# GATE Chemistry

## Sample Paper – 7

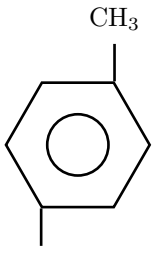
**Duration: 128 Minutes** **Maximum Marks: 72**

### 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 $^1$H NMR spectroscopy, chemically equivalent protons give a single signal. For para-xylene ($1,4$-dimethylbenzene), whose skeletal structure is shown below, the number of distinct proton environments (and hence NMR signals) is: **[1 mark]**




para-xylene

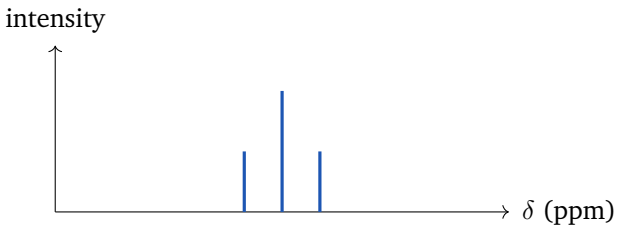
(A) 1

(B) 2

(C) 3

(D) 4

**Q2.** According to the $n+1$ rule in $^1$H NMR, a proton signal is split by $n$ equivalent neighbouring protons into $n+1$ lines. The $CH_3$ group of ethanol ($CH_3CH_2OH$) has two neighbouring $CH_2$ protons, giving the stick pattern shown below. This signal is a: **[1 mark]**




intensity ratio 1 : 2 : 1

(A) singlet

(B) doublet

(C) quartet

(D) triplet

**Q3.** The number of radial nodes in an atomic orbital is given by $n-l-1$, where $n$ is the principal quantum number and $l$ the azimuthal quantum number. For a $3s$ orbital, the number of radial nodes is: **[1 mark]**

(A) 2

(B) 0

(C) 1

(D) 3

**Q4.** A vibrational mode of a molecule is active in the infrared (IR) spectrum only if the vibration produces a change in a particular molecular property. That property is the: [1 mark]

(A) polarizability

(B) dipole moment

(C) bond length only

(D) nuclear spin

**Q5.** The energy of a photon of frequency $\nu$ is $E = h\nu$, with Planck's constant $h = 6.626 \times 10^{-34}\ \mathrm{J\,s}$. A photon of frequency $6.0 \times 10^{14}\ \mathrm{Hz}$ has an energy nearest to: [1 mark]

(A) $6.6 \times 10^{-34}\ \mathrm{J}$

(B) $1.1 \times 10^{-48}\ \mathrm{J}$

(C) $4.0 \times 10^{-19}\ \mathrm{J}$

(D) $2.0 \times 10^{-19}\ \mathrm{J}$

**Q6.** In $^{1}\mathrm{H}$ NMR spectroscopy, chemical shifts are quoted relative to an internal reference compound whose signal is assigned a value of exactly $0$ ppm. That reference compound is: [1 mark]

(A) chloroform, $\mathrm{CHCl_3}$

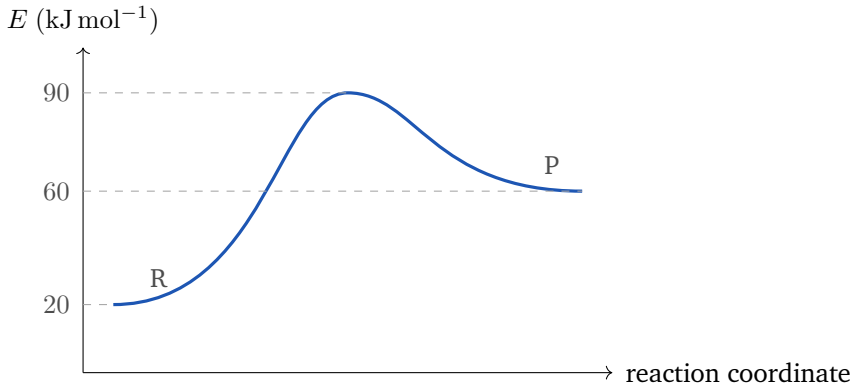
(B) tetramethylsilane (TMS)

(C) water, $\mathrm{H_2O}$

(D) benzene, $\mathrm{C_6H_6}$

## Physical Chemistry: Thermodynamics, Kinetics and Electrochemistry

**Q7.** The reaction-coordinate (potential-energy) diagram for a one-step reaction is shown below. The reactants lie at $20\ \mathrm{kJ\,mol^{-1}}$, the transition state at $90\ \mathrm{kJ\,mol^{-1}}$ and the products at $60\ \mathrm{kJ\,mol^{-1}}$. The activation energy of the *forward* reaction, $E_a(\text{forward})$, is: **[1 mark]**




(A) $40\ \mathrm{kJ\,mol^{-1}}$

(B) $30\ \mathrm{kJ\,mol^{-1}}$

(C) $60\ \mathrm{kJ\,mol^{-1}}$

(D) $70\ \mathrm{kJ\,mol^{-1}}$

**Q8.** The rate constant of a reaction follows the Arrhenius equation $k = A\,e^{-E_a/RT}$. A reaction with an activation energy of $50\ \mathrm{kJ\,mol^{-1}}$ is run in the presence of a catalyst that provides an alternative path of activation energy $30\ \mathrm{kJ\,mol^{-1}}$. The activation energy is lowered by: **[1 mark]**

(A) $80\ \mathrm{kJ\,mol^{-1}}$

(B) $20\ \mathrm{kJ\,mol^{-1}}$

(C) $30\ \mathrm{kJ\,mol^{-1}}$

(D) $50\ \mathrm{kJ\,mol^{-1}}$

**Q9.** For the elementary reaction $2\mathrm{A} \rightarrow$ products obeying the rate law rate $= k[\mathrm{A}]^2$, the SI-consistent units of the rate constant $k$ (with concentration in $\mathrm{mol\,L^{-1}}$ and time in seconds) are: **[1 mark]**

(A) $\mathrm{s^{-1}}$

(B) $\mathrm{L\,mol^{-1}\,s^{-1}}$

(C) $\mathrm{mol\,L^{-1}\,s^{-1}}$

(D) $\mathrm{mol^2\,L^{-2}\,s^{-1}}$

**Q10.** The Nernst equation at $298\ \mathrm{K}$ is written $E = E^\circ - \dfrac{0.0591}{n}\log Q$. For an electrode process involving the transfer of $n = 2$ electrons, the numerical value of the coefficient $\dfrac{0.0591}{n}$ (in volts) is: **[1 mark]**

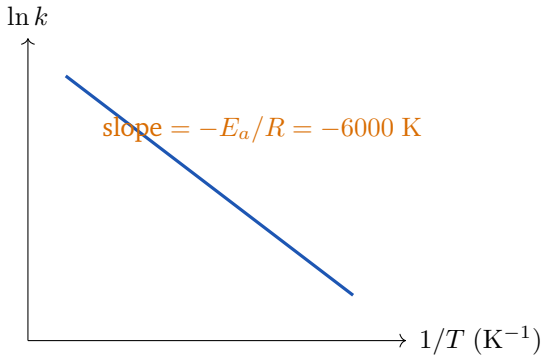
(A) $0.0591$

(B) $0.118$

(C) $0.0296$

(D) $0.0197$

**Q11.** The Arrhenius plot of $\ln k$ against $1/T$ for a reaction is a straight line of slope $-6000\ \mathrm{K}$, as shown. Using slope $= -E_a/R$ with $R = 8.314\ \mathrm{J\,mol^{-1}K^{-1}}$, the activation energy $E_a$ is nearest to: **[1 mark]**




(A) $49.9\ \mathrm{kJ\,mol^{-1}}$

(B) $6.0\ \mathrm{kJ\,mol^{-1}}$

(C) $12.0\ \mathrm{kJ\,mol^{-1}}$

(D) $720\ \mathrm{kJ\,mol^{-1}}$

**Q12.** For a process occurring at constant temperature and pressure, the criterion for spontaneity is stated in terms of the Gibbs free-energy change $\Delta G$. A spontaneous process must have a value of $\Delta G$ that is: **[1 mark]**

(A) exactly zero

(B) positive

(C) negative

(D) equal to $\Delta H$

**Q13.** In the electrolytic extraction of aluminium, $Al^{3+}$ is reduced by $Al^{3+} + 3e^- \rightarrow Al$. Taking $F = 96500\ C\,mol^{-1}$, the charge required to deposit exactly one mole of aluminium is: **[1 mark]**

(A) $96500\ C$

(B) $193000\ C$

(C) $48250\ C$

(D) $289500\ C$

**Q14.** A first-order reaction is found to be $75\%$ complete in $40$ minutes. Since a $75\%$ conversion corresponds to exactly two successive half-lives, the half-life of the reaction is: **[1 mark]**

(A) $40$ min

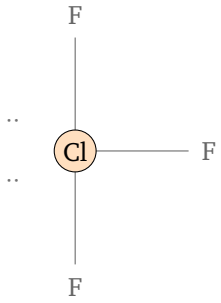
(B) $10$ min

(C) $30$ min

(D) $20$ min

## Inorganic Chemistry: Main Group and Periodic Properties

**Q15.** The interhalogen compound chlorine trifluoride $ClF_3$ has a central chlorine atom surrounded by three bonding pairs and two lone pairs (VSEPR type $AX_3E_2$), as sketched below. The molecular shape of $ClF_3$ is: **[1 mark]**




(A) trigonal planar

(B) T-shaped

(C) trigonal pyramidal

(D) bent

**Q16.** Among the oxoacids of chlorine, the acid strength increases with the number of terminal oxygen atoms on the central chlorine. Among $HClO$, $HClO_2$, $HClO_3$ and $HClO_4$, the *strongest* acid is: **[1 mark]**

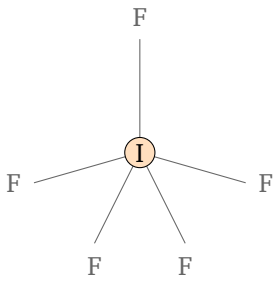
(A) $HClO_4$

(B) $HClO$

(C) $HClO_2$

(D) $HClO_3$

**Q17.** The interhalogen $IF_5$ has a central iodine atom bearing five bonding pairs and one lone pair (VSEPR type $AX_5E$), as sketched below. The molecular shape of $IF_5$ is: **[1 mark]**




(A) octahedral

(B) trigonal bipyramidal

(C) pentagonal planar

(D) square pyramidal

**Q18.** In sulfuric acid $H_2SO_4$, each of the four oxygen atoms is assigned an oxidation number of $-2$ and each of the two hydrogen atoms $+1$, while the molecule is neutral overall. The oxidation state of sulfur in $H_2SO_4$ is: **[1 mark]**

(A) $+6$

(B) $+4$

(C) $+2$

(D) $+7$

**Q19.** On moving from left to right across the second period from lithium ($\mathrm{Li}$) to fluorine ($\mathrm{F}$), the electronegativity of the elements generally: **[1 mark]**

(A) increases

(B) decreases

(C) stays essentially constant

(D) first decreases and then increases

**Q20.** The basic strength of the group-$15$ hydrides depends on the availability of the nitrogen/pnictogen lone pair and decreases down the group. Among $\mathrm{NH_3}$, $\mathrm{PH_3}$, $\mathrm{AsH_3}$ and $\mathrm{SbH_3}$, the *strongest* Brønsted base is: **[1 mark]**

(A) $\mathrm{SbH_3}$

(B) $\mathrm{AsH_3}$

(C) $\mathrm{PH_3}$

(D) $\mathrm{NH_3}$

## Inorganic Chemistry: Coordination Compounds and Organometallics

**Q21.** Many octahedral complexes undergo ligand substitution through a rate-determining step in which one ligand *leaves first* to give a five-coordinate intermediate, before the incoming ligand binds. The rate then depends only on the concentration of the complex. This substitution pathway is classified as: **[2 marks]**

(A) associative (A)

(B) interchange-associative ($I_a$)

(C) dissociative (D)

(D) concerted bimolecular

**Q22.** In the kinetics of coordination compounds, a complex whose ligands are replaced *rapidly* in a substitution reaction (its ligand-exchange rate being fast) is described by the term: **[2 marks]**

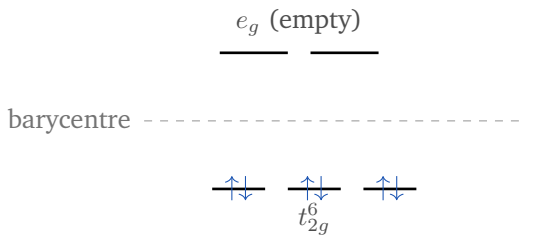
(A) labile

(B) inert

(C) chiral

(D) racemic

**Q23.** In an octahedral crystal field the $d$ orbitals split into a lower $t_{2g}$ set and an upper $e_g$ set. For a *low-spin* $d^6$ complex the six electrons all pair up in $t_{2g}$, as shown. Using the spin-only formula $\mu = \sqrt{n(n+2)}$ BM, the magnetic moment of this complex is: **[2 marks]**




(A) $2.83$ BM

(B) $1.73$ BM

(C) $4.90$ BM

(D) $0$ BM

**Q24.** Ferrocene, $[\mathrm{Fe}(\eta^5\text{-}\mathrm{C_5H_5})_2]$, is a sandwich complex that obeys the $18$-electron rule. Taking iron(II) as a $d^6$ centre contributing $6$ electrons and each cyclopentadienyl ($\mathrm{C_5H_5^-}$) ring donating $6$ electrons, the total valence-electron count of ferrocene is: **[2 marks]**

(A) $18$

(B) $16$

(C) $20$

(D) $14$

**Q25.** The octahedral complex ion $[Co(NH_3)_4Cl_2]^+$ can exist as two distinct geometric isomers that differ in the relative placement of the two chloride ligands. These two isomers are described as: [2 marks]

(A) fac and mer

(B) $d$ and $l$

(C) cis and trans

(D) ionization isomers

**Q26.** In the ligand substitution of square-planar $Pt(II)$ complexes, certain ligands strongly accelerate the replacement of the ligand located *trans* to them, directing the stereochemistry of the product. This kinetic phenomenon is called the: [2 marks]

(A) chelate effect

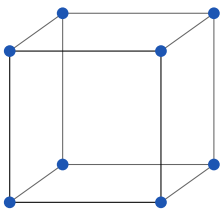
(B) trans effect

(C) inert-pair effect

(D) Jahn–Teller effect

## Inorganic Chemistry: Solid State and Bioinorganic

**Q27.** A simple (primitive) cubic unit cell has atoms located only at its eight corners, as shown below, with each corner atom shared among eight neighbouring cells. The number of atoms belonging to one simple cubic unit cell is: [2 marks]



corner atoms only

(A) $4$

(B) $2$

(C) $8$

(D) $1$

**Q28.** Chlorophyll, the green pigment responsible for photosynthesis, contains a porphyrin-type ring with a single metal ion held at its centre. That central metal ion is: **[2 marks]**

(A) $Fe^{2+}$

(B) $Ca^{2+}$

(C) $Mg^{2+}$

(D) $Zn^{2+}$

**Q29.** In haemoglobin, molecular oxygen binds reversibly to the iron centre of the heme group without oxidising it; the iron must remain in the ferrous state for reversible $O_2$ transport. The oxidation state of iron in functional (oxygen-carrying) haemoglobin is: **[2 marks]**

(A) $+3$

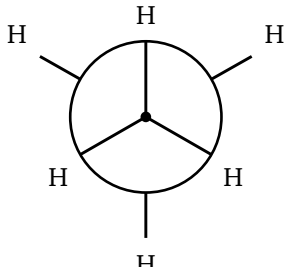
(B) $0$

(C) $+2$

(D) $+4$

## Organic Chemistry: Stereochemistry and Reaction Mechanisms

**Q30.** The Newman projection of ethane, viewed along the $C-C$ bond, is shown below in its staggered conformation. In this most stable (staggered) conformation, the dihedral (torsion) angle between a front $C-H$ bond and the nearest back $C-H$ bond is: **[2 marks]**



staggered ethane

(A) $0^\circ$

(B) $60^\circ$

(C) $120^\circ$

(D) $180^\circ$

**Q31.** Tartaric acid has two stereogenic centres, so the simple $2^n$ count predicts four stereoisomers; however, one pair coincides as an achiral *meso* form. The actual number of distinct stereoisomers of tartaric acid is: **[2 marks]**

(A) $4$

(B) $2$

(C) $3$

(D) $1$

**Q32.** The rate law of a unimolecular nucleophilic substitution ($S_N1$) reaction is first order overall, because the slow, rate-determining step is the ionisation of the substrate to a carbocation. Therefore the $S_N1$ rate depends on the concentration of: **[2 marks]**

(A) the substrate only

(B) both the substrate and the nucleophile

(C) the nucleophile only

(D) the solvent only

**Q33.** In assigning the $R/S$ (Cahn–Ingold–Prelog) configuration at a stereocentre, the four groups attached to the carbon are ranked in order of priority. The primary criterion used to set this priority is the: **[2 marks]**

(A) overall size of each group

(B) alphabetical order of the group names

(C) atomic number of the directly attached atoms

(D) length of each bond to the centre

**Q34.** A bimolecular nucleophilic substitution ($S_N2$) at a stereogenic carbon proceeds through a single backside attack of the nucleophile on the carbon bearing the leaving group. The stereochemical outcome at that carbon is: [2 marks]

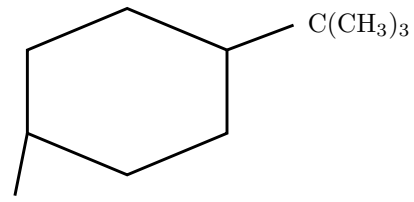
(A) inversion of configuration

(B) complete retention of configuration

(C) full racemisation

(D) no change in connectivity or configuration

**Q35.** The chair conformation of a monosubstituted cyclohexane is shown below. A bulky substituent such as a *tert*-butyl group strongly prefers one type of ring position in order to avoid $1,3$-diaxial steric strain. That preferred position is: [2 marks]



chair conformation

(A) axial

(B) it makes no difference to the energy

(C) eclipsed

(D) equatorial

**Q36.** An $E2$ elimination is a concerted, single-step reaction whose transition state requires a specific geometry: the departing hydrogen and the leaving group must lie in the same plane and point in opposite directions across the $\mathrm{C}-\mathrm{C}$ bond. This required relationship is: [2 marks]

(A) syn-periplanar

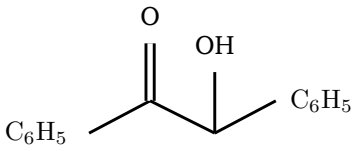
(B) anti-periplanar

(C) gauche

(D) fully eclipsed

## Organic Chemistry: Named Reactions and Synthesis

**Q37.** Two molecules of benzaldehyde ($C_6H_5CHO$) condense in the presence of a cyanide catalyst to form benzoin, an $\alpha$-hydroxy ketone whose skeletal structure is shown below. This carbon–carbon bond-forming reaction is the: **[2 marks]**




benzoin ($\alpha$-hydroxy ketone)

(A) Cannizzaro reaction

(B) aldol reaction

(C) benzoin condensation

(D) Perkin reaction

**Q38.** Benzaldehyde ($C_6H_5CHO$), which has no $\alpha$-hydrogen, reacts with concentrated sodium hydroxide to disproportionate into benzyl alcohol and sodium benzoate. This base-induced self oxidation–reduction of a non-enolisable aldehyde is the: **[2 marks]**

(A) Cannizzaro reaction

(B) benzoin condensation

(C) aldol condensation

(D) Claisen condensation

**Q39.** The benzoin condensation of two aromatic aldehyde molecules requires a specific catalyst that adds reversibly to a carbonyl carbon, making it nucleophilic (an "umpolung" of reactivity). The classic catalyst for the benzoin condensation is: **[2 marks]**

(A) cyanide ion, $CN^-$

(B) concentrated $H_2SO_4$

(C) zinc amalgam, $Zn(Hg)$

(D) lithium aluminium hydride, $LiAlH_4$

**Q40.** In a crossed Cannizzaro reaction between formaldehyde ($HCHO$) and benzaldehyde ($C_6H_5CHO$), formaldehyde is the better hydride donor and drives the reduction of the other partner. In this reaction formaldehyde is: [2 marks]

(A) reduced to methanol

(B) left unchanged

(C) oxidised to sodium formate

(D) polymerised to paraformaldehyde

**Q41.** An aromatic aldehyde is heated with an acid anhydride and the sodium (or potassium) salt of the corresponding carboxylic acid to give an $\alpha,\beta$-unsaturated aromatic acid (for example, benzaldehyde gives cinnamic acid). This named reaction is the: [2 marks]

(A) Cannizzaro reaction

(B) Perkin reaction

(C) benzoin condensation

(D) aldol reaction

**Q42.** The carbonyl group of an aldehyde or ketone is reduced completely to a methylene group ($CH_2$) by heating with hydrazine ($NH_2NH_2$) followed by a strong base such as $KOH$ in a high-boiling solvent. This carbonyl-to-methylene reduction is the: [2 marks]

(A) Wolff–Kishner reduction

(B) Clemmensen reduction

(C) Rosenmund reduction

(D) Cannizzaro reduction

**Q43.** An acyl chloride ($\mathrm{RCOCl}$) is reduced selectively to an aldehyde ($\mathrm{RCHO}$) by hydrogen over a palladium catalyst poisoned with barium sulfate ($\mathrm{Pd/BaSO_4}$). This controlled partial reduction of an acid chloride is the: **[2 marks]**

(A) Clemmensen reduction

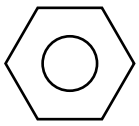
(B) Rosenmund reduction

(C) Wolff–Kishner reduction

(D) Stephen reduction

## Organic Chemistry: Pericyclic, Photochemistry and Biomolecules

**Q44.** According to Hückel's rule, a planar, fully conjugated, cyclic molecule is aromatic when it contains $(4n + 2)$ $\pi$ electrons for an integer $n = 0, 1, 2, \ldots$ Benzene, shown below, has six $\pi$ electrons in its ring. The value of the integer $n$ for benzene is: **[2 marks]**



benzene ($6\pi$)

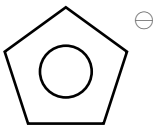
(A) $0$

(B) $2$

(C) $3$

(D) $1$

**Q45.** Among the following planar cyclic species, aromaticity requires a $(4n + 2)$ $\pi$-electron count. The cyclopentadienyl anion, shown below, carries six $\pi$ electrons over its five-membered ring. Which of the following is aromatic? **[2 marks]**



cyclopentadienyl anion ($6\pi$)

(A) cyclobutadiene ($4\pi$)

(B) cyclopentadienyl cation ($4\pi$)

(C) cyclooctatetraene ($8\pi$)

(D) cyclopentadienyl anion ($6\pi$)

**Q46.** At its isoelectric point (pI), an amino acid carries no net electric charge because its acidic carboxyl group is deprotonated ($-\mathrm{COO}^-$) while its basic amino group is protonated ($-\mathrm{NH}_3^+$). This internally charged but overall neutral species is called a: **[2 marks]**

(A) cation

(B) zwitterion

(C) anion

(D) free radical

## Detailed Solutions

### Q1.

**Solution**

**Concept – equivalent protons give one NMR signal:** The number of $^1$H NMR signals equals the number of sets of chemically (magnetically) equivalent protons.

**Step 1 – identify the proton types in para-xylene:** Para-xylene has two $CH_3$ groups at opposite (1,4) ring positions and four aromatic ring protons.

**Step 2 – test the methyl protons:** By the molecule's symmetry the two methyl groups are related by a mirror plane, so all six methyl protons are equivalent and form one set.

**Step 3 – test the aromatic protons:** The four aromatic hydrogens all sit on carbons flanked by identical neighbours; by symmetry they are all equivalent and form a second set.

**Step 4 – count the sets:** Methyl set $+$ aromatic set $= 2$ distinct environments, so the spectrum shows $2$ signals.

**Final Answer:** $2$ NMR signals $\Rightarrow$ $\boxed{\text{B}}$

**Answer: (B)** Go Back to Q1

### Q2.

**Solution**

**Concept – the $n+1$ multiplicity rule:** A proton with $n$ equivalent neighbouring protons is split into $n+1$ lines, with intensities following Pascal's triangle.

**Step 1 – count the neighbours of the $CH_3$ protons:** In $CH_3CH_2OH$ the methyl protons are adjacent to the two protons of the $CH_2$ group, so $n = 2$.

**Step 2 – apply the rule:** Number of lines $= n + 1 = 2 + 1 = 3$.

**Step 3 – name the three-line pattern:** A signal split into three lines is a *triplet*.

**Step 4 – check the intensities:** For $n = 2$, Pascal's triangle gives the ratio $1 : 2 : 1$, exactly the stick pattern drawn.

**Final Answer:** the $CH_3$ signal is a triplet $\Rightarrow$ $\boxed{\text{D}}$

**Answer: (D)** Go Back to Q2

## Q3.

**Solution**

**Concept – radial nodes of an atomic orbital:** The number of radial (spherical) nodes is $n - l - 1$.

**Step 1 – read the quantum numbers for a $3s$ orbital:** Principal quantum number $n = 3$; for an $s$ orbital the azimuthal quantum number $l = 0$.

**Step 2 – substitute into the formula:** Radial nodes $= n - l - 1 = 3 - 0 - 1$.

**Step 3 – evaluate:** $= 2$.

**Step 4 – cross-check the total node count:** Total nodes $= n - 1 = 2$; with $l = 0$ angular nodes, all 2 are radial, which is consistent.

**Final Answer:** 2 radial nodes $\Rightarrow$ A

**Answer: (A)** Go Back to Q3

## Q4.

**Solution**

**Concept – the IR selection rule:** A vibrational mode absorbs infrared radiation only if the motion changes the molecule's electric dipole moment.

**Step 1 – state the rule:** $\left(\frac{\partial \mu}{\partial Q}\right) \neq 0$ is required for IR activity, where $\mu$ is the dipole moment and $Q$ the normal coordinate.

**Step 2 – contrast with Raman:** A change in *polarizability* governs Raman activity, not IR activity, so option (A) is the wrong selection rule.

**Step 3 – eliminate the remaining options:** Bond length always changes during a stretch even for IR-inactive modes, and nuclear spin governs NMR, not IR.

**Step 4 – conclude:** The controlling quantity for IR activity is the dipole moment.

**Final Answer:** a change in dipole moment $\Rightarrow$ B

**Answer: (B)** Go Back to Q4

## Q5.

**Solution**

**Concept – photon energy:** The energy of a single photon is $E = h\nu$.

**Step 1 – list the data:** $h = 6.626 \times 10^{-34}$ J s and $\nu = 6.0 \times 10^{14}$ Hz.

**Step 2 – substitute:** $E = (6.626 \times 10^{-34})(6.0 \times 10^{14})$.

**Step 3 – multiply the mantissas:** $6.626 \times 6.0 = 39.76$.

**Step 4 – combine the powers of ten:** $10^{-34} \times 10^{14} = 10^{-20}$, so $E = 39.76 \times 10^{-20}$ J.

**Step 5 – normalise:** $E = 3.976 \times 10^{-19}$ J $\approx 4.0 \times 10^{-19}$ J.

**Final Answer:** $E \approx 4.0 \times 10^{-19}$ J $\Rightarrow$ C

**Answer: (C)** Go Back to Q5

## Q6.

### Solution

**Concept – the NMR chemical-shift reference:** Chemical shifts $\delta$ are measured relative to a standard whose resonance defines $0$ ppm.

**Step 1 – recall the standard for $^{1}$H (and $^{13}$C) NMR:** Tetramethylsilane, $\mathrm{Si(CH_3)_4}$ (TMS), is the accepted internal reference.

**Step 2 – why TMS is chosen:** Its twelve equivalent protons give one sharp signal, it is chemically inert, volatile (easily removed), and highly shielded so it sits at one edge of the usual proton range.

**Step 3 – eliminate the others:** $\mathrm{CHCl_3}$, water and benzene all resonate at non-zero, sample-dependent shifts and are not the zero reference.

**Final Answer:** the reference is TMS $\Rightarrow$ B

**Answer: (B)** Go Back to Q6

## Q7.

### Solution

**Concept – forward activation energy from an energy profile:** $E_a(\text{forward})$ is the vertical height of the transition state above the reactant level.

**Step 1 – read the levels off the diagram:** Reactants $= 20$ kJ mol$^{-1}$; transition state $= 90$ kJ mol$^{-1}$.

**Step 2 – subtract:** $E_a(\text{forward}) = 90 - 20$.

**Step 3 – evaluate:** $E_a(\text{forward}) = 70$ kJ mol$^{-1}$.

**Step 4 – cross-check with related quantities:** $\Delta H = 60 - 20 = +40$ kJ mol$^{-1}$ (endothermic) and $E_a(\text{reverse}) = 90 - 60 = 30$ kJ mol$^{-1}$; indeed $E_a(\text{forward}) - E_a(\text{reverse}) = 70 - 30 = 40 = \Delta H$.

**Final Answer:** $E_a(\text{forward}) = 70$ kJ mol$^{-1}$ $\Rightarrow$ D

**Answer: (D)** Go Back to Q7

## Q8.

**Solution**

**Concept – a catalyst lowers the activation energy:** The catalyst supplies a new path with a smaller $E_a$; the reduction is the difference between the two barriers.

**Step 1 – note the two activation energies:** Uncatalysed $E_a = 50\ \text{kJ mol}^{-1}$; catalysed $E_a = 30\ \text{kJ mol}^{-1}$.

**Step 2 – take the difference:** $\Delta E_a = 50 - 30$.

**Step 3 – evaluate:** $\Delta E_a = 20\ \text{kJ mol}^{-1}$.

**Step 4 – interpret:** Through $k = A\,e^{-E_a/RT}$, this $20\ \text{kJ mol}^{-1}$ drop raises the rate constant markedly, though $\Delta H$ of the reaction is unchanged.

**Final Answer:** activation energy lowered by $20\ \text{kJ mol}^{-1} \Rightarrow \boxed{\text{B}}$

**Answer: (B)** Go Back to Q8

## Q9.

**Solution**

**Concept – units of a rate constant:** For an overall order $m$, the rate constant has units $(\text{mol L}^{-1})^{1-m}\,\text{s}^{-1}$.

**Step 1 – identify the order:** rate $= k[\text{A}]^2$ is second order, so $m = 2$.

**Step 2 – write rate and concentration units:** Rate has units $\text{mol L}^{-1}\,\text{s}^{-1}$; $[\text{A}]^2$ has units $\text{mol}^2\,\text{L}^{-2}$.

**Step 3 – solve $k$ = rate/$[\text{A}]^2$ for units:** $k$ units $= \dfrac{\text{mol L}^{-1}\,\text{s}^{-1}}{\text{mol}^2\,\text{L}^{-2}}$.

**Step 4 – simplify:** $= \text{mol}^{1-2}\,\text{L}^{-1+2}\,\text{s}^{-1} = \text{mol}^{-1}\,\text{L}\,\text{s}^{-1} = \text{L mol}^{-1}\,\text{s}^{-1}$.

**Final Answer:** $k$ has units $\text{L mol}^{-1}\,\text{s}^{-1} \Rightarrow \boxed{\text{B}}$

**Answer: (B)** Go Back to Q9

## Q10.

**Solution**

**Concept – the Nernst prefactor at 298 K:** The term $\dfrac{2.303\,RT}{F}$ equals $0.0591\ \text{V}$ at $298\ \text{K}$, and it is divided by $n$ in the Nernst equation.

**Step 1 – write the coefficient:** Coefficient $= \dfrac{0.0591}{n}$.

**Step 2 – substitute $n = 2$:** $= \dfrac{0.0591}{2}$.

**Step 3 – divide:** $= 0.02955\ \text{V}$.

**Step 4 – round:** $\approx 0.0296$ V.

**Final Answer:** $\frac{0.0591}{2} \approx 0.0296$ V $\Rightarrow$ C

**Answer: (C)** Go Back to Q10

## Q11.

### Solution

**Concept – activation energy from the Arrhenius slope:** A plot of $\ln k$ versus $1/T$ has slope $= -E_a/R$, so $E_a = -\text{slope} \times R$.

**Step 1 – read the slope:** Slope $= -6000$ K.

**Step 2 – solve for $E_a$:** $E_a = -(-6000\ \text{K}) \times R = 6000 \times 8.314\ \text{J mol}^{-1}$.

**Step 3 – multiply:** $6000 \times 8.314 = 49884\ \text{J mol}^{-1}$.

**Step 4 – convert to kJ:** $E_a = 49.884\ \text{kJ mol}^{-1} \approx 49.9\ \text{kJ mol}^{-1}$.

**Final Answer:** $E_a \approx 49.9\ \text{kJ mol}^{-1} \Rightarrow$ A

**Answer: (A)** Go Back to Q11

## Q12.

### Solution

**Concept – the spontaneity criterion at constant $T$ and $P$:** A process is spontaneous (thermodynamically allowed) only when $\Delta G < 0$.

**Step 1 – recall the sign convention:** $\Delta G < 0$: spontaneous; $\Delta G = 0$: equilibrium; $\Delta G > 0$: non-spontaneous.

**Step 2 – select the spontaneous case:** Spontaneity requires $\Delta G$ to be negative.

**Step 3 – eliminate the distractors:** $\Delta G = 0$ is equilibrium, $\Delta G > 0$ is non-spontaneous, and $\Delta G = \Delta H$ only if $T\Delta S = 0$, which is not a general spontaneity test.

**Final Answer:** $\Delta G$ must be negative $\Rightarrow$ C

**Answer: (C)** Go Back to Q12

## Q13.

**Solution**

**Concept – Faraday's law for deposition:** Charge needed = (moles of electrons) × $F$, and the moles of electrons follow from the ion's charge.

**Step 1 – write the electrode reaction:** $Al^{3+} + 3e^- \rightarrow Al$, so 3 mol of electrons deposit 1 mol of Al.

**Step 2 – set up the charge:** $Q = 3 \times F = 3 \times 96500$ C.

**Step 3 – multiply:** $Q = 289500$ C.

**Step 4 – sanity check:** Depositing Al ($3^+$) needs three times the charge of a $1^+$ ion such as Na (96500 C), which matches.

**Final Answer:** $Q = 289500$ C $\Rightarrow$ D

**Answer: (D)** Go Back to Q13

## Q14.

**Solution**

**Concept – successive half-lives of a first-order reaction:** Each half-life halves the remaining reactant, and half-life is constant for a first-order process.

**Step 1 – convert 75% complete into fraction remaining:** $100\% - 75\% = 25\%$ of the reactant remains.

**Step 2 – express 25% as halvings:** $100\% \rightarrow 50\%$ (one $t_{1/2}$) $\rightarrow 25\%$ (two $t_{1/2}$), so $25\%$ remaining $= 2$ half-lives.

**Step 3 – relate to the given time:** $2\,t_{1/2} = 40$ min.

**Step 4 – solve:** $t_{1/2} = \dfrac{40}{2} = 20$ min.

**Final Answer:** $t_{1/2} = 20$ min $\Rightarrow$ D

**Answer: (D)** Go Back to Q14

## Q15.

**Solution**

**Concept – VSEPR shape of $AX_3E_2$:** Five electron domains adopt a trigonal-bipyramidal arrangement; lone pairs take the equatorial sites to minimise repulsion.

**Step 1 – count domains on chlorine in $ClF_3$:** Three bonding pairs + two lone pairs = 5 electron domains.

**Step 2 – place the lone pairs:** The two lone pairs occupy two of the three equatorial positions of the trigonal bipyramid.

**Step 3 – locate the bonding pairs:** The three $\mathrm{Cl-F}$ bonds then lie along the two axial positions and the one remaining equatorial position.

**Step 4 – name the resulting shape:** Two axial atoms plus one equatorial atom around the centre trace out a "T", so the molecule is T-shaped (slightly bent below $90^\circ$).

**Final Answer:** $\mathrm{ClF_3}$ is T-shaped $\Rightarrow \boxed{\text{B}}$

**Answer: (B)** Go Back to Q15

## Q16.

### Solution

**Concept – acid strength of oxoacids:** For oxoacids $\mathrm{HOClO_m}$, more terminal (double-bonded) oxygens spread the negative charge of the conjugate base, making the acid stronger.

**Step 1 – list oxidation states / oxygen counts:** $\mathrm{HClO}$ (Cl: $+1$), $\mathrm{HClO_2}$ ($+3$), $\mathrm{HClO_3}$ ($+5$), $\mathrm{HClO_4}$ ($+7$).

**Step 2 – apply the trend:** Acid strength rises with the number of terminal oxygens: $\mathrm{HClO} < \mathrm{HClO_2} < \mathrm{HClO_3} < \mathrm{HClO_4}$.

**Step 3 – justify with the conjugate base:** $\mathrm{ClO_4^-}$ delocalises its charge over four equivalent oxygens, so it is the most stable anion and $\mathrm{HClO_4}$ the strongest acid.

**Step 4 – select the strongest:** $\mathrm{HClO_4}$ (perchloric acid).

**Final Answer:** strongest acid is $\mathrm{HClO_4} \Rightarrow \boxed{\text{A}}$

**Answer: (A)** Go Back to Q16

## Q17.

### Solution

**Concept – VSEPR shape of $\mathrm{AX_5E}$:** Six electron domains give an octahedral arrangement; one lone pair leaves a square-pyramidal set of atoms.

**Step 1 – count domains on iodine in $\mathrm{IF_5}$:** Five bonding pairs $+$ one lone pair $= 6$ electron domains (octahedral electron geometry).

**Step 2 – remove the lone-pair position:** The single lone pair occupies one octahedral vertex, leaving five $\mathrm{I-F}$ bonds.

**Step 3 – describe the remaining atom positions:** Four fluorines form a square

base and one fluorine sits at the apex, giving a square pyramid.

**Step 4 – note the distortion:** Lone-pair repulsion pushes the iodine slightly below the basal plane, but the shape is still called square pyramidal.

**Final Answer:** $IF_5$ is square pyramidal $\Rightarrow$ $\boxed{D}$

**Answer: (D)** Go Back to Q17

## Q18.

### Solution

**Concept – oxidation-state balance in a neutral molecule:** The sum of all oxidation numbers in a neutral molecule is zero.

**Step 1 – assign the known oxidation numbers in $H_2SO_4$:** Each H is $+1$ (total $+2$); each O is $-2$ (total $-8$).

**Step 2 – write the neutrality equation:** $2(+1) + x + 4(-2) = 0$, where $x$ is the oxidation state of sulfur.

**Step 3 – simplify:** $2 + x - 8 = 0$.

**Step 4 – solve for $x$:** $x - 6 = 0 \Rightarrow x = +6$.

**Final Answer:** sulfur is $+6$ in $H_2SO_4$ $\Rightarrow$ $\boxed{A}$

**Answer: (A)** Go Back to Q18

## Q19.

### Solution

**Concept – periodic trend in electronegativity:** Across a period the nuclear charge rises while electrons enter the same shell, so the atom pulls bonding electrons more strongly.

**Step 1 – note the change in effective nuclear charge:** From Li to F the effective nuclear charge increases steadily.

**Step 2 – note the atomic-size change:** Atomic radius shrinks across the period, bringing bonding electrons closer to the nucleus.

**Step 3 – combine the two effects:** A larger pull on a shorter bond means the atoms attract shared electrons more strongly, so electronegativity increases.

**Step 4 – state the trend:** Electronegativity rises from Li (low) to F (highest in the period).

**Final Answer:** electronegativity increases across the period $\Rightarrow$ $\boxed{A}$

**Answer: (A)** Go Back to Q19

## Q20.

### Solution

**Concept – basicity of group-15 hydrides:** Basic strength depends on how readily the central-atom lone pair is donated; a smaller, more concentrated lone pair is a better base.

**Step 1 – note the size trend:** Going down $\mathrm{N} \to \mathrm{P} \to \mathrm{As} \to \mathrm{Sb}$, the central atom grows larger and the lone pair becomes more diffuse.

**Step 2 – link size to donor ability:** The compact lone pair on the small nitrogen of $\mathrm{NH_3}$ is the most available for donation.

**Step 3 – order the basicity:** $\mathrm{NH_3} > \mathrm{PH_3} > \mathrm{AsH_3} > \mathrm{SbH_3}$.

**Step 4 – pick the strongest base:** $\mathrm{NH_3}$.

**Final Answer:** strongest base is $\mathrm{NH_3} \Rightarrow \boxed{\mathrm{D}}$

**Answer: (D)** Go Back to Q20

## Q21.

### Solution

**Concept – classifying substitution mechanisms:** The mechanism is named by how bond-making and bond-breaking are timed at the metal centre.

**Step 1 – identify the rate-determining event:** Here a ligand *leaves first* in the slow step, reducing the coordination number from six to five.

**Step 2 – match to a mechanism label:** Rate-determining ligand loss to give a lower-coordinate intermediate is the *dissociative* (D) pathway.

**Step 3 – check the rate law:** Because the incoming ligand enters only after the slow step, the rate depends only on [complex], consistent with a dissociative mechanism.

**Step 4 – eliminate the others:** Associative (A) and $I_a$ involve rate-determining *bond-making* by the incoming ligand, and "concerted bimolecular" describes associative behaviour.

**Final Answer:** dissociative (D) mechanism $\Rightarrow \boxed{\mathrm{C}}$

**Answer: (C)** Go Back to Q21

## Q22.

**Solution**

**Concept – kinetic terms for coordination complexes:** "Labile" and "inert" are *kinetic* (rate) terms, distinct from the thermodynamic terms "stable" and "unstable".

**Step 1 – match the description to the term:** A complex whose ligands exchange *rapidly* is, by definition, kinetically labile.

**Step 2 – contrast with "inert":** An inert complex exchanges its ligands slowly, which is the opposite of the case described.

**Step 3 – eliminate the unrelated options:** "Chiral" and "racemic" describe stereochemistry, not substitution rate.

**Step 4 – conclude:** The correct kinetic descriptor is labile.

**Final Answer:** the complex is labile $\Rightarrow$ A

**Answer: (A)** Go Back to Q22

## Q23.

**Solution**

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

**Step 1 – work out the low-spin $d^6$ configuration:** In a strong octahedral field the six $d$ electrons fill $t_{2g}$ as three pairs: $t_{2g}^6 e_g^0$.

**Step 2 – count unpaired electrons:** All six electrons are paired, so $n = 0$.

**Step 3 – substitute into the formula:** $\mu = \sqrt{0(0+2)} = \sqrt{0}$.

**Step 4 – evaluate:** $\mu = 0$ BM, i.e. the complex is diamagnetic.

**Final Answer:** $\mu = 0$ BM $\Rightarrow$ D

**Answer: (D)** Go Back to Q23

## Q24.

**Solution**

**Concept – electron counting by the ionic method:** Total valence electrons = metal $d$-electrons + electrons donated by all ligands.

**Step 1 – count the metal contribution:** Iron(II) is $d^6$, contributing $6$ electrons.

**Step 2 – count the ligand contribution:** Each $\eta^5$-cyclopentadienyl anion donates

6 electrons; two rings give $2 \times 6 = 12$.

**Step 3 – add:** Total $= 6 + 12 = 18$ valence electrons.

**Step 4 – interpret:** The 18-electron count matches the noble-gas configuration and explains ferrocene's marked stability.

**Final Answer:** valence-electron count $= 18 \Rightarrow$ A

**Answer: (A)** Go Back to Q24

## Q25.

### Solution

**Concept – geometric isomerism in $MA_4B_2$ octahedra:** An octahedral $MA_4B_2$ complex has two ways to arrange the two B ligands.

**Step 1 – place the two chlorides adjacent:** When the two Cl ligands occupy neighbouring $(90°)$ positions, the isomer is *cis*.

**Step 2 – place the two chlorides opposite:** When the two Cl ligands sit at opposite $(180°)$ positions, the isomer is *trans*.

**Step 3 – name the pair:** These two forms are the cis and trans geometric isomers.

**Step 4 – eliminate the others:** fac/mer applies to $MA_3B_3$, $d/l$ describes optical isomers, and ionisation isomers differ in the counter-ion, none of which fits $[Co(NH_3)_4Cl_2]^+$ here.

**Final Answer:** the isomers are cis and trans $\Rightarrow$ C

**Answer: (C)** Go Back to Q25

## Q26.

### Solution

**Concept – kinetic labilising in square-planar substitution:** In Pt(II) chemistry, some ligands greatly speed up replacement of the group directly opposite (trans) to them.

**Step 1 – name the phenomenon:** This directing, rate-accelerating influence on the trans position is the *trans effect*.

**Step 2 – note its use:** The trans effect lets chemists control which ligand is substituted, e.g. in the selective synthesis of cis- and trans-$[Pt(NH_3)_2Cl_2]$.

**Step 3 – eliminate the distractors:** The chelate effect is a thermodynamic stabilisation by ring formation; the inert-pair effect concerns $ns^2$ oxidation states; the Jahn–Teller effect is a geometric distortion of degenerate states.

**Final Answer:** the phenomenon is the trans effect $\Rightarrow$ B

**Answer: (B)** Go Back to Q26

## Q27.

### Solution

**Concept – atoms per unit cell from shared positions:** A corner atom is shared among $8$ cells, contributing $\frac{1}{8}$ to each.

**Step 1 – count the corner atoms:** A cube has $8$ corners, each holding one atom.

**Step 2 – apply the sharing factor:** Each corner atom contributes $\frac{1}{8}$ to the cell.

**Step 3 – sum the contributions:** $8 \times \frac{1}{8} = 1$.

**Step 4 – add any interior atoms:** A simple cubic cell has no body-centre or face atoms, so the total stays $1$.

**Final Answer:** $1$ atom per simple cubic cell $\Rightarrow$ D

**Answer: (D)** Go Back to Q27

## Q28.

### Solution

**Concept – the metal centre of chlorophyll:** Chlorophyll is a magnesium-porphyrin (a chlorin) pigment.

**Step 1 – recall the biological role:** Chlorophyll absorbs light for photosynthesis in green plants.

**Step 2 – identify the central ion:** The four pyrrole nitrogens of the chlorin ring coordinate a single $Mg^{2+}$ ion at the centre.

**Step 3 – contrast with related pigments:** Haemoglobin and cytochromes use $Fe$, and vitamin $B_{12}$ uses $Co$; chlorophyll is the magnesium pigment.

**Step 4 – conclude:** The central metal ion is $Mg^{2+}$.

**Final Answer:** chlorophyll's central ion is $Mg^{2+}$ $\Rightarrow$ C

**Answer: (C)** Go Back to Q28

## Q29.

**Solution**

**Concept – oxidation state of iron in haemoglobin:** Reversible oxygen binding requires the heme iron to stay ferrous.

**Step 1 – state the functional oxidation state:** In oxygen-carrying (oxy- and deoxy-) haemoglobin, the heme iron is $\mathrm{Fe(II)}$, i.e. $+2$.

**Step 2 – explain why not $+3$:** If the iron is oxidised to $\mathrm{Fe(III)}$ the pigment becomes methaemoglobin, which cannot bind and release $\mathrm{O_2}$ normally.

**Step 3 – describe the binding:** $\mathrm{O_2}$ coordinates end-on to the $\mathrm{Fe(II)}$ centre of the porphyrin, held on the opposite face by a histidine of the globin.

**Step 4 – conclude:** The functional oxidation state of iron is $+2$.

**Final Answer:** iron is $+2$ in functional haemoglobin $\Rightarrow$ $\boxed{\mathrm{C}}$

**Answer: (C)** Go Back to Q29

## Q30.

**Solution**

**Concept – staggered conformation of ethane:** In the staggered form the front and back $\mathrm{C-H}$ bonds are offset to keep bonding electrons as far apart as possible.

**Step 1 – describe the geometry:** Each carbon carries three $\mathrm{C-H}$ bonds spaced $120^\circ$ apart around the $\mathrm{C-C}$ axis.

**Step 2 – offset the two sets:** In the staggered conformation the back set is rotated so its bonds bisect the gaps of the front set.

**Step 3 – compute the offset:** Half of the $120^\circ$ spacing is $60^\circ$, so each back $\mathrm{C-H}$ lies $60^\circ$ from the nearest front $\mathrm{C-H}$.

**Step 4 – interpret:** This $60^\circ$ dihedral gives the minimum torsional strain, the most stable conformation shown.

**Final Answer:** dihedral angle $= 60^\circ \Rightarrow$ $\boxed{\mathrm{B}}$

**Answer: (B)** Go Back to Q30

## Q31.

**Solution**

**Concept – meso compounds reduce the isomer count:** Two identical stereocentres allow an internally symmetric (meso) form, so $2^n$ over-counts.

**Step 1 – apply the naive count:** With $n = 2$ stereocentres, $2^n = 2^2 = 4$ would be the maximum.

**Step 2 – recognise the meso form:** Tartaric acid's two stereocentres are constitutionally identical, so the $(R, S)$ and $(S, R)$ forms are the same achiral *meso* compound.

**Step 3 – recount the distinct isomers:** The chiral pair $(R, R)$ and $(S, S)$ are enantiomers (2 isomers), plus the single meso form (1 isomer).

**Step 4 – total:** $2 + 1 = 3$ distinct stereoisomers.

**Final Answer:** 3 stereoisomers of tartaric acid $\Rightarrow$ $\boxed{\text{C}}$

**Answer: (C)** Go Back to Q31

## Q32.

**Solution**

**Concept – rate law of an $S_N1$ reaction:** The slowest step controls the rate, and only species present in or before that step appear in the rate law.

**Step 1 – identify the slow step:** In $S_N1$, the substrate ionises to a carbocation in the rate-determining step.

**Step 2 – write the rate law:** rate $= k[\text{substrate}]$, which is first order overall.

**Step 3 – note the nucleophile's role:** The nucleophile attacks the carbocation only in a fast, later step, so it does not appear in the rate law.

**Step 4 – conclude:** The $S_N1$ rate depends on the substrate concentration alone.

**Final Answer:** rate depends on the substrate only $\Rightarrow$ $\boxed{\text{A}}$

**Answer: (A)** Go Back to Q32

## Q33.

**Solution**

**Concept – CIP priority rules:** Priorities of the four groups on a stereocentre are set by comparing atoms outward from the centre.

**Step 1 – state the first rule:** Rank the atoms directly bonded to the stereocentre

by *atomic number*; higher atomic number means higher priority.

**Step 2 – state the tie-breaker:** If two attached atoms are the same, move to the next shell of atoms and again compare atomic numbers.

**Step 3 – read the $R/S$ label:** With the lowest priority pointing away, $1 \rightarrow 2 \rightarrow 3$ clockwise is $R$ and anticlockwise is $S$.

**Step 4 – eliminate the distractors:** Group size, alphabetical name and bond length are not the CIP criteria.

**Final Answer:** priority is set by the atomic number of the attached atoms $\Rightarrow$ C

**Answer: (C)** Go Back to Q33

## Q34.

### Solution

**Concept – stereochemistry of $S_N2$:** The nucleophile attacks from the side opposite the leaving group in a single, concerted step.

**Step 1 – describe the attack:** Backside (anti) approach forces the three other groups to flatten and then fold back, like an umbrella turning inside out.

**Step 2 – name the result:** This Walden inversion means the configuration at the carbon is inverted.

**Step 3 – link to optical activity:** A single enantiomer of substrate gives predominantly the inverted product, not a racemate.

**Step 4 – eliminate the others:** Retention and "no change" contradict backside attack, and full racemisation is characteristic of $S_N1$ (via a planar carbocation), not $S_N2$.

**Final Answer:** $S_N2$ gives inversion of configuration $\Rightarrow$ A

**Answer: (A)** Go Back to Q34

## Q35.

### Solution

**Concept – axial vs equatorial preference:** A bulky substituent avoids the crowded axial site to minimise $1,3$-diaxial repulsions.

**Step 1 – recall the two positions:** Each ring carbon of a chair offers one axial and one equatorial site, interconverted by ring flip.

**Step 2 – assess axial crowding:** An axial group clashes with the two other axial hydrogens on the same face ($1,3$-diaxial strain).

**Step 3 – assess the equatorial site:** An equatorial group points outward, away from those axial hydrogens, avoiding the strain.

**Step 4 – apply to *tert*-butyl:** The very large $C(CH_3)_3$ group locks the ring so that it is essentially always equatorial.

**Final Answer:** the bulky group prefers the equatorial position $\Rightarrow$ D

**Answer: (D)** Go Back to Q35

## Q36.

### Solution

**Concept – stereochemical requirement of $E2$:** $E2$ is concerted, so the breaking $C-H$ and $C-LG$ bonds must be aligned to overlap into the forming $\pi$ bond.

**Step 1 – state the geometry:** The hydrogen and the leaving group must lie in the same plane and point in opposite directions across the $C-C$ bond (dihedral $180°$).

**Step 2 – name it:** This arrangement is called anti-periplanar.

**Step 3 – explain why it is favoured:** Anti-periplanar alignment gives the best orbital overlap for the developing double bond and keeps the substituents staggered (low strain) in the transition state.

**Step 4 – eliminate the others:** Syn-periplanar overlap is possible but strained and rare; gauche and fully eclipsed do not provide the required coplanar antiperiplanar overlap.

**Final Answer:** H and leaving group must be anti-periplanar $\Rightarrow$ B

**Answer: (B)** Go Back to Q36

## Q37.

### Solution

**Concept – cyanide-catalysed coupling of aromatic aldehydes:** Two $ArCHO$ molecules join to give an $\alpha$-hydroxy ketone.

**Step 1 – recognise the transformation:** $2\,C_6H_5CHO \xrightarrow{CN^-} C_6H_5CH(OH)COC_6H_5$ (benzoin).

**Step 2 – name the reaction:** This cyanide-catalysed dimerisation of an aromatic aldehyde is the benzoin condensation.

**Step 3 – outline the mechanism:** $CN^-$ adds to one aldehyde, the resulting carbanion (umpolung) attacks the second aldehyde, and loss of $CN^-$ regenerates the catalyst.

**Step 4 – eliminate the others:** Cannizzaro is a disproportionation, aldol needs an $\alpha$-hydrogen, and Perkin uses an anhydride and base.

**Final Answer:** the reaction is the benzoin condensation $\Rightarrow$ C

**Answer: (C)** Go Back to Q37

## Q38.

### Solution

**Concept – disproportionation of a non-enolisable aldehyde:** An aldehyde lacking an $\alpha$-hydrogen cannot enolise, so with strong base it undergoes self oxidation–reduction.

**Step 1 – write the reaction:** $2\,C_6H_5CHO + NaOH \rightarrow C_6H_5CH_2OH + C_6H_5COONa$.

**Step 2 – identify the redox roles:** One molecule is reduced to benzyl alcohol while the other is oxidised to benzoate.

**Step 3 – name the reaction:** This base-induced disproportionation of a non-enolisable aldehyde is the Cannizzaro reaction.

**Step 4 – eliminate the others:** Benzoin condensation needs cyanide and gives an $\alpha$-hydroxy ketone; aldol and Claisen require an $\alpha$-hydrogen, which benzaldehyde lacks.

**Final Answer:** the reaction is the Cannizzaro reaction $\Rightarrow$ A

**Answer: (A)** Go Back to Q38

## Q39.

### Solution

**Concept – the catalyst for the benzoin condensation:** A good catalyst must add reversibly to the carbonyl and stabilise the resulting carbanion.

**Step 1 – recall the classic catalyst:** Cyanide ion, $CN^-$, is the traditional benzoin-condensation catalyst.

**Step 2 – explain the role:** $CN^-$ adds to the aldehyde carbon; its electron-withdrawing nature stabilises the carbanion (acyl anion equivalent), reversing the carbon's normal polarity (umpolung).

**Step 3 – note a modern alternative:** $N$-heterocyclic carbenes and thiamine (vitamin $B_1$) work the same way in biological and green versions.

**Step 4 – eliminate the others:** Concentrated $H_2SO_4$, $Zn(Hg)$ and $LiAlH_4$ do not catalyse this coupling.

**Final Answer:** the catalyst is cyanide ion $\Rightarrow$ A

**Answer: (A)** Go Back to Q39

## Q40.

### Solution

**Concept – selectivity in the crossed Cannizzaro:** The aldehyde that is the better hydride donor is itself oxidised while it reduces the partner.

**Step 1 – identify the better hydride donor:** Formaldehyde, being small and lacking steric or electronic hindrance, donates hydride most readily.

**Step 2 – assign the redox outcome:** As the hydride donor, formaldehyde is oxidised to formate; the benzaldehyde it reduces becomes benzyl alcohol.

**Step 3 – write the products:** $\mathrm{HCHO} + \mathrm{C_6H_5CHO} + \mathrm{NaOH} \rightarrow \mathrm{HCOONa} + \mathrm{C_6H_5CH_2OH}$.

**Step 4 – state the fate of formaldehyde:** Formaldehyde is oxidised to sodium formate.

**Final Answer:** formaldehyde is oxidised to sodium formate $\Rightarrow$ C

**Answer: (C)** Go Back to Q40

## Q41.

### Solution

**Concept – forming an $\alpha,\beta$-unsaturated acid from an aldehyde:** An aromatic aldehyde reacts with an anhydride and its carboxylate salt to give a cinnamic-type acid.

**Step 1 – recall the reagents:** Benzaldehyde + acetic anhydride + sodium acetate, on heating, give cinnamic acid.

**Step 2 – name the reaction:** This condensation is the Perkin reaction.

**Step 3 – outline the mechanism:** The carboxylate base generates the anhydride's $\alpha$-carbanion, which adds to the aldehyde; dehydration then installs the $\alpha,\beta$-double bond.

**Step 4 – eliminate the others:** Cannizzaro gives alcohol + acid, benzoin gives an $\alpha$-hydroxy ketone, and the simple aldol does not use an anhydride.

**Final Answer:** the reaction is the Perkin reaction $\Rightarrow$ B

**Answer: (B)** Go Back to Q41

## Q42.

**Solution**

**Concept – carbonyl-to-methylene reduction:** Reducing $C{=}O$ fully to $CH_2$ can be done under basic or acidic conditions.

**Step 1 – match reagents to name:** Hydrazine ($NH_2NH_2$) followed by strong base ($KOH$, heat) is the Wolff–Kishner reduction.

**Step 2 – outline the path:** The carbonyl first forms a hydrazone, which loses $N_2$ under base to leave the methylene group.

**Step 3 – contrast with Clemmensen:** Clemmensen uses $Zn(Hg)$ and concentrated $HCl$ (acidic conditions) for the same net reduction, so it is unsuitable for base-sensitive substrates but is not the reagent set here.

**Step 4 – eliminate the others:** Rosenmund reduces acid chlorides to aldehydes, and there is no "Cannizzaro reduction" of this kind.

**Final Answer:** the reaction is the Wolff–Kishner reduction $\Rightarrow \boxed{A}$

**Answer: (A)** Go Back to Q42

## Q43.

**Solution**

**Concept – selective reduction of an acid chloride:** Partial hydrogenation stops at the aldehyde when the catalyst is deactivated.

**Step 1 – recall the reagents:** $RCOCl + H_2$ over $Pd/BaSO_4$ (a poisoned catalyst) gives $RCHO$.

**Step 2 – name the reaction:** This is the Rosenmund reduction.

**Step 3 – explain the poison:** Barium sulfate (often with quinoline/sulfur) lowers the palladium's activity so the aldehyde is not further reduced to the alcohol.

**Step 4 – eliminate the others:** Clemmensen and Wolff–Kishner reduce carbonyls to $CH_2$, and the Stephen reduction converts nitriles (not acid chlorides) to aldehydes.

**Final Answer:** the reaction is the Rosenmund reduction $\Rightarrow \boxed{B}$

**Answer: (B)** Go Back to Q43

## Q44.

**Solution**

**Concept – Hückel's $(4n+2)$ rule:** A planar cyclic conjugated ring is aromatic when its $\pi$-electron count equals $4n+2$ for some integer $n$.

**Step 1 – set the count equal to benzene's:** Benzene has $6\ \pi$ electrons, so $4n+2=6$.

**Step 2 – solve for $n$:** $4n=6-2=4$.

**Step 3 – divide:** $n=\dfrac{4}{4}=1$.

**Step 4 – verify:** $4(1)+2=6$, matching benzene's $\pi$-electron count, so $n=1$.

**Final Answer:** $n=1$ for benzene $\Rightarrow$ D

**Answer: (D)** Go Back to Q44

## Q45.

**Solution**

**Concept – aromatic vs antiaromatic by $\pi$-electron count:** $(4n+2)\ \pi$ electrons in a planar conjugated ring means aromatic; $4n$ means antiaromatic (or the ring puckers to avoid it).

**Step 1 – test each species:** Cyclobutadiene $(4\pi)$ and the cyclopentadienyl cation $(4\pi)$ are $4n$ systems, hence antiaromatic.

**Step 2 – test cyclooctatetraene:** With $8\pi$ $(4n,\ n=2)$ it is not aromatic; it puckers into a non-planar tub shape.

**Step 3 – test the cyclopentadienyl anion:** It has $6\pi$ electrons $(4n+2,\ n=1)$ delocalised over a planar five-membered ring, so it is aromatic.

**Step 4 – select the aromatic one:** Only the cyclopentadienyl anion satisfies the $(4n+2)$ rule.

**Final Answer:** the aromatic species is the cyclopentadienyl anion $\Rightarrow$ D

**Answer: (D)** Go Back to Q45

## Q46.

**Solution**

**Concept – amino acids at the isoelectric point:** At the pI the molecule bears equal and opposite internal charges and zero net charge.

**Step 1 – describe the charged groups:** The carboxyl group is deprotonated

($-\mathrm{COO}^-$) and the amino group is protonated ($-\mathrm{NH}_3^+$).

**Step 2 – assess the net charge:** $(-1)+(+1)=0$, so the species is overall neutral.

**Step 3 – name the species:** A dipolar ion carrying both a positive and a negative site with no net charge is a zwitterion.

**Step 4 – eliminate the others:** A cation dominates below the pI, an anion above the pI, and a free radical is irrelevant to acid–base speciation.

**Final Answer:** the species is a zwitterion $\Rightarrow$ $\boxed{\text{B}}$

**Answer: (B)** Go Back to Q46

# Answer Key

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