GATE Chemistry

Sample Paper – 5

Duration: 128 Minutes **Maximum Marks: 72**

Instructions

- This paper contains **46 questions** covering the core **Chemistry (CY)** subject of the GATE paper conducted by the IITs and IISc (General Aptitude and Engineering Mathematics are provided as separate papers).
- **Q1–Q20 carry 1 mark each** and **Q21–Q46 carry 2 marks each**, for a total of **72 marks**.
- Each question carries **negative marking of one-third of its allotted marks**: a wrong 1-mark question costs **0.33** and a wrong 2-mark question costs **0.67**. Unattempted questions carry no penalty.
- Every question here is a single-correct **MCQ**. The real GATE paper also has Multiple Select (MSQ) and Numerical Answer Type (NAT) questions, and **those carry no negative marking**.
- Attempt this paper in one timed sitting of about **128 minutes**, the share this core subject earns at GATE's overall pace of 180 minutes for 65 questions. Take $R = 8.314\ \mathrm{J\,mol^{-1}K^{-1}}$, $F = 96500\ \mathrm{C\,mol^{-1}}$ and $N_A = 6.022 \times 10^{23}\ \mathrm{mol^{-1}}$ unless stated otherwise.

Physical Chemistry: Quantum Chemistry and Spectroscopy

Q1. In the Bohr model of the hydrogen atom the energy of the electron in the nth orbit is $E_n = -\dfrac{13.6}{n^2}\ \mathrm{eV}$, with $n = 1, 2, 3, \ldots$ The energy of the electron in the first excited state ($n = 2$) is: **[1 mark]**

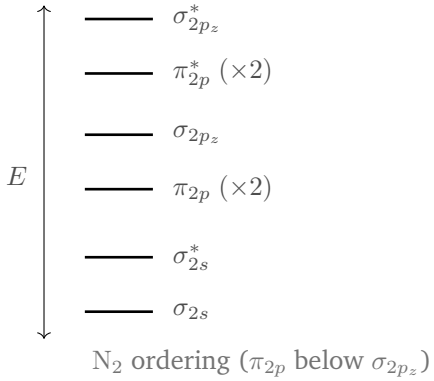
(A) $-3.40\ \mathrm{eV}$

(B) $-13.6\ \mathrm{eV}$

(C) $-6.80\ \mathrm{eV}$

(D) -1.51 eV

Q2. The molecular-orbital energy ladder for the second-period homonuclear diatomic N_2 is sketched below. Counting the core and valence orbitals, N_2 has 10 electrons in bonding MOs and 4 electrons in antibonding MOs. The bond order of N_2 is: **[1 mark]**



(A) 1

(B) 2

(C) 2.5

(D) 3

Q3. The number of normal (fundamental) modes of vibration of a *non-linear* molecule such as water (H_2O, with $N = 3$ atoms) is given by $3N - 6$. This number is: **[1 mark]**

(A) 5

(B) 6

(C) 3

(D) 4

Q4. For a hydrogen-like orbital, the total number of nodes equals $n - 1$, of which the angular nodes number l and the radial nodes number $n - l - 1$. The number of *radial* nodes in a $3s$ orbital is: **[1 mark]**

(A) 0

(B) 1

(C) 3

(D) 2

Q5. A molecule can show a pure rotational (microwave) absorption spectrum only if it possesses a permanent electric dipole moment. Among the molecules N_2, HCl, O_2 and H_2, the one that is microwave active is: **[1 mark]**

(A) N_2

(B) HCl

(C) O_2

(D) H_2

Q6. When an electron in a hydrogen atom falls from the level $n = 4$ to all lower levels, the number of distinct spectral lines produced is given by $\frac{n(n-1)}{2}$. For $n = 4$, this number of lines is: **[1 mark]**

(A) 3

(B) 4

(C) 6

(D) 10

Physical Chemistry: Thermodynamics, Kinetics and Electrochemistry

Q7. The standard cell potential and the standard Gibbs free-energy change are related by $\Delta G^\circ = -nFE^\circ$. For a cell reaction with $n = 2$ electrons transferred and $E^\circ = 0.50$ V, the value of ΔG° is: **[1 mark]**

(A) $-48.25\ \text{kJ mol}^{-1}$

(B) $-96.5\ \text{kJ mol}^{-1}$

(C) $+96.5\ \text{kJ mol}^{-1}$

(D) $-193\ \text{kJ mol}^{-1}$

Q8. For the Daniell cell $\mathrm{Zn}\,|\,\mathrm{Zn^{2+}}\,||\,\mathrm{Cu^{2+}}\,|\,\mathrm{Cu}$ with $E^\circ_{\text{cell}} = 1.10\ \mathrm{V}$ and $n = 2$, the Nernst equation at $298\ \mathrm{K}$ is $E = E^\circ - \dfrac{0.0591}{n}\log\dfrac{[\mathrm{Zn^{2+}}]}{[\mathrm{Cu^{2+}}]}$. If $[\mathrm{Zn^{2+}}] = 1.0\ \mathrm{M}$ and $[\mathrm{Cu^{2+}}] = 0.01\ \mathrm{M}$, the cell potential E is nearest to: **[1 mark]**

(A) $1.04\ \mathrm{V}$

(B) $1.16\ \mathrm{V}$

(C) $1.10\ \mathrm{V}$

(D) $0.94\ \mathrm{V}$

Q9. A first-order reaction is found to be 75% complete in 60 minutes. The half-life of the reaction is: **[1 mark]**

(A) $60\ \mathrm{min}$

(B) $30\ \mathrm{min}$

(C) $15\ \mathrm{min}$

(D) $45\ \mathrm{min}$

Q10. In the electrolysis of aqueous $\mathrm{CuSO_4}$, copper is deposited by $\mathrm{Cu^{2+}} + 2e^- \rightarrow \mathrm{Cu}$ (atomic mass of $\mathrm{Cu} = 63.5$). The mass of copper deposited when 2 faradays of charge are passed is: **[1 mark]**

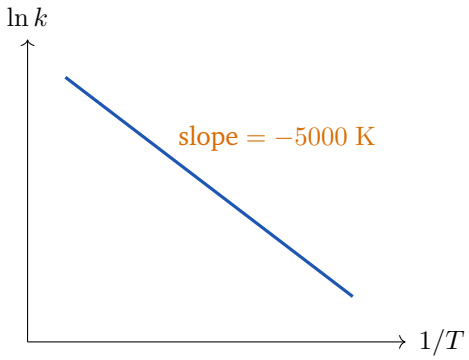
(A) $31.75\ \mathrm{g}$

(B) $63.5\ \mathrm{g}$

(C) $127\ \mathrm{g}$

(D) $15.9\ \mathrm{g}$

Q11. The Arrhenius plot of $\ln k$ against $1/T$ for a reaction is a straight line of slope $-5000\ \mathrm{K}$, as shown. Using slope $= -E_a/R$, the activation energy E_a of the reaction is nearest to: **[1 mark]**



(A) $41.6\ \text{kJ mol}^{-1}$

(B) $5000\ \text{kJ mol}^{-1}$

(C) $0.60\ \text{kJ mol}^{-1}$

(D) $8.31\ \text{kJ mol}^{-1}$

Q12. An endothermic reaction has $\Delta H = +30\ \text{kJ mol}^{-1}$ and $\Delta S = +100\ \text{J mol}^{-1}\text{K}^{-1}$, both taken as temperature-independent. The temperature above which the reaction becomes spontaneous (that is, $\Delta G = \Delta H - T\Delta S < 0$) is: [1 mark]

(A) $300\ \text{K}$

(B) $100\ \text{K}$

(C) $3000\ \text{K}$

(D) $30\ \text{K}$

Q13. At $298\ \text{K}$ the standard cell potential and equilibrium constant are linked by $\log K = \dfrac{nE^\circ}{0.0591}$. For a cell with $n = 1$ and $E^\circ = 0.0591\ \text{V}$, the equilibrium constant K is: [1 mark]

(A) 1

(B) 10

(C) 100

(D) 0.1

Q14. A reaction obeys the rule that its rate constant doubles for every 10 K rise in temperature (temperature coefficient $= 2$). If the rate constant at 300 K is k, then the rate constant at 330 K is: **[1 mark]**

(A) $2k$

(B) $4k$

(C) $8k$

(D) $16k$

Inorganic Chemistry: Main Group and Periodic Properties

Q15. Among the oxides of nitrogen NO, N_2O, N_2O_5 and N_2O_3, the oxidation state of nitrogen is *highest* in: **[1 mark]**

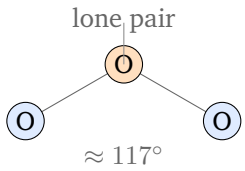
(A) NO

(B) N_2O

(C) N_2O_5

(D) N_2O_3

Q16. According to VSEPR theory, the central oxygen atom of the ozone molecule O_3 carries one lone pair and two bonding regions, as sketched below. The shape of the O_3 molecule is: **[1 mark]**



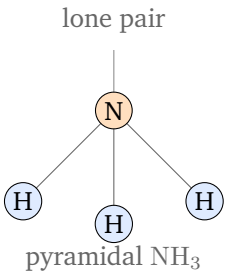
(A) linear

(B) bent (angular)

(C) trigonal planar

(D) T-shaped

Q17. In the ammonia molecule NH_3, shown below, the central nitrogen atom is surrounded by three bonding pairs and one lone pair (steric number 4). The hybridization of the nitrogen atom is: **[1 mark]**



(A) sp

(B) sp^2

(C) sp^3d

(D) sp^3

Q18. In the thiosulfate ion $S_2O_3^{2-}$, each oxygen is assigned an oxidation number of -2 and the ion bears a charge of -2. The *average* oxidation state of sulfur in $S_2O_3^{2-}$ is: **[1 mark]**

(A) $+6$

(B) $+2$

(C) $+4$

(D) -2

Q19. In group 16 (the oxygen family), the element with the *most negative* (most exothermic) electron gain enthalpy is not oxygen but the next member, because the small, compact oxygen atom suffers strong electron–electron repulsion on adding an electron. That element is: **[1 mark]**

(A) O

(B) S

(C) Te

(D) Se

Q20. Among the group-16 hydrides H_2S, H_2Te, H_2Se and H_2O, one has an anomalously high boiling point because of intermolecular hydrogen bond-

ing. That hydride is: [1 mark]

(A) H_2S

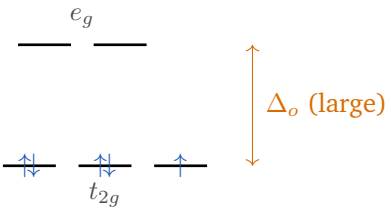
(B) H_2Te

(C) H_2Se

(D) H_2O

Inorganic Chemistry: Coordination Compounds and Organometallics

Q21. The low-spin octahedral complex $[Fe(CN)_6]^{3-}$ has an iron(III) (d^5) centre; the strong-field CN^- ligands force the electrons into the t_{2g} set as shown, leaving one unpaired electron. Using the spin-only formula $\mu = \sqrt{n(n+2)}$ BM, the magnetic moment is nearest to: [2 marks]



(A) 5.92 BM

(B) 3.87 BM

(C) 1.73 BM

(D) 4.90 BM

Q22. The pentacarbonyliron(0) complex $[Fe(CO)_5]$ obeys the effective-atomic-number (18-electron) rule. Taking iron(0) to contribute 8 valence electrons and each CO ligand to donate 2 electrons, the total valence electron count of the complex is: [2 marks]

(A) 16

(B) 20

(C) 18

(D) 14

Q23. The octahedral complex $[CoF_6]^{3-}$ has a cobalt(III) (d^6) centre; the weak-field fluoride ligands give a high-spin arrangement with four unpaired electrons. Using $\mu = \sqrt{n(n+2)}$ BM, the spin-only magnetic moment is nearest to: **[2 marks]**

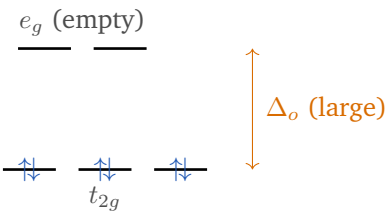
(A) 4.90 BM

(B) 5.92 BM

(C) 2.83 BM

(D) 1.73 BM

Q24. The complex $[Co(NH_3)_6]^{3+}$ has a cobalt(III) (d^6) centre in a strong (low-spin) octahedral field, so all six d electrons pair up in the t_{2g} set, as shown. The number of unpaired electrons in this complex is: **[2 marks]**



(A) 4

(B) 2

(C) 0

(D) 6

Q25. The square-planar complex $[Pt(NH_3)_2Cl_2]$ (a platinum(II) d^8 centre) can exist in two forms in which the two chloride ligands are either adjacent or opposite. The number of geometrical (cis/trans) isomers of this complex is: **[2 marks]**

(A) 2

(B) 1

(C) 3

(D) 4

Q26. Among the four-coordinate complexes below, exactly one is diamagnetic (zero unpaired electrons) because it is square planar with a low-spin d^8 configuration. That diamagnetic complex is: **[2 marks]**

(A) $[Ni(CN)_4]^{2-}$

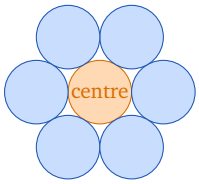
(B) $[NiCl_4]^{2-}$

(C) $[CoF_6]^{3-}$

(D) $[Mn(H_2O)_6]^{2+}$

Inorganic Chemistry: Solid State and Bioinorganic

Q27. In a cubic close-packed (ccp / fcc) or hexagonal close-packed (hcp) arrangement of identical spheres, each sphere touches a fixed number of nearest neighbours, as suggested by the in-plane ring of six shown below (with three more above and three below). This coordination number is: **[2 marks]**



six in-plane neighbours (+3 above, +3 below)

(A) 8

(B) 12

(C) 6

(D) 4

Q28. In a cubic close-packed (ccp) lattice made up of N atoms, the octahedral voids number N and the tetrahedral voids number twice as many. The number of *tetrahedral* voids in such a lattice of N atoms is: **[2 marks]**

(A) N

(B) $2N$

(C) $N/2$

(D) $4N$

Q29. The vitamin B_{12} (cyanocobalamin) molecule contains a corrin ring that coordinates a central metal ion, in a manner analogous to the metal at the centre of a porphyrin. The metal ion at the centre of vitamin B_{12} is: [2 marks]

(A) Fe

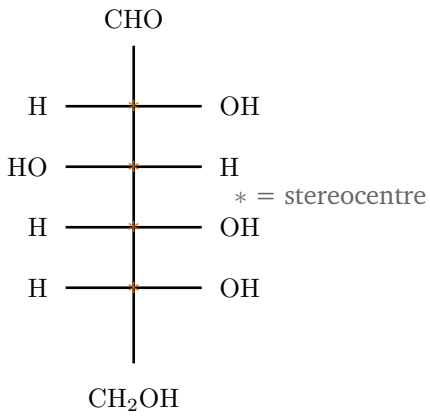
(B) Mg

(C) Zn

(D) Co

Organic Chemistry: Stereochemistry and Reaction Mechanisms

Q30. The open-chain (Fischer) form of D-glucose is shown below. Counting only the carbon atoms bearing four different groups, the number of chiral (stereogenic) carbon atoms in open-chain glucose is: [2 marks]



(A) 2

(B) 3

(C) 4

(D) 5

Q31. Tartaric acid, $HOOC{-}CH(OH){-}CH(OH){-}COOH$, has two similar stereocentres. Because one arrangement is an internal-mirror (meso) form, the actual number of distinct stereoisomers is one fewer than the maximum $2^2 = 4$. The number of stereoisomers of tartaric acid is: [2 marks]

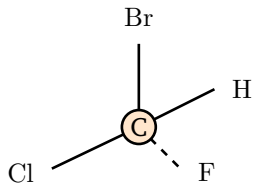
(A) 4

(B) 1

(C) 2

(D) 3

Q32. To assign R/S configuration at the stereocentre of $\mathrm{CHFClBr}$ (shown below), the four substituents are ranked by the Cahn–Ingold–Prelog rule, that is by decreasing atomic number of the first atom. The correct priority order (highest first) is: **[2 marks]**



(A) $\mathrm{Br} > \mathrm{Cl} > \mathrm{F} > \mathrm{H}$

(B) $\mathrm{H} > \mathrm{F} > \mathrm{Cl} > \mathrm{Br}$

(C) $\mathrm{F} > \mathrm{Cl} > \mathrm{Br} > \mathrm{H}$

(D) $\mathrm{Cl} > \mathrm{Br} > \mathrm{F} > \mathrm{H}$

Q33. An S_N1 substitution proceeds through a carbocation intermediate, so its rate is governed by how easily that cation forms. Among the following bromides, the one that reacts *fastest* by an S_N1 mechanism is: **[2 marks]**

(A) $\mathrm{CH_3Br}$ (methyl bromide)

(B) $\mathrm{CH_3CH_2Br}$ (ethyl bromide)

(C) $(\mathrm{CH_3})_2\mathrm{CHBr}$ (isopropyl bromide)

(D) $(\mathrm{CH_3})_3\mathrm{CBr}$ (*tert*-butyl bromide)

Q34. The rate of an S_N2 reaction is controlled by steric access to the carbon under attack, so it falls as that carbon becomes more substituted. The correct order of S_N2 reactivity (fastest first) is: **[2 marks]**

(A) tertiary $>$ secondary $>$ primary $>$ methyl

(B) secondary $>$ tertiary $>$ primary $>$ methyl

(C) methyl $>$ primary $>$ secondary $>$ tertiary

(D) primary $>$ methyl $>$ tertiary $>$ secondary

Q35. A racemic mixture (an equimolar mixture of two enantiomers) shows no net optical rotation. The reason it is optically inactive is that: **[2 marks]**

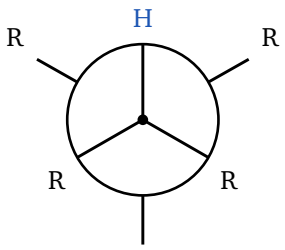
(A) it contains equal amounts of two enantiomers whose equal and opposite rotations cancel (external compensation)

(B) it possesses an internal plane of symmetry within a single molecule

(C) it contains no chiral (stereogenic) carbon at all

(D) it is a single pure enantiomer

Q36. The bimolecular $E2$ elimination is stereospecific: the departing leaving group and the β-hydrogen removed must lie in the same plane on opposite sides, as in the Newman projection below. This required geometry is described as: **[2 marks]**



H and Br are 180° apart

(A) syn-periplanar

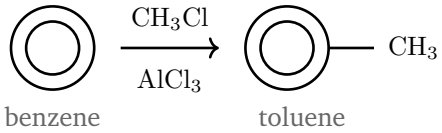
(B) gauche

(C) eclipsed

(D) anti-periplanar

Organic Chemistry: Named Reactions and Synthesis

Q37. Benzene reacts with methyl chloride (CH_3Cl) in the presence of anhydrous $AlCl_3$ to give toluene, as shown. This carbon–carbon bond-forming electrophilic aromatic substitution is the: **[2 marks]**



(A) Friedel–Crafts alkylation

(B) Friedel–Crafts acylation

(C) Wurtz–Fittig reaction

(D) Sandmeyer reaction

Q38. Benzene reacts with acetyl chloride (CH_3COCl) in the presence of anhydrous $AlCl_3$ to give acetophenone ($C_6H_5COCH_3$). This electrophilic aromatic substitution, which installs an acyl group on the ring, is the: **[2 marks]**

(A) Friedel–Crafts alkylation

(B) nitration

(C) sulfonation

(D) Friedel–Crafts acylation

Q39. In electrophilic aromatic substitution, the hydroxyl ($-OH$) group attached to a benzene ring donates electron density into the ring by resonance. The $-OH$ group is therefore: **[2 marks]**

(A) meta directing and deactivating

(B) meta directing and activating

(C) ortho/para directing and activating

(D) ortho/para directing and deactivating

Q40. In electrophilic aromatic substitution, the nitro ($-NO_2$) group attached to a benzene ring withdraws electron density from the ring by resonance and induction. The $-NO_2$ group is therefore: **[2 marks]**

(A) ortho/para directing and activating

(B) ortho/para directing and deactivating

(C) meta directing and deactivating

(D) meta directing and activating

Q41. Benzene is converted into benzenesulfonic acid ($C_6H_5SO_3H$) by electrophilic aromatic substitution, in which the attacking electrophile is SO_3. The reagent used to carry out this sulfonation of benzene is: **[2 marks]**

(A) HNO_3 with H_2SO_4

(B) CH_3Cl with $AlCl_3$

(C) Br_2 with $FeBr_3$

(D) fuming sulfuric acid (oleum, SO_3/H_2SO_4)

Q42. Phenol is treated with chloroform ($CHCl_3$) and aqueous sodium hydroxide, then acidified, to introduce a $-CHO$ group at the ortho position, giving salicylaldehyde. This named reaction is the: **[2 marks]**

(A) Kolbe reaction

(B) Gattermann reaction

(C) Cannizzaro reaction

(D) Reimer–Tiemann reaction

Q43. Aniline ($C_6H_5NH_2$) is treated with sodium nitrite and hydrochloric acid at 0–$5\ ^\circ C$ to form benzenediazonium chloride ($C_6H_5N_2^+Cl^-$). This conversion of a primary aromatic amine to a diazonium salt is called: **[2 marks]**

(A) diazotization

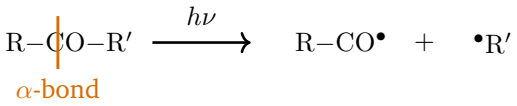
(B) nitration

(C) acylation

(D) azo coupling

Organic Chemistry: Pericyclic, Photochemistry and Biomolecules

Q44. When a ketone is electronically excited by ultraviolet light, the excited carbonyl can break the carbon–carbon bond adjacent to the C=O group (α-cleavage), producing an acyl radical and an alkyl radical, as sketched below. This photochemical α-cleavage of a carbonyl compound is the: **[2 marks]**



(A) Norrish Type I reaction

(B) Norrish Type II reaction

(C) Paterno–Büchi reaction

(D) Diels–Alder reaction

Q45. On ultraviolet irradiation, a ketone bearing a γ-hydrogen can abstract that hydrogen intramolecularly through a six-membered cyclic transition state, generating a $1,4$-biradical that then fragments or cyclizes. This photoreaction is the: **[2 marks]**

(A) Norrish Type I reaction (α-cleavage)

(B) Norrish Type II reaction (γ-hydrogen abstraction)

(C) thermal $[2+2]$ cycloaddition

(D) disrotatory electrocyclization

Q46. A thermal $[1,5]$-hydrogen shift in a $1,3$-pentadiene is a sigmatropic rearrangement involving six π-electrons in its cyclic transition state. According to the Woodward–Hoffmann rules, the migrating hydrogen moves across the same face of the π-system, that is: **[2 marks]**

(A) antarafacially

(B) suprafacially

(C) in a symmetry-forbidden manner

(D) conrotatorily

Detailed Solutions

Q1.

Solution

Concept – Bohr energy levels of hydrogen scale as $1/n^2$: The bound-state energy is $E_n = -\dfrac{13.6}{n^2}$ eV, so each level is fixed by the quantum number n.

Step 1 – identify the first excited state: The ground state is $n = 1$; the first excited state is the next one up, $n = 2$.

Step 2 – substitute $n = 2$: $E_2 = -\dfrac{13.6}{2^2}$ eV

Step 3 – evaluate the denominator: $E_2 = -\dfrac{13.6}{4}$ eV

Step 4 – divide: $E_2 = -3.40$ eV

Why the other options are wrong: -13.6 eV is the ground state ($n = 1$); -6.80 and -1.51 eV come from mis-substituting n.

Final Answer: $E_2 = -3.40$ eV $\Rightarrow$ A

Answer: (A) Go Back to Q1

Q2.

Solution

Concept – bond order from molecular-orbital populations: Bond order $= \dfrac{N_b - N_a}{2}$, where N_b and N_a are the electrons in bonding and antibonding MOs.

Step 1 – read the populations from the diagram: For N_2 (14 electrons), the filled MOs give $N_b = 10$ bonding and $N_a = 4$ antibonding electrons.

Step 2 – substitute into the formula: Bond order $= \dfrac{10 - 4}{2}$

Step 3 – evaluate the numerator: Bond order $= \dfrac{6}{2}$

Step 4 – divide: Bond order $= 3$

Step 5 – cross-check: A bond order of 3 matches the N≡N triple bond, consistent with N_2 being diamagnetic and very stable.

Final Answer: bond order of $N_2 = 3 \Rightarrow$ D

Answer: (D) Go Back to Q2

Q3.

Solution

Concept – vibrational degrees of freedom: A non-linear molecule has $3N - 6$ vibrational modes; a linear molecule has $3N - 5$.

Step 1 – identify the geometry of water: H_2O is bent (non-linear), so the correct formula is $3N - 6$.

Step 2 – insert the number of atoms: $N = 3$, so number of modes $= 3(3) - 6$.

Step 3 – evaluate: $= 9 - 6 = 3$

Step 4 – name the three modes: symmetric stretch, asymmetric stretch and bend $= 3$ modes in all, which matches.

Final Answer: number of vibrational modes of $H_2O = 3 \Rightarrow$ C

Answer: (C) Go Back to Q3

Q4.

Solution

Concept – nodes in a hydrogen-like orbital: Radial nodes $= n - l - 1$, angular nodes $= l$, and total nodes $= n - 1$.

Step 1 – identify the quantum numbers of a $3s$ orbital: For $3s$: $n = 3$ and $l = 0$.

Step 2 – apply the radial-node formula: Radial nodes $= n - l - 1 = 3 - 0 - 1$

Step 3 – evaluate: Radial nodes $= 2$

Step 4 – cross-check with total nodes: Total nodes $= n - 1 = 2$, and since $l = 0$ there are no angular nodes, so all 2 nodes are radial, which agrees.

Final Answer: number of radial nodes in $3s = 2 \Rightarrow$ D

Answer: (D) Go Back to Q4

Q5.

Solution

Concept – gross selection rule for pure rotation: A molecule is microwave (rotationally) active only if it has a permanent electric dipole moment.

Step 1 – test the homonuclear diatomics: N_2, O_2 and H_2 are homonuclear, so they have zero dipole moment and are microwave inactive.

Step 2 – test HCl: HCl is heteronuclear; the difference in electronegativity gives it a permanent dipole moment.

Step 3 – conclude: Only HCl satisfies the dipole requirement and shows a pure rotational spectrum.

Final Answer: microwave-active molecule = HCl $\Rightarrow$ B

Answer: (B) Go Back to Q5

Q6.

Solution

Concept – number of spectral lines from a given level: When electrons cascade from level n down to the ground state, the number of distinct emission lines is $\frac{n(n-1)}{2}$.

Step 1 – set the starting level: Here $n = 4$.

Step 2 – substitute into the formula: Number of lines $= \frac{4(4-1)}{2}$

Step 3 – simplify the bracket: $= \frac{4 \times 3}{2}$

Step 4 – evaluate: $= \frac{12}{2} = 6$

Final Answer: number of spectral lines $= 6 \Rightarrow$ C

Answer: (C) Go Back to Q6

Q7.

Solution

Concept – linking cell potential to free energy: $\Delta G^\circ = -nFE^\circ$, with $F = 96500\ \text{C mol}^{-1}$.

Step 1 – list the data: $n = 2$, $E^\circ = 0.50\ \text{V}$, $F = 96500\ \text{C mol}^{-1}$.

Step 2 – substitute into the equation: $\Delta G^\circ = -(2)(96500)(0.50)$

Step 3 – multiply the numbers: $\Delta G^\circ = -96500\ \text{J mol}^{-1}$

Step 4 – convert to kilojoules: $\Delta G^\circ = -96.5\ \text{kJ mol}^{-1}$

The negative sign confirms the cell reaction is spontaneous.

Final Answer: $\Delta G^\circ = -96.5\ \text{kJ mol}^{-1} \Rightarrow$ B

Answer: (B) Go Back to Q7

Q8.

Solution

Concept – the Nernst equation: $E = E^\circ - \dfrac{0.0591}{n}\log Q$, with $Q = \dfrac{[Zn^{2+}]}{[Cu^{2+}]}$ for the Daniell cell.

Step 1 – compute the reaction quotient: $Q = \dfrac{1.0}{0.01} = 100$

Step 2 – take its logarithm: $\log Q = \log 100 = 2$

Step 3 – evaluate the correction term: $\dfrac{0.0591}{2} \times 2 = 0.0591\ \text{V}$

Step 4 – substitute into the Nernst equation: $E = 1.10 - 0.0591$

Step 5 – evaluate: $E = 1.041 \approx 1.04\ \text{V}$

Why not the others: the potential drops below $E^\circ = 1.10$ because the product ion Zn^{2+} is more concentrated than the reactant Cu^{2+}.

Final Answer: $E \approx 1.04\ \text{V} \Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q8

Q9.

Solution

Concept – half-life counting for a first-order reaction: Each half-life halves the remaining reactant, and $t_{1/2}$ is constant.

Step 1 – translate 75% complete into fraction left: 75% reacted means 25%, i.e. $\frac{1}{4}$, of the reactant remains.

Step 2 – count the half-lives: $1 \to \frac{1}{2} \to \frac{1}{4}$ takes two successive half-lives.

Step 3 – relate to the given time: $2\,t_{1/2} = 60\ \text{min}$

Step 4 – solve for $t_{1/2}$: $t_{1/2} = \dfrac{60}{2} = 30\ \text{min}$

Final Answer: $t_{1/2} = 30\ \text{min} \Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q9

Q10.

Solution

Concept – Faraday's laws of electrolysis: Depositing one mole of a metal needing n electrons requires n faradays of charge.

Step 1 – write the electrode reaction: $Cu^{2+} + 2e^- \to Cu$, so $n = 2$ faradays deposit one mole of Cu.

Step 2 – relate charge passed to moles deposited: 2 faradays $\rightarrow$ 1 mole of Cu.

Step 3 – convert moles to mass: 1 mole of Cu $= 63.5$ g.

Step 4 – state the deposited mass: Mass of Cu deposited $= 63.5$ g.

Final Answer: mass of copper $= 63.5$ g $\Rightarrow$ B

Answer: (B) Go Back to Q10

Q11.

Solution

Concept – reading E_a from an Arrhenius plot: The linear form $\ln k = \ln A - \dfrac{E_a}{R} \cdot \dfrac{1}{T}$ has slope $= -\dfrac{E_a}{R}$.

Step 1 – equate the given slope to $-E_a/R$: $-\dfrac{E_a}{R} = -5000$ K

Step 2 – solve for E_a: $E_a = 5000 \times R$

Step 3 – insert $R = 8.314$ J mol^{-1}K^{-1}: $E_a = 5000 \times 8.314$

Step 4 – multiply: $E_a = 41570$ J mol^{-1}

Step 5 – convert to kilojoules: $E_a \approx 41.6$ kJ mol^{-1}

Final Answer: $E_a \approx 41.6$ kJ mol^{-1} $\Rightarrow$ A

Answer: (A) Go Back to Q11

Q12.

Solution

Concept – crossover temperature for spontaneity: An endothermic, entropy-increasing reaction turns spontaneous once $T\Delta S$ overtakes ΔH, i.e. above $T = \dfrac{\Delta H}{\Delta S}$.

Step 1 – set $\Delta G = 0$ at the crossover: $0 = \Delta H - T\Delta S$

Step 2 – solve for T: $T = \dfrac{\Delta H}{\Delta S}$

Step 3 – convert units so they match: $\Delta H = +30$ kJ mol^{-1} $= 30000$ J mol^{-1}, $\Delta S = +100$ J mol^{-1}K^{-1}.

Step 4 – substitute: $T = \dfrac{30000}{100}$

Step 5 – evaluate: $T = 300$ K

Above 300 K, ΔG becomes negative and the reaction is spontaneous.

Final Answer: crossover temperature $= 300$ K $\Rightarrow$ A

Answer: (A) Go Back to Q12

Q13.

Solution

Concept – equilibrium constant from standard cell potential: At 298 K, $\log K = \dfrac{nE^\circ}{0.0591}$.

Step 1 – insert the given values: $\log K = \dfrac{(1)(0.0591)}{0.0591}$

Step 2 – simplify the ratio: $\log K = 1$

Step 3 – take the antilog: $K = 10^1$

Step 4 – evaluate: $K = 10$

Final Answer: $K = 10 \Rightarrow$ B

Answer: (B) Go Back to Q13

Q14.

Solution

Concept – temperature coefficient of a rate constant: If k doubles per 10 K rise, then over a rise of ΔT the factor is $2^{\Delta T/10}$.

Step 1 – find the temperature rise: $\Delta T = 330 - 300 = 30$ K.

Step 2 – count the number of 10 K steps: $\dfrac{30}{10} = 3$ steps.

Step 3 – apply the doubling factor: Rate constant multiplies by 2^3.

Step 4 – evaluate: $2^3 = 8$, so the new rate constant is $8k$.

Final Answer: rate constant at 330 K $= 8k \Rightarrow$ C

Answer: (C) Go Back to Q14

Q15.

Solution

Concept – oxidation state from charge balance: In a neutral oxide the sum of oxidation states is zero, with oxygen taken as -2.

Step 1 – work out nitrogen's oxidation state in each oxide: NO: $x + (-2) = 0 \Rightarrow x = +2$.

N_2O: $2x + (-2) = 0 \Rightarrow x = +1$.

N_2O_3: $2x + 3(-2) = 0 \Rightarrow x = +3$.

N_2O_5: $2x + 5(-2) = 0 \Rightarrow 2x = 10 \Rightarrow x = +5$.

Step 2 – pick the largest: The highest oxidation state is $+5$, found in N_2O_5.

Final Answer: highest nitrogen oxidation state is in N_2O_5 $(+5) \Rightarrow$ C

Answer: (C) Go Back to Q15

Q16.

Solution

Concept – VSEPR shape from bonding and lone pairs: The molecular shape counts only the atom positions, but lone pairs still push the bonds together.

Step 1 – count the electron domains on central O: Two bonding regions to the terminal oxygens plus one lone pair give a steric number of 3.

Step 2 – assign the electron geometry: Three domains give a trigonal-planar electron arrangement.

Step 3 – remove the lone pair to get the molecular shape: With one position taken by a lone pair, the three-atom framework is bent (angular), with an $O-O-O$ angle near $117°$.

Final Answer: O_3 is bent (angular) $\Rightarrow$ B

Answer: (B) Go Back to Q16

Q17.

Solution

Concept – hybridization from steric number: Steric number 4 (bond pairs $+$ lone pairs) corresponds to sp^3 hybridization.

Step 1 – count the domains on nitrogen in NH_3: Three $N-H$ bonding pairs plus one lone pair give steric number $= 4$.

Step 2 – map steric number to hybridization: Four electron domains $\Rightarrow sp^3$.

Step 3 – confirm with the geometry: sp^3 with one lone pair gives a trigonal-pyramidal molecule (bond angle $\approx 107°$), exactly as drawn.

Final Answer: nitrogen is sp^3 hybridized $\Rightarrow$ D

Answer: (D) Go Back to Q17

Q18.

Solution

Concept – average oxidation state from charge balance: The sum of oxidation states equals the ionic charge; equal atoms share the average.

Step 1 – let the average sulfur oxidation state be x: Oxygen is -2 and there are three of them; the ion charge is -2.

Step 2 – write the balance for $S_2O_3^{2-}$: $2x + 3(-2) = -2$

Step 3 – simplify: $2x - 6 = -2$

Step 4 – solve for x: $2x = 4$, so $x = +2$.

Final Answer: average oxidation state of sulfur $= +2 \Rightarrow \boxed{B}$

Answer: (B) Go Back to Q18

Q19.

Solution

Concept – electron gain enthalpy anomaly in group 16: Adding an electron to a very small atom is resisted by electron–electron repulsion in its compact valence shell.

Step 1 – note the size of oxygen: Oxygen is unusually small, so its incoming electron feels strong repulsion, making its electron gain enthalpy less negative than expected.

Step 2 – compare with sulfur: Sulfur is larger; the added electron enters a more spacious $3p$ shell with less repulsion, giving a more negative electron gain enthalpy.

Step 3 – conclude: Sulfur, not oxygen, has the most negative electron gain enthalpy in group 16 (values then become less negative down to Se and Te).

Final Answer: the element is $S \Rightarrow \boxed{B}$

Answer: (B) Go Back to Q19

Q20.

Solution

Concept – hydrogen bonding raises boiling points anomalously: Only hydrogen bonded to the small, highly electronegative atoms N, O or F forms strong hydrogen bonds.

Step 1 – look at the trend down group 16: Normally boiling point rises with

molar mass, so $H_2S < H_2Se < H_2Te$.

Step 2 – spot the anomaly: H_2O breaks this trend and boils far higher than expected for its small size.

Step 3 – explain it: The strongly electronegative, small oxygen atom lets water form an extensive hydrogen-bond network, raising its boiling point above all the heavier hydrides.

Final Answer: the hydride is $H_2O \Rightarrow$ D

Answer: (D) Go Back to Q20

Q21.

Solution

Concept – spin-only magnetic moment: $\mu = \sqrt{n(n+2)}$ BM, with n the number of unpaired electrons.

Step 1 – find the d-electron count: Fe^{3+} is d^5.

Step 2 – apply the strong-field (low-spin) filling: The strong-field CN^- ligands force all five electrons into t_{2g}: $t_{2g}^5\, e_g^0$, leaving $n = 1$ unpaired electron.

Step 3 – substitute into the formula: $\mu = \sqrt{1(1+2)}$

Step 4 – simplify inside the root: $\mu = \sqrt{3}$

Step 5 – take the square root: $\mu \approx 1.73$ BM

Why not 5.92**:** that would be the high-spin d^5 value ($n = 5$); the strong field here makes the complex low-spin.

Final Answer: $\mu \approx 1.73$ BM $\Rightarrow$ C

Answer: (C) Go Back to Q21

Q22.

Solution

Concept – the 18-electron (EAN) rule: Total valence electron count = metal valence electrons + electrons donated by ligands.

Step 1 – count the metal contribution: Iron is in group 8; as $Fe(0)$ it contributes 8 valence electrons.

Step 2 – count the ligand contribution: Each CO donates 2 electrons; five CO give $5 \times 2 = 10$.

Step 3 – add the contributions: Total $= 8 + 10 = 18$

Step 4 – interpret: The 18-electron count is a closed, noble-gas-like shell, which is why $[Fe(CO)_5]$ is a stable trigonal-bipyramidal carbonyl.

Final Answer: valence electron count $= 18 \Rightarrow$ C

Answer: (C) Go Back to Q22

Q23.

Solution

Concept – spin-only moment for a high-spin ion: $\mu = \sqrt{n(n+2)}$ BM.

Step 1 – find the d-electron count: Co^{3+} is d^6.

Step 2 – apply the weak-field (high-spin) filling: The weak-field F^- ligands give $t_{2g}^4\, e_g^2$, so there are $n = 4$ unpaired electrons.

Step 3 – substitute into the formula: $\mu = \sqrt{4(4+2)}$

Step 4 – simplify inside the root: $\mu = \sqrt{4 \times 6} = \sqrt{24}$

Step 5 – take the square root: $\mu = 4.899 \approx 4.90$ BM

Final Answer: $\mu \approx 4.90$ BM $\Rightarrow$ A

Answer: (A) Go Back to Q23

Q24.

Solution

Concept – unpaired electrons in a low-spin d^6 complex: A large Δ_o (strong field) forces electrons to pair up in t_{2g} before occupying e_g.

Step 1 – find the d-electron count: Co^{3+} is d^6.

Step 2 – fill the orbitals for a strong field: NH_3 gives a large split, so all six electrons pair in t_{2g}: $t_{2g}^6\, e_g^0$.

Step 3 – count unpaired electrons: All six electrons are paired, so $n = 0$.

Step 4 – interpret: The complex is diamagnetic and has the maximum CFSE for d^6, which is why low-spin $[Co(NH_3)_6]^{3+}$ is so stable.

Final Answer: number of unpaired electrons $= 0 \Rightarrow$ C

Answer: (C) Go Back to Q24

Q25.

Solution

Concept – geometrical isomerism in square-planar MA_2B_2: A square-planar complex with two pairs of ligands has cis and trans forms.

Step 1 – place the two Cl ligands adjacent: Adjacent chlorides (90° apart) give the cis isomer (cisplatin).

Step 2 – place the two Cl ligands opposite: Opposite chlorides (180° apart) give the trans isomer.

Step 3 – count the distinct forms: There are exactly two geometrical isomers, cis and trans.

Why not more: a square-planar MA_2B_2 complex has no further arrangements, and neither isomer is chiral.

Final Answer: number of geometrical isomers $= 2 \Rightarrow \boxed{A}$

Answer: (A) Go Back to Q25

Q26.

Solution

Concept – diamagnetism requires zero unpaired electrons: Geometry and ligand field together decide the electron pairing.

Step 1 – analyse $[Ni(CN)_4]^{2-}$: Ni^{2+} is d^8; with strong-field CN^- it is square planar, and all eight electrons pair, giving 0 unpaired electrons (diamagnetic).

Step 2 – analyse $[NiCl_4]^{2-}$: Ni^{2+} (d^8) with weak-field Cl^- is tetrahedral, with 2 unpaired electrons (paramagnetic).

Step 3 – analyse the other two: $[CoF_6]^{3-}$ has 4 unpaired electrons and $[Mn(H_2O)_6]^{2+}$ has 5; both are paramagnetic.

Step 4 – pick the diamagnetic one: Only $[Ni(CN)_4]^{2-}$ has no unpaired electrons.

Final Answer: diamagnetic complex $= [Ni(CN)_4]^{2-} \Rightarrow \boxed{A}$

Answer: (A) Go Back to Q26

Q27.

Solution

Concept – coordination number in close packing: In the closest packing of equal spheres, each sphere touches its nearest neighbours in three layers.

Step 1 – count the in-plane neighbours: Within one layer, a sphere is surrounded by 6 touching spheres, as the figure shows.

Step 2 – count the neighbours in the layer above: Three spheres of the upper layer nestle into the hollows above, touching the central sphere.

Step 3 – count the neighbours in the layer below: By symmetry, three more spheres of the lower layer touch it.

Step 4 – add them up: $6 + 3 + 3 = 12$ nearest neighbours.

Final Answer: coordination number $= 12 \Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q27

Q28.

Solution

Concept – voids in a close-packed lattice: In a close-packed lattice of N spheres there are N octahedral voids and $2N$ tetrahedral voids.

Step 1 – recall the octahedral-void count: Number of octahedral voids $= N$ (one per sphere).

Step 2 – recall the tetrahedral-void count: There are twice as many tetrahedral voids as spheres.

Step 3 – write the result: Number of tetrahedral voids $= 2 \times N = 2N$.

Step 4 – cross-check with FCC: An FCC cell has 4 atoms and 8 tetrahedral voids, and indeed $8 = 2 \times 4$, confirming the $2N$ rule.

Final Answer: number of tetrahedral voids $= 2N \Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q28

Q29.

Solution

Concept – metal at the centre of a biological macrocycle: Each natural macrocycle holds a characteristic metal ion.

Step 1 – identify the macrocycle in vitamin B_{12}: Vitamin B_{12} contains a corrin

ring, closely related to a porphyrin.

Step 2 – identify the central metal: The corrin ring coordinates a cobalt ion at its centre (hence the name cobalamin).

Step 3 – reject the distractors: Fe sits in heme, Mg in chlorophyll and Zn in enzymes such as carbonic anhydrase, none of which is vitamin $\mathrm{B_{12}}$.

Final Answer: central metal of vitamin $\mathrm{B_{12}} = \mathrm{Co} \Rightarrow \boxed{\mathrm{D}}$

Answer: (D) Go Back to Q29

Q30.

Solution

Concept – counting stereogenic carbons: A carbon is a stereocentre if it carries four different groups.

Step 1 – label the six carbons of open-chain glucose: C1 is the aldehyde (CHO) and C6 is $\mathrm{CH_2OH}$; neither carries four different groups.

Step 2 – examine the middle carbons: Carbons C2, C3, C4 and C5 each bear H, OH and two different chain fragments, so each is a stereocentre.

Step 3 – count them: Stereocentres $=$ C2, C3, C4, C5 $= 4$ carbons (matching the four $*$ marks in the figure).

Step 4 – cross-check with isomer count: $2^4 = 16$ aldohexose stereoisomers are known, which is consistent with four stereocentres.

Final Answer: number of chiral carbons in glucose $= 4 \Rightarrow \boxed{\mathrm{C}}$

Answer: (C) Go Back to Q30

Q31.

Solution

Concept – meso reduction of the stereoisomer count: The 2^n rule gives the maximum, but an internal mirror plane merges a pair into a single achiral (meso) form.

Step 1 – apply the 2^n rule: With $n = 2$ stereocentres, the maximum is $2^2 = 4$.

Step 2 – test for a meso form: The two stereocentres of tartaric acid are constitutionally identical, so the (R, S) arrangement has an internal plane of symmetry and is a single meso compound.

Step 3 – adjust the count: The would-be (R, S) and (S, R) are one and the same meso form, removing one isomer from the four.

Step 4 – list the survivors: (R,R) and (S,S) (an enantiomeric pair) plus the single meso form give 3 distinct stereoisomers.

Final Answer: number of stereoisomers of tartaric acid $= 3 \Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q31

Q32.

Solution

Concept – Cahn–Ingold–Prelog (CIP) priority: Rank substituents by decreasing atomic number of the first point of difference.

Step 1 – list the atomic numbers of the attached atoms: Br (35), Cl (17), F (9), H (1).

Step 2 – order them from highest to lowest: $35 > 17 > 9 > 1$.

Step 3 – translate back to the substituents: $\text{Br} > \text{Cl} > \text{F} > \text{H}$.

Step 4 – interpret: Hydrogen, the lowest priority, is the group pointed away when reading the R/S sense of rotation.

Final Answer: priority order $= \text{Br} > \text{Cl} > \text{F} > \text{H} \Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q32

Q33.

Solution

Concept – S_N1 rate follows carbocation stability: The slow step is ionization to a carbocation, so the more stable that cation, the faster the S_N1 reaction.

Step 1 – rank the carbocations formed: CH_3^+ (methyl) $< 1^\circ < 2^\circ < 3^\circ$ in stability.

Step 2 – identify the most stable cation: *tert*-Butyl bromide ionizes to the tertiary carbocation $(\text{CH}_3)_3\text{C}^+$, stabilized by hyperconjugation and three $+I$ methyl groups.

Step 3 – conclude the fastest substrate: Because it forms the most stable cation most easily, *tert*-butyl bromide reacts fastest by S_N1.

Final Answer: fastest S_N1 substrate $=$ *tert*-butyl bromide $\Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q33

Q34.

Solution

Concept – S_N2 rate is governed by steric hindrance: The nucleophile attacks the carbon from the back, so more bulky substituents slow the reaction.

Step 1 – compare crowding at the reacting carbon: A methyl substrate is least hindered; a tertiary substrate is most hindered.

Step 2 – order the reactivity: Reactivity falls as crowding rises: methyl $>$ primary $>$ secondary $>$ tertiary.

Step 3 – note the extreme: Tertiary halides essentially do not react by S_N2 because backside approach is blocked.

Final Answer: S_N2 order $=$ methyl $>$ primary $>$ secondary $>$ tertiary $\Rightarrow \boxed{\text{C}}$

Answer: (C) Go Back to Q34

Q35.

Solution

Concept – optical inactivity of a racemate: A racemic mixture is optically inactive by external compensation.

Step 1 – describe the composition: A racemate contains the two enantiomers in exactly equal $(50:50)$ amounts.

Step 2 – add up their rotations: One enantiomer rotates plane-polarized light by $+\alpha$, the other by $-\alpha$; the sum is zero.

Step 3 – distinguish from a meso compound: A meso compound is inactive by *internal* compensation (one molecule, internal mirror plane), whereas a racemate is inactive by *external* compensation between two different molecules.

Final Answer: the equal, opposite rotations of the two enantiomers cancel $\Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q35

Q36.

Solution

Concept – stereochemical requirement of $E2$: $E2$ is concerted and needs the β-hydrogen and the leaving group anti-periplanar (dihedral $180°$).

Step 1 – recall why the geometry matters: The developing π bond forms best when the breaking $\mathrm{C{-}H}$ and $\mathrm{C{-}X}$ bonds are parallel and on opposite sides.

Step 2 – read the Newman projection: The hydrogen on the front carbon and

the bromine on the back carbon are drawn 180° apart, i.e. anti.

Step 3 – name the arrangement: This required opposite-side, coplanar geometry is called anti-periplanar.

Why not syn: syn-periplanar elimination is possible but far higher in energy and rarely dominant.

Final Answer: the required geometry is anti-periplanar $\Rightarrow$ D

Answer: (D) Go Back to Q36

Q37.

Solution

Concept – Friedel–Crafts alkylation: An alkyl halide plus a Lewis acid ($AlCl_3$) generates a carbocation that substitutes onto the aromatic ring.

Step 1 – generate the electrophile: $CH_3Cl + AlCl_3 \rightarrow CH_3^+ + AlCl_4^-$.

Step 2 – attack on the ring: The benzene π-electrons attack CH_3^+ to form an arenium ion.

Step 3 – restore aromaticity: Loss of a proton regenerates the aromatic ring, giving toluene.

Step 4 – name it: Installing an alkyl group this way is Friedel–Crafts alkylation.

Final Answer: the reaction is Friedel–Crafts alkylation $\Rightarrow$ A

Answer: (A) Go Back to Q37

Q38.

Solution

Concept – Friedel–Crafts acylation: An acyl halide plus $AlCl_3$ generates an acylium ion that substitutes onto the ring, giving an aryl ketone.

Step 1 – generate the electrophile: $CH_3COCl + AlCl_3 \rightarrow CH_3CO^+$ (acylium ion) $+AlCl_4^-$.

Step 2 – attack on the ring: Benzene attacks the acylium ion to form an arenium intermediate.

Step 3 – restore aromaticity: Loss of a proton gives acetophenone, $C_6H_5COCH_3$.

Step 4 – name it: Installing an acyl ($RCO-$) group this way is Friedel–Crafts acylation (and, unlike alkylation, it avoids carbocation rearrangement and poly-substitution).

Final Answer: the reaction is Friedel–Crafts acylation $\Rightarrow$ D

Answer: (D) Go Back to Q38

Q39.

Solution

Concept – directing and activating effect of $-\mathrm{OH}$: Substituents that donate electron density into the ring activate it and direct incoming electrophiles to the ortho and para positions.

Step 1 – assess the electronic effect: The oxygen lone pair of $-\mathrm{OH}$ donates into the ring by resonance $(+M)$, raising the electron density.

Step 2 – locate the extra density: Resonance places the negative charge at the ortho and para carbons, so those sites react fastest.

Step 3 – classify: $-\mathrm{OH}$ is therefore ortho/para directing and ring-activating.

Final Answer: $-\mathrm{OH}$ is ortho/para directing and activating $\Rightarrow$ C

Answer: (C) Go Back to Q39

Q40.

Solution

Concept – directing and deactivating effect of $-\mathrm{NO_2}$: Strongly electron-withdrawing groups deactivate the ring and direct electrophiles to the meta position.

Step 1 – assess the electronic effect: The nitro group withdraws electron density by both resonance $(-M)$ and induction $(-I)$, lowering the ring's reactivity.

Step 2 – locate the least-deactivated position: Resonance withdraws density most from the ortho and para carbons, leaving the meta position comparatively richer, so attack occurs there.

Step 3 – classify: $-\mathrm{NO_2}$ is therefore meta directing and deactivating.

Final Answer: $-\mathrm{NO_2}$ is meta directing and deactivating $\Rightarrow$ C

Answer: (C) Go Back to Q40

Q41.

Solution

Concept – sulfonation of benzene: The electrophile in sulfonation is sulfur trioxide, SO_3, supplied by fuming sulfuric acid (oleum).

Step 1 – identify the electrophile: SO_3 (or protonated SO_3H^+) attacks the ring.

Step 2 – choose the reagent that supplies it: Fuming sulfuric acid, SO_3/H_2SO_4 (oleum), is the source of SO_3.

Step 3 – reject the others: HNO_3/H_2SO_4 nitrates, $CH_3Cl/AlCl_3$ alkylates, and $Br_2/FeBr_3$ brominates the ring.

Step 4 – conclude: Benzene + oleum $\rightarrow$ benzenesulfonic acid.

Final Answer: the reagent is fuming sulfuric acid (oleum) $\Rightarrow$ D

Answer: (D) Go Back to Q41

Q42.

Solution

Concept – the Reimer–Tiemann reaction: Phenol, chloroform and aqueous base install a $-CHO$ group ortho to the $-OH$, giving salicylaldehyde.

Step 1 – generate the reactive species: $CHCl_3$ with $NaOH$ gives dichlorocarbene, $:CCl_2$, the electrophile.

Step 2 – attack the phenoxide ring: The carbene adds ortho to the activating phenoxide oxygen.

Step 3 – hydrolyse and acidify: Hydrolysis of the resulting benzal chloride, then acidification, gives the ortho $-CHO$, i.e. salicylaldehyde.

Step 4 – name it: This is the Reimer–Tiemann reaction.

Final Answer: the reaction is the Reimer–Tiemann reaction $\Rightarrow$ D

Answer: (D) Go Back to Q42

Q43.

Solution

Concept – diazotization: A primary aromatic amine reacts with nitrous acid (from $NaNO_2/HCl$) at low temperature to give a diazonium salt.

Step 1 – generate nitrous acid in situ: $NaNO_2 + HCl \rightarrow HNO_2 + NaCl$.

Step 2 – react with aniline at 0–5 °C**:** $C_6H_5NH_2 + HNO_2 + HCl \rightarrow C_6H_5N_2^+Cl^- +$

$2\,H_2O$.

Step 3 – note the temperature control: The cold (0–$5\ ^\circ C$) keeps the unstable diazonium salt from decomposing.

Step 4 – name it: Forming a diazonium salt from a primary aromatic amine is called diazotization.

Final Answer: the reaction is diazotization $\Rightarrow$ $\boxed{A}$

Answer: (A) Go Back to Q43

Q44.

Solution

Concept – Norrish Type I (α-cleavage): On photoexcitation, a carbonyl compound can homolyse the bond between the carbonyl carbon and the adjacent (α) carbon.

Step 1 – excite the carbonyl: Absorption of ultraviolet light promotes the ketone to an excited $n \rightarrow \pi^*$ state.

Step 2 – break the α-bond: The excited carbonyl undergoes homolytic α-cleavage, giving an acyl radical $R{-}CO^{\bullet}$ and an alkyl radical $^{\bullet}R'$.

Step 3 – name it: This photochemical α-cleavage is the Norrish Type I reaction.

Why not Type II: Norrish Type II instead abstracts a γ-hydrogen without cleaving the α-bond first.

Final Answer: the reaction is the Norrish Type I reaction $\Rightarrow$ $\boxed{A}$

Answer: (A) Go Back to Q44

Q45.

Solution

Concept – Norrish Type II (γ-hydrogen abstraction): An excited carbonyl can reach back to a γ-hydrogen and abstract it through a six-membered ring.

Step 1 – excite the carbonyl: UV light gives the excited $n \rightarrow \pi^*$ ketone, with radical character on oxygen.

Step 2 – abstract the γ-hydrogen: The excited oxygen abstracts a hydrogen from the γ-carbon via a six-membered cyclic transition state, giving a $1,4$-biradical.

Step 3 – fate of the biradical: The $1,4$-biradical either fragments (to an alkene + an enol) or cyclizes (to a cyclobutanol).

Step 4 – name it: This γ-hydrogen abstraction is the Norrish Type II reaction.

Final Answer: the reaction is the Norrish Type II reaction $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q45

Q46.

Solution

Concept – Woodward–Hoffmann rule for sigmatropic shifts: For a thermal $[1, j]$ shift, the count of electrons in the cyclic transition state decides the allowed geometry.

Step 1 – count the electrons: A $[1, 5]$-hydrogen shift in a $1, 3$-pentadiene involves 6 electrons in the transition state ($4n + 2$, with $n = 1$).

Step 2 – apply the thermal selection rule: For a thermal $4n + 2$ system, the allowed pathway is suprafacial (the hydrogen migrates across the same face of the π-system).

Step 3 – conclude: The thermal $[1, 5]$-H shift therefore proceeds suprafacially, as observed experimentally with retention on one face.

Why not antarafacial: an antarafacial $[1, 5]$-H shift is geometrically strained and is the thermally forbidden mode here.

Final Answer: the thermal $[1, 5]$-H shift is suprafacial $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q46

Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	A	2	D	3	C	4	D	5	B
6	C	7	B	8	A	9	B	10	B
11	A	12	A	13	B	14	C	15	C
16	B	17	D	18	B	19	B	20	D
21	C	22	C	23	A	24	C	25	A
26	A	27	B	28	B	29	D	30	C
31	D	32	A	33	D	34	C	35	A
36	D	37	A	38	D	39	C	40	C
41	D	42	D	43	A	44	A	45	B
46	B								