JEE Main Chemistry

Sample Paper – 3

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. 44 g of carbon dioxide (CO_2, molar mass = 44 g/mol) is taken at STP. What volume does it occupy? (Use: 1 mol of any ideal gas occupies 22.4 L at STP.)

(A) 44.0 L

(B) 11.2 L

(C) 2.24 L

(D) 22.4 L

Q2. Chromium (Cr, $Z = 24$) has the observed ground-state electronic configuration $[\mathrm{Ar}]\,3d^5 4s^1$ instead of the expected $[\mathrm{Ar}]\,3d^4 4s^2$. Which of the

following best explains this observation?

(A) The $4s$ orbital is always lower in energy than the $3d$ orbital, making $4s^2$ unfavourable.

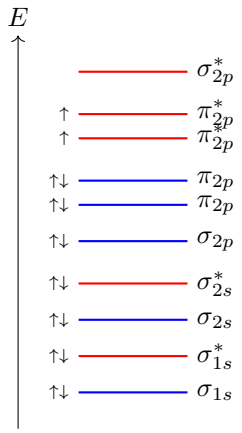
(B) The half-filled $3d^5$ sub-shell achieves extra stability due to high exchange energy and symmetrical electron distribution.

(C) The $3d^4$ configuration is more stable than $3d^5$ because of reduced inter-electron repulsion.

(D) The $4s$ electrons shield the $3d$ electrons completely, making $4s^1$ the preferred configuration.

Q3. Using Molecular Orbital (MO) theory, which of the following correctly describes the bond order and magnetic character of O_2?

The partial MO energy-level diagram for O_2 is shown below:



O_2 MO diagram (16 electrons)

(A) Bond order $= 1$, diamagnetic

(B) Bond order $= 3$, paramagnetic

(C) Bond order $= 2$, paramagnetic

(D) Bond order $= 2$, diamagnetic

Q4. A closed container holds a mixture of 2 mol N_2 and 3 mol O_2 exerting a total pressure of 5 atm. What is the partial pressure of O_2?

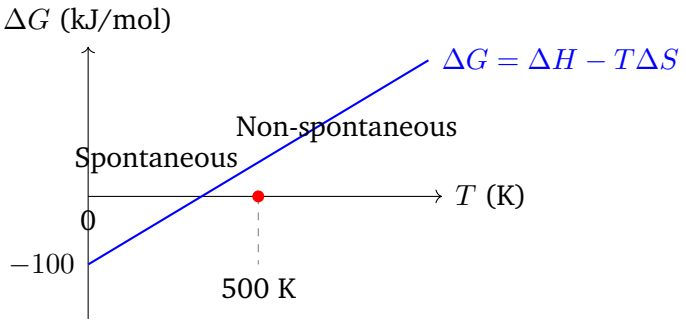
(A) 3 atm

(B) 2 atm

(C) 5 atm

(D) 1.5 atm

Q5. For a chemical reaction, $\Delta H = -100$ kJ/mol and $\Delta S = -200$ J/(mol·K). The reaction becomes **non-spontaneous** at temperatures:



(A) Below 500 K

(B) Above 1000 K

(C) At all temperatures (always non-spontaneous)

(D) Above 500 K

Q6. For the equilibrium $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$, $K_p = 1$ atm at a certain temperature. If the initial pressure of PCl_5 is 2 atm, what is the degree of dissociation (α) at equilibrium?

(A) $\alpha = 0.50$

(B) $\alpha = \dfrac{1}{\sqrt{3}} \approx 0.577$

(C) $\alpha = \dfrac{1}{\sqrt{2}} \approx 0.707$

(D) $\alpha = 0.25$

Q7. A 0.1 mol/L aqueous solution of a weak acid HA has pH = 3. What is the acid dissociation constant K_a of HA?

(A) $K_a = 10^{-3}$

(B) $K_a = 10^{-4}$

(C) $K_a = 10^{-5}$

(D) $K_a = 10^{-6}$

Q8. In the electrochemical corrosion of iron in the presence of an electrolyte (e.g., moist air), which region of the iron surface acts as the **anode**?

(A) Regions of higher stress or lower oxygen concentration, where Fe $\rightarrow$ Fe^{2+} + $2e^-$ (oxidation) occurs.

(B) The cathodic region, where oxygen is reduced: O_2 + $2H_2O$ + $4e^-$ $\rightarrow$ $4OH^-$.

(C) Both the anode and cathode are at the same location on the iron surface.

(D) The region covered by the Fe_2O_3 rust layer, which acts as the primary anodic site.

Q9. For a first-order reaction A $\rightarrow$ Products, which **graph** gives a straight line that can be used to determine the rate constant k?

(A) [A] vs. t

(B) $[A]^2$ vs. t

(C) $1/[A]$ vs. t

(D) $\ln[A]$ vs. t

Q10. Henry's law constant for CO_2 dissolved in water is $K_H = 167$ bar. If the partial pressure of CO_2 above the solution is 0.835 bar, what is the mole fraction (χ) of CO_2 in water?

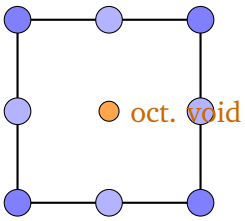
(A) 5×10^{-4}

(B) 5×10^{-3}

(C) 0.835

(D) 167

Q11. In a face-centred cubic (FCC / CCP) unit cell containing N atoms, how many **octahedral voids** are present?



FCC face: 1 oct. void at body centre per unit cell

(A) $2N$

(B) $4N$

(C) N

(D) $N/2$

Q12. Which of the following statements is **correct** about the diagonal relationship between Be and Al?

(A) Both BeO and Al_2O_3 are amphoteric oxides that dissolve in both acids and strong bases.

(B) Be and Al belong to the same group of the periodic table.

(C) BeO is a basic oxide similar to MgO.

(D) Be does not react with aqueous NaOH, unlike Al.

Q13. Which of the following statements **correctly** describes dinitrogen pentoxide (N_2O_5)?

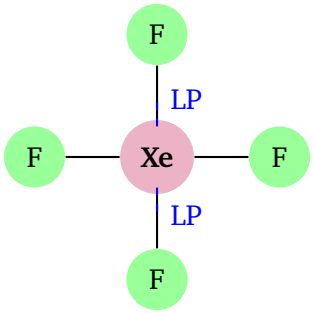
(A) N_2O_5 is ionic, existing as NO_2^+ and O_2^- in the solid state.

(B) The structure of N_2O_5 contains a direct N–N bond with oxygen substituents.

(C) In N_2O_5, nitrogen is in the $+3$ oxidation state.

(D) N_2O_5 contains an N–O–N bridge with two NO_2 groups, and nitrogen is in the $+5$ oxidation state.

Q14. What is the **shape** and **hybridization** of XeF_4?



XeF_4 structure

(A) Tetrahedral, sp^3 hybridization

(B) Square planar, sp^3d^2 hybridization

(C) See-saw, sp^3d hybridization

(D) Octahedral (regular), sp^3d^2 hybridization

Q15. Due to lanthanide contraction, the ionic radii of Zr^{4+} and Hf^{4+} are nearly identical (both ≈ 72 pm). What is the most significant **consequence** of this?

(A) Hf is lighter than Zr because of the smaller atomic radius.

(B) Zr is chemically more reactive than Hf due to its larger size.

(C) Zr and Hf cannot be separated by ordinary chemical methods due to their nearly identical chemical behaviour.

(D) Lanthanide contraction causes Zr and Hf to be radioactive.

Q16. Which of the following represents the **correct** order of crystal field splitting (Δ_o) for the given ligands in **increasing** order?

(A) $Cl^- < H_2O < NH_3 < CN^-$

(B) $CN^- < NH_3 < H_2O < Cl^-$

(C) $H_2O < Cl^- < CN^- < NH_3$

(D) $NH_3 < H_2O < Cl^- < CN^-$

Q17. The stability order of carbocations is observed to be:

$$(CH_3)_3C^+ > (CH_3)_2CH^+ > CH_3CH_2^+ > CH_3^+$$

The **primary reason** for this stability trend is:

(A) Hydrogen bonding with solvent molecules

(B) Resonance stabilisation by adjacent π bonds

(C) Greater electronegativity of carbon in tertiary carbocations

(D) Hyperconjugation and inductive effect of the methyl groups

Q18. Lactic acid (2-hydroxypropanoic acid, $CH_3CH(OH)COOH$) has one chiral centre. How many **stereoisomers** does lactic acid have?

(A) 1

(B) 2

(C) 3

(D) 4

Q19. Ethyl methyl ether (CH_3–O–C_2H_5) is to be synthesised by the **Williamson ether synthesis**. Which combination of reactants gives the **best** yield?

$$CH_3O^-\ \text{(methoxide)} \xrightarrow{S_N2} C_2H_5\mathbf{Br} \longrightarrow CH_3OC_2H_5 + Br^-$$

(A) CH_3OH + C_2H_5OH (acid-catalysed dehydration)

(B) C_2H_5ONa + CH_3Br (sodium ethoxide + methyl bromide)

(C) CH_3ONa + C_2H_5Br (sodium methoxide + ethyl bromide)

(D) CH_3ONa + C_2H_5ONa (two sodium alkoxides)

Q20. Phenol is treated with $CHCl_3$ and NaOH (Reimer–Tiemann reaction). What is the **major product**?

(A) Salicylaldehyde (2-hydroxybenzaldehyde)

(B) 4-Hydroxybenzaldehyde

(C) Benzoic acid

(D) Phenol is oxidised to benzoquinone

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

Q21. The standard enthalpy of neutralisation of a strong acid by a strong base is -57 kJ per mole of water formed. How many **kJ** of heat is released when 1 mol of HCl(aq) reacts completely with 1 mol of NaOH(aq)? *(Enter the exact numerical value as your answer.)*

Q22. A first-order reaction is 50% complete in 10 minutes. How many **minutes** does it take for the reaction to be 75% complete? *(Enter the exact numerical value as your answer.)*

Q23. How many **moles of electrons** (Faradays) are required to deposit 1 mole of aluminium from an aqueous solution of $AlCl_3$?

(Electrode reaction: $Al^{3+} + 3e^- \rightarrow Al$) *(Enter the exact numerical value as your answer.)*

Q24. 5.85 g of NaCl (molar mass = 58.5 g/mol) is dissolved in water to make 1 litre of solution. What is the concentration of the solution in **millimolar** (mM)? *(Enter the exact numerical value as your answer.)*

Q25. For the equilibrium $A(g) + B(g) \rightleftharpoons 2C(g)$, the equilibrium concentrations are: $[A] = 1.00$ M, $[B] = 1.00$ M, $[C] = \sqrt{2}$ M. Calculate the value of K_c. *(Enter the exact numerical value as your answer.)*

Q26. A 1.6 g sample of a hydrocarbon is found to contain 1.2 g of carbon and 0.4 g of hydrogen (and no other elements). What is the molar mass (in g/mol) of the **empirical formula unit**?

(Atomic masses: C = 12, H = 1) *(Enter the exact numerical value as your answer.)*

Q27. What is the **oxidation state** of iodine (I) in the iodate ion, IO_3^-? *(Enter the exact numerical value as your answer.)*

Q28. What is the **dipole moment** (in Debye) of a CO_2 molecule?

(Hint: Consider the geometry and symmetry of CO_2.) *(Enter the exact numerical value as your answer.)*

Q29. For a second-order reaction, the rate law is: rate $= k[A]^2$, where $k = 0.5$ L mol^{-1} s^{-1} and $[A] = \sqrt{10}$ mol/L. What is the rate of reaction in mol L^{-1} s^{-1}? *(Enter the exact numerical value as your answer.)*

Q30. How many **sigma (σ) bonds** are present in one molecule of methane (CH_4)? *(Enter the exact numerical value as your answer.)*

Detailed Solutions

Q1.

Solution

Concept — Mole Concept and Gas Volume at STP: At Standard Temperature and Pressure (STP: 0°C, 1 atm), one mole of any ideal gas occupies exactly 22.4 L. This is the molar volume of an ideal gas at STP.

Step 1 — Calculate moles of CO_2:

$$n = \frac{\text{mass}}{\text{molar mass}} = \frac{44 \text{ g}}{44 \text{ g/mol}} = 1 \text{ mol}$$

Step 2 — Calculate volume at STP:

$$V = n \times 22.4 \text{ L/mol} = 1 \times 22.4 = 22.4 \text{ L}$$

Why other options are wrong:

- Option A (44 L): Incorrectly equates mass in grams with volume in litres.
- Option B (11.2 L): This would be the volume of 0.5 mol (half of 22.4 L).
- Option C (2.24 L): This would be the volume of 0.1 mol.

Final Answer: 1 mol CO_2 at STP occupies $\Rightarrow \boxed{22.4 \text{ L}}$

Answer: (D) Go Back to Q1

Q2.

Solution

Concept — Electronic Configuration and Exchange Energy: According to Hund's rule and the concept of exchange energy, a half-filled (d^5) or fully-filled (d^{10}) sub-shell has special extra stability. When $3d^5$ is half-filled, every electron can exchange with every other d electron of the same spin, maximising the exchange energy and lowering the overall energy.

Step 1 — Expected vs. observed configuration of Cr ($Z = 24$):

- Expected: $[\text{Ar}]\, 3d^4\, 4s^2$ (filling by Aufbau)
- Observed: $[\text{Ar}]\, 3d^5\, 4s^1$ (one electron promoted from $4s$ to $3d$)

Step 2 — Reason: The half-filled $3d^5$ configuration has 10 possible exchange pairs

for the 5 parallel-spin electrons, giving maximum exchange energy. This energetic gain outweighs the cost of having only one electron in $4s$.

Why other options are wrong:

- Option A: The $4s$ is not always lower in energy; in transition metals the $3d$ and $4s$ energies are very close.
- Option C: $3d^4$ is less stable than $3d^5$, not more.
- Option D: The $4s$ electrons do not "completely shield" the $3d$; shielding is partial.

Final Answer: $\Rightarrow$ Option (B)

Answer: (B) Go Back to Q2

Q3.

Solution

Concept — Molecular Orbital Theory (MO Theory): Bond order $= \frac{1}{2}$(bonding electrons $-$ antibonding electrons). If unpaired electrons are present, the molecule is paramagnetic.

Step 1 — Electron count and MO filling for O_2 (16 electrons):

$$(\sigma_{1s})^2(\sigma^*_{1s})^2(\sigma_{2s})^2(\sigma^*_{2s})^2(\sigma_{2p})^2(\pi_{2p})^4(\pi^*_{2p})^2$$

Bonding electrons $= 2+2+2+4 = 10$; Antibonding electrons $= 2+2+2 = 6$.

Step 2 — Bond order:

$$\text{BO} = \frac{10-6}{2} = \frac{4}{2} = 2$$

Step 3 — Magnetic character: The two π^*_{2p} electrons occupy *two degenerate* antibonding orbitals with **one electron each** (Hund's rule). Therefore O_2 has 2 unpaired electrons $\Rightarrow$ **paramagnetic**.

Why other options are wrong:

- Option A (BO=1): Incorrect counting of bonding/antibonding electrons.
- Option B (BO=3): Over-counts bonding electrons and ignores π^* filling.
- Option D (BO=2, diamagnetic): Incorrectly states O_2 is diamagnetic; the two unpaired π^* electrons make it paramagnetic.

Final Answer: Bond order $= 2$, paramagnetic $\Rightarrow$ Option (C)

Answer: (C) Go Back to Q3

Q4.

Solution

Concept — Dalton's Law of Partial Pressures: The partial pressure of a gas in a mixture equals its mole fraction times the total pressure:

$$p_i = \chi_i \times P_{\text{total}}$$

Step 1 — Mole fraction of O_2: Total moles $= 2 + 3 = 5$ mol.

$$\chi(O_2) = \frac{3}{5} = 0.60$$

Step 2 — Partial pressure of O_2:

$$p(O_2) = 0.60 \times 5 \text{ atm} = 3 \text{ atm}$$

Why other options are wrong:

- Option B (2 atm): This is the partial pressure of N_2, not O_2.
- Option C (5 atm): This is the total pressure, not the partial pressure.
- Option D (1.5 atm): Incorrect; this would correspond to a mole fraction of 0.30.

Final Answer: $p(O_2) \Longrightarrow \boxed{3 \text{ atm}}$

Answer: (A) Go Back to Q4

Q5.

Solution

Concept — Gibbs Free Energy and Spontaneity: $\Delta G = \Delta H - T\Delta S$. A reaction is spontaneous when $\Delta G < 0$, non-spontaneous when $\Delta G > 0$, and at equilibrium when $\Delta G = 0$.

Step 1 — Given data: $\Delta H = -100$ kJ/mol; $\Delta S = -200$ J/(mol·K) $= -0.200$ kJ/(mol·K).

Step 2 — Expression for ΔG:

$$\Delta G = -100 - T(-0.200) = -100 + 0.200T \text{ (kJ/mol)}$$

Step 3 — Find crossover temperature: $\Delta G = 0 \Rightarrow 0.200T = 100 \Rightarrow T = 500$ K.

Step 4 — Analyse sign of ΔG:

- $T < 500$ K: $\Delta G < 0$ (spontaneous, since $|\Delta H|$ dominates)
- $T > 500$ K: $\Delta G > 0$ (non-spontaneous, since $-T\Delta S$ dominates and is positive because $\Delta S < 0$)

Why other options are wrong:

- Option A: Reaction is spontaneous *below* 500 K, not non-spontaneous.
- Option B: 1000 K is incorrect; the crossover is at 500 K.
- Option C: The reaction IS spontaneous at low temperatures.

Final Answer: Non-spontaneous above 500 K $\Rightarrow$ Option (D)

Answer: (D) Go Back to Q5

Q6.

Solution

Concept — Degree of Dissociation and K_p: For $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$, starting with pressure P_0 of pure PCl_5, at degree of dissociation α and total pressure P:

$$K_p = \frac{\alpha^2 P}{1 - \alpha^2}$$

Step 1 — Set up equilibrium pressures: Let initial pressure of $PCl_5 = P_0 = 2$ atm, degree of dissociation = α. At equilibrium, total moles $\propto (1-\alpha) + \alpha + \alpha = 1 + \alpha$ (per mole PCl_5).

Partial pressures (using mole fractions at total pressure P; but here, since no inert gas, total pressure P changes — the initial 2 atm is the initial pressure before dissociation):

Using the standard result for this system at total pressure P:

$$K_p = \frac{\alpha^2 P}{1 - \alpha^2}$$

where P is the total equilibrium pressure. If initial pressure $P_0 = 2$ atm at $\alpha = 0$, and assuming volume is constant (the question implies total pressure at equilibrium):

Alternatively, treating the initial pressure as the starting point, the total equilibrium pressure at α is $P = P_0(1+\alpha)/(1) = 2(1+\alpha)$ (if at constant volume and using ideal gas). But the standard K_p expression for this dissociation gives:

$$K_p = \frac{\alpha^2}{1-\alpha^2} \times P_{\text{total}}$$

With $K_p = 1$ atm and $P_{\text{total}} = 2$ atm (given as initial/equilibrium total pressure):

$$1 = \frac{\alpha^2 \times 2}{1-\alpha^2}$$

$$1 - \alpha^2 = 2\alpha^2 \implies 3\alpha^2 = 1 \implies \alpha = \frac{1}{\sqrt{3}} \approx 0.577$$

Why other options are wrong:

- Option A ($\alpha = 0.5$): Would give $K_p = 0.25 \times 2/0.75 = 0.67 \neq 1$.
- Option C ($\alpha = 1/\sqrt{2}$): Would give $K_p = 0.5 \times 2/0.5 = 2 \neq 1$.
- Option D ($\alpha = 0.25$): Would give $K_p = 0.0625 \times 2/0.9375 \approx 0.133 \neq 1$.

Final Answer: $\alpha = \frac{1}{\sqrt{3}} \approx 0.577 \Rightarrow$ Option (B)

Answer: (B) Go Back to Q6

Q7.

Solution

Concept — Weak Acid Equilibrium and K_a: For a weak acid HA $\rightleftharpoons$ H^+ + A^-, if the degree of dissociation is small:

$$K_a \approx \frac{[H^+]^2}{C}$$

where C is the initial concentration.

Step 1 — Find $[H^+]$ from pH:

$$\text{pH} = 3 \implies [H^+] = 10^{-3}\ \text{M}$$

Step 2 — Calculate K_a:

$$K_a = \frac{(10^{-3})^2}{0.1} = \frac{10^{-6}}{10^{-1}} = 10^{-5}$$

Verification: Degree of dissociation $= \frac{10^{-3}}{0.1} = 0.01 = 1\%$, which is small enough to justify the approximation.

Why other options are wrong:

- Option A (10^{-3}): This equals $[H^+]$, not K_a.
- Option B (10^{-4}): Off by one order of magnitude.
- Option D (10^{-6}): Would require $[H^+] = \sqrt{10^{-6} \times 0.1} = 3.16 \times 10^{-4}$, i.e., pH ≈ 3.5.

Final Answer: $K_a = 10^{-5} \Rightarrow$ Option (C)

Answer: (C) Go Back to Q7

Q8.

Solution

Concept — Electrochemical Corrosion of Iron: Corrosion of iron is an electrochemical process. The iron surface acts as a galvanic cell with local anodic and cathodic areas. At the **anode**, oxidation occurs: $Fe \rightarrow Fe^{2+} + 2e^-$. At the **cathode**, reduction occurs: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$.

Step 1 — Identify the anode: Regions of the iron surface with higher mechanical stress, grain boundaries, or lower dissolved oxygen concentration become electron-rich (anodic). At these sites, iron is oxidised and dissolves as Fe^{2+} ions.

Step 2 — Overall process: The Fe^{2+} ions migrate through the electrolyte (moisture) and are further oxidised to Fe^{3+}, eventually forming $Fe_2O_3 \cdot xH_2O$ (rust) in regions away from the original anodic sites.

Why other options are wrong:

- Option B: The cathodic region undergoes *reduction*, not oxidation; it is not the anode.
- Option C: The anode and cathode are at *different* locations on the surface.
- Option D: The rust layer (Fe_2O_3) forms as the *product* of corrosion, not as the primary anodic site.

Final Answer: Stressed or oxygen-deficient regions act as anodes $\Rightarrow$ Option (A)

Answer: (A) Go Back to Q8

Q9.

Solution

Concept — Integrated Rate Laws and Linear Plots: The integrated rate law for a first-order reaction is:

$$\ln[\text{A}] = \ln[\text{A}]_0 - kt$$

This has the form $y = mx + c$, so a plot of $\ln[\text{A}]$ (or equivalently $\log[\text{A}]$) vs. t gives a straight line with slope $= -k$.

First-order: $\ln[\text{A}]$ vs. t is linear

Why other options are wrong:

- Option A ($[\text{A}]$ vs. t): Linear for a *zero-order* reaction.
- Option B ($[\text{A}]^2$ vs. t): This is not a standard linear form for any common order.
- Option C ($1/[\text{A}]$ vs. t): Linear for a *second-order* reaction.

Final Answer: $\ln[\text{A}]$ vs. t gives a straight line for first-order $\Rightarrow$ Option (D)

Answer: (D) Go Back to Q9

Q10.

Solution

Concept — Henry's Law: Henry's law states that the partial pressure of a gas above a solution is proportional to its mole fraction in the solution:

$$p = K_H \cdot \chi$$

where K_H is Henry's law constant and χ is the mole fraction of the dissolved gas.

Step 1 — Apply Henry's law:

$$\chi(\text{CO}_2) = \frac{p(\text{CO}_2)}{K_H} = \frac{0.835 \text{ bar}}{167 \text{ bar}} = 5 \times 10^{-3}$$

Why other options are wrong:

- Option A (5×10^{-4}): Off by a factor of 10 (arithmetic error).
- Option C (0.835): This is the partial pressure in bar, not the mole fraction.
- Option D (167): This is K_H itself, not the mole fraction.

Final Answer: $\chi(\text{CO}_2) = 5 \times 10^{-3} \Rightarrow$ Option (B)

Answer: (B) Go Back to Q10

Q11.

Solution

Concept — Voids in Close-Packed Structures: In a close-packed structure (FCC/CCP) with N atoms:

- Number of octahedral voids $= N$ (one per atom)
- Number of tetrahedral voids $= 2N$ (two per atom)

Step 1 — Count octahedral voids in one FCC unit cell:

- Body centre: 1 octahedral void $\times$ 1 (fully inside) $= 1$
- Edge centres: 12 edges $\times \frac{1}{4}$ (shared by 4 cells) $= 3$
- Total octahedral voids per unit cell $= 1 + 3 = 4$

Step 2 — Atoms per unit cell: FCC has $8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 4$ atoms.

Step 3 — Ratio: Octahedral voids per atom $= \frac{4}{4} = 1$.

Why other options are wrong:

- Option A ($2N$): This is the number of *tetrahedral* voids, not octahedral.
- Option B ($4N$): Incorrect; there are only 4 octahedral voids and 4 atoms per FCC cell.
- Option D ($N/2$): Incorrect ratio.

Final Answer: N octahedral voids for N atoms $\Rightarrow$ Option (C)

Answer: (C) Go Back to Q11

Q12.

Solution

Concept — Diagonal Relationship (Be and Al): Be (Group 2, Period 2) and Al (Group 13, Period 3) show a diagonal relationship because their charge-to-radius ratios (charge density) are similar. As a result, they share several chemical properties.

Step 1 — Key shared properties of Be and Al:

- Both form amphoteric oxides: BeO dissolves in acid and in NaOH; Al_2O_3 similarly dissolves in both.
- Both form covalent chlorides ($BeCl_2$ and $AlCl_3$) that are Lewis acids.
- Both react with NaOH to release H_2 gas.
- Both form similar complex anions: $[Be(OH)_4]^{2-}$ and $[Al(OH)_4]^{-}$.

Why other options are wrong:

- Option B: Be is in Group 2 and Al is in Group 13 — they are in *different* groups.
- Option C: BeO is *amphoteric* (not basic like MgO). MgO is basic; BeO reacts with both acids and bases.
- Option D: Be *does* react with NaOH: $Be + 2NaOH + 2H_2O \rightarrow Na_2[Be(OH)_4] + H_2\uparrow$.

Final Answer: Both BeO and Al_2O_3 are amphoteric $\Rightarrow$ Option (A)

Answer: (A) Go Back to Q12

Q13.

Solution

Concept — Structure of N_2O_5 and Oxidation State: Dinitrogen pentoxide (N_2O_5) is the anhydride of nitric acid. In the gaseous/liquid covalent form, it has the structure $O_2N–O–NO_2$ (two NO_2 groups joined by a bridging oxygen atom).

Step 1 — Determine oxidation state of N in N_2O_5: Let oxidation state of N $= x$. Oxygen is -2.

$$2x + 5(-2) = 0 \implies 2x = 10 \implies x = +5$$

Step 2 — Structure: The covalent structure is $O_2N–O–NO_2$, with an N–O–N bridge. The two nitrogen atoms are each bonded to three oxygens, with one bridging oxygen shared.

Why other options are wrong:

- Option A: N_2O_5 is *covalent* in the gaseous state (it exists as $NO_2^+NO_3^-$ only in the solid/crystal state, not as NO_2^+ and O^{2-}).
- Option B: N_2O_5 does not contain a direct N–N bond; the two N atoms are bridged by oxygen.
- Option C: The oxidation state of N is $+5$, not $+3$.

Final Answer: N–O–N bridge, oxidation state of N = $+5 \Rightarrow$ Option (D)

Answer: (D) Go Back to Q13

Q14.

Solution

Concept — VSEPR Theory and Hybridization of XeF_4: Xenon in XeF_4 has 8 valence electrons. After forming 4 bonds with F, Xe has 4 bonding pairs (BP) and 2 lone pairs (LP) $\Rightarrow$ 6 electron groups total $\Rightarrow$ sp^3d^2 hybridization.

Step 1 — Electron geometry: 6 electron pairs around Xe $\Rightarrow$ octahedral electron geometry.

Step 2 — Molecular geometry: The 2 lone pairs occupy the two axial positions (to minimise LP–LP repulsion). The 4 F atoms are in the equatorial plane $\Rightarrow$ **square planar** molecular geometry.

Hybridization: sp^3d^2 (uses one s, three p, and two d orbitals of Xe).

Why other options are wrong:

- Option A (tetrahedral, sp^3): Ignores the two lone pairs; tetrahedral requires only 4 electron pairs.
- Option C (see-saw, sp^3d): See-saw is the shape for 5 electron pairs (e.g., SF_4), not 6.
- Option D (octahedral, sp^3d^2): Correct hybridization, but the *molecular* shape is square planar (not octahedral) because 2 positions are occupied by lone pairs.

Final Answer: Square planar, $sp^3d^2 \Rightarrow$ Option (B)

Answer: (B) Go Back to Q14

Q15.

Solution

Concept — Lanthanide Contraction and Its Consequences: The 14 lanthanide elements ($Z = 57$–71) have poor shielding by $4f$ electrons. This causes the nuclear charge to pull the outer electrons inward progressively, resulting in a steady decrease in atomic and ionic radii across the lanthanides. By the time we reach Hf ($Z = 72$), its radius is almost the same as Zr ($Z = 40$) directly above it in Group 4.

Step 1 — Effect on Zr and Hf: Zr^{4+}: ionic radius ≈ 72 pm; Hf^{4+}: ionic radius ≈ 71 pm. These nearly identical sizes mean that Zr and Hf have almost identical chemical behaviours in solution, forming analogous compounds with very similar solubilities and stabilities.

Step 2 — Practical consequence: Separating Zr and Hf by conventional chemical methods (precipitation, crystallisation) is extremely difficult because their compounds are nearly isomorphous. Separation typically requires specialised techniques like solvent extraction or fractional distillation of volatile compounds.

Why other options are wrong:

- Option A: Hf is actually *heavier* than Zr (Hf has $Z = 72$, Zr has $Z = 40$); higher atomic number means more protons/neutrons.
- Option B: Hf is *less* reactive than Zr (or comparable), not more; the statement inverts the effect.
- Option D: Radioactivity is not caused by lanthanide contraction and is unrelated to this phenomenon.

Final Answer: Zr and Hf are inseparable by ordinary chemical methods $\Rightarrow$ Option (C)

Answer: (C) Go Back to Q15

Q16.

Solution

Concept — Spectrochemical Series: The spectrochemical series ranks ligands from weakest to strongest field (increasing Δ_o):

$$I^- < Br^- < Cl^- < F^- < OH^- < H_2O < NH_3 < en < CN^- < CO$$

This order is based on the ability of the ligand to cause crystal field splitting. Strong-field ligands (like CN^- and CO) are π-acceptors and cause large splitting.

Weak-field ligands (like Cl^-) cause smaller splitting.

Step 1 — Order for the given ligands:

$$\Delta_o : Cl^- < H_2O < NH_3 < CN^-$$

- Cl^-: weak π-donor $\Rightarrow$ smallest Δ_o
- H_2O: moderate field, σ-donor only
- NH_3: stronger σ-donor than H_2O
- CN^-: strong-field π-acceptor $\Rightarrow$ largest Δ_o

Why other options are wrong:

- Option B: Completely inverts the correct order.
- Option C: Places H_2O below Cl^- and CN^- below NH_3, both incorrect.
- Option D: Places NH_3 below H_2O and Cl^-, which contradicts the spectrochemical series.

Final Answer: $Cl^- < H_2O < NH_3 < CN^- \Rightarrow$ Option (A)

Answer: (A) Go Back to Q16

Q17.

Solution

Concept — Hyperconjugation and Carbocation Stability: Hyperconjugation involves the delocalisation of electrons from a filled σ (C–H or C–C) bond orbital into an adjacent empty p orbital (as in a carbocation). More α-hydrogen atoms (adjacent C–H bonds) means more hyperconjugative structures and greater stabilisation.

Step 1 — Count hyperconjugative H atoms:

- CH_3^+: 0 adjacent α-H atoms $\Rightarrow$ 0 hyperconjugative structures (least stable)
- $CH_3CH_2^+$: 3 α-H atoms $\Rightarrow$ 3 hyperconjugative structures
- $(CH_3)_2CH^+$: 6 α-H atoms $\Rightarrow$ 6 hyperconjugative structures
- $(CH_3)_3C^+$: 9 α-H atoms $\Rightarrow$ 9 hyperconjugative structures (most stable)

Step 2 — Inductive effect: The electron-donating inductive effect ($+I$) of methyl groups also contributes. More methyl groups $\Rightarrow$ greater electron donation toward the cationic centre $\Rightarrow$ greater stabilisation.

Why other options are wrong:

- Option A: Hydrogen bonding is not relevant to isolated carbocations in the gas phase or hydrocarbon solvents.
- Option B: Resonance stabilises carbocations only when there is an adjacent π system (e.g., allylic or benzylic), not in simple alkyl carbocations.
- Option C: Electronegativity of carbon does not increase in tertiary systems; this is incorrect.

Final Answer: Hyperconjugation and inductive effect of methyl groups $\Rightarrow$ Option (D)

Answer: (D) Go Back to Q17

Q18.

Solution

Concept — Optical Isomerism and Chiral Centres: A molecule with n chiral (stereo) centres has a maximum of 2^n stereoisomers. For a molecule with exactly one chiral centre and no other stereogenic elements, there are exactly 2 stereoisomers: the (R)- and (S)-enantiomers (or equivalently, d- and l-forms).

Step 1 — Identify the chiral centre in lactic acid: Lactic acid: CH_3–$\underset{*}{C}H(OH)$–COOH

The central carbon (C-2) bears four different groups: $-CH_3$, –OH, –COOH, and –H $\Rightarrow$ **one chiral centre**.

Step 2 — Number of stereoisomers: With $n = 1$ chiral centre: $2^1 = 2$ stereoisomers. These are (R)-lactic acid (d-lactic acid) and (S)-lactic acid (l-lactic acid), which are non-superimposable mirror images (enantiomers). No meso form is possible with only one chiral centre.

Why other options are wrong:

- Option A (1): A single chiral centre always gives 2 stereoisomers, not 1.
- Option C (3): Would require a special case (e.g., two chiral centres with a meso compound) giving $2^2 - 1 = 3$; not applicable here.
- Option D (4): Would require two independent chiral centres: $2^2 = 4$; lactic acid has only one.

Final Answer: 2 stereoisomers (one pair of enantiomers) $\Rightarrow$ Option (B)

Answer: (B) Go Back to Q18

Q19.

Solution

Concept — Williamson Ether Synthesis: Williamson synthesis is an S_N2 reaction between a sodium alkoxide (R–ONa) and a primary alkyl halide (R'–X):

$$\text{R–ONa} + \text{R'–X} \longrightarrow \text{R–O–R'} + \text{NaX}$$

The alkoxide acts as the nucleophile attacking the less-hindered (primary) alkyl halide. Using a secondary or tertiary alkyl halide leads to elimination (E2) instead of substitution.

Step 1 — Target molecule: CH_3–O–C_2H_5 (ethyl methyl ether).

Step 2 — Best choice of reactants: Option C: CH_3ONa (sodium methoxide) + C_2H_5Br (ethyl bromide, primary halide).

$$CH_3O^- + C_2H_5Br \xrightarrow{S_N2} CH_3OC_2H_5 + Br^-$$

This is ideal: the nucleophile is the methoxide anion and the electrophile is the primary ethyl bromide, minimising elimination side reactions.

Why other options are wrong:

- Option A: Acid-catalysed dehydration of alcohols is the *Lucas method*, not Williamson synthesis.
- Option B: C_2H_5ONa + CH_3Br also gives $CH_3OC_2H_5$, but CH_3Br is more volatile and expensive; Option C is the preferred, standard preparation.
- Option D: Two sodium alkoxides would not react with each other to form an ether.

Final Answer: CH_3ONa + $C_2H_5Br \Rightarrow$ Option (C)

Answer: (C) Go Back to Q19

Q20.

Solution

Concept — Reimer–Tiemann Reaction: When phenol is treated with chloroform ($CHCl_3$) and aqueous sodium hydroxide (NaOH), the Reimer–Tiemann reaction occurs. $CHCl_3$ generates dichlorocarbene (:CCl_2) in the presence of NaOH. This highly reactive electrophile attacks the *ortho* position of the phenoxide anion preferentially (due to electronic and steric effects), and after hydrolysis, gives an aldehyde group at the *ortho* position.

Step 1 — Mechanism outline:

(a) NaOH deprotonates phenol → phenoxide ion (PhO^-), which activates the ring at *ortho* and *para* positions.
(b) $CHCl_3$ + NaOH → $:CCl_2$ (dichlorocarbene, an electrophile).
(c) $:CCl_2$ attacks at the *ortho* position of phenoxide (major product) or *para* (minor product).
(d) Hydrolysis of the intermediate gives –CHO at the site of attack.

Step 2 — Major product: *Ortho* attack gives **salicylaldehyde** (2-hydroxybenzaldehyde) as the major product. The *para* isomer (4-hydroxybenzaldehyde) is a minor by-product.

Why other options are wrong:

- Option B (4-hydroxybenzaldehyde): This is the minor product (para attack), not the major product.
- Option C (benzoic acid): Phenol oxidation or Kolbe reaction would give benzoic acid/salicylic acid, not the Reimer–Tiemann reaction.
- Option D (benzoquinone): Benzoquinone is an oxidation product of phenol, not a product of the Reimer–Tiemann reaction.

Final Answer: Salicylaldehyde (2-hydroxybenzaldehyde) is the major product ⇒ Option (A)

Answer: (A) Go Back to Q20

Q21.

Solution

Concept — Enthalpy of Neutralisation: The neutralisation of a strong acid by a strong base is essentially the reaction:

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l), \quad \Delta H_{neut} = -57 \text{ kJ/mol}$$

The value -57 kJ/mol is constant for all strong acid–strong base neutralisations because both are fully dissociated and the only net reaction is the combination of H^+ and OH^-.

Calculation: 1 mol HCl reacts with 1 mol NaOH ⇒ 1 mol H_2O is formed. Heat released $= 1 \times 57 = 57$ kJ.

Final Answer: ⇒ $\boxed{57}$ kJ

Answer: (57) Go Back to Q21

Q22.

Solution

Concept — First-Order Kinetics and Half-Life: For a first-order reaction, the half-life $t_{1/2}$ is constant and independent of concentration:

$$t_{1/2} = \frac{\ln 2}{k}$$

Step 1 — Find $t_{1/2}$: The reaction is 50% complete in 10 min $\Rightarrow t_{1/2} = 10$ min.

Step 2 — Time for 75% completion: 75% completion means 25% of reactant remains. $\frac{[A]_t}{[A]_0} = \frac{1}{4} = \left(\frac{1}{2}\right)^2$

This requires exactly **2 half-lives**:

$$t_{75\%} = 2 \times t_{1/2} = 2 \times 10 = 20 \text{ min}$$

Final Answer: $\Rightarrow \boxed{20}$ minutes

Answer: (20) Go Back to Q22

Q23.

Solution

Concept — Faraday's Laws of Electrolysis: The amount of substance deposited at an electrode is directly proportional to the charge passed. 1 Faraday (96485 C) deposits 1 mole of a monovalent ion.

Step 1 — Electrode reaction for Al:

$$Al^{3+}(aq) + 3e^- \longrightarrow Al(s)$$

To deposit 1 mole of Al, 3 moles of electrons are required.

Step 2 — Charge in Faradays: 3 moles of electrons $= 3$ Faradays.

Final Answer: $\Rightarrow \boxed{3}$ Faradays (moles of electrons)

Answer: (3) Go Back to Q23

Q24.

Solution

Concept — Molarity and Unit Conversion: Molarity $M = \dfrac{\text{moles of solute}}{\text{volume of solution in litres}}$. Millimolar (mM) $= 10^{-3}$ M, so 1 M $= 1000$ mM.

Step 1 — Moles of NaCl:

$$n(\text{NaCl}) = \frac{5.85 \text{ g}}{58.5 \text{ g/mol}} = 0.100 \text{ mol}$$

Step 2 — Molarity:

$$M = \frac{0.100 \text{ mol}}{1.00 \text{ L}} = 0.100 \text{ mol/L} = 0.100 \text{ M}$$

Step 3 — Convert to millimolar:

$$0.100 \text{ M} \times 1000 \text{ mM/M} = 100 \text{ mM}$$

Final Answer: $\Rightarrow \boxed{100}$ mM

Answer: (100) Go Back to Q24

Q25.

Solution

Concept — Equilibrium Constant K_c: For the reaction A(g) + B(g) $\rightleftharpoons$ 2C(g):

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

Substituting equilibrium concentrations: [A] $= 1.00$ M, [B] $= 1.00$ M, [C] $= \sqrt{2}$ M.

$$K_c = \frac{(\sqrt{2})^2}{(1.00)(1.00)} = \frac{2}{1} = 2$$

Final Answer: $K_c \Longrightarrow \boxed{2}$

Answer: (2) Go Back to Q25

Q26.

Solution

Concept — Empirical Formula from Composition: The empirical formula is the simplest whole-number ratio of atoms in a compound.

Step 1 — Find moles of C and H:

$$n(\text{C}) = \frac{1.2 \text{ g}}{12 \text{ g/mol}} = 0.10 \text{ mol}$$

$$n(\text{H}) = \frac{0.4 \text{ g}}{1 \text{ g/mol}} = 0.40 \text{ mol}$$

Step 2 — Mole ratio C : H:

$$\text{C} : \text{H} = 0.10 : 0.40 = 1 : 4$$

Step 3 — Empirical formula and molar mass: Empirical formula: CH_4 Molar mass of $CH_4 = 12 + 4(1) = 16$ g/mol.

Note: The molecular formula could be CH_4 (methane, if the molecular mass $= 16$ g/mol).

Final Answer: Molar mass of empirical formula unit $CH_4 \Longrightarrow \boxed{16}$ g/mol

Answer: (16) Go Back to Q26

Q27.

Solution

Concept — Oxidation State Calculation: In any compound or ion, the sum of oxidation states of all atoms equals the overall charge. Oxygen has oxidation state -2 (in most compounds).

Step 1 — Set up the equation for IO_3^-: Let oxidation state of I $= x$.

$$x + 3(-2) = -1$$

$$x - 6 = -1$$

$$x = +5$$

Verification: IO_3^- is the iodate ion; I in $+5$ state is consistent with the known chemistry of iodine in period 5 (Group 17), where common oxidation states are $-1, +1, +3, +5, +7$.

Final Answer: Oxidation state of I in IO_3^- $\Longrightarrow \boxed{+5}$

Answer: (5) Go Back to Q27

Q28.

Solution

Concept — Dipole Moment and Molecular Symmetry: The dipole moment of a molecule is the vector sum of all bond dipoles. If the molecule is symmetric, individual bond dipoles cancel, giving a net dipole moment of zero.

Step 1 — Structure of CO_2: CO_2 is a linear molecule: O = C = O, with the carbon atom in the centre and both C=O bonds at 180 to each other.

Step 2 — Bond dipoles: Each C=O bond is polar (oxygen is more electronegative). However, the two C=O bond dipoles point in exactly opposite directions and are of equal magnitude. Their vector sum $= 0$.

Step 3 — Net dipole moment: $\mu(CO_2) = 0$ Debye.

This explains why CO_2 (despite polar bonds) is a nonpolar molecule with zero dipole moment.

Final Answer: $\mu(CO_2) \Longrightarrow \boxed{0}$ Debye

Answer: (0) Go Back to Q28

Q29.

Solution

Concept — Rate Law Calculation: The rate of a second-order reaction with rate law rate $= k[A]^2$ is calculated by substituting the concentration and rate constant directly.

Step 1 — Substitute values: $k = 0.5\ \text{L mol}^{-1}\,\text{s}^{-1}$; $[A] = \sqrt{10}$ mol/L.

$$\text{rate} = k[A]^2 = 0.5 \times (\sqrt{10})^2 = 0.5 \times 10 = 5\ \text{mol L}^{-1}\text{s}^{-1}$$

Note: $(\sqrt{10})^2 = 10$, so the rate is simply $0.5 \times 10 = 5$.

Final Answer: Rate $\Longrightarrow \boxed{5}\ \text{mol L}^{-1}\,\text{s}^{-1}$

Answer: (5) Go Back to Q29

Q30.

Solution

Concept — Types of Bonds in Methane: A sigma (σ) bond is formed by the direct (head-on) overlap of atomic orbitals along the internuclear axis. Every single bond in a covalent molecule is a sigma bond. Pi (π) bonds are formed by sideways overlap and occur in double or triple bonds (in addition to the sigma bond already present).

Step 1 — Structure of CH_4: Methane has 4 C–H single bonds. Each C–H bond is formed by head-on overlap of a carbon sp^3 hybrid orbital with a hydrogen $1s$ orbital $\Rightarrow$ each is a σ bond.

Step 2 — Count sigma bonds: 4 C–H bonds, all sigma $\Rightarrow$ **4 sigma bonds** in total. There are no pi bonds in methane.

Final Answer: Number of σ bonds in CH_4 $\Longrightarrow \boxed{4}$

Answer: (4) Go Back to Q30

Answer Key

Section A — MCQ Answers

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

Section B — Numerical Value Answers

Q	Ans	Q	Ans
21	57	22	20
23	3	24	100
25	2	26	16
27	5	28	0
29	5	30	4