

a) RX + NaOR' → ?

b) $C_6H_5COCH_3$ (acetophenone) + H_2/Pd-$BaSO_4$ → ?

c) C_6H_6 (benzene) + CO + HCl → ($AlCl_3$/Cu_2Cl_2) ?

OR

i) Explain standard hydrogen electrode potential with diagram. (1)

ii) Give an example of optical isomerism. (1)

iii) Complete the following reactions (1+1+1):

a) CH_3CH_2OH → (H_2SO_4, 413 K) ?

b) RCN + $SnCl_2$ + HCl → ?

c) $C_6H_5CH_3$ (toluene) + CrO_2Cl_2 + CS_2 → ?

Correct Answer: —

Solution:

Option 1:

Step 1: i) Standard electrode potential. It is the electrode potential of an electrode measured with respect to the standard hydrogen electrode under standard conditions, that is, all ions at unit concentration (1 M / unit activity), temperature 298 K and any gas at 1 bar pressure. It is denoted E°.

Step 2: ii) Bidentate ligand. A ligand that has two donor atoms, each carrying a lone pair, through which it binds to the central metal atom or ion at the same time. Examples: ethylenediamine (en, two N donor atoms) and the oxalate ion $C_2O_4^{2-}$ (two O donor atoms).

Step 3: iii-a) Williamson ether synthesis. The alkoxide ion of NaOR' displaces the halide of the alkyl halide by nucleophilic substitution: RX + NaOR' → R–O–R' + NaX (an ether).

Step 4: iii-b) Reduction of the ketone. Catalytic hydrogenation adds H_2 across the C=O group of acetophenone, reducing the ketone to a secondary alcohol:
$C_6H_5COCH_3 + H_2 \rightarrow C_6H_5CH(OH)CH_3$ (1-phenylethanol).

Step 5: iii-c) Gattermann-Koch reaction. Benzene reacts with carbon monoxide and hydrogen chloride in the presence of anhydrous $AlCl_3$ and Cu_2Cl_2 to give benzaldehyde:
$C_6H_6 + CO + HCl \rightarrow C_6H_5CHO + HCl$.

Option 2:

Step 1: i) Standard hydrogen electrode (SHE). It is the reference electrode whose potential is fixed at exactly zero volt. A platinum foil coated with platinum black is dipped in a 1 M H^+ (HCl) solution, and pure H_2 gas at 1 bar is bubbled over it at 298 K (see diagram above). The electrode reaction is $2H^+ + 2e^- \rightarrow H_2$. All other electrode potentials are measured against it.

Step 2: ii) Example of optical isomerism. The complex $[Co(en)_3]^{3+}$ exists as two non-superimposable mirror images (d and l forms) and so shows optical isomerism. (Lactic acid is a simple organic example.)

Step 3: iii-a) Dehydration to an ether. With concentrated H_2SO_4 at 413 K, two molecules of ethanol lose one molecule of water to give diethyl ether:
$2C_2H_5OH \rightarrow C_2H_5OC_2H_5 + H_2O$. (At the higher temperature 443 K the product would be ethene instead.)

Step 4: iii-b) Stephen reaction. A nitrile is reduced by stannous chloride and HCl to an aldimine, which on hydrolysis gives an aldehyde:
$RCN + SnCl_2 + HCl \rightarrow RCH{=}NH$, then $+ H_2O \rightarrow RCHO + NH_3$.

Step 5: iii-c) Etard reaction. Toluene is oxidised by chromyl chloride (CrO_2Cl_2) in CS_2 to a brown chromium complex, which on hydrolysis gives benzaldehyde:
$C_6H_5CH_3 + CrO_2Cl_2$, then $H_2O \rightarrow C_6H_5CHO$.

Quick Tip: Standard electrode potential is measured against the standard hydrogen electrode at 1 M, 298 K and 1 bar. The named reactions here are the Williamson ether synthesis, the Gattermann-Koch reaction, ethanol dehydration to ether at 413 K, the Stephen reduction and the Etard reaction.