JEE Main Chemistry

Sample Paper – 4

Duration: 60 Minutes **Maximum Marks: 100**

Instructions

- This paper contains **30 questions** modelled on the Chemistry portion of **JEE Main** entrance examination.
- **Section A** (Q1–Q20): 20 Single Correct MCQ. **+4 marks** for correct; **−1 mark** for wrong; **0** for unattempted.
- **Section B** (Q21–Q30): 10 Numerical Value Questions. Attempt **any 5**. **+4 marks** for correct; **0** for incorrect or unattempted.
- Syllabus: Class 11 & 12 NCERT Chemistry (JEE Main official syllabus).
- Personal calculators, log tables, and electronic gadgets are strictly prohibited. A simple on-screen virtual calculator is provided in the CBT interface.
- Rough sheets will be provided at the examination centre.

Section A — Single Correct
MCQ (Q1–Q20) [+4 / −1]

Q1. Which of the following concentration units is **independent of temperature**?

(A) Molality

(B) Molarity

(C) Normality

(D) Formality

Q2. Photons of frequency ν strike a metal surface that has a work function $\phi = 4.0$ eV. If $h\nu = 5.5$ eV, what is the maximum kinetic energy of the emitted photoelectrons?

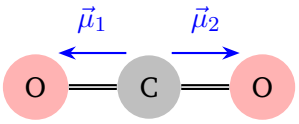
(A) 9.5 eV

(B) 4.0 eV

(C) 1.5 eV

(D) 5.5 eV

Q3. Which of the following molecules has a **zero net dipole moment**?



Net $\mu = 0$ (cancel by symmetry)

(A) H_2O

(B) CO_2

(C) NH_3

(D) HCl

Q4. For an ideal gas at temperature T, what is the ratio of the **rms speed** (u_{rms}) to the **most probable speed** (u_{mp})?

(A) $\sqrt{2} : \sqrt{3}$

(B) $1 : 1$

(C) $\sqrt{2} : 1$

(D) $\sqrt{3} : \sqrt{2}$

Q5. For a chemical reaction in which $\Delta C_p = C_p(\text{products}) - C_p(\text{reactants}) > 0$, which of the following statements is **correct**?

(A) ΔH increases as temperature increases.

(B) ΔH decreases as temperature increases.

(C) ΔH remains unchanged with temperature.

(D) ΔH becomes zero at sufficiently high temperature.

Q6. For the equilibrium $N_2O_4(g) \rightleftharpoons 2\,NO_2(g)$, the equilibrium constant $K_c = 5.0 \times 10^{-3}$ mol L^{-1} at 300 K. If the reaction quotient at a particular instant is $Q_c = 1.0 \times 10^{-2}$ mol L^{-1}, in which direction will the reaction proceed?

(A) In the forward direction (toward NO_2).

(B) The system is already at equilibrium; no net change.

(C) In the reverse direction (toward N_2O_4).

(D) No reaction occurs under these conditions.

Q7. For phosphoric acid (H_3PO_4), which of the following correctly represents the order of its stepwise acid dissociation constants?

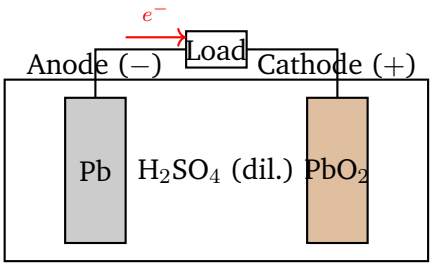
(A) $K_{a1} < K_{a2} < K_{a3}$

(B) $K_{a1} > K_{a2} > K_{a3}$

(C) $K_{a1} = K_{a2} = K_{a3}$

(D) $K_{a3} > K_{a1} > K_{a2}$

Q8. The diagram below shows a lead storage battery during discharge. Which equation correctly represents the reaction at the **cathode**?



(A) $Pb \rightarrow PbSO_4 + 2e^-$

(B) $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$

(C) $2H^+ + 2e^- \rightarrow H_2$

(D) $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$

Q9. For the reaction $2A \rightarrow B + C$, the rate law is rate $= k[A]^2$. What is the **rate of formation of B**?

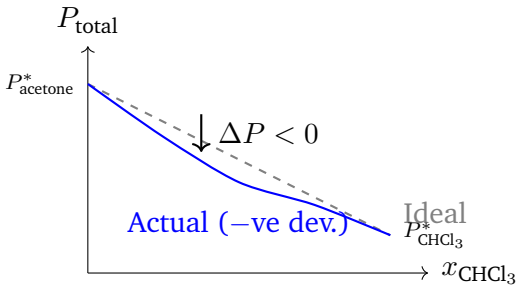
(A) $k[\text{A}]^2$ (half the rate of disappearance of A)

(B) $2k[\text{A}]^2$

(C) $k^2[\text{A}]^4$

(D) $\dfrac{k[\text{A}]}{2}$

Q10. The graph below shows the vapour pressure of a binary liquid mixture exhibiting **negative deviation** from Raoult's law. Which of the following pairs of liquids shows this behaviour?



(A) Ethanol + Water

(B) Benzene + Toluene

(C) Acetone + Chloroform

(D) n-Hexane + n-Heptane

Q11. Which of the following correctly identifies the **composition of stainless steel**?

(A) Copper and zinc (Cu + Zn)

(B) Iron, chromium, and nickel (Fe + Cr + Ni)

(C) Copper and tin (Cu + Sn)

(D) Aluminium and copper (Al + Cu)

Q12. Permanent hardness of water (caused by dissolved $CaCl_2$, $MgCl_2$, $CaSO_4$) **cannot** be removed by boiling. Which of the following methods effectively removes **permanent hardness**?

(A) Boiling the water

(B) Adding slaked lime [$Ca(OH)_2$] alone

(C) Simple distillation

(D) Ion-exchange resin (permutit) process

Q13. Which of the following statements about the **allotropes of phosphorus** is **correct**?

(A) White phosphorus is more reactive than red phosphorus because it has strained P_4 tetrahedral units with bond angles of $60°$.

(B) Red phosphorus is more toxic than white phosphorus.

(C) Black phosphorus is the most reactive allotrope of phosphorus.

(D) White phosphorus is thermally stable in air at room temperature.

Q14. Which property is **unique to fluorine** compared to all other halogens?

(A) Chlorine also shows only the -1 oxidation state in all compounds.

(B) Bromine has higher electronegativity than fluorine.

(C) Fluorine exhibits only the -1 oxidation state, as it lacks d-orbitals and has the highest electronegativity of all elements.

(D) Iodine does not form any oxoacids.

Q15. Actinides exhibit **more variable oxidation states** than lanthanides. What is the primary reason for this?

(A) Actinide ions are larger, so more oxidation states are possible.

(B) The $5f$, $6d$, and $7s$ orbitals in actinides have comparable energies, allowing all three sets to participate in bonding.

(C) Lanthanides have more $4f$ electrons available for bonding.

(D) All actinides are radioactive, which increases their chemical reactivity.

Q16. EDTA forms highly stable complexes with metal ions. The **chelate effect** is responsible for this enhanced stability. The primary thermodynamic reason is:

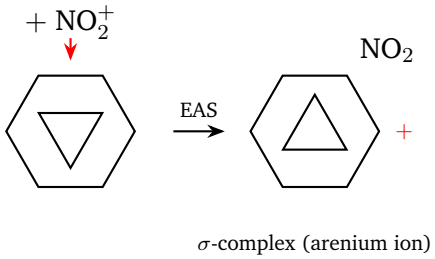
(A) EDTA donates more electron density per donor atom than monodentate ligands.

(B) The metal ion carries a higher charge when complexed with EDTA.

(C) Activation energy for EDTA complex formation is lower.

(D) Formation of multiple chelate rings releases several water molecules, resulting in a large positive ΔS and a more negative ΔG.

Q17. In the nitration of benzene (using conc. HNO_3 + conc. H_2SO_4), the diagram below shows the electrophile attacking the ring. What is the **electrophile** in this reaction?



σ-complex (arenium ion)

(A) NO_2^+ (nitronium ion)

(B) NO_2 (nitrogen dioxide radical)

(C) HNO_3 (nitric acid)

(D) N_2O_5 (dinitrogen pentoxide)

Q18. Phenylmagnesium bromide (C_6H_5MgBr) is treated with dry CO_2 gas and the product is then hydrolysed with dilute acid (H_3O^+). What is the **final organic product**?

(A) Phenol (C_6H_5OH)

(B) Benzaldehyde (C_6H_5CHO)

(C) Benzoic acid (C_6H_5COOH)

(D) Diphenyl ketone ($(C_6H_5)_2CO$)

Q19. 2-Methylbutan-2-ol undergoes acid-catalyzed dehydration. According to **Zaitsev's rule**, what is the **major product**?

(A) 2-Methylbut-1-ene (less substituted alkene)

(B) 2-Methylbut-2-ene (more substituted alkene)

(C) 3-Methylbut-1-ene

(D) An equal mixture of 2-methylbut-1-ene and 2-methylbut-2-ene

Q20. The Fischer esterification of acetic acid with ethanol is:

$$CH_3COOH + C_2H_5OH \overset{\text{conc. } H_2SO_4}{\underset{\Delta}{\rightleftharpoons}} CH_3COOC_2H_5 + H_2O$$

Which of the following conditions would **NOT** increase the equilibrium yield of ethyl acetate?

(A) Removing water as it forms (e.g. using a Dean–Stark trap)

(B) Using a large excess of ethanol

(C) Using molecular sieves to absorb water

(D) Adding more concentrated H_2SO_4 catalyst

Section B — Numerical Value Questions (Q21–Q30) [Attempt Any 5]

Q21. At $T = 500$ K, the enthalpy change for a reaction is $\Delta H = +1000\ \text{J mol}^{-1}$ and the entropy change is $\Delta S = -2\ \text{J mol}^{-1}\text{K}^{-1}$. Calculate ΔG in **kJ mol^{-1}**. *(Enter the exact numerical value as your answer.)*

Q22. A radioactive nuclide has a half-life of $t_{1/2} = 693$ s. Calculate the time (in **seconds**) required for **75%** of the nuclide to decay. (Use $\ln 2 = 0.693$.) *(Enter the exact numerical value as your answer.)*

Q23. One Faraday ($F = 96500$ C) of electricity is passed through an aqueous solution of $CuSO_4$. What **mass of copper** (in grams) is deposited at the cathode? [Molar mass of Cu $= 64\ \text{g mol}^{-1}$; $n = 2$] *(Enter the exact numerical value as your answer.)*

Q24. One mole of a non-electrolyte solute is dissolved in 1 kg of water. If the ebullioscopic constant $K_b = 0.52\ \text{K kg mol}^{-1}$, find $\Delta T_b \times 100$ (where ΔT_b is the elevation in boiling point in °C). *(Enter the exact numerical value as your answer.)*

Q25. For the reaction $2\text{A(g)} \rightleftharpoons \text{B(g)} + \text{C(g)}$, the equilibrium concentrations are: [A] $= 1$ M, [B] $= 5$ M, [C] $= 2$ M. Calculate K_c. *(Enter the exact numerical value as your answer.)*

Q26. A gas occupies 22.4 L at STP and has a mass of 44 g. What is its **molar mass** in g mol^{-1}? *(Enter the exact numerical value as your answer.)*

Q27. How many **moles of hydrogen atoms** are present in 72 g of water? [Molar mass of $H_2O = 18\ \text{g mol}^{-1}$] *(Enter the exact numerical value as your answer.)*

Q28. What is the **oxidation state of nickel** in the complex $[\text{Ni(CO)}_4]$? *(Enter*

the exact numerical value as your answer.)

Q29. In the Bohr model of the hydrogen atom, the radius of the n^{th} orbit is $r_n = n^2 a_0$, where $a_0 = 0.529$ Å is the first Bohr radius. For an orbit whose radius is $16\,a_0$, find the **principal quantum number** n. *(Enter the exact numerical value as your answer.)*

Q30. What is the **mass in grams** of 1 mol of dinitrogen gas (N_2)? [Atomic mass of N $= 14$ u] *(Enter the exact numerical value as your answer.)*

Detailed Solutions

Q1.

Solution

Concept — Concentration Units: Molarity, normality, and formality depend on volume of solution, which changes with temperature (liquids expand/contract). Molality (mol per kg of solvent) and mole fraction involve only masses; masses do not change with temperature.

Step 1 — Identify temperature-dependent units: Molarity $= \frac{\text{moles solute}}{\text{volume of solution (L)}}$. Since volume changes with temperature, molarity is temperature-dependent.

Step 2 — Identify the temperature-independent unit: Molality $= \frac{\text{moles solute}}{\text{mass of solvent (kg)}}$. Mass does not change with temperature $\Rightarrow$ molality is temperature-independent.

Why other options are wrong:

- Option B (Molarity): Volume of solution changes with T; hence molarity changes.
- Option C (Normality): Also volume-based; temperature-dependent.
- Option D (Formality): Volume-based; temperature-dependent.

Final Answer: Molality is independent of temperature. $\Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q1

Q2.

Solution

Concept — Photoelectric Effect: When a photon of energy $h\nu$ strikes a metal with work function ϕ, the maximum kinetic energy of the emitted electron is:

$$KE_{\max} = h\nu - \phi$$

This follows from Einstein's photoelectric equation.

Step 1 — Substitute given values:

$$KE_{\max} = 5.5 \text{ eV} - 4.0 \text{ eV} = 1.5 \text{ eV}$$

Why other options are wrong:

- Option A (9.5 eV): This is $h\nu + \phi$, which is incorrect.
- Option B (4.0 eV): This equals the work function ϕ, not KE.
- Option D (5.5 eV): This is the energy of the photon, not the kinetic energy of the electron.

Final Answer: $KE_{\text{max}} = 1.5$ eV $\Rightarrow$ C

Answer: (C) Go Back to Q2

Q3.

Solution

Concept — Dipole Moment and Molecular Symmetry: A molecule has zero net dipole moment when the individual bond dipoles cancel due to the molecule's geometry. CO_2 is linear (O=C=O) and perfectly symmetric; the two C=O bond dipoles are equal in magnitude but opposite in direction, giving a net dipole of zero.

Step 1 — Analyse CO_2: Linear geometry (180° bond angle). The two bond dipoles $\vec{\mu}_1$ and $\vec{\mu}_2$ point in opposite directions along the molecular axis and cancel exactly:

$$\vec{\mu}_{\text{net}} = \vec{\mu}_1 + \vec{\mu}_2 = 0$$

Why other options are wrong:

- Option A (H_2O): Bent geometry (104.5°); dipoles do not cancel; $\mu \approx 1.85$ D.
- Option C (NH_3): Trigonal pyramidal; has a lone pair; $\mu \approx 1.46$ D $\neq 0$.
- Option D (HCl): Diatomic, only one bond; $\mu \neq 0$.

Final Answer: CO_2 has zero net dipole moment. $\Rightarrow$ B

Answer: (B) Go Back to Q3

Q4.

Solution

Concept — Kinetic Theory of Gases: For an ideal gas with molar mass M at temperature T:

$$u_{\text{rms}} = \sqrt{\frac{3RT}{M}}, \qquad u_{\text{mp}} = \sqrt{\frac{2RT}{M}}$$

Step 1 — Calculate the ratio:

$$\frac{u_{\text{rms}}}{u_{\text{mp}}} = \frac{\sqrt{3RT/M}}{\sqrt{2RT/M}} = \sqrt{\frac{3}{2}} = \frac{\sqrt{3}}{\sqrt{2}}$$

Step 2 — Express as ratio:

$$u_{\text{rms}} : u_{\text{mp}} = \sqrt{3} : \sqrt{2} \approx 1.732 : 1.414 \approx 1.22 : 1$$

Hence $u_{\text{rms}} > u_{\text{mp}}$.

Why other options are wrong:

- Option A ($\sqrt{2} : \sqrt{3}$): This is the inverse ratio; incorrect.
- Option B ($1 : 1$): Incorrect; the two speeds differ.
- Option C ($\sqrt{2} : 1$): This would correspond to $u_{\text{rms}}/u_{\text{av}} \approx \sqrt{3/\pi}$, not u_{mp}.

Final Answer: $u_{\text{rms}} : u_{\text{mp}} = \sqrt{3} : \sqrt{2} \Rightarrow$ D

Answer: (D) Go Back to Q4

Q5.

Solution

Concept — Kirchhoff's Equation: The temperature dependence of ΔH is given by Kirchhoff's equation:

$$\frac{d(\Delta H)}{dT} = \Delta C_p$$

where $\Delta C_p = \sum C_p(\text{products}) - \sum C_p(\text{reactants})$.

Step 1 — Apply the condition $\Delta C_p > 0$: Since $\frac{d(\Delta H)}{dT} = \Delta C_p > 0$, ΔH is an increasing function of temperature.

Step 2 — Integrated form:

$$\Delta H(T_2) = \Delta H(T_1) + \Delta C_p\,(T_2 - T_1)$$

For $T_2 > T_1$ and $\Delta C_p > 0$: $\Delta H(T_2) > \Delta H(T_1)$. ΔH increases with T.

Why other options are wrong:

- Option B: ΔH decreases only when $\Delta C_p < 0$.
- Option C: ΔH is constant only when $\Delta C_p = 0$ (Hess's law approximation).
- Option D: $\Delta H \to 0$ at high T is not a consequence of Kirchhoff's equation.

Final Answer: ΔH increases as temperature increases. $\Rightarrow$ A

Answer: (A) Go Back to Q5

Q6.

Solution

Concept — Reaction Quotient Q_c vs K_c: The direction of a reaction is determined by comparing Q_c with K_c:

- $Q_c < K_c$: Reaction proceeds in the **forward** direction.
- $Q_c = K_c$: System is **at equilibrium**.
- $Q_c > K_c$: Reaction proceeds in the **reverse** direction.

Step 1 — Compare values: $Q_c = 1.0 \times 10^{-2}$ mol L^{-1} and $K_c = 5.0 \times 10^{-3}$ mol L^{-1}.

$$Q_c > K_c \quad (1.0 \times 10^{-2} > 5.0 \times 10^{-3})$$

Step 2 — Determine direction: Since $Q_c > K_c$, the system has too many products (NO_2) relative to equilibrium. The reaction will shift in the **reverse direction** to form more N_2O_4 until equilibrium is re-established.

Why other options are wrong:

- Option A: Forward direction applies only when $Q_c < K_c$.
- Option B: Equilibrium is only when $Q_c = K_c$.
- Option D: Reaction always proceeds; $Q \neq K$ means it is not at equilibrium.

Final Answer: Reaction proceeds in the reverse direction (toward N_2O_4). $\Rightarrow$ C

Answer: (C) Go Back to Q6

Q7.

Solution

Concept — Stepwise Dissociation of Polyprotic Acids: For a triprotic acid like H_3PO_4, each successive ionisation step is harder because (i) the negative charge on the anion opposes further proton loss, and (ii) fewer protons remain to ionise.

Step 1 — Write the three ionisation steps:

$$\begin{aligned} H_3PO_4 &\rightleftharpoons H^+ + H_2PO_4^-, \quad K_{a1} \approx 7.5 \times 10^{-3} \\ H_2PO_4^- &\rightleftharpoons H^+ + HPO_4^{2-}, \quad K_{a2} \approx 6.2 \times 10^{-8} \\ HPO_4^{2-} &\rightleftharpoons H^+ + PO_4^{3-}, \quad K_{a3} \approx 2.1 \times 10^{-13} \end{aligned}$$

Step 2 — Order: $K_{a1} \gg K_{a2} \gg K_{a3}$, i.e., $K_{a1} > K_{a2} > K_{a3}$.

Why other options are wrong:

- Option A: Reverse order is incorrect; first ionisation is always the most favourable.
- Option C: Equal constants would require identical environments for each step, which is impossible.
- Option D: K_{a3} is the smallest of all three.

Final Answer: $K_{a1} > K_{a2} > K_{a3} \Rightarrow \boxed{B}$

Answer: (B) Go Back to Q7

Q8.

Solution

Concept — Lead Storage Battery (Discharge): During discharge, the lead storage battery operates as a galvanic cell:

- **Anode** (oxidation, $-$): $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$
- **Cathode** (reduction, $+$): $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$

Step 1 — Identify the cathode: The cathode is the positive electrode (PbO_2 plate) where reduction occurs during discharge.

Step 2 — Write the cathode half-reaction:

$$PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$$

This is a reduction (gain of electrons), consistent with a cathode.

Why other options are wrong:

- Option A and B: These describe **anode** (oxidation) reactions, not the cathode.

- Option C ($2H^+ + 2e^- \rightarrow H_2$): This occurs in simple electrolytic cells, not in a lead battery cathode during discharge.

Final Answer: $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$ at cathode. $\Rightarrow \boxed{D}$

Answer: (D) Go Back to Q8

Q9.

Solution

Concept — Stoichiometric Relationship Between Rates: For a reaction $a\text{A} \rightarrow b\text{B} + c\text{C}$, the relationship between rates is:

$$\text{rate of reaction} = -\frac{1}{a}\frac{d[\text{A}]}{dt} = \frac{1}{b}\frac{d[\text{B}]}{dt}$$

Step 1 — Apply to $2\text{A} \rightarrow \text{B} + \text{C}$ with rate $= k[\text{A}]^2$:

$$\text{rate of reaction} = -\frac{1}{2}\frac{d[\text{A}]}{dt} = k[\text{A}]^2$$

Therefore:

$$-\frac{d[\text{A}]}{dt} = 2k[\text{A}]^2 \quad \text{(rate of disappearance of A)}$$

Step 2 — Find rate of formation of B:

$$\frac{d[\text{B}]}{dt} = \text{rate of reaction} = k[\text{A}]^2$$

(Since the stoichiometric coefficient of B is 1, same as the rate of reaction.)

Why other options are wrong:

- Option B ($2k[\text{A}]^2$): This is the rate of disappearance of A (not B).
- Option C ($k^2[\text{A}]^4$): No basis; rate law cannot be squared this way.
- Option D ($k[\text{A}]/2$): Incorrect dimensions and form.

Final Answer: Rate of formation of B $= k[\text{A}]^2 \Rightarrow \boxed{A}$

Answer: (A) Go Back to Q9

Q10.

Solution

Concept — Deviations from Raoult's Law: A binary mixture shows **negative deviation** when the intermolecular attractions between *unlike* molecules (A–B) are stronger than those between *like* molecules (A–A or B–B). This lowers the tendency of molecules to escape to the vapour phase, giving a vapour pressure *lower* than predicted by Raoult's law ($\Delta P < 0$).

Step 1 — Identify the pair: Acetone (CH_3COCH_3) + Chloroform ($CHCl_3$): the C=O group of acetone forms a hydrogen bond with the C–H of chloroform ($CHCl_3$ is a good H-bond donor due to electron-withdrawing Cl atoms). This strong A–B interaction ($>$ A–A, B–B) causes **negative deviation**.

Why other options are wrong:

- Option A (Ethanol + Water): Shows positive deviation at moderate concentrations (H-bonds in pure liquids are disrupted on mixing, $\Delta P > 0$).
- Option B (Benzene + Toluene): Behaves nearly ideally; both are non-polar aromatics.
- Option D (n-Hexane + n-Heptane): Nearly ideal; both are similar non-polar alkanes.

Final Answer: Acetone + Chloroform shows negative deviation from Raoult's law.
$\Rightarrow$ C

Answer: (C) Go Back to Q10

Q11.

Solution

Concept — Alloys and Their Compositions:

Alloy	Main Components	Use
Stainless steel	Fe + Cr (∼18%) + Ni (∼8%)	Cutlery, surgical
Brass	Cu + Zn	Decorative items
Bronze	Cu + Sn	Coins, bells
Duralumin	Al + Cu + Mg + Mn	Aircraft

Step 1: Stainless steel contains iron as the base metal with chromium (for corrosion resistance) and nickel (for toughness). The chromium forms a passive Cr_2O_3 layer that prevents rusting.

Why other options are wrong:

- Option A (Cu + Zn): This is **brass**.
- Option C (Cu + Sn): This is **bronze**.
- Option D (Al + Cu): This is the basis of **duralumin**.

Final Answer: Stainless steel = Fe + Cr + Ni. $\Rightarrow$ B

Answer: (B) Go Back to Q11

Q12.

Solution

Concept — Hardness of Water:

- **Temporary hardness**: caused by $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$; removed by boiling or by Clark's process (adding lime).
- **Permanent hardness**: caused by chlorides and sulphates ($CaCl_2$, $MgCl_2$, $CaSO_4$); **cannot** be removed by boiling. Removed by: (i) ion-exchange/permutit process, (ii) washing soda (Na_2CO_3), or (iii) Calgon.

Step 1 — Ion-exchange (permutit) process: Hard water is passed through a bed of zeolite (sodium aluminium silicate) or a synthetic resin. Ca^{2+} and Mg^{2+} ions are exchanged for Na^+ ions, effectively removing permanent hardness.

Why other options are wrong:

- Option A (Boiling): Removes only temporary hardness; $CaCl_2$ and $CaSO_4$ remain.
- Option B (Adding lime alone): Clark's process removes only temporary hardness.
- Option C (Distillation): Effective but impractical on a large scale; also not a standard method for permanent hardness.

Final Answer: Ion-exchange resin / permutit process removes permanent hardness. $\Rightarrow$ D

Answer: (D) Go Back to Q12

Q13.

Solution

Concept — Allotropes of Phosphorus: Phosphorus exists in several allotropic forms. White phosphorus (P_4) consists of tetrahedral P_4 units with bond angles of $60°$, which is far less than the normal tetrahedral angle of $109.5°$. This acute angle causes severe bond strain, making white P very reactive. Red phosphorus has a polymeric structure with less strain, and black phosphorus (the most stable and least reactive) has a layer structure.

Step 1 — Reactivity trend: White P (most reactive, most toxic) $>$ Red P $>$ Black P (least reactive, most stable).

Why other options are wrong:

- Option B: Red phosphorus is **less** toxic than white phosphorus; white P is highly poisonous and ignites spontaneously in air.
- Option C: Black phosphorus is the **least** reactive allotrope.
- Option D: White phosphorus is **not** stable in air; it must be stored under water to prevent spontaneous combustion.

Final Answer: White phosphorus is most reactive due to strained P_4 tetrahedra ($60°$ bond angles). $\Rightarrow$ A

Answer: (A) Go Back to Q13

Q14.

Solution

Concept — Unique Properties of Fluorine Among Halogens: Fluorine is the most electronegative element ($\chi = 3.98$ on Pauling scale). Its valence shell contains only $2s$ and $2p$ orbitals (no d-orbitals available). Therefore, fluorine:

(a) Can show **only** the -1 oxidation state (cannot expand octet, unlike Cl, Br, I which can use d-orbitals for positive oxidation states).
(b) Does **not** form oxoacids (no positive oxidation states possible).
(c) Has the highest oxidising power of all halogens.

Step 1: Other halogens (Cl, Br, I) have d-orbitals available and can form compounds with positive oxidation states (e.g., ClO_4^-, BrF_3, IF_7). Fluorine cannot.

Why other options are wrong:

- Option A: Cl shows $-1, +1, +3, +5, +7$ oxidation states; it does **not** show

only -1.

- Option B: Fluorine has **higher** electronegativity than bromine ($F = 3.98$, $Br = 2.96$).
- Option D: Iodine forms several oxoacids (HIO_3, HIO_4, etc.); this statement about I is **wrong**.

Final Answer: F shows only -1 oxidation state due to absence of d-orbitals and highest electronegativity. $\Rightarrow$ C

Answer: (C) Go Back to Q14

Q15.

Solution

Concept — Variable Oxidation States in Actinides vs Lanthanides:

- **Lanthanides** ($4f$): $4f$, $5d$, and $6s$ orbitals differ greatly in energy. Predominantly $+3$ oxidation state; $4f$ electrons are too tightly held and deeply shielded to participate in bonding (except occasional $+2$ and $+4$).
- **Actinides** ($5f$): The $5f$, $6d$, and $7s$ orbitals have comparable energies (all accessible). This allows all three sets to be involved in bonding, giving a wide range of oxidation states (e.g., U: $+3$ to $+6$, Pu: $+3$ to $+7$).

Step 1 — Energy comparison: In actinides, $5f$ orbitals are not as deeply buried as $4f$ in lanthanides. The energy differences among $5f$, $6d$, and $7s$ are small enough that electrons from all three can be involved in bonding, enabling higher and more variable oxidation states.

Why other options are wrong:

- Option A: Ionic radius is not the reason for variable oxidation states.
- Option C: Lanthanides having more $4f$ electrons is true but does not explain actinide variability.
- Option D: Radioactivity is a nuclear property unrelated to chemical oxidation states.

Final Answer: $5f$, $6d$, $7s$ orbital energies are comparable in actinides, enabling diverse oxidation states. $\Rightarrow$ B

Answer: (B) Go Back to Q15

Q16.

Solution

Concept — Chelate Effect: EDTA (ethylenediaminetetraacetic acid) is a hexadentate ligand that forms six bonds to a single metal ion, creating five 5-membered chelate rings. When EDTA (as a single molecule) replaces six monodentate water molecules from a metal ion, the reaction releases six water molecules:

$$[\mathrm{M(H_2O)_6}]^{n+} + \mathrm{EDTA}^{4-} \rightarrow [\mathrm{M(EDTA)}]^{(n-4)+} + 6\,\mathrm{H_2O}$$

Step 1 — Thermodynamic analysis: Going from 2 species (metal complex + EDTA) to 7 species (chelate + 6 H_2O) gives a large increase in the number of molecules, and hence a large **positive entropy change** ($\Delta S \gg 0$). From $\Delta G = \Delta H - T\Delta S$, a large positive ΔS makes ΔG more negative, greatly stabilising the EDTA complex.

Why other options are wrong:

- Option A: Per-donor-atom donation is not significantly different between EDTA and monodentate ligands.
- Option B: The metal charge is fixed by the metal ion; EDTA does not change it.
- Option C: Activation energy pertains to kinetics, not thermodynamic stability (chelate effect is thermodynamic).

Final Answer: Large positive ΔS (release of water molecules) makes ΔG more negative $\Rightarrow$ $\boxed{\mathrm{D}}$

Answer: (D) Go Back to Q16

Q17.

Solution

Concept — Electrophilic Aromatic Substitution (EAS): Nitration of Benzene: In the nitration of benzene, concentrated H_2SO_4 protonates HNO_3 to generate the nitronium ion (NO_2^+):

$$\mathrm{HNO_3} + \mathrm{H_2SO_4} \rightarrow \mathrm{NO_2^+} + \mathrm{HSO_4^-} + \mathrm{H_2O}$$

The nitronium ion is the actual **electrophile** that attacks the benzene π-system.

Step 1 — Generation of electrophile:

$$H_2SO_4 + HNO_3 \rightarrow [H_2NO_3]^+ + HSO_4^- \rightarrow NO_2^+ + H_2O + HSO_4^-$$

Step 2 — Mechanism: NO_2^+ attacks the benzene ring forming a σ-complex (Wheland intermediate / arenium ion), which then loses H^+ to restore aromaticity, giving nitrobenzene.

Why other options are wrong:

- Option B (NO_2 radical): EAS involves ions, not radicals.
- Option C (HNO_3): HNO_3 is the *source* of the electrophile, not the electrophile itself.
- Option D (N_2O_5): N_2O_5 can generate NO_2^+ but is not present in the conventional H_2SO_4/HNO_3 mixture.

Final Answer: The electrophile in benzene nitration is NO_2^+ (nitronium ion). $\Rightarrow$ A

Answer: (A) Go Back to Q17

Q18.

Solution

Concept — Grignard Reaction with CO_2: When a Grignard reagent (RMgX) is treated with dry CO_2 (as solid or gas), the carbanion (R^-) acts as a nucleophile and attacks the electrophilic carbon of CO_2:

$$R - MgX + CO_2 \rightarrow R - COO^-MgX^+ \xrightarrow{H_3O^+} R - COOH$$

Step 1 — Apply to phenylmagnesium bromide:

$$C_6H_5MgBr \longrightarrow + CO_2 \longrightarrow C_6H_5COOMgBr \xrightarrow{H_3O^+} C_6H_5COOH$$

The product after hydrolysis is **benzoic acid** (C_6H_5COOH).

Why other options are wrong:

- Option A (Phenol): Phenol would be formed by reacting a Grignard with O_2, not CO_2.
- Option B (Benzaldehyde): Aldehydes are formed by reacting with DMF or $HC(OEt)_3$, not CO_2.

- Option D (Diphenyl ketone): Ketones from Grignard require reaction with an ester or acid chloride, not CO_2.

Final Answer: $C_6H_5MgBr + CO_2 \xrightarrow{H_3O^+} C_6H_5COOH$ (Benzoic acid) $\Rightarrow$ C

Answer: (C) Go Back to Q18

Q19.

Solution

Concept — Zaitsev's Rule (Saytzeff's Rule): In acid-catalyzed dehydration of alcohols, the **major product** is the **more substituted alkene** (the one with more alkyl groups on the double bond carbons). This is the thermodynamically more stable alkene.

Step 1 — Draw 2-methylbutan-2-ol:

$$CH_3C(OH)(CH_3)CH_2CH_3 \quad \text{(tertiary alcohol)}$$

Step 2 — Acid-catalyzed dehydration (via E1 mechanism): The tertiary carbocation forms readily. Two possible β-H eliminations give:

- Loss of H from C3: gives **2-methylbut-2-ene** (trisubstituted, Zaitsev product — **major**)
- Loss of H from C1: gives **2-methylbut-1-ene** (disubstituted, Hofmann-type — minor)

Step 3 — Apply Zaitsev: The more substituted product (2-methylbut-2-ene, trisubstituted alkene) is the major product.

Why other options are wrong:

- Option A (2-methylbut-1-ene): Minor product; less substituted.
- Option C (3-methylbut-1-ene): Not formed from 2-methylbutan-2-ol by simple dehydration.
- Option D (equal mixture): Not true; Zaitsev's rule predicts preferential formation of the more substituted alkene.

Final Answer: 2-Methylbut-2-ene is the major product (Zaitsev's rule). $\Rightarrow$ B

Answer: (B) Go Back to Q19

Q20.

Solution

Concept — Fischer Esterification (Reversible Equilibrium): Fischer esterification is an equilibrium reaction:

$$\text{RCOOH} + \text{R'OH} \underset{\Delta}{\overset{\text{H}^+}{\rightleftharpoons}} \text{RCOOR'} + \text{H}_2\text{O}$$

To increase **yield**, the equilibrium must be shifted to the right. This requires removing products or adding excess reactants. A catalyst speeds up attainment of equilibrium but does **not** shift the equilibrium position.

Step 1 — Evaluate each option:

- Option A (Remove water): Shifts equilibrium forward; **increases yield**. ✓
- Option B (Excess ethanol): Shifts equilibrium toward ester by Le Chatelier's principle; **increases yield**. ✓
- Option C (Molecular sieves): Absorb water in situ; effectively removes product; **increases yield**. ✓
- Option D (More H_2SO_4): H_2SO_4 is a catalyst. It increases the *rate* of reaching equilibrium but does **not** change K_{eq} or the equilibrium yield.

Step 2 — Conclusion: Adding more catalyst (H_2SO_4) does NOT increase equilibrium yield.

Final Answer: Adding more H_2SO_4 catalyst does not increase equilibrium yield. $\Rightarrow$ D

Answer: (D) Go Back to Q20

Q21.

Solution

Concept — Gibbs Free Energy ($\Delta G = \Delta H - T\Delta S$): The Gibbs free energy change is related to enthalpy and entropy changes by:

$$\Delta G = \Delta H - T\Delta S$$

Step 1 — Substitute given values:

$$\Delta H = +1000\ \text{J mol}^{-1}, \quad T = 500\ \text{K}, \quad \Delta S = -2\ \text{J mol}^{-1}\text{K}^{-1}$$

$$\Delta G = 1000 - (500) \times (-2) = 1000 + 1000 = 2000\ \text{J mol}^{-1}$$

Step 2 — Convert to kJ:

$$\Delta G = \frac{2000}{1000} = 2 \text{ kJ mol}^{-1}$$

Note: Both $\Delta H > 0$ (endothermic) and $\Delta S < 0$ (entropy decreases) are unfavourable; $\Delta G > 0$ means the reaction is non-spontaneous under these conditions.

Final Answer: $\Delta G = +2 \text{ kJ mol}^{-1} \Rightarrow \boxed{2}$

Answer: (2) Go Back to Q21

Q22.

Solution

Concept — First-Order Radioactive Decay: Radioactive decay follows first-order kinetics. The time for a fraction to decay is:

$$t = \frac{t_{1/2}}{\ln 2} \ln\left(\frac{N_0}{N}\right)$$

Step 1 — Determine N/N_0 after 75% decay: If 75% has decayed, 25% remains: $\frac{N}{N_0} = \frac{1}{4} = \left(\frac{1}{2}\right)^2$. This corresponds to **two half-lives**.

Step 2 — Calculate time:

$$t = 2 \times t_{1/2} = 2 \times 693 \text{ s} = 1386 \text{ s}$$

Verification using decay law: $N = N_0 e^{-\lambda t}$, where $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{693} = 0.001 \text{ s}^{-1}$. At $t = 1386$ s: $N/N_0 = e^{-0.001 \times 1386} = e^{-1.386} = 0.25$. Indeed 75% has decayed. ✓

Final Answer: $t = 1386 \text{ s} \Rightarrow \boxed{1386}$

Answer: (1386) Go Back to Q22

Q23.

Solution

Concept — Faraday's First Law of Electrolysis:

$$m = \frac{M \times Q}{n \times F}$$

where m = mass deposited, M = molar mass, Q = charge passed, n = number of electrons per ion, F = Faraday constant.

Step 1 — Write the cathode half-reaction:

$$\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu} \quad (n = 2)$$

Two moles of electrons (2 Faradays) deposit 1 mole (64 g) of copper.

Step 2 — Calculate mass for 1 Faraday:

$$1\ \text{F} \rightarrow \frac{64}{2} = 32\ \text{g of Cu}$$

Verification using formula:

$$m = \frac{64 \times 1 \times 96500}{2 \times 96500} = \frac{64}{2} = 32\ \text{g}$$

Final Answer: Mass of copper deposited $= 32$ g $\Rightarrow \boxed{32}$

Answer: (32) Go Back to Q23

Q24.

Solution

Concept — Elevation in Boiling Point (Ebullioscopy):

$$\Delta T_b = K_b \times m$$

where K_b is the ebullioscopic constant (K·kg/mol) and m is the molality of the solution.

Step 1 — Calculate molality: 1 mol solute dissolved in 1 kg of water.

$$m = \frac{1\ \text{mol}}{1\ \text{kg}} = 1\ \text{mol kg}^{-1}$$

Step 2 — Calculate ΔT_b:

$$\Delta T_b = 0.52\ \text{K kg mol}^{-1} \times 1\ \text{mol kg}^{-1} = 0.52\ ^\circ\text{C}$$

Step 3 — Find $\Delta T_b \times 100$:

$$\Delta T_b \times 100 = 0.52 \times 100 = 52$$

Final Answer: $\Delta T_b \times 100 = 52 \Rightarrow \boxed{52}$

Answer: (52) Go Back to Q24

Q25.

Solution

Concept — Equilibrium Constant K_c: For the reaction $2\text{A} \rightleftharpoons \text{B} + \text{C}$:

$$K_c = \frac{[\text{B}][\text{C}]}{[\text{A}]^2}$$

Step 1 — Substitute equilibrium concentrations:

$$[\text{A}] = 1\ \text{M}, \quad [\text{B}] = 5\ \text{M}, \quad [\text{C}] = 2\ \text{M}$$

$$K_c = \frac{5 \times 2}{(1)^2} = \frac{10}{1} = 10\ (\text{M})$$

Since both B and C have coefficient 1, and A has coefficient 2:

$$K_c = \frac{[\text{B}]^1[\text{C}]^1}{[\text{A}]^2} = \frac{5 \times 2}{1} = 10\ \text{mol L}^{-1}$$

Final Answer: $K_c = 10\ \text{mol L}^{-1} \Rightarrow \boxed{10}$

Answer: (10) Go Back to Q25

Q26.

Solution

Concept — Molar Mass from STP Data: At STP (Standard Temperature and Pressure: 0°C, 1 atm), 1 mole of any ideal gas occupies exactly 22.4 L (molar volume).

Step 1 — Find the number of moles:

$$n = \frac{V}{V_{\text{molar}}} = \frac{22.4\ \text{L}}{22.4\ \text{L mol}^{-1}} = 1\ \text{mol}$$

Step 2 — Calculate molar mass:

$$M = \frac{\text{mass}}{n} = \frac{44\ \text{g}}{1\ \text{mol}} = 44\ \text{g mol}^{-1}$$

This molar mass corresponds to CO_2 (12 + 2×16 = 44 g/mol) or N_2O (14×2+16 = 44 g/mol).

Final Answer: Molar mass $= 44\ \text{g mol}^{-1} \Rightarrow \boxed{44}$

Answer: (44) Go Back to Q26

Q27.

Solution

Concept — Mole Concept and Atomic Composition: Each water molecule (H_2O) contains 2 hydrogen atoms and 1 oxygen atom.

Step 1 — Find moles of H_2O:

$$n(\text{H}_2\text{O}) = \frac{72\ \text{g}}{18\ \text{g mol}^{-1}} = 4\ \text{mol}$$

Step 2 — Find moles of H atoms: Each H_2O contains 2 H atoms:

$$n(\text{H atoms}) = 4\ \text{mol} \times 2 = 8\ \text{mol}$$

Final Answer: 8 mol of hydrogen atoms $\Rightarrow \boxed{8}$

Answer: (8) Go Back to Q27

Q28.

Solution

Concept — Oxidation State in Coordination Compounds: To find the oxidation state of the central metal, use the fact that the sum of oxidation states of all atoms in a neutral complex equals zero.

Step 1 — Identify ligands in [Ni(CO)$_4$]: CO (carbon monoxide) is a neutral ligand; oxidation state $= 0$.

Step 2 — Apply electroneutrality: [Ni(CO)$_4$] is a neutral complex:

$$\text{Oxidation state of Ni} + 4 \times (\text{OS of CO}) = 0$$

$$x + 4(0) = 0 \implies x = 0$$

Note: [Ni(CO)$_4$] (tetracarbonylnickel) is one of the few stable metal carbonyls with a metal in the zero oxidation state. It is also a classic example of back-bonding ($d \to \pi^*$) from Ni to CO.

Final Answer: Oxidation state of Ni in [Ni(CO)$_4$] $= 0 \Rightarrow \boxed{0}$

Answer: (0) Go Back to Q28

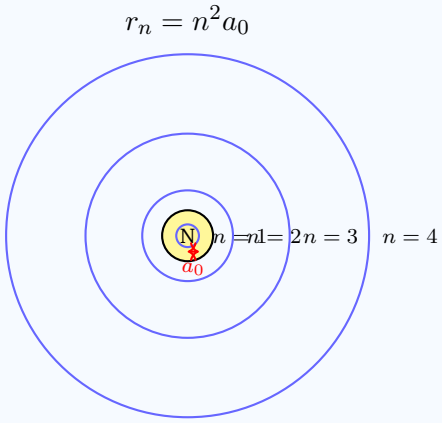
Q29.

Solution

Concept — Bohr Model Orbital Radius: In the Bohr model of the hydrogen atom, the radius of the n^{th} orbit is:

$$r_n = n^2 a_0$$

where $a_0 = 0.529$ Å (first Bohr radius, $n = 1$).



Step 1 — Set up the equation: Given $r_n = 16\,a_0$:

$$n^2 a_0 = 16\,a_0$$

$$n^2 = 16 \implies n = 4$$

Verification: $r_4 = 4^2 a_0 = 16a_0 = 16 \times 0.529 = 8.464$ Å ✓

Final Answer: $n = 4 \Rightarrow \boxed{4}$

Answer: (4) Go Back to Q29

Q30.

Solution

Concept — Molar Mass of a Diatomic Gas: Dinitrogen (N_2) consists of two nitrogen atoms bonded together. The molar mass is the sum of atomic masses of both N atoms.

Step 1 — Calculate molar mass of N_2:

$$M(\mathrm{N_2}) = 2 \times M(\mathrm{N}) = 2 \times 14\ \mathrm{g\,mol^{-1}} = 28\ \mathrm{g\,mol^{-1}}$$

Step 2 — Mass of 1 mol N_2:

$$\text{Mass} = 1\ \text{mol} \times 28\ \mathrm{g\,mol^{-1}} = 28\ \mathrm{g}$$

Note: At STP, 1 mol N_2 (mass $= 28$ g) occupies 22.4 L. N_2 comprises approximately 78% of the Earth's atmosphere by volume.

Final Answer: Mass of 1 mol $N_2 = 28$ g $\Rightarrow \boxed{28}$

Answer: (28) Go Back to Q30

Answer Key

Section A — MCQ (Q1–Q20):

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	A	2	C	3	B	4	D	5	A
6	C	7	B	8	D	9	A	10	C
11	B	12	D	13	A	14	C	15	B
16	D	17	A	18	C	19	B	20	D

Section B — Numerical Value Questions (Q21–Q30):

Q	Ans	Q	Ans
21	2	22	1386
23	32	24	52
25	10	26	44
27	8	28	0
29	4	30	28