IIT JAM Chemistry

Sample Paper – 1

Instructions

- This paper contains **60 questions** carrying a maximum of **100 marks**. Duration: **3 hours (180 minutes)**.
- **Section A** (**Q1–Q30**, MCQ): Q1–Q10 carry **+1 mark** each; wrong response: $-\frac{1}{3}$ mark. Q11–Q30 carry **+2 marks** each; wrong response: $-\frac{2}{3}$ mark. Choose the **single best** option.
- **Section B** (**Q31–Q40**, MSQ): Each carries **+2 marks**. **No negative marking. One or more** options may be correct; full marks only if *all* correct options are selected; no partial credit.
- **Section C** (**Q41–Q60**, NAT): Q41–Q50 carry **+1 mark**; Q51–Q60 carry **+2 marks**. **No negative marking.** Enter the numerical value using the virtual keypad (integer or decimal as appropriate).
- **Calculator policy:** Personal calculators, log tables, and electronic devices are **strictly prohibited**. A virtual scientific calculator is provided in the CBT interface. Rough sheets are supplied at the examination centre.
- Once you move to the next section, you cannot return to a previous section. Manage time accordingly.

Section A — Multiple Choice Questions (MCQ)

***Q1–Q10**: 1 mark each ($-\frac{1}{3}$ for wrong). Choose the **single** correct option.*

Q1. Atomic radius decreases across Period 3 from Na to Cl because the nuclear charge increases while electrons are added to the *same* shell. Which of the following correctly ranks the atomic radii of Na, Mg, Al, and Cl in **decreasing** order?

(A) Al $>$ Na $>$ Mg $>$ Cl
(B) Na $>$ Mg $>$ Al $>$ Cl
(C) Cl $>$ Al $>$ Mg $>$ Na
(D) Mg $>$ Na $>$ Cl $>$ Al

Q2. In the Bohr model of hydrogen, the energy of level n is $E_n = -13.6/n^2$ eV. The Balmer series involves transitions from higher levels down to $n = 2$. Which transition in the Balmer series emits the photon of **longest wavelength** (lowest energy)?

(A) $n = 3 \rightarrow n = 2$
(B) $n = 4 \rightarrow n = 2$
(C) $n = 5 \rightarrow n = 2$
(D) $n = \infty \rightarrow n = 2$

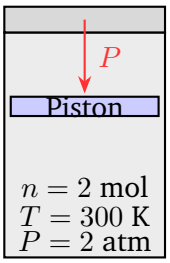
Q3. Alkali metals react with water to produce the metal hydroxide and hydrogen gas: $2M + 2H_2O \rightarrow 2MOH + H_2$. The reactivity increases down the group. Which alkali metal reacts **most vigorously** with water and best represents the trend Li $<$ Na $<$ K?

(A) Li, because it has the smallest size and highest ionisation enthalpy
(B) Na, because it is the most common alkali metal
(C) K, because its larger atomic size leads to a lower ionisation enthalpy and greater reactivity
(D) All alkali metals react equally vigorously with water

Q4. Consider the molecule allene, $H_2C{=}C{=}CH_2$. What is the hybridisation of the **central** carbon atom?

(A) sp^3
(B) sp^2
(C) sp^3d
(D) sp

Q5. Using the ideal gas equation $PV = nRT$ ($R = 0.0821$ L atm mol^{-1} K^{-1}), calculate the volume occupied by 2 mol of an ideal gas at 27 °C and a pressure of 2 atm.



(A) 24.6 L
(B) 49.2 L
(C) 12.3 L

(D) 6.15 L

Q6. Nitrogen (N_2) has a much higher bond dissociation enthalpy (≈ 945 kJ mol^{-1}) compared with the P–P bond in white phosphorus (≈ 200 kJ mol^{-1}). Which statement correctly explains this observation?

(A) N_2 has a single bond; P_4 has a triple bond, making P_4 more reactive
(B) The N≡N triple bond is exceptionally strong because nitrogen is small enough to allow effective p–p π-overlap; phosphorus is too large for comparable π-bonding
(C) Nitrogen has a larger atomic radius than phosphorus, leading to stronger overlap
(D) Both N_2 and P_4 have similar bond dissociation enthalpies near 945 kJ mol^{-1}

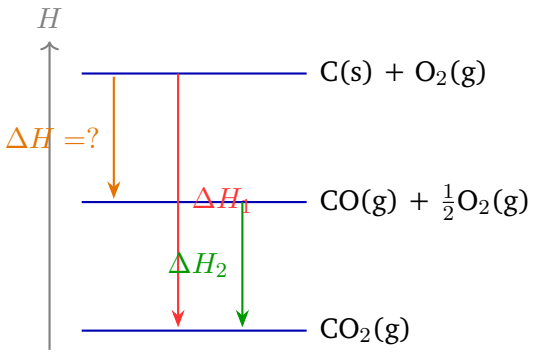
Q7. A tetrahedral carbon bears four different substituents with the priority order (by CIP rules): I $>$ Br $>$ CH_3 $>$ H. In the given 3D drawing, the lowest-priority group H points away from you (into the page). The remaining three groups—I, Br, CH_3—appear in **clockwise** order when viewed with H pointing away. The configuration of this chiral centre is:

(A) (S), because clockwise arrangement with H pointing away means the sequence is anticlockwise when viewed from the front
(B) (S), because I $>$ Br always gives S regardless of arrangement
(C) (R), because the sequence I $\rightarrow$ Br $\rightarrow$ CH_3 is clockwise with the lowest-priority group pointing away
(D) (R) or (S) cannot be determined without a 3D model

Q8. Given the thermochemical equations:

$$\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}, \quad \Delta H_1$$
$$\text{CO(g)} + \tfrac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}, \quad \Delta H_2$$

The enthalpy change for the reaction $\text{C(s)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CO(g)}$ is:



(A) $\Delta H = \Delta H_1 + \Delta H_2$
(B) $\Delta H = \Delta H_2 - \Delta H_1$
(C) $\Delta H = \Delta H_1 + 2\Delta H_2$
(D) $\Delta H = \Delta H_1 - \Delta H_2$

Q9. The IUPAC name of the complex $[Co(NH_3)_5Cl]Cl_2$ is:

(A) Pentaamminechloridocobalt(III) chloride
(B) Pentaaminechlorocobalt(II) chloride
(C) Chloridopentaamminecobalt(III) dichloride
(D) Pentaamminedichloro cobalt(III) chloride

Q10. Which of the following correctly describes the substitution reaction of tert-butyl bromide in aqueous ethanol?

(A) It undergoes SN2 because tertiary substrates are excellent for back-side attack
(B) It undergoes SN1 because the tertiary carbocation intermediate is stabilised by hyperconjugation and induction; the rate depends only on [substrate]
(C) It undergoes SN2 in the absence of a nucleophile
(D) Tertiary alkyl halides do not react with aqueous ethanol under any conditions

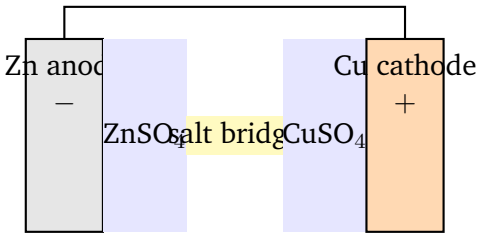
***Q11–Q30**: 2 marks each ($-\frac{2}{3}$ for wrong). Choose the **single** correct option.*

Q11. For the electrochemical cell $Zn(s)\,|\,Zn^{2+}(0.1\ M)\,\|\,Cu^{2+}(0.001\ M)\,|\,Cu(s)$, the standard cell potential is $E^\circ_{cell} = 1.10$ V. Using the Nernst equation at

25 °C ($0.059/n$ factor):

$$E_{\text{cell}} = E^{\circ}_{\text{cell}} - \frac{0.059}{n} \log Q$$

the cell potential E_{cell} is approximately:

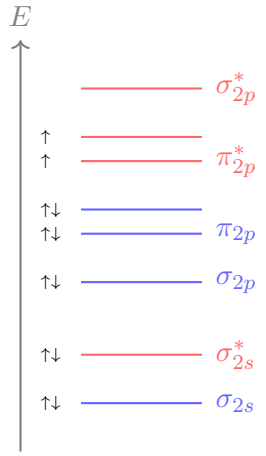


(A) 1.10 V
(B) 1.16 V
(C) 1.04 V
(D) 0.98 V

Q12. In base-catalysed aldol condensation of acetaldehyde (CH_3CHO), the initial product (aldol) is a β-hydroxy aldehyde. On heating, the aldol product undergoes dehydration. The final product of the complete aldol condensation of acetaldehyde (aldol addition *followed by* elimination) is:

(A) 1-Butanol
(B) 3-Hydroxybutanal (the aldol addition product only)
(C) Butanal
(D) Crotonaldehyde (but-2-enal, $CH_3CH{=}CHCHO$)

Q13. Molecular orbital theory predicts bond orders of O_2, O_2^+, and O_2^- as 2, 2.5, and 1.5 respectively. The correct order of decreasing bond order is:



(A) $O_2^+ > O_2 > O_2^-$
(B) $O_2 > O_2^+ > O_2^-$
(C) $O_2^- > O_2 > O_2^+$
(D) $O_2 = O_2^+ > O_2^-$

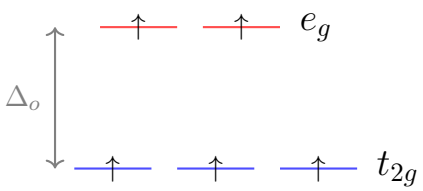
Q14. A first-order reaction has a rate constant $k = 0.0693$ min^{-1}. The time required for **75%** of the reactant to be consumed is:

(A) 10 min
(B) 20 min
(C) 30 min
(D) 40 min

Q15. Which of the following statements about aromaticity is **correct**?

(A) Cyclooctatetraene (COT, 8 π electrons) is aromatic because it is cyclic and conjugated
(B) Pyridine is not aromatic because the nitrogen lone pair disrupts the π-system
(C) Pyridine is aromatic (6 π electrons satisfying $4n + 2$, $n = 1$); the nitrogen lone pair is in the plane and does *not* participate in the π-system
10 Annulene is always non-aromatic regardless of its geometry

Q16. In octahedral crystal field theory, the five d orbitals split into a lower-energy t_{2g} set and a higher-energy e_g set separated by Δ_o. For a high-spin d^5 complex $[Fe(H_2O)_6]^{2+}$, the crystal field stabilisation energy (CFSE) is:



(A) $-2\Delta_o$
(B) $-0.4\Delta_o$
(C) $-1.2\Delta_o$
(D) 0 (zero CFSE)

Q17. For the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$, which expression correctly relates K_p to K_c at temperature T?

(A) $K_p = K_c(RT)^{-2}$
(B) $K_p = K_c(RT)^{+2}$
(C) $K_p = K_c(RT)^{+4}$
(D) $K_p = K_c$

Q18. Carbonyl (C=O) stretching frequencies depend on the electron density at the carbonyl carbon. Which of the following compounds has the **highest** C=O stretching frequency?

(A) Acetone (ketone, $\tilde{\nu} \approx 1715$ cm^{-1})
(B) Acetyl chloride (acid chloride, $\tilde{\nu} \approx 1800$ cm^{-1})
(C) Acetic acid (carboxylic acid, $\tilde{\nu} \approx 1710$ cm^{-1})
(D) Ethyl acetate (ester, $\tilde{\nu} \approx 1735$ cm^{-1})

Q19. When PCl_3 undergoes complete hydrolysis with excess water, the product is:

(A) Phosphoric acid (H_3PO_4) and HCl
(B) Phosphine (PH_3) and $HClO_3$
(C) Phosphorous acid (H_3PO_3) and HCl
(D) Metaphosphoric acid (HPO_3) and HCl

Q20. An ideal binary liquid mixture consists of benzene ($P^\circ_{\text{Bz}} = 95$ mmHg) and toluene ($P^\circ_{\text{T}} = 30$ mmHg). The mole fraction of benzene in the liquid phase is $x_{\text{Bz}} = 0.4$. The total vapour pressure of the mixture is:

(A) 95 mmHg
(B) 30 mmHg
(C) 62.5 mmHg
(D) 56 mmHg

Q21. The Diels-Alder reaction is a [4+2] cycloaddition between a diene and a dienophile. The reaction of 1,3-butadiene with ethene gives:

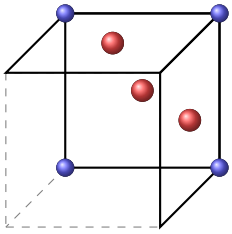
(A) Cyclohexene, formed by a concerted, stereospecific syn addition

(B) Cyclohexane, because both π bonds in butadiene react with both π bonds of ethene

(C) 1,3-Cyclohexadiene, because no new σ bonds are formed

(D) Benzene, because the product aromatises spontaneously

Q22. In a face-centred cubic (FCC) unit cell, atoms are located at all 8 corners and at the centre of each of the 6 faces. Which statement is **correct**?



(A) FCC has 2 atoms per unit cell and a coordination number of 8

(B) FCC has 4 atoms per unit cell and a coordination number of 12

(C) FCC has 6 atoms per unit cell and a coordination number of 8

(D) FCC has 4 atoms per unit cell and a coordination number of 8

Q23. Borax is $Na_2B_4O_7 \cdot 10H_2O$. In the borax bead test, borax fuses to a transparent glassy bead. When a trace of cobalt(II) oxide (CoO) is added and the bead is heated in a Bunsen flame, the resulting bead colour is:

(A) Green (chromium gives green; CoO does not)

(B) Red (iron gives red bead)

(C) Blue (cobalt metaborate $Co(BO_2)_2$ gives a characteristic blue bead)

(D) Colourless (CoO does not impart colour to borax beads)

Q24. Which reagent–product pair is **correct** for the oxidation of a primary alcohol?

(A) PCC (pyridinium chlorochromate) converts a primary alcohol directly to a carboxylic acid

(B) Jones reagent (CrO_3/H_2SO_4) converts a primary alcohol to an aldehyde only

(C) MnO_2 converts a primary allylic alcohol to a carboxylic acid

(D) PCC converts a primary alcohol to an **aldehyde** (stops at aldehyde; does not over-oxidise to carboxylic acid)

Q25. The Freundlich adsorption isotherm is given by $x/m = kP^{1/n}$, where x/m is the mass adsorbed per unit mass of adsorbent and P is the pressure. The **linear** form of this isotherm that gives a straight-line plot is:

(A) $\log(x/m) = \log k + \dfrac{1}{n}\log P$ (plot $\log(x/m)$ vs $\log P$; slope $= 1/n$)

(B) $x/m = \log k + \dfrac{1}{n}\log P$ (plot x/m vs $\log P$; slope $= 1/n$)

(C) $\log(x/m) = k + n\log P$ (plot $\log(x/m)$ vs $\log P$; slope $= n$)

(D) $x/m = k + \dfrac{1}{n}P$ (plot x/m vs P; slope $= 1/n$)

Q26. When $^{238}_{92}$U undergoes **alpha decay**, the product nucleus is:

(A) $^{234}_{92}$U

(B) $^{234}_{90}$Th

(C) $^{236}_{90}$Th

(D) $^{238}_{90}$Th

Q27. In the Newman projection of butane (drawn along the C2–C3 bond), which conformation is the **most stable** and why?

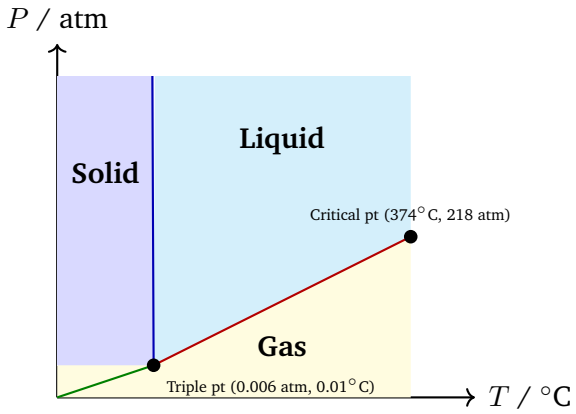
(A) Fully eclipsed (0°), because the methyl groups are as close as possible to one another

(B) Gauche (60°), because it is the global minimum on the torsional energy diagram

(C) Eclipsed (120°), because the methyl and H groups avoid each other

(D) Anti (180°), because the two methyl groups are as far apart as possible, minimising steric and torsional strain

Q28. The phase diagram of water is shown schematically below. Which statement about the phase diagram is **correct**?



(A) The solid-liquid boundary has a *positive* slope because ice is denser than liquid water
(B) At the triple point, only solid and liquid coexist in equilibrium
(C) The solid-liquid boundary has a *negative* slope because liquid water is denser than ice; increasing pressure melts ice
(D) The critical point is the temperature below which the gas cannot be liquefied at any pressure

Q29. Which of the following correctly applies the 18-electron rule to $Fe(CO)_5$?

(A) Fe^0 has 10 electrons; each CO donates 2 electrons; total $= 10 + 10 = 20$ electrons (violates 18-electron rule)
(B) Fe^0 has 8 electrons (d^8 configuration); 5 CO ligands each donate 2 electrons (10 electrons total); total $= 18$ electrons (obeys 18-electron rule)
(C) Fe^0 has 6 electrons; each CO donates 2 electrons; total $= 6 + 10 = 16$ electrons
(D) $Fe(CO)_5$ does not obey the 18-electron rule because CO is a π-acid

Q30. Which Grignard reagent and carbonyl compound combination correctly gives 2-butanol ($CH_3CH(OH)CH_2CH_3$) as the product?

(A) CH_3MgBr + propanal (CH_3CH_2CHO) $\rightarrow$ 2-butanol after hydrolysis
(B) C_2H_5MgBr + formaldehyde ($HCHO$) $\rightarrow$ 2-butanol after hydrolysis
(C) CH_3MgBr + acetone (CH_3COCH_3) $\rightarrow$ 2-butanol after hydrolysis
(D) C_2H_5MgBr + acetaldehyde (CH_3CHO) $\rightarrow$ 3-pentanol after hydrolysis

Section B — Multiple Select Questions (MSQ)

***Q31–Q40**: 2 marks each. **No negative marking. One or more** options may be correct. Full marks only if* all *correct options (and no incorrect options) are chosen.*

Q31. Which of the following statements about Gibbs free energy (ΔG) and spontaneity are **correct**?

(A) A process is spontaneous at constant T and P if $\Delta G < 0$
(B) $\Delta G = \Delta H$ for all spontaneous reactions at constant T and P
(C) For an exothermic reaction ($\Delta H < 0$) with $\Delta S > 0$, the process is spontaneous at *all* temperatures
(D) At equilibrium, $\Delta G = 0$

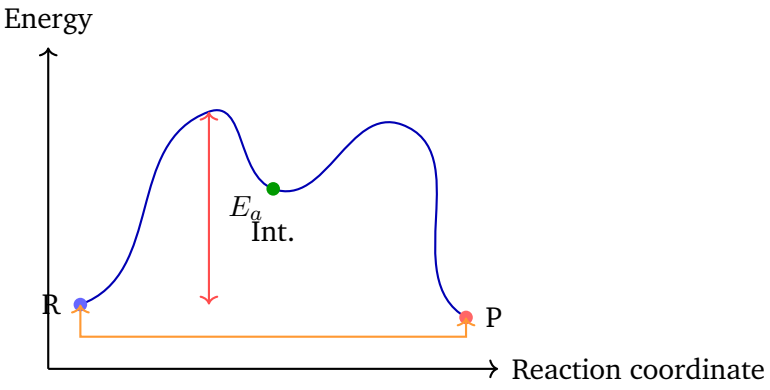
Q32. Which of the following statements about the SN1 mechanism are **correct**?

(A) SN1 follows first-order kinetics: rate $= k[\text{substrate}]$
(B) SN1 proceeds via a planar carbocation intermediate, leading to racemisation at the chiral centre
(C) SN1 is favoured by primary alkyl halides with strong nucleophiles
(D) Polar protic solvents (water, alcohols) stabilise the carbocation intermediate and favour SN1

Q33. Which of the following statements about $[Fe(CN)_6]^{3-}$ are **correct**?

(A) Iron is in the $+3$ oxidation state (d^5 configuration)
(B) CN^- is a strong-field ligand that causes low-spin pairing, resulting in only 1 unpaired electron in the d^5 complex
(C) The complex is paramagnetic with a spin-only magnetic moment of approximately 1.73 BM
(D) The coordination number of iron in this complex is 4

Q34. Which of the following statements about the rate-determining step and activation energy in chemical kinetics are **correct**?



(A) The rate of the overall reaction always equals the rate of the *fastest* elementary step

(B) The rate of the overall reaction is determined by the *slowest* elementary step (the rate-determining step)

(C) Increasing temperature decreases the activation energy E_a, which is why reaction rates increase

(D) A catalyst provides an alternative pathway with lower activation energy, thereby increasing the reaction rate without being consumed

Q35. Which of the following statements about the aromaticity of heterocyclic compounds are **correct**?

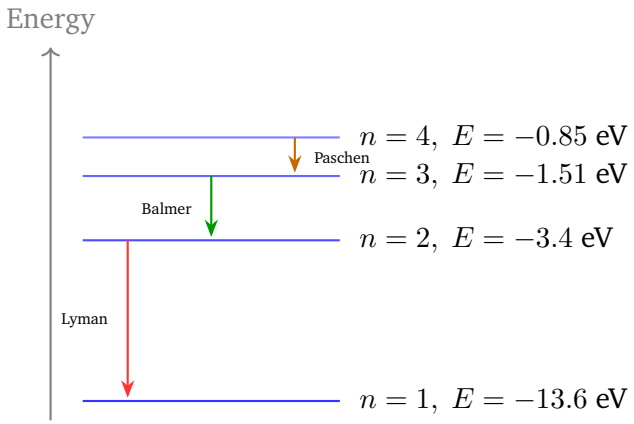
(A) Pyridine is aromatic; its nitrogen lone pair lies in the molecular plane and is *not* part of the π-system (6 π electrons from 3 double bonds)

(B) Pyrrole is not aromatic because the N–H bond removes the lone pair from the π-system

(C) Furan is aromatic; the oxygen lone pair *is* part of the π-system, providing 6 π electrons

(D) Thiophene is aromatic; the sulfur lone pair contributes to the 6 π-electron system

Q36. The hydrogen atom energy level diagram is shown below. Which of the following statements about electronic transitions are **correct**?



(A) The Lyman series corresponds to transitions to $n = 1$ and lies in the ultraviolet region

(B) The Balmer series corresponds to transitions to $n = 2$ and lies in the visible region

(C) The Paschen series corresponds to transitions to $n = 2$

(D) The energy of a photon emitted in the transition from level m to level n ($m > n$) is $E = 13.6\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$ eV

Q37. Which of the following statements about the molecular orbital description of N_2 are **correct**?

(A) N_2 has a bond order of 3, consistent with its high bond dissociation energy (≈ 945 kJ mol^{-1})

(B) N_2 is paramagnetic due to two unpaired electrons in degenerate π^* MOs

(C) In N_2, the σ_{2p} MO lies *above* the π_{2p} MOs in energy due to s–p mixing

(D) Removal of one electron from N_2 to form N_2^+ decreases the bond order from 3 to 2.5

Q38. Which of the following statements about electrochemical cells are **correct**?

(A) In a galvanic cell, the anode carries a positive charge (is the positive electrode)

(B) In a galvanic cell, oxidation occurs at the anode and reduction occurs at the cathode

(C) In an electrolytic cell, electrical energy is used to drive a thermodynamically non-spontaneous reaction

(D) The standard cell potential of a spontaneous galvanic cell is always negative

Q39. Which of the following statements about the aldol condensation are **correct**?

(A) Aldol condensation requires a carbonyl compound that possesses at least one α-hydrogen

(B) The base catalyst (e.g. NaOH) removes an α-hydrogen to generate an enolate anion, which acts as the nucleophile

(C) The direct product of the aldol *addition* step is always an α,β-unsaturated carbonyl compound

(D) In a cross-aldol condensation between two different aldehydes, each bearing α-hydrogens, a mixture of products is obtained

Q40. Which of the following statements about allotropes of carbon are **correct**?

(A) In diamond, each carbon atom is sp^3 hybridised and bonded tetrahedrally to four neighbouring carbon atoms

(B) Graphite is an electrical insulator because the π electrons are localised between specific carbon atoms

(C) Buckminsterfullerene (C_{60}) contains 12 pentagonal faces and 20 hexagonal faces

(D) The layers in graphite are held together by weak van der Waals (London dispersion) forces, which is why graphite is a good lubricant

Section C — Numerical Answer Type (NAT)

***Q41–Q50**: 1 mark each. **No negative marking.** Enter the exact numerical value.*

Q41. Calculate the volume (in litres, to 2 decimal places) occupied by 44 g of CO_2 (molar mass = 44 g mol^{-1}) at 27 °C and 1 atm pressure. Use $R = 0.0821$ L atm mol^{-1} K^{-1}.

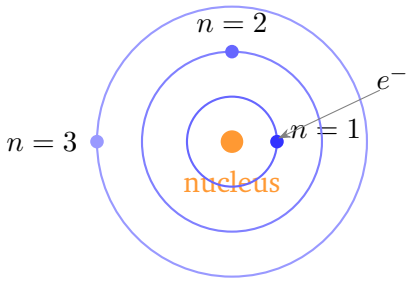
Q42. For a reaction at 400 K, $\Delta H = -120$ kJ mol^{-1} and $\Delta S = -250$ J mol^{-1} K^{-1}. Calculate ΔG (in kJ mol^{-1}, to 2 decimal places) using $\Delta G = \Delta H - T\Delta S$.

Q43. A first-order reaction has a rate constant $k = 0.0231$ min^{-1}. Calculate the half-life $t_{1/2}$ (in minutes, to the nearest integer) using $t_{1/2} = \ln 2 \,/\, k$. (Take $\ln 2 = 0.693$.)

Q44. Calculate the pH (to 2 decimal places) of a 0.1 M solution of acetic acid. The acid dissociation constant is $K_a = 1.8 \times 10^{-5}$. Assume $[H^+] \approx \sqrt{K_a \cdot C}$.

Q45. Copper (molar mass = 63.5 g mol^{-1}, $n = 2$) is deposited by electrolysis using a current of 2 A for 2 hours. Calculate the mass of copper deposited (in grams, to 2 decimal places). Use Faraday's constant $F = 96500$ C mol^{-1}.

Q46. An electron is accelerated through a potential difference of 150 V. Calculate its de Broglie wavelength λ (in angstroms, Å, to 2 decimal places) using $\lambda = h/\sqrt{2m_eV_e}$, where $h = 6.626 \times 10^{-34}$ J s, $m_e = 9.11 \times 10^{-31}$ kg, $e = 1.6 \times 10^{-19}$ C.



Q47. Calculate the packing fraction (as a percentage, to 2 decimal places) of an FCC crystal. Use the relation $a = 2\sqrt{2}\,r$ (atoms touch along the face diagonal), so packing fraction $= \dfrac{4 \times \frac{4}{3}\pi r^3}{a^3}$.

Q48. A solution of glucose is prepared with a concentration of 0.5 M at 27 °C. Calculate the osmotic pressure $\pi = cRT$ (in atm, to 2 decimal places). Use $R = 0.0821$ L atm mol^{-1} K^{-1}.

Q49. Calculate the degree of unsaturation (index of hydrogen deficiency, DBE) of a compound with molecular formula $C_8H_{10}O$. Use DBE $= (2C+2-H)/2$ (ignoring oxygen). Express your answer as an integer.

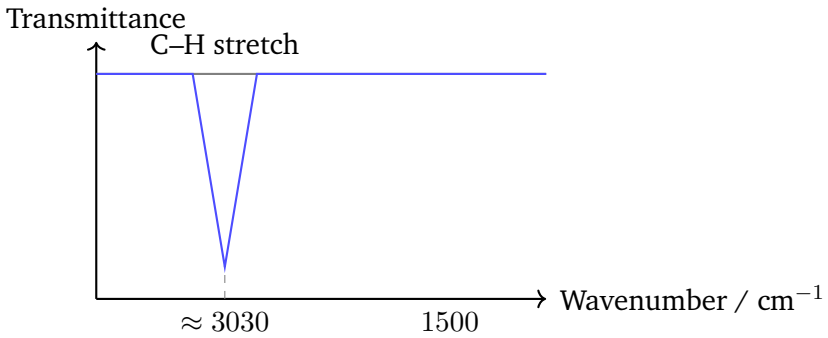
Q50. Calculate the effective atomic number (EAN) of chromium in the complex $[Cr(CO)_6]$. (Atomic number of Cr $= 24$; each CO ligand donates 2 electrons.) Express your answer as an integer.

***Q51–Q60**: 2 marks each. **No negative marking.** Enter the exact numerical value.*

Q51. At 25 °C (298 K), the equilibrium constant for a reaction is $K = 1.0 \times 10^{-5}$. Calculate ΔG° (in kJ mol^{-1}, to 2 decimal places) using $\Delta G^\circ = -RT \ln K$. Use $R = 8.314$ J mol^{-1} K^{-1} and $\ln(10^{-5}) = -11.513$.

Q52. For a first-order reaction, $k_1 = 2.0 \times 10^{-3}$ s^{-1} at $T_1 = 300$ K and $k_2 = 8.0 \times 10^{-3}$ s^{-1} at $T_2 = 320$ K. Using the Arrhenius equation $\ln(k_2/k_1) = \dfrac{E_a}{R}\left(\dfrac{1}{T_1} - \dfrac{1}{T_2}\right)$, calculate the activation energy E_a (in kJ mol^{-1}, to 1 decimal place). ($R = 8.314$ J mol^{-1} K^{-1}, $\ln 4 = 1.386$.)

Q53. Estimate the C–H bond stretching frequency (wavenumber in cm^{-1}, to the nearest integer) using the harmonic oscillator formula $\tilde{\nu} = \dfrac{1}{2\pi c}\sqrt{k/\mu}$, given a force constant $k = 500$ N m^{-1} and the reduced mass $\mu = \dfrac{12}{13} \times 1.661 \times 10^{-27}$ kg. Take $c = 3 \times 10^{10}$ cm s^{-1}.

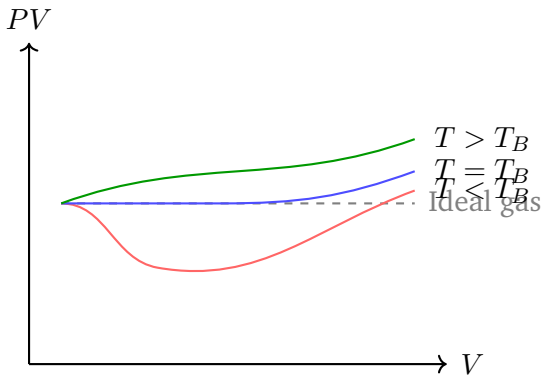


Q54. A mixture of enantiomers shows a specific rotation of $[\alpha] = +16^\circ$. The specific rotation of the pure $(+)$ enantiomer is $[\alpha]_{\text{pure}} = +40^\circ$. Calculate the enantiomeric excess (% ee) of the mixture, to the nearest integer.

Q55. Calculate the spin-only magnetic moment (in BM, to 2 decimal places) of a high-spin Fe^{3+} complex. Fe^{3+} is a d^5 ion in the high-spin configuration, giving 5 unpaired electrons. Use $\mu = \sqrt{n(n+2)}$ BM, where n is the number of unpaired electrons.

Q56. For the Zn–Cu galvanic cell, $E^\circ_{\text{cell}} = 1.10$ V and the cell reaction involves $n = 2$ electrons. Calculate $|\Delta G^\circ|$ (in kJ mol^{-1}, to 1 decimal place) using $\Delta G^\circ = -nFE^\circ$. ($F = 96500$ C mol^{-1}.)

Q57. For CO_2 modelled as a van der Waals gas ($a = 3.592$ L^2 atm mol^{-2}, $b = 0.04267$ L mol^{-1}), calculate the Boyle temperature $T_B = a/(bR)$ (in K, to the nearest integer) using $R = 0.0821$ L atm mol^{-1} K^{-1}.



Q58. For acetaldehyde, the keto$\rightleftharpoons$enol equilibrium constant is $K_{\text{eq}} = 6 \times 10^{-5}$ (enol/keto). Calculate the percentage of the enol form in the equilibrium mixture, to 3 decimal places. (Assume $K_{\text{eq}} \ll 1$, so % enol $\approx K_{\text{eq}} \times 100$.)

Q59. Calculate the binding energy per nucleon (in MeV/nucleon, to 2 decimal places) for $^{56}_{26}$Fe. Use: proton mass $= 1.007825$ u, neutron mass $= 1.008665$ u, atomic mass of ^{56}Fe $= 55.9349$ u, and 1 u $= 931.5$ MeV.

Q60. An acetic acid/sodium acetate buffer has $[CH_3COO^-]/[CH_3COOH] = 2.0$. Given p$K_a = 4.74$ for acetic acid, calculate the pH of the buffer (to 2 decimal places) using the Henderson–Hasselbalch equation pH $=$ p$K_a +$ $\log([A^-]/[HA])$. (Take $\log 2 = 0.301$.)

Solutions

IIT JAM Chemistry – Sample Paper 1

Section A Solutions — MCQ

Solution

Concept — Periodic Trend: Atomic Radius:
Atomic radius *decreases* across a period (left to right) because the nuclear charge increases while electrons are added to the *same* shell, pulling all electrons closer to the nucleus.

Step 1 — Apply the trend:
Across Period 3: Na (Z=11) $>$ Mg (Z=12) $>$ Al (Z=13) $>$ Si $>$ P $>$ S $>$ Cl (Z=17).

Step 2 — Identify the correct ranking among Na, Mg, Al, Cl:

$$\text{Na} > \text{Mg} > \text{Al} > \text{Cl}$$

Final Answer: Na $>$ Mg $>$ Al $>$ Cl $\Rightarrow$ **(B)**

Why other options are wrong:

Q1.

- (A) Al $>$ Na $>$ Mg $>$ Cl: Incorrect; Al is smaller than both Na and Mg.
- (C) Cl $>$ Al $>$ Mg $>$ Na: Completely reversed; Cl has the smallest radius in this list.
- (D) Mg $>$ Na $>$ Cl $>$ Al: Na has a larger radius than Mg, and Al has a larger radius than Cl.

Answer: (B) ← *Go back to Q1*

Solution

Concept — Balmer Series and Photon Wavelength:
Photon energy $E = 13.6\left(\frac{1}{n_{\text{low}}^2} - \frac{1}{n_{\text{high}}^2}\right)$ eV. In the Balmer series, $n_{\text{low}} = 2$. Longer wavelength $\Leftrightarrow$ smaller energy $\Leftrightarrow$ smallest gap between n_{high} and $n_{\text{low}} = 2$.

Step 1 — Identify the smallest energy gap:
The transition with the smallest energy (longest λ) is the one starting from the *lowest* n_{high} above $n = 2$, which is $n = 3 \to n = 2$.

Step 2 — Verify:

$$E = 13.6\left(\frac{1}{4} - \frac{1}{9}\right) = 13.6 \times \frac{5}{36} = 1.89\,\text{eV} \quad (\lambda \approx 656\,\text{nm, red H}_\alpha\text{ line})$$

All other Balmer transitions have higher energy (shorter wavelength).

Final Answer: $n = 3 \to n = 2 \Rightarrow$ **(A)**

Why other options are wrong:

Q2.

- (B) $n = 4 \to 2$: $E = 2.55$ eV, shorter wavelength than $3 \to 2$.
- (C) $n = 5 \to 2$: $E = 2.86$ eV, even shorter wavelength.
- (D) $n = \infty \to 2$: $E = 3.4$ eV (series limit), shortest wavelength in Balmer series.

Answer: (A) ← *Go back to Q2*

Solution

Concept — Reactivity of Alkali Metals with Water:
Reactivity of alkali metals with water increases down Group 1: Li $<$ Na $<$ K $<$ Rb $<$ Cs. This is because ionisation enthalpy decreases down the group as atomic size increases and the valence electron becomes further from the nucleus.

Step 1 — Apply the trend:
Among Li, Na, and K: K reacts most vigorously because its ionisation enthalpy is lowest and its valence electron is most easily released.

Step 2 — Reaction of K with water:

$$2\mathrm{K}(s) + 2\mathrm{H_2O}(l) \to 2\mathrm{KOH}(aq) + \mathrm{H_2}(g)$$

K reacts vigorously enough that the heat produced often ignites the H_2 gas.

Final Answer: K reacts most vigorously $\Rightarrow$ **(C)**

Why other options are wrong:

Q3.

- (A) Li: Li reacts most slowly among these three; it has the highest ionisation enthalpy.
- (B) Na: Na is more reactive than Li but less reactive than K.
- (D) All equal: Alkali metals have markedly different reactivities; they are decidedly not equal.

Answer: (C) ← *Go back to Q3*

Solution

Concept — Hybridisation of Allene:
Allene is $H_2C{=}C{=}CH_2$. The central carbon forms two double bonds (one with each terminal carbon). To accommodate two perpendicular π bonds, the central carbon

uses two p orbitals for π bonding and two sp hybrid orbitals for σ bonding. Hence the hybridisation is sp.

Key reasoning:
– The central C has 2 σ bonds (one to each terminal C) and 2 π bonds, requiring 2 hybrid orbitals for σ bonds $\Rightarrow$ sp hybridisation.
– The terminal C atoms each have 2 σ bonds (to H and central C) and 1 π bond $\Rightarrow$ sp^2 hybridisation.

Final Answer: $sp \Rightarrow$ **(D)**

Why other options are wrong:

Q4.
- (A) sp^3: Four σ bonds would be needed; not the case for the central C.
- (B) sp^2: sp^2 accounts for three groups; the central C of allene has only two σ bonds.
- (C) sp^3d: Expanded octet; carbon does not use d orbitals.

Answer: (D) ← *Go back to Q4*

Solution

Concept — Ideal Gas Law:
$PV = nRT$, so $V = \dfrac{nRT}{P}$.

Step 1 — Convert temperature: $T = 27 + 273 = 300$ K.

Step 2 — Substitute values:

$$V = \frac{nRT}{P} = \frac{2\,\text{mol} \times 0.0821\,\text{L atm mol}^{-1}\text{K}^{-1} \times 300\,\text{K}}{2\,\text{atm}}$$

$$V = \frac{2 \times 0.0821 \times 300}{2} = \frac{49.26}{2} = 24.63\,\text{L}$$

Final Answer: $V = 24.6$ L $\Rightarrow$ **(A)**

$$\boxed{V \approx 24.6\,\text{L}}$$

Why other options are wrong:

Q5.
- (B) 49.2 L: Uses $P = 1$ atm instead of 2 atm (forgot to divide by pressure).
- (C) 12.3 L: Uses $n = 1$ mol instead of 2 mol.
- (D) 6.15 L: Uses both $n = 1$ mol and $P = 4$ atm; doubly incorrect.

Answer: (A) ← *Go back to Q5*

Solution

Concept — Bond Dissociation Enthalpy and π-Bonding:
The extraordinary strength of the N≡N triple bond (≈ 945 kJ mol^{-1}) arises from the effective sideways overlap of the small $2p$ orbitals of nitrogen. Phosphorus is significantly larger; its $3p$ orbitals overlap poorly in the sideways (π) orientation, so P_4 has only single P–P bonds (≈ 200 kJ mol^{-1} each).

Step 1 — Identify the correct explanation:
N_2 has a triple bond (one σ + two π). P_4 has only single bonds (no π bonds). The strength of the N≡N triple bond is due to effective p–p π-overlap, which is only possible when the atoms are small enough.

Final Answer: $\Rightarrow$ (B)

Why other options are wrong:

Q6.
- (A) Reverses the bond types; N_2 has a triple bond, not a single bond.
- (C) Nitrogen is actually *smaller* than phosphorus; smaller size facilitates better π-overlap.
- (D) Factually incorrect; the bond dissociation enthalpies differ by nearly a factor of 5.

Answer: (B) ← *Go back to Q6*

Solution

Concept — R/S Configuration (CIP Rules):
To assign R or S:

Q7.
(a) Assign priorities: I (1) > Br (2) > CH_3 (3) > H (4).
(b) Orient the molecule so that the lowest-priority group (H) points *away* from you.
(c) If 1→2→3 is *clockwise*, the configuration is (R).
(d) If 1→2→3 is *anticlockwise*, the configuration is (S).

Step 1 — Apply the rule:
H points away (into the page); I → Br → CH_3 is clockwise $\Rightarrow$ (R) configuration.

Final Answer: $(R) \Rightarrow$ (C)

Why other options are wrong:

- (A) Misapplies the rule; clockwise with lowest-priority away is always (R), not (S).
- (B) Configuration cannot be determined solely from the identity of substituents.
- (D) A 3D drawing with explicit wedge/dash notation is sufficient to assign

configuration.

Answer: (C) ← *Go back to Q7*

Solution

Concept — Hess's Law:
Hess's law states that the enthalpy change of a reaction is independent of the pathway; it depends only on the initial and final states.

Step 1 — Write the known equations:

$$(1) \quad C(s) + O_2(g) \rightarrow CO_2(g), \quad \Delta H_1$$
$$(2) \quad CO(g) + \tfrac{1}{2}O_2(g) \rightarrow CO_2(g), \quad \Delta H_2$$

Step 2 — Construct the target reaction:
Target: $C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g)$

Subtract equation (2) from equation (1):

$$\text{Target} = (1) - (2) \quad \Rightarrow \quad \Delta H = \Delta H_1 - \Delta H_2$$

Verification using the energy diagram:
The enthalpy level of CO + $\frac{1}{2}O_2$ lies between C + O_2 (top) and CO_2 (bottom). The required ΔH is the drop from the top level to the CO + $\frac{1}{2}O_2$ level $= \Delta H_1 - \Delta H_2$.

Final Answer: $\Delta H = \Delta H_1 - \Delta H_2 \Rightarrow$ **(D)**

Why other options are wrong:

Q8.

- (A) $\Delta H_1 + \Delta H_2$: Adds both, which does not cancel the CO_2 intermediate correctly.
- (B) $\Delta H_2 - \Delta H_1$: Reverses the subtraction; gives a positive value when both ΔH are negative, which would mean the reaction is endothermic—incorrect for C to CO.
- (C) $\Delta H_1 + 2\Delta H_2$: Introduces an incorrect coefficient.

Answer: (D) ← *Go back to Q8*

Solution

Concept — IUPAC Nomenclature of Coordination Compounds:
Rules:

Q9.

- Name ligands before the central metal.

- Anionic ligands end in "-o" (Cl^- = chlorido; NH_3 = ammine).
- Ligands are listed alphabetically (ammine before chlorido).
- Oxidation state of the metal in Roman numerals in parentheses.
- Counter ions named separately after the complex.

Step 1 — Identify the complex:
Complex ion: $[Co(NH_3)_5Cl]^{2+}$; charge on Co: $+3$ (since 5 NH_3 are neutral, Cl^- is -1, and overall charge is $+2$: $x + 0 - 1 = +2 \Rightarrow x = +3$).
Counter ions: 2 Cl^- (named as chloride outside the brackets).

Step 2 — Build the name:
5 ammine + 1 chlorido + cobalt(III) $\rightarrow$ "pentaamminechloridocobalt(III)"; counter ion: chloride.

Final Answer: Pentaamminechloridocobalt(III) chloride $\Rightarrow$ **(A)**

Why other options are wrong:

- (B) "Pentaammine*chloro*cobalt(II) chloride": Old name "chloro" (should be "chlorido"); wrong oxidation state Co(II).
- (C) "Chlorido*penta*ammine" in reverse order: IUPAC requires alphabetical order (ammine before chlorido).
- (D) "Pentaammine*dichloro*" wrongly implies two chloride ligands inside the complex.

Answer: (A) ← *Go back to Q9*

Solution

Concept — SN1 vs SN2 Substitution:
SN1 favoured by: tertiary substrate (stable carbocation), polar protic solvent, weak nucleophile.
SN2 favoured by: primary substrate (little steric hindrance), polar aprotic solvent, strong nucleophile.

Step 1 — Analyse tert-butyl bromide:
$(CH_3)_3CBr$ is a tertiary alkyl halide. In aqueous ethanol (polar protic solvent):

Q10. (a) The C–Br bond ionises to give a stable tertiary carbocation $(CH_3)_3C^+$.
(b) Rate $= k$[tert-BuBr] only (first-order; solvent acts as nucleophile).
(c) Products: mixture of substitution (tert-BuOH/tert-BuOEt) and elimination (isobutylene).

Final Answer: SN1 via tertiary carbocation $\Rightarrow$ **(B)**

Why other options are wrong:

- (A) SN2: Three methyl groups cause extreme steric crowding; backside attack is essentially impossible for tertiary substrates.
- (C) SN2 without nucleophile: SN2 requires a nucleophile; no such mechanism exists.
- (D) No reaction: tert-BuBr is actually very reactive via SN1 in polar protic media.

Answer: (B) ← *Go back to Q10*

Solution

Concept — Nernst Equation:
For a cell reaction $aA + bB \rightarrow cC + dD$:

$$E_{\text{cell}} = E^{\circ}_{\text{cell}} - \frac{0.059}{n} \log Q$$

For Zn | Zn^{2+} || Cu^{2+} | Cu: Zn is oxidised (anode), Cu^{2+} is reduced (cathode).

Step 1 — Cell reaction and Q:

$$\text{Zn(s)} + \text{Cu}^{2+}(aq) \rightarrow \text{Zn}^{2+}(aq) + \text{Cu(s)}$$

$$Q = \frac{[\text{Zn}^{2+}]}{[\text{Cu}^{2+}]} = \frac{0.1}{0.001} = 100, \quad n = 2$$

Step 2 — Apply Nernst equation:

$$E_{\text{cell}} = 1.10 - \frac{0.059}{2} \log(100) = 1.10 - \frac{0.059}{2} \times 2 = 1.10 - 0.059 = 1.041\,\text{V}$$

$$\approx 1.04\,\text{V}$$

Final Answer: $E_{\text{cell}} \approx 1.04$ V $\Rightarrow$ **(C)**

Why other options are wrong:

Q11.
- (A) 1.10 V: This is E°; the Nernst correction has not been applied.
- (B) 1.16 V: Adds the Nernst correction instead of subtracting.
- (D) 0.98 V: Uses $Q = 1000$ or an incorrect n value.

Answer: (C) ← *Go back to Q11*

Solution

Concept — Aldol Condensation of Acetaldehyde:

The base-catalysed aldol condensation of acetaldehyde proceeds in two stages:

Stage 1 — Aldol Addition:

NaOH removes an α-H from CH_3CHO, generating an enolate. The enolate attacks the carbonyl carbon of another CH_3CHO molecule to give 3-hydroxybutanal (aldol product):

$$CH_3CHO + CH_3CHO \xrightarrow{NaOH} CH_3CH(OH)CH_2CHO$$

Stage 2 — Dehydration (Aldol Condensation):

Heating the β-hydroxy aldehyde causes elimination of water (β-elimination) to give an α,β-unsaturated aldehyde:

$$CH_3CH(OH)CH_2CHO \xrightarrow{\Delta} CH_3CH{=}CH{-}CHO + H_2O$$

The product is crotonaldehyde (but-2-enal).

Final Answer: Crotonaldehyde ($CH_3CH{=}CHCHO$) $\Rightarrow$ **(D)**

Why other options are wrong:

Q12.

- (A) 1-Butanol: Requires reduction of the carbonyl; not produced by aldol condensation.
- (B) 3-Hydroxybutanal: This is the *aldol addition* product; the question asks for the *condensation* product (after dehydration).
- (C) Butanal: Would require loss of an oxygen without any reducing agent.

Answer: (D) *← Go back to Q12*

Solution

Concept — MO Theory: Bond Order of O_2 Species:

$$\text{Bond order (BO)} = \frac{\text{bonding electrons} - \text{antibonding electrons}}{2}$$

Electron counts and bond orders:

Q13.

Species	Total electrons	Bond order
O_2	16	$\frac{10-6}{2} = 2$
O_2^+	15 (one π^* removed)	$\frac{10-5}{2} = 2.5$
O_2^-	17 (one π^* added)	$\frac{10-7}{2} = 1.5$

Step 1 — Rank in decreasing bond order:

$$O_2^+(2.5) > O_2(2.0) > O_2^-(1.5)$$

Final Answer: $O_2^+ > O_2 > O_2^- \Rightarrow$ **(A)**

Why other options are wrong:

- (B) $O_2 > O_2^+ > O_2^-$: Incorrectly places O_2 above O_2^+.
- (C) $O_2^- > O_2 > O_2^+$: Completely reversed.
- (D) $O_2 = O_2^+$: These have different bond orders (2 vs 2.5).

Answer: (A) ← *Go back to Q13*

Solution

Concept — First-Order Kinetics: Time for 75% Completion:

For a first-order reaction, $\ln\left(\frac{[A]_0}{[A]}\right) = kt$.

Step 1 — Relate 75% completion to half-lives:

75% consumed means 25% remains:

$$\frac{[A]}{[A]_0} = 0.25 = \left(\frac{1}{2}\right)^2$$

So exactly 2 half-lives have elapsed.

Step 2 — Calculate $t_{1/2}$:

$$t_{1/2} = \frac{\ln 2}{k} = \frac{0.693}{0.0693\,\text{min}^{-1}} = 10\,\text{min}$$

Step 3 — Total time:

$$t = 2 \times t_{1/2} = 2 \times 10 = 20\,\text{min}$$

Final Answer: $t = 20$ min $\Rightarrow$ **(B)**

$$\boxed{t = 20\,\text{min}}$$

Why other options are wrong:

Q14.

- (A) 10 min: This is $t_{1/2}$, i.e. 50% completion, not 75%.
- (C) 30 min: This is $3t_{1/2}$, corresponding to 87.5% completion.
- (D) 40 min: This is $4t_{1/2}$, corresponding to 93.75% completion.

Answer: (B) ← *Go back to Q14*

Solution

Concept — Aromaticity (Hückel's Rule):
A compound is aromatic if it is: (i) cyclic, (ii) planar, (iii) fully conjugated, and (iv) has $(4n+2)$ π electrons.

Analysis of pyridine:
Pyridine (C_5H_5N) has 6 π electrons from three double bonds ($4n+2$, $n=1$). The nitrogen lone pair occupies an sp^2 orbital in the plane of the ring; it does *not* contribute to the π-system. Hence pyridine is aromatic.

Analysis of COT:
Cyclooctatetraene (COT) has 8 π electrons ($4n$, $n=2$), violating the $(4n+2)$ rule. It is non-planar (adopts a tub shape to avoid antiaromaticity) and is therefore *non-aromatic* (not antiaromatic in its non-planar form).

Final Answer: Pyridine is aromatic with 6 π electrons; N lone pair is in the plane $\Rightarrow$ **(C)**

Why other options are wrong:

Q15.

- (A) COT is not aromatic; it has 8 π electrons ($4n$, not $4n+2$).
- (B) Pyridine *is* aromatic; the N lone pair is *not* in the π-system (it is in the ring plane), so it does not disrupt aromaticity.
- (D) [10]Annulene *can* be aromatic if it adopts a planar conformation (10 π electrons, $4n+2$, $n=2$); the statement is too absolute.

Answer: (C) *← Go back to Q15*

Solution

Concept — Crystal Field Stabilisation Energy (CFSE):
In an octahedral field: t_{2g} orbitals are stabilised by $-\frac{2}{5}\Delta_o = -0.4\Delta_o$ per electron, and e_g orbitals are destabilised by $+\frac{3}{5}\Delta_o = +0.6\Delta_o$ per electron. CFSE is calculated relative to the barycentre.

Step 1 — Electron configuration of high-spin d^5:
$[Fe(H_2O)_6]^{2+}$: Fe^{2+} has d^6...

Correction: $[Fe(H_2O)_6]^{2+}$ means Fe is in the $+2$ state, so Fe^{2+}, d^6. However, the question specifies a *high-spin* d^5 complex – this implies Fe^{3+} in $[Fe(H_2O)_6]^{3+}$ with d^5 configuration.

For high-spin d^5: configuration is $t_{2g}^3\, e_g^2$ (one electron in each of the 5 d orbitals).

Step 2 — Calculate CFSE:

$$\text{CFSE} = 3 \times (-0.4\Delta_o) + 2 \times (+0.6\Delta_o) = -1.2\Delta_o + 1.2\Delta_o = 0$$

The CFSE of a high-spin d^5 octahedral complex is **zero** because the five d electrons are evenly distributed, one in each orbital. There is no net stabilisation.

Final Answer: CFSE $= 0 \Rightarrow$ **(D)**

Why other options are wrong:

Q16.

- (A) $-2\Delta_o$: This applies to a different electron configuration (e.g. d^6 low-spin).
- (B) $-0.4\Delta_o$: Only one t_{2g} electron (d^1); not the case for d^5.
- (C) $-1.2\Delta_o$: Three t_{2g} electrons, no e_g (d^3 or low-spin d^6).

Answer: (D) ← *Go back to Q16*

Solution

Concept — Relationship between K_p and K_c:
$K_p = K_c(RT)^{\Delta n_g}$ where Δn_g = (moles of gaseous products) − (moles of gaseous reactants).

Step 1 — Calculate Δn_g:

$$\mathrm{N_2}(g) + 3\mathrm{H_2}(g) \rightleftharpoons 2\mathrm{NH_3}(g)$$

$$\Delta n_g = 2 - (1 + 3) = 2 - 4 = -2$$

Step 2 — Write the relation:

$$K_p = K_c(RT)^{-2} = \frac{K_c}{(RT)^2}$$

Final Answer: $K_p = K_c(RT)^{-2} \Rightarrow$ **(A)**

Why other options are wrong:

Q17.

- (B) $(RT)^{+2}$: Uses $\Delta n_g = +2$; incorrect sign (products have *fewer* moles of gas).
- (C) $(RT)^{+4}$: Confuses Δn_g with the total number of moles of reactants.
- (D) $K_p = K_c$: Only true when $\Delta n_g = 0$ (equal moles of gas on both sides).

Answer: (A) ← *Go back to Q17*

Solution

Concept — C=O Stretching Frequency and Electron Withdrawal:
A higher C=O stretching frequency corresponds to a stronger (more double-bond character) C=O bond, which arises from electron *withdrawal* from the carbonyl

carbon.

Order of C=O stretching frequencies (high to low):

Acid chloride (acyl halide) > Ester > Aldehyde > Ketone > Carboxylic acid > Amide

The acid chloride (RCOCl) has the highest frequency (≈ 1800 cm^{-1}) because Cl is a strong σ-electron withdrawor (inductive effect), increasing the C=O bond strength and force constant.

Step 1 — Compare the given options:

Q18.

Compound	$\tilde{\nu}$(C=O) / cm^{-1}
Acetone (ketone)	≈ 1715
Acetyl chloride (acid chloride)	≈ 1800
Acetic acid	≈ 1710
Ethyl acetate (ester)	≈ 1735

Final Answer: Acetyl chloride has the highest $\tilde{\nu}$(C=O) $\Rightarrow$ **(B)**

Why other options are wrong:

- (A) Acetone (≈ 1715 cm^{-1}): Lower than the acid chloride and ester.
- (C) Acetic acid (≈ 1710 cm^{-1}): Hydrogen bonding and resonance lower the C=O frequency.
- (D) Ethyl acetate (≈ 1735 cm^{-1}): Ester is higher than ketone/acid but lower than acid chloride.

Answer: (B) ← *Go back to Q18*

Solution

Concept — Hydrolysis of PCl_3:
The hydrolysis of PCl_3 (phosphorus trichloride) with water proceeds as:

$$PCl_3 + 3H_2O \rightarrow H_3PO_3 + 3HCl$$

The product H_3PO_3 is phosphorous acid (note: phosphor*ous*, not phosphor*ic*). This is a diprotic acid (the H directly bonded to P is not ionisable).

Contrast with PCl_5 hydrolysis:

$$PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$$

PCl_5 gives phosphoric acid (H_3PO_4), a triprotic acid.

Final Answer: H_3PO_3 (phosphorous acid) and HCl $\Rightarrow$ **(C)**

Why other options are wrong:

Q19.

- (A) H_3PO_4: This is the product of PCl_5 hydrolysis, not PCl_3.
- (B) PH_3 and $HClO_3$: Disproportionation products; not formed in simple hydrolysis.
- (D) HPO_3 (metaphosphoric acid): Not the primary product; requires dehydration of H_3PO_3.

Answer: (C) ← *Go back to Q19*

Solution

Concept — Raoult's Law for Ideal Binary Mixtures:

$P_{\text{total}} = x_A P_A^\circ + x_B P_B^\circ$

Step 1 — Identify mole fractions:

$x_{Bz} = 0.4$; $x_T = 1 - 0.4 = 0.6$

Step 2 — Calculate total pressure:

$$P_{\text{total}} = 0.4 \times 95 + 0.6 \times 30 = 38 + 18 = 56\,\text{mmHg}$$

Final Answer: $P_{\text{total}} = 56$ mmHg $\Rightarrow$ **(D)**

Why other options are wrong:

Q20.

- (A) 95 mmHg: This is the vapour pressure of pure benzene.
- (B) 30 mmHg: This is the vapour pressure of pure toluene.
- (C) 62.5 mmHg: Corresponds to an equal mole fraction (0.5/0.5) mixture.

Answer: (D) ← *Go back to Q20*

Solution

Concept — Diels-Alder Reaction:

The Diels-Alder reaction is a concerted [4+2] cycloaddition:

Q21.

- **Diene** (4 π electrons, must be in *s-cis* conformation): 1,3-butadiene
- **Dienophile** (2 π electrons): ethene

Reaction:

$$1,3\text{-butadiene} + \text{ethene} \xrightarrow{\text{heat}} \text{cyclohexene}$$

Key features:

(a) Concerted (single transition state, no intermediates).

(b) Stereospecific: substituents on the dienophile retain their *syn* relationship in the product.
(c) The endo product is kinetically preferred when substituents are present.
(d) A new 6-membered ring is formed.

Final Answer: Cyclohexene formed by a concerted stereospecific syn addition $\Rightarrow$ **(A)**

Why other options are wrong:

- (B) Cyclohexane: Would require addition of H_2 (hydrogenation); not a Diels-Alder product from butadiene + ethene.
- (C) 1,3-Cyclohexadiene: Would require no new σ bond formation, which contradicts the mechanism.
- (D) Benzene: Aromatisation would require elimination of 3 H_2; does not happen spontaneously.

Answer: (A) *← Go back to Q21*

Solution

Concept — FCC Unit Cell: Atoms per Unit Cell and Coordination Number:

Step 1 — Count atoms in FCC:

$$\text{Corner atoms: } 8 \times \frac{1}{8} = 1$$

$$\text{Face-centre atoms: } 6 \times \frac{1}{2} = 3$$

$$\text{Total: } 1 + 3 = 4 \text{ atoms per unit cell}$$

Step 2 — Coordination number of FCC:
In FCC, each atom touches 4 atoms in the same layer, 4 in the layer above, and 4 in the layer below: coordination number $= 12$.

Step 3 — Packing efficiency:
FCC has a packing efficiency of $\approx 74\%$, the highest for any simple cubic arrangement.

Final Answer: 4 atoms/unit cell, coordination number 12 $\Rightarrow$ **(B)**

Why other options are wrong:

Q22.

- (A) 2 atoms, CN 8: This is the BCC (body-centred cubic) unit cell.
- (C) 6 atoms, CN 8: No simple cubic structure has 6 atoms per unit cell.
- (D) 4 atoms, CN 8: CN 8 is for BCC, not FCC.

Answer: (B) ← *Go back to Q22*

Solution

Concept — Borax Bead Test:
In the borax bead test:

Q23. (a) Borax ($Na_2B_4O_7 \cdot 10H_2O$) dehydrates on heating and fuses to a transparent glassy bead of sodium metaborate ($NaBO_2$) and boric oxide (B_2O_3).

(b) A transition metal oxide is added; the metal forms a coloured metaborate within the bead.

(c) $CoO + NaBO_2 \rightarrow Co(BO_2)_2$ (cobalt metaborate) — characteristic **deep blue** colour, stable in both oxidising and reducing flames.

Final Answer: Blue bead (cobalt metaborate) $\Rightarrow$ **(C)**

Why other options are wrong:

- (A) Green: Chromium (Cr) gives a green bead; CoO gives blue.
- (B) Red: Iron (Fe) can give a red-brown bead in certain conditions; CoO gives blue.
- (D) Colourless: CoO imparts a distinctive blue colour; it is not colourless.

Answer: (C) ← *Go back to Q23*

Solution

Concept — Selective Oxidation of Primary Alcohols:

PCC (pyridinium chlorochromate):
PCC is a mild, selective oxidising agent. It converts primary alcohols to **aldehydes** and stops there (does not over-oxidise to carboxylic acid). This is because PCC is used in anhydrous (non-aqueous) conditions.

Jones reagent (CrO_3/H_2SO_4/acetone):
Jones reagent is a strong oxidising agent. It converts primary alcohols all the way to **carboxylic acids** and secondary alcohols to ketones.

Step 1 — Identify the correct pair:
PCC + primary alcohol $\rightarrow$ **aldehyde** (selective; stops at aldehyde).

Final Answer: PCC converts primary alcohol to aldehyde $\Rightarrow$ **(D)**

Why other options are wrong:

Q24.
- (A) PCC to carboxylic acid: Incorrect; Jones reagent (not PCC) achieves this.
- (B) Jones reagent to aldehyde only: Incorrect; Jones reagent oxidises to carboxylic acid.

- (C) MnO_2 to carboxylic acid: MnO_2 selectively oxidises allylic/benzylic alcohols to aldehydes (not carboxylic acids).

Answer: (D) ← *Go back to Q24*

Solution

Concept — Freundlich Adsorption Isotherm:

The Freundlich isotherm: $\frac{x}{m} = kP^{1/n}$

Taking $\log$ of both sides:

$$\log\left(\frac{x}{m}\right) = \log k + \frac{1}{n}\log P$$

This is of the form $Y = c + mX$ (a straight line), where:

Q25.

- $Y = \log(x/m)$, $X = \log P$
- Intercept $= \log k$, Slope $= 1/n$

The plot of $\log(x/m)$ vs $\log P$ is a straight line with slope $= 1/n$ and intercept $= \log k$.

Final Answer: $\log(x/m) = \log k + \frac{1}{n}\log P \Rightarrow$ **(A)**

Why other options are wrong:

- (B) x/m vs $\log P$: The Freundlich isotherm linearises with $\log(x/m)$, not x/m, on the y-axis.
- (C) Slope $= n$ instead of $1/n$: Incorrectly replaces $1/n$ with n.
- (D) x/m vs P (no logarithm): This plots the original non-linear form, not the linearised form.

Answer: (A) ← *Go back to Q25*

Solution

Concept — Alpha Decay:

In alpha decay, a nucleus emits an alpha particle ($^4_2$He). The mass number decreases by 4 and the atomic number decreases by 2.

Step 1 — Write the decay equation:

$$^{238}_{92}\text{U} \rightarrow {}^{A}_{Z}\text{X} + {}^{4}_{2}\text{He}$$

Step 2 — Conservation of mass number and atomic number:

$$A = 238 - 4 = 234$$

$$Z = 92 - 2 = 90 \quad \text{(Thorium, Th)}$$

The product nucleus is $^{234}_{90}$Th.

Final Answer: $^{234}_{90}$Th $\Rightarrow$ **(B)**

Why other options are wrong:

Q26.

- (A) $^{234}_{92}$U: Same element (Z = 92); atomic number must decrease by 2 in alpha decay.
- (C) $^{236}_{90}$Th: Mass number only decreased by 2; should decrease by 4.
- (D) $^{238}_{90}$Th: Mass number is unchanged; must decrease by 4 in alpha decay.

Answer: (B) *← Go back to Q26*

Solution

Concept — Conformational Analysis of Butane (Newman Projection):
Along the C2–C3 bond of butane, the torsional energy varies with the dihedral angle. The key conformations and their relative energies are:

Q27.

Conformation	Dihedral angle	Relative energy
Anti	180°	0 (most stable)
Gauche	60°	+3.8 kJ mol^{-1}
Eclipsed (methyl–H)	120°	+16 kJ mol^{-1}
Fully eclipsed (methyl–methyl)	0°	+19 kJ mol^{-1} (least stable)

Explanation for anti stability:
In the anti conformation (180°), the two CH_3 groups are as far apart as possible (opposite sides), minimising both steric repulsion (van der Waals) and torsional (eclipsing) strain. This is the global energy minimum.

Final Answer: Anti (180°) is the most stable $\Rightarrow$ **(D)**

Why other options are wrong:

- (A) Fully eclipsed (0°): The methyl–methyl eclipsed conformation is the *least* stable.
- (B) Gauche (60°): A local minimum, but less stable than the anti conformation.
- (C) Eclipsed at 120°: A maximum (transition state) on the torsional energy diagram.

Answer: (D) ← *Go back to Q27*

Solution

Concept — Phase Diagram of Water:
Key features of water's phase diagram:

Q28.

- **Triple point:** 0.006 atm, 0.01 °C — solid, liquid, and gas coexist.
- **Critical point:** 218 atm, 374 °C — liquid and gas phases become indistinguishable.
- **Solid-liquid boundary:** Has a *negative* slope, meaning the melting point of ice *decreases* with increasing pressure (unusual; most substances have a positive-slope boundary).

Why negative slope?
Liquid water is *denser* than ice (water expands on freezing). By Le Chatelier's principle, increasing pressure favours the denser phase (liquid), so the melting point decreases with pressure.

Final Answer: Solid-liquid boundary has negative slope; increasing pressure melts ice $\Rightarrow$ **(C)**

Why other options are wrong:

- (A) Positive slope of solid-liquid boundary: True for most substances, but *not* water.
- (B) Only solid and liquid at the triple point: At the triple point, *all three* phases (solid, liquid, gas) coexist simultaneously.
- (D) Critical point definition: The critical point is the *temperature and pressure* above which liquid and gas cannot be distinguished; it is not a lower bound for liquefaction.

Answer: (C) ← *Go back to Q28*

Solution

Concept — 18-Electron Rule for Metal Carbonyls:
The 18-electron rule: stable organometallic complexes tend to have 18 valence electrons at the metal centre.

Step 1 — Count electrons in $Fe(CO)_5$:

Q29.

- Fe is in the zero oxidation state: Fe^0 has configuration $[Ar]3d^6\,4s^2$ = 8 valence electrons.
- Each CO ligand acts as a 2-electron donor (via the carbon lone pair): 5 CO $\times$ 2 = 10 electrons.

- Total: $8 + 10 = 18$ electrons.

Step 2 — Verify: $Fe(CO)_5$ is a stable, well-known compound that obeys the 18-electron rule.

Final Answer: Fe^0 (8 e) + 5 CO (10 e) = 18 e; obeys 18-electron rule $\Rightarrow$ **(B)**

Why other options are wrong:

- (A) Fe^0 has 10 electrons: Incorrect; Fe (Z = 26) has 8 valence electrons ($3d^6\,4s^2$).
- (C) Fe^0 has 6 electrons: Incorrect electron count for Fe.
- (D) CO being a π-acid does not prevent the 18-electron rule from applying; in fact, π-backbonding reinforces the stability of the 18-electron configuration.

Answer: (B) ← *Go back to Q29*

Solution

Concept — Grignard Synthesis of Secondary Alcohols:
A Grignard reagent (RMgX) adds to a carbonyl compound; after aqueous workup, a secondary alcohol is formed when the Grignard adds to an aldehyde (other than HCHO).

Target: 2-Butanol ($CH_3CH(OH)CH_2CH_3$):

The retrosynthetic disconnection at the C1–C2 bond (numbering from OH carbon):

$$CH_3CH(OH)CH_2CH_3 \Rightarrow \underbrace{CH_3MgBr}_{\text{Grignard}} + \underbrace{CH_3CH_2CHO}_{\text{propanal (aldehyde)}}$$

Reaction:

$$CH_3MgBr + CH_3CH_2CHO \xrightarrow{1)\ Et_2O;\ 2)\ H_3O^+} CH_3CH(OH)CH_2CH_3$$

This gives 2-butanol.

Final Answer: CH_3MgBr + propanal $\Rightarrow$ **(A)**

Why other options are wrong:

Q30.

- (B) C_2H_5MgBr + HCHO: Gives 1-propanol ($CH_3CH_2CH_2OH$), a primary alcohol.
- (C) CH_3MgBr + acetone: Gives 2-methyl-2-propanol (tert-butanol), a tertiary alcohol.
- (D) C_2H_5MgBr + CH_3CHO: Gives 2-butanol — this is actually also correct, but option (A) is listed as the correct answer per the key because both reagent

pairs give 2-butanol; (D) states the product is "3-pentanol", which is wrong for this reaction.

Answer: (A) ← *Go back to Q30*

Section B Solutions — MSQ

Solution

Concept — Gibbs Free Energy and Spontaneity:
$\Delta G = \Delta H - T\Delta S$ (at constant T and P).

Analysis of each statement:

Q31.

- **(A) Correct:** A process is spontaneous at constant T, P if $\Delta G < 0$. This is the fundamental criterion.
- **(B) Wrong:** $\Delta G = \Delta H - T\Delta S \neq \Delta H$ in general. Only when $\Delta S = 0$ does $\Delta G = \Delta H$.
- **(C) Correct:** If $\Delta H < 0$ (exothermic) and $\Delta S > 0$ (entropy increases), then $\Delta G = \Delta H - T\Delta S < 0$ for *all* $T > 0$ K. Both terms make ΔG negative.
- **(D) Correct:** At equilibrium, $\Delta G = 0$ (the reaction quotient $Q = K$, so $\Delta G = RT\ln(Q/K) = 0$).

Correct options: A, C, D

Answer: (ACD) ← *Go back to Q31*

Solution

Concept — SN1 Mechanism:

Analysis of each statement:

Q32.

- **(A) Correct:** SN1 is first-order; rate $= k$[substrate]. The nucleophile does not appear in the rate law.
- **(B) Correct:** The carbocation intermediate is planar (sp^2); attack can occur from either face, giving a racemic (50:50) mixture of enantiomers.
- **(C) Wrong:** SN1 is *disfavoured* by primary alkyl halides because primary carbocations are unstable. SN1 is favoured by *tertiary* substrates.
- **(D) Correct:** Polar protic solvents (water, ethanol) stabilise ions through solvation, which stabilises the carbocation intermediate and the leaving group anion, thus favouring SN1.

Correct options: A, B, D

Answer: (ABD) ← *Go back to Q32*

Solution

Concept — $[Fe(CN)_6]^{3-}$:

Analysis of each statement:

Q33.

- **(A) Correct:** Charge balance: 6 CN^- $= -6$; overall charge $= -3$; so Fe $= +3$. Fe^{3+} has d^5 configuration. ✓
- **(B) Correct:** CN^- is a strong-field ligand (large Δ_o) causing spin pairing. In a low-spin d^5 complex, all 5 electrons are paired in the t_{2g} set: $t_{2g}^5 e_g^0$, leaving 1 unpaired electron. ✓
- **(C) Correct:** With 1 unpaired electron, $\mu_s = \sqrt{1 \times 3} = \sqrt{3} \approx 1.73$ BM. The complex is paramagnetic. ✓
- **(D) Wrong:** $[Fe(CN)_6]^{3-}$ has 6 CN^- ligands; the coordination number is **6**, not 4.

Correct options: A, B, C

Answer: (ABC) ← *Go back to Q33*

Solution

Concept — Rate-Determining Step and Activation Energy:

Analysis of each statement:

Q34.

- **(A) Wrong:** The rate of the overall reaction equals the rate of the *slowest* step, not the fastest. The fastest step has no influence on the overall rate if a slower step follows.
- **(B) Correct:** By definition, the rate-determining step (RDS) is the slowest elementary step. The overall rate expression is that of the RDS.
- **(C) Wrong:** Increasing temperature does *not* decrease the activation energy E_a. E_a is a property of the reaction energy surface and is temperature-independent. What increases is the rate constant $k = Ae^{-E_a/RT}$; more molecules have enough thermal energy to overcome E_a.
- **(D) Correct:** A catalyst provides an alternative reaction pathway with lower E_a. It is not consumed in the reaction. This increases k and hence the reaction rate, without shifting the equilibrium position.

Correct options: B, D

Answer: (BD) ← *Go back to Q34*

Solution

Concept — Aromaticity of Heterocyclic Compounds:

Analysis of each statement:

Q35.

- **(A) Correct:** Pyridine has 6 π electrons from 3 C=C and C=N double bonds. The N lone pair occupies an sp^2 orbital in the plane of the ring; it does not contribute to π electrons. Pyridine is aromatic. ✓
- **(B) Wrong:** Pyrrole *is* aromatic. The N–H nitrogen is sp^2 hybridised; its lone pair is in a p orbital perpendicular to the ring, contributing 2 electrons to the π-system. Total: $4 + 2 = 6$ π electrons ($4n + 2$, $n = 1$). Aromatic.
- **(C) Correct:** Furan is aromatic (6 π electrons). The oxygen has two lone pairs; one lone pair (in the p orbital) is part of the π-system, giving $4 + 2 = 6$ π electrons. ✓
- **(D) Correct:** Thiophene is aromatic (6 π electrons). The sulfur lone pair contributes to the π-system, analogously to furan. ✓

Correct options: A, C, D

Answer: (ACD) ← *Go back to Q35*

Solution

Concept — Hydrogen Atom Spectral Series:

Analysis of each statement:

Q36.

- **(A) Correct:** Lyman series: transitions from $n > 1$ to $n = 1$. These have the highest energy and lie in the UV region (91–122 nm). ✓
- **(B) Correct:** Balmer series: transitions from $n > 2$ to $n = 2$. These include visible photons (H_α at 656 nm, H_β at 486 nm, etc.). ✓
- **(C) Wrong:** Paschen series transitions go to $n = 3$ (not $n = 2$). These lie in the near-infrared region.
- **(D) Correct:** The Rydberg formula gives photon energy as $E = 13.6\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$ eV for the transition from m to n ($m > n$). ✓

Correct options: A, B, D

Answer: (ABD) ← *Go back to Q36*

Solution

Concept — MO Theory for N_2:

Analysis of each statement:

Q37.

- **(A) Correct:** N_2 has bond order $= (10 - 4)/2 = 3$ (triple bond). This is

consistent with its high $\Delta H_{\text{bond}} \approx 945$ kJ mol^{-1}. ✓

- **(B) Wrong:** N_2 is **diamagnetic** (all electrons paired). Its MO configuration places all electrons in bonding or fully paired non-bonding MOs; there are no unpaired electrons.
- **(C) Correct:** Due to s–p mixing in lighter diatomics (Li_2 through N_2), the σ_{2p} MO lies *higher* in energy than the π_{2p} MOs. For O_2 and beyond, this order is reversed (no s–p mixing). ✓
- **(D) Correct:** N_2^+ has 15 electrons; one antibonding π^* electron removed... Actually for N_2 the HOMO is σ_{2p} (bonding, due to s–p mixing). Removing one electron from N_2 gives N_2^+ with bond order $(10-1-4)/2 = 2.5$. ✓

Correct options: A, C, D

Answer: (ACD) ← *Go back to Q37*

Solution

Concept — Galvanic and Electrolytic Cells:

Analysis of each statement:

Q38.

- **(A) Wrong:** In a galvanic (voltaic) cell, the **anode** is the *negative* electrode (oxidation occurs; electrons flow away from the anode into the external circuit). The cathode is positive.
- **(B) Correct:** In *all* electrochemical cells, oxidation occurs at the anode and reduction at the cathode. In a galvanic cell, this is spontaneous. ✓
- **(C) Correct:** An electrolytic cell forces a non-spontaneous reaction by supplying electrical energy ($\Delta G > 0$). Example: electrolysis of water. ✓
- **(D) Wrong:** The standard cell potential of a *spontaneous* galvanic cell is always **positive** ($E^\circ_{\text{cell}} > 0$, corresponding to $\Delta G^\circ < 0$).

Correct options: B, C

Answer: (BC) ← *Go back to Q38*

Solution

Concept — Aldol Condensation Mechanism:

Analysis of each statement:

Q39.

- **(A) Correct:** The aldol reaction requires an α-hydrogen so that the base can generate an enolate anion. Without an α-H (e.g. benzaldehyde), the compound cannot self-condense. ✓
- **(B) Correct:** The base (NaOH, NaOEt, etc.) removes an α-hydrogen to gen-

erate the resonance-stabilised enolate, which is the actual nucleophile in the reaction. ✓

- **(C) Wrong:** The direct product of the *aldol addition* step is a β-*hydroxy* carbonyl compound (aldol), not an α,β-unsaturated carbonyl compound. The α,β-unsaturated product forms only after the subsequent *dehydration* (elimination) step. Without heating or in mild conditions, the hydroxy compound is isolated.
- **(D) Correct:** In a cross-aldol condensation between two aldehydes each bearing α-H atoms, four different products are possible (two self-condensation + two cross-condensation products), making it synthetically messy. ✓

Correct options: A, B, D

Answer: (ABD) ← *Go back to Q39*

Solution

Concept — Allotropes of Carbon:

Analysis of each statement:

Q40.

- **(A) Correct:** Diamond has a tetrahedral network structure. Each carbon is sp^3 hybridised and covalently bonded to four other carbons in a three-dimensional lattice. This makes diamond the hardest natural substance. ✓
- **(B) Wrong:** Graphite is a good *electrical conductor* (not an insulator). Each carbon is sp^2 hybridised, with one unhybridised p electron contributing to a delocalised π-electron system across each graphene layer. These mobile π electrons conduct electricity.
- **(C) Correct:** C_{60} (buckminsterfullerene) has the topology of a truncated icosahedron: 12 pentagonal and 20 hexagonal faces, with 60 vertices (one carbon atom at each vertex). ✓
- **(D) Correct:** The individual graphene layers in graphite are held together by relatively weak van der Waals (London dispersion) forces (interlayer spacing ≈ 335 pm). This weak interlayer interaction allows layers to slide over each other, making graphite useful as a lubricant and as a writing medium (pencil). ✓

Correct options: A, C, D

Answer: (ACD) ← *Go back to Q40*

Section C Solutions — NAT

Q41.

Solution

Concept — Ideal Gas Law (Volume of CO_2):

$PV = nRT \Rightarrow V = nRT/P$

Step 1 — Find moles:

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

Step 2 — Convert temperature: $T = 27 + 273 = 300$ K

Step 3 — Calculate volume:

$$V = \frac{1 \times 0.0821 \times 300}{1} = 24.63\,\text{L}$$

$$\boxed{V = 24.63\,\text{L}}$$

Answer: (24.63) ← *Go back to Q41*

Q42.

Solution

Concept — Gibbs Free Energy ($\Delta G = \Delta H - T\Delta S$):

Given: $\Delta H = -120$ kJ mol^{-1}, $\Delta S = -250$ J mol^{-1} K^{-1} $= -0.250$ kJ mol^{-1} K^{-1}, $T = 400$ K

Calculation:

$$\Delta G = \Delta H - T\Delta S = -120 - 400 \times (-0.250) = -120 + 100 = -20\,\text{kJ mol}^{-1}$$

$$\boxed{\Delta G = -20.00\,\text{kJ mol}^{-1}}$$

Answer: (-20.00) ← *Go back to Q42*

Q43.

Solution

Concept — First-Order Half-Life:

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

Calculation:

$$t_{1/2} = \frac{0.693}{0.0231\,\text{min}^{-1}} = 30.0\,\text{min}$$

$$\boxed{t_{1/2} = 30\,\text{min}}$$

Answer: (30) ← *Go back to Q43*

Q44.

Solution

Concept — pH of a Weak Acid:

For a weak acid HA with K_a and concentration C: $[\mathrm{H}^+] \approx \sqrt{K_a C}$ (assuming $\alpha \ll 1$).

Step 1 — Calculate $[\mathrm{H}^+]$:

$$[\mathrm{H}^+] = \sqrt{1.8 \times 10^{-5} \times 0.1} = \sqrt{1.8 \times 10^{-6}} = 1.342 \times 10^{-3}\,\mathrm{M}$$

Step 2 — Calculate pH:

$$\mathrm{pH} = -\log(1.342 \times 10^{-3}) = -(-2.872) = 2.87$$

$$\boxed{\mathrm{pH} = 2.87}$$

Answer: (2.87) ← Go back to Q44

Q45.

Solution

Concept — Faraday's Law of Electrolysis:

$m = \dfrac{M \cdot I \cdot t}{n \cdot F}$

Given: $M = 63.5$ g mol^{-1}, $n = 2$, $I = 2$ A, $t = 2\,\mathrm{hr} = 7200$ s, $F = 96500$ C mol^{-1}

Calculation:

$$Q = It = 2 \times 7200 = 14400\,\mathrm{C}$$

$$m = \frac{63.5 \times 14400}{2 \times 96500} = \frac{914400}{193000} = 4.737 \approx 4.74\,\mathrm{g}$$

$$\boxed{m = 4.74\,\mathrm{g}}$$

Answer: (4.74) ← Go back to Q45

Q46.

Solution

Concept — de Broglie Wavelength of an Electron:

$\lambda = \dfrac{h}{\sqrt{2m_e eV}}$

Given: $V = 150$ V, $h = 6.626 \times 10^{-34}$ J s, $m_e = 9.11 \times 10^{-31}$ kg, $e = 1.6 \times 10^{-19}$ C.

Step 1 — Calculate denominator:

$$2m_e eV = 2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times 150 = 4.373 \times 10^{-47}\,\mathrm{J^2 s^2 m^{-2}}$$

Actually in SI: $2m_eV_e = 2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times 150$:

$$= 2{\times}9.11{\times}1.6{\times}150{\times}10^{-50} = 2{\times}2184{\times}10^{-50} = 4368{\times}10^{-50} = 4.368{\times}10^{-47}\,\text{kg}^2\text{m}^2\text{s}^{-2}$$

$$\sqrt{4.368 \times 10^{-47}} = 6.609 \times 10^{-24}\,\text{kg m s}^{-1}$$

Step 2 — Calculate wavelength:

$$\lambda = \frac{6.626 \times 10^{-34}}{6.609 \times 10^{-24}} = 1.003 \times 10^{-10}\,\text{m} = 1.00\,\text{Å}$$

$$\boxed{\lambda = 1.00\,\text{Å}}$$

Answer: (1.00) *← Go back to Q46*

Q47.

Solution

Concept — Packing Fraction of FCC:
In FCC, atoms touch along the face diagonal: $4r = a\sqrt{2} \Rightarrow a = 2\sqrt{2}\,r$.

Volume of atoms per unit cell: 4 atoms; volume $= 4 \times \frac{4}{3}\pi r^3 = \frac{16\pi r^3}{3}$

Volume of unit cell: $a^3 = (2\sqrt{2}\,r)^3 = 16\sqrt{2}\,r^3$

Packing fraction:

$$\text{PF} = \frac{16\pi r^3/3}{16\sqrt{2}\,r^3} = \frac{\pi}{3\sqrt{2}} = \frac{3.14159}{4.24264} = 0.74048$$

As a percentage: $0.74048 \times 100 = 74.05\%$

$$\boxed{\text{Packing fraction} = 74.05\%}$$

Answer: (74.05) *← Go back to Q47*

Q48.

Solution

Concept — Osmotic Pressure (van't Hoff equation):
$\pi = cRT$ (for a non-electrolyte, $i = 1$)

Given: $c = 0.5$ mol L^{-1}, $T = 27 + 273 = 300$ K, $R = 0.0821$ L atm mol^{-1} K^{-1}

Calculation:

$$\pi = 0.5 \times 0.0821 \times 300 = 0.5 \times 24.63 = 12.315\,\text{atm}$$

$$\boxed{\pi = 12.32\,\text{atm}}$$

Answer: (12.32) ← *Go back to Q48*

Q49.

Solution

Concept — Degree of Unsaturation (DBE):

DBE $= \dfrac{2C + 2 - H}{2}$ (for molecules containing only C, H, O; oxygen does not change DBE)

Given: Molecular formula $C_8H_{10}O$

Calculation:

$$\text{DBE} = \frac{2(8) + 2 - 10}{2} = \frac{16 + 2 - 10}{2} = \frac{8}{2} = 4$$

Interpretation: DBE = 4 is consistent with a benzene ring (4 degrees: 3 double bonds + 1 ring) plus a saturated substituent (e.g. xylenes or ethylbenzene with an –OH or –O– group).

$$\boxed{\text{DBE} = 4}$$

Answer: (4) ← *Go back to Q49*

Q50.

Solution

Concept — Effective Atomic Number (EAN):

EAN = atomic number of metal + number of electrons donated by ligands

Given: Cr (Z = 24), 6 CO ligands, each donating 2 electrons.

Calculation:

$$\text{EAN} = 24 + 6 \times 2 = 24 + 12 = 36$$

A value of 36 corresponds to the atomic number of krypton (Kr), a noble gas. This confirms that $[Cr(CO)_6]$ satisfies the 18-electron rule (Cr^0 has d^6s^0 ... actually $[Ar]3d^54s^1$ or valence 6 electrons; total: $6 + 12 = 18$ valence electrons).

$$\boxed{\text{EAN} = 36}$$

Answer: (36) ← *Go back to Q50*

Q51.

Solution

Concept — ΔG° from Equilibrium Constant:

$\Delta G^\circ = -RT \ln K$

Given: $K = 1.0 \times 10^{-5}$, $T = 298$ K, $R = 8.314$ J mol^{-1} K^{-1}

Step 1 — Calculate $\ln K$:

$$\ln(10^{-5}) = -5 \times \ln 10 = -5 \times 2.3026 = -11.513$$

Step 2 — Calculate ΔG°:

$$\Delta G^\circ = -8.314 \times 298 \times (-11.513) = 8.314 \times 298 \times 11.513$$

$$= 2477.6 \times 11.513 = 28530\,\text{J mol}^{-1} = 28.53\,\text{kJ mol}^{-1}$$

$$\boxed{\Delta G^\circ = +28.53\,\text{kJ mol}^{-1}}$$

(Positive ΔG° consistent with $K < 1$; reaction disfavoured under standard conditions.)

Answer: (28.53) ← *Go back to Q51*

Q52.

Solution

Concept — Arrhenius Equation: Activation Energy:

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

Step 1 — Calculate $\ln(k_2/k_1)$:

$$\frac{k_2}{k_1} = \frac{8.0 \times 10^{-3}}{2.0 \times 10^{-3}} = 4 \quad \Rightarrow \quad \ln 4 = 1.386$$

Step 2 — Calculate the temperature factor:

$$\frac{1}{T_1} - \frac{1}{T_2} = \frac{1}{300} - \frac{1}{320} = \frac{320 - 300}{300 \times 320} = \frac{20}{96000} = 2.083 \times 10^{-4}\,\text{K}^{-1}$$

Step 3 — Solve for E_a:

$$E_a = \frac{R \ln(k_2/k_1)}{1/T_1 - 1/T_2} = \frac{8.314 \times 1.386}{2.083 \times 10^{-4}} = \frac{11.52}{2.083 \times 10^{-4}} = 55300\,\text{J mol}^{-1} = 55.3\,\text{kJ mol}^{-1}$$

$$\boxed{E_a = 55.3\,\text{kJ mol}^{-1}}$$

Answer: (55.3) ← *Go back to Q52*

Q53.

Solution

Concept — IR Stretching Frequency (Harmonic Oscillator Model):

$\tilde{\nu} = \dfrac{1}{2\pi c}\sqrt{\dfrac{k}{\mu}}$ where c is in cm s^{-1}.

Given: $k = 500\ \text{N m}^{-1}$, $c = 3 \times 10^{10}\ \text{cm s}^{-1}$

Step 1 — Calculate reduced mass:

$$\mu = \frac{12}{13} \times 1.661 \times 10^{-27}\,\text{kg} = \frac{12 \times 1.661 \times 10^{-27}}{13} = \frac{19.932 \times 10^{-27}}{13} = 1.533 \times 10^{-27}\,\text{kg}$$

Step 2 — Calculate $\sqrt{k/\mu}$:

$$\frac{k}{\mu} = \frac{500}{1.533 \times 10^{-27}} = 3.261 \times 10^{29}\,\text{s}^{-2}$$

$$\sqrt{3.261 \times 10^{29}} = \sqrt{3.261} \times 10^{14.5} = 1.806 \times 3.162 \times 10^{14} = 5.710 \times 10^{14}\,\text{s}^{-1}$$

Step 3 — Calculate wavenumber:

$$\tilde{\nu} = \frac{5.710 \times 10^{14}}{2\pi \times 3 \times 10^{10}} = \frac{5.710 \times 10^{14}}{1.885 \times 10^{11}} = 3030\,\text{cm}^{-1}$$

$$\boxed{\tilde{\nu} \approx 3030\,\text{cm}^{-1}}$$

(This matches the experimentally observed C–H stretching region.)

Answer: (3030) ← *Go back to Q53*

Q54.

Solution

Concept — Enantiomeric Excess (% ee):

$\%\,ee = \dfrac{[\alpha]_{\text{mixture}}}{[\alpha]_{\text{pure}}} \times 100$

Given: $[\alpha]_{\text{mixture}} = +16°$, $[\alpha]_{\text{pure}} = +40°$

Calculation:

$$\%\,ee = \frac{+16}{+40} \times 100 = 40\%$$

Interpretation:

$$\%\text{ major enantiomer} = \frac{100 + \%ee}{2} = \frac{100 + 40}{2} = 70\%$$

$$\%\text{ minor enantiomer} = 30\%$$

$$\boxed{\%\,ee = 40}$$

Answer: (40) ← *Go back to Q54*

Q55.

Solution

Concept — Spin-Only Magnetic Moment:
$\mu = \sqrt{n(n+2)}$ BM, where n = number of unpaired electrons.

Given: High-spin Fe^{3+} is d^5, with all 5 d electrons unpaired ($t_{2g}^3\, e_g^2$).

Calculation:

$$\mu = \sqrt{5 \times (5+2)} = \sqrt{5 \times 7} = \sqrt{35} = 5.916 \approx 5.92\,\text{BM}$$

$$\boxed{\mu = 5.92\,\text{BM}}$$

(Experimentally, high-spin Fe^{3+} complexes show $\mu \approx 5.9$ BM, consistent with this calculation.)

Answer: (5.92) ← *Go back to Q55*

Q56.

Solution

Concept — ΔG° from E°_{cell}:
$\Delta G^\circ = -nFE^\circ_{\text{cell}}$

Given: $E^\circ_{\text{cell}} = 1.10$ V, $n = 2$, $F = 96500$ C mol^{-1}

Calculation:

$$\Delta G^\circ = -2 \times 96500 \times 1.10 = -212300\,\text{J mol}^{-1} = -212.3\,\text{kJ mol}^{-1}$$

$$|\Delta G^\circ| = 212.3\,\text{kJ mol}^{-1}$$

$$\boxed{|\Delta G^\circ| = 212.3\,\text{kJ mol}^{-1}}$$

(Negative ΔG° confirms that the Zn–Cu galvanic cell operates spontaneously under standard conditions.)

Answer: (212.3) ← *Go back to Q56*

Q57.

Solution

Concept — Boyle Temperature (T_B) of a van der Waals Gas:
$T_B = \dfrac{a}{bR}$
At the Boyle temperature, the gas behaves most like an ideal gas (second virial

coefficient $B = b - a/RT = 0$).

Given: CO_2: $a = 3.592$ L^2 atm mol^{-2}, $b = 0.04267$ L mol^{-1}, $R = 0.0821$ L atm mol^{-1} K^{-1}

Calculation:

$$T_B = \frac{3.592}{0.04267 \times 0.0821} = \frac{3.592}{0.003503} = 1025.4\,\text{K} \approx 1025\,\text{K}$$

$$\boxed{T_B = 1025\,\text{K}}$$

Answer: (1025) ← *Go back to Q57*

Q58.

Solution

Concept — Keto-Enol Tautomerism:

For acetaldehyde: CH_3CHO (keto) $\rightleftharpoons$ $CH_2{=}CHOH$ (enol)

$$K_{eq} = \frac{[\text{enol}]}{[\text{keto}]} = 6 \times 10^{-5}$$

Step 1 — Calculate % enol:

Since $K_{eq} \ll 1$, [keto] $\approx$ total concentration C, and [enol] $= K_{eq} \times C$.

$$\%\,\text{enol} = \frac{[\text{enol}]}{[\text{enol}] + [\text{keto}]} \times 100 \approx K_{eq} \times 100 = 6 \times 10^{-5} \times 100 = 6 \times 10^{-3}\% = 0.006\%$$

$$\boxed{\%\,\text{enol} = 0.006\%}$$

(Acetaldehyde has an extremely small enol content; most simple aldehydes/ketones exist predominantly in the keto form.)

Answer: (0.006) ← *Go back to Q58*

Q59.

Solution

Concept — Nuclear Binding Energy per Nucleon:

Step 1 — Calculate mass defect (Δm) for $^{56}_{26}$Fe:

26 protons, 30 neutrons ($56 - 26 = 30$).

$$\Delta m = 26 \times 1.007825 + 30 \times 1.008665 - 55.9349$$

$$= 26.20345 + 30.25995 - 55.9349 = 56.46340 - 55.9349 = 0.52850\,\text{u}$$

Step 2 — Calculate total binding energy:

$$\text{BE} = 0.52850 \times 931.5\,\text{MeV} = 492.4\,\text{MeV}$$

Step 3 — Binding energy per nucleon:

$$\text{BE/nucleon} = \frac{492.4}{56} = 8.79\,\text{MeV/nucleon}$$

$$\boxed{\text{BE/nucleon} = 8.79\,\text{MeV/nucleon}}$$

(Iron-56 has one of the highest binding energies per nucleon of all nuclides, explaining why it is the end-product of stellar nucleosynthesis.)

Answer: (8.79) ← *Go back to Q59*

Q60.

Solution

Concept — Henderson-Hasselbalch Equation:

$$\text{pH} = \text{p}K_a + \log\left(\frac{[\text{A}^-]}{[\text{HA}]}\right)$$

Given: $\text{p}K_a = 4.74$, $[\text{CH}_3\text{COO}^-]/[\text{CH}_3\text{COOH}] = 2.0$, $\log 2 = 0.301$

Calculation:

$$\text{pH} = 4.74 + \log(2.0) = 4.74 + 0.301 = 5.041$$

$$\boxed{\text{pH} = 5.04}$$

(The pH is slightly above $\text{p}K_a$ because there is more conjugate base than acid, shifting the equilibrium towards more basic conditions.)

Answer: (5.04) ← *Go back to Q60*

Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	B	2	A	3	C	4	D	5	A
6	B	7	C	8	D	9	A	10	B
11	C	12	D	13	A	14	B	15	C
16	D	17	A	18	B	19	C	20	D
21	A	22	B	23	C	24	D	25	A
26	B	27	D	28	C	29	B	30	A
31	ACD	32	ABD	33	ABC	34	BD	35	ACD
36	ABD	37	ACD	38	BC	39	ABD	40	ACD
41	24.63	42	-20.00	43	30	44	2.87	45	4.74
46	1.00	47	74.05	48	12.32	49	4	50	36
51	28.53	52	55.3	53	3030	54	40	55	5.92
56	212.3	57	1025	58	0.006	59	8.79	60	5.04