JELET Chemistry Sample Paper-4

Duration: 25 Minutes **Maximum Marks: 25**

Instructions

- This paper contains **20** Multiple Choice Questions divided into **2 Sections**.
- **Section A (Q1–Q15):** Each correct answer carries +1 mark. Incorrect answer: **−0.25** marks. Only **one** correct option.
- **Section B (Q16–Q20):** Each correct answer carries **+2 marks**. **No negative marking.** One or **more** correct options may be correct; full marks only if all correct options are marked.
- Use of mobile phones, smartwatches, or any electronic gadgets is strictly prohibited.

Section–A — 15 Questions × 1 Mark Each (Negative Marking: −0.25) [Single Correct]

Q1. An electron stream is captured by a highly ionized hydrogenic element ($Z = 3$) in a state described by the radial wave function parameters. If the electron makes a transition from an initial state where the total number of radial nodes is 3 and angular nodes is 1 to its ground state ($n = 1$), what is the frequency of the emitted photon in terms of the Rydberg constant R_∞ and speed of light c?

(A) $\frac{216}{25}R_\infty c$

(B) $\frac{24}{25}R_\infty c$

(C) $\frac{54}{25}R_\infty c$

(D) $\frac{200}{21}R_\infty c$

Q2. A complex aquatic solution system is designed at 25°C containing a mixture of 0.1 M sodium salt of a weak acid (NaA) and 0.05 M of another weak acid HB. Given that the ionization constants of the respective acids are $K_a(\text{HA}) = 1.0\times10^{-5}$ and $K_a(\text{HB}) = 4.0\times10^{-6}$, the equilibrium constant K_c for the competitive proton exchange reaction $A^-(aq) + HB(aq) \rightleftharpoons HA(aq) + B^-(aq)$ is computed as:

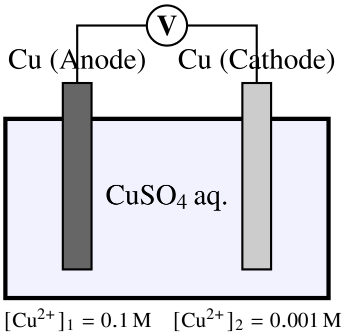
(A) 0.40

(B) 2.50

(C) 4.00

(D) 0.25

Q3. An advanced industrial copper electrodeposition refinery cell uses a high-density acidic electrolyte matrix. The electrical work profile is monitored by tracking the concentration gradients between two parallel non-identical plates as depicted below. If the activity coefficient changes according to the profile shown, find the net cell potential E_{cell} at 298 K when the concentration at Electrode-1 is exactly 0.1 M and at Electrode-2 is 0.001 M:



(A) +0.0591 V

(B) −0.0591 V

(C) +0.1182 V

(D) +0.0295 V

Q4. During the extraction of copper using a reverberatory furnace, a chemical fluxing agent is intentionally added to separate the highly undesirable iron impurities present within the copper concentrates. The chemical identity of the flux added and the composition of the resulting fusible slag layer are respectively:

(A) Limestone ($CaCO_3$), $CaSiO_3$

(B) Silica (SiO_2), $FeSiO_3$

(C) Alumina (Al_2O_3), $FeAl_2O_4$

(D) Iron Oxide (FeO), $FeSiO_3$

Q5. Consider the complex polyfunctional organic compound layout given by the following condensed formula structure: $HC \equiv C - C(CH_3) = CH - CH(OH) - CH_2 - CHO$. The correct IUPAC name assigned to this highly unsaturated oxygenated molecule is:

(A) 5-Hydroxy-3-methylhept-3-en-6-ynal

(B) 3-Hydroxy-5-methylhept-4-en-1-ynal

(C) 5-Hydroxy-3-methylhept-3-en-1-ynal

(D) 3-Hydroxy-5-methylhept-4-en-6-ynal

Q6. The classic destructive sequence of the ozone shield by halogen radical species can be shut down temporarily through the formation of atmospheric chemical reservoir states. Which pair of chemical combinations acts exclusively as the primary global reservoir sinks for active chlorine radicals in the lower stratosphere?

(A) HCl and $ClONO_2$

(B) HOCl and ClO

(C) CF_2Cl_2 and CCl_4

(D) Cl_2O and $HClO_4$

Q7. A central interhalogen coordination cluster is identified as XeF_5^-. Evaluating this anion framework via the Valence Shell Electron Pair Rejection (VSEPR) theory, what is the exact hybridization of the central Xenon nucleus along with the correct spatial arrangement of its total non-bonding lone pair clouds?

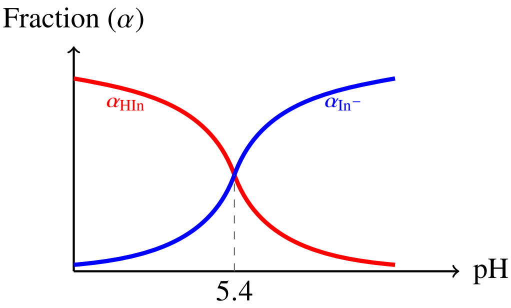
(A) sp^3d^3, Planar Pentagonal with 2 axial lone pairs

(B) sp^3d^2, Pentagonal Pyramidal with 1 equatorial lone pair

(C) d^2sp^3, Distorted Octahedral with 2 trans lone pairs

(D) sp^3d^3, Pentagonal Bipyramidal with 2 equatorial lone pairs

Q8. A precise weak acid neutralization analysis tracks the shift of ionic species inside a solution chamber using a multi-step analytical sensor array. The system evaluates the dynamic distribution fraction (α) of an indicator acid HIn as a function of the solution pH, as sketched below. If the color transmission switches exactly at the crossing point threshold where $\alpha_{\mathrm{In}^-} = \alpha_{\mathrm{HIn}}$, evaluate the corresponding value of K_a for this indicator:



(A) 3.98×10^{-6}

(B) 2.51×10^{-5}

(C) 5.40×10^{-6}

(D) 1.00×10^{-7}

Q9. An industrial electrolytic cell contains 1.0 L of an aqueous solution of 1.0 M nickel sulfate ($NiSO_4$) equipped with smooth platinum electrodes. A steady external current density of 9.65 A is passed continuously through this liquid column for exactly 1000 seconds. What is the final theoretical pH value of the remaining residual electrolyte solution at 25°C?

(A) 1.00

(B) 2.00

(C) 1.30

(D) 7.00

Q10. The modern Contact Process relies heavily on optimizing thermodynamic conditions during the oxidation stage of sulfur dioxide. If an industrial plant runs the reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ ($\Delta H = -198$ kJ/mol) at a temperature of 450°C and 2 atm pressure over a V_2O_5 bed, what happens to the equilibrium yield of SO_3 and the reaction rate if the operational pressure is boosted to 10 atm?

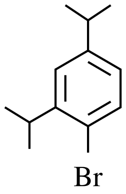
(A) SO_3 yield drops; reaction rate scales up

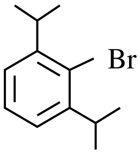
(B) SO_3 yield scales up; reaction rate scales up

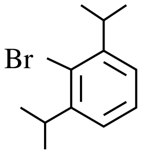
(C) SO_3 yield drops; reaction rate drops

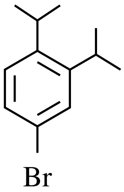
(D) SO_3 yield scales up; reaction rate remains unaffected

Q11. An advanced organic synthesis pathway requires the selective monobromination of a highly sterically hindered aromatic substrate, 1,3-di-tert-butylbenzene, using bromine in the presence of an anhydrous iron(III) bromide catalyst ($Br_2/FeBr_3$). Evaluating the competitive electronic positioning effects versus localized thermodynamic steric strain, select the geometric structural option representing the principal isolated regioisomer product among the choices plotted below:

(A)


(B)


(C)


(D)


Q12. An environmental monitoring unit assesses the chemical configuration of an open industrial effluent stream. The laboratory measures the Chemical Oxygen Demand (COD) and the 5-day Biochemical Oxygen Demand (BOD_5) parameters of the source fluid. If the analysis gives a BOD_5/COD ratio value of exactly 0.15, what conclusion must be drawn regarding the treatability profile of this waste stream?

(A) The water stream is highly biodegradable and can undergo direct aerobic bacterial treatment.

(B) The water contains a massive fraction of non-biodegradable toxic chemical pollutants requiring advanced chemical oxidation.

(C) The oxygen content of the wastewater stream is perfectly balanced for direct domestic discharge.

(D) Pathogenic bacterial load is completely absent from the wastewater Matrix.

Q13. The configuration of molecular orbitals for the heteronuclear diatomic chemical species nitric oxide (NO) is derived using the linear combination of atomic orbitals (LCAO) approach. What is the precise distribution of the single unpaired electron in the ground state electronic blueprint of the NO molecule?

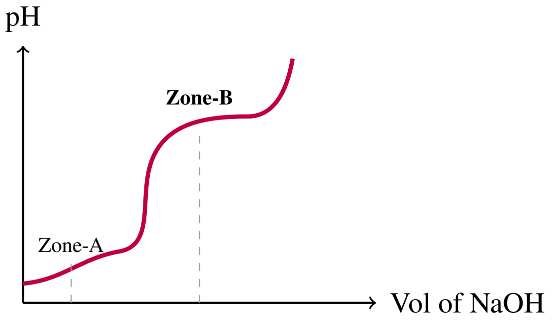
(A) It occupies a bonding σ_{2p_z} molecular orbital.

(B) It resides inside a non-bonding $2p$ atomic orbital of the nitrogen atom.

(C) It is localized within an antibonding π^*_{2p} molecular orbital.

(D) It is placed inside an antibonding $\sigma^*_{2p_z}$ molecular orbital.

Q14. A precise analytical titration is conducted by adding an aqueous solution of a strong base (NaOH) to a complex weak polyprotic acid matrix as outlined in the titration graph below. Identify the exact operating buffer equation model that governs the system's flat stabilization plateau region marked as Zone-B:



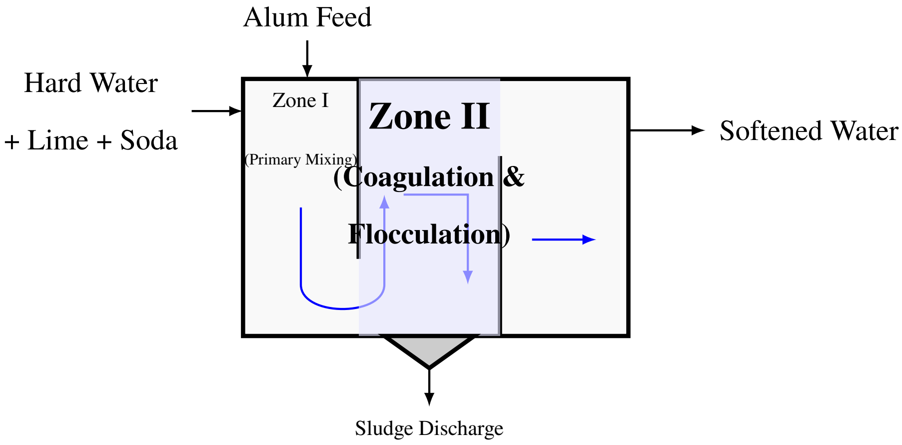
(A) $\text{pH} = \text{p}K_{a1} + \log \frac{[\text{H}_2\text{A}^-]}{[\text{H}_3\text{A}]}$

(B) $\text{pH} = \text{p}K_{a2} + \log \frac{[\text{HA}^{2-}]}{[\text{H}_2\text{A}^-]}$

(C) $\text{pH} = \frac{\text{p}K_{a1}+\text{p}K_{a2}}{2}$

(D) $\mathrm{pH} = 14 - \mathrm{p}K_b - \log \frac{[\mathrm{A}^{3-}]}{[\mathrm{HA}^{2-}]}$

Q15. An industrial water treatment plant utilizes a continuous cold lime-soda softening reactor configuration to eliminate temporary and permanent hardness from a municipal feed. Identify the specific structural compartment or phase zone within the processing basin layout shown below where the addition of alum ($Al_2(SO_4)_3$) completes the flocculation of fine suspended precipitates ($CaCO_3$ and $Mg(OH)_2$) right before entering the clear water sedimentation filter bed:



(A) Zone I (Primary Mixing)

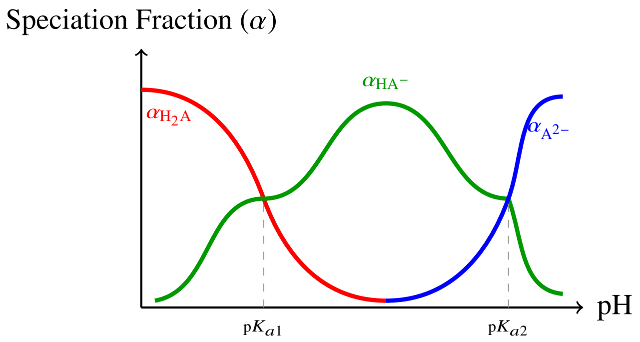
(B) Zone II (Coagulation & Flocculation)

(C) Sludge Discharge Chamber

(D) Softened Water Filter Bed Outlet

Section–B — 5 Questions × 2 Marks Each (No Negative Marking) [One or More Correct]

Q16. A high-precision analytical laboratory monitors the step-wise hydrolysis equilibria of a dibasic sodium salt (Na_2A) in an aqueous chamber. The relative fractional distributions (α) of the conjugate species (A^{2-}, HA^-, and H_2A) are recorded via an electrochemical sensor array as the system pH varies. Select all the scientifically true declarations from the evaluation choices provided:



(A) At the distinct intersection thresholds where $\alpha_{H_2A} = \alpha_{HA^-}$ and $\alpha_{HA^-} = \alpha_{A^{2-}}$, the pH coordinates of the solution become numerically equal to pK_{a1} and pK_{a2} of the parent polyprotic acid respectively.

(B) The first-stage hydrolysis constant (K_{h1}) for the dianion particle ($A^{2-} + H_2O \rightleftharpoons HA^- + OH^-$) is mathematically interrelated to the water autoionization constant (K_w) via the expression $K_{h1} = \frac{K_w}{K_{a1}}$.

(C) A solution containing purely the intermediate amphiprotic macro-ion HA^- establishes a pH profile that can be closely approximated by the independent relationship $\text{pH} = \frac{\text{p}K_{a1}+\text{p}K_{a2}}{2}$, provided the concentration is sufficiently higher than K_{a1}.

(D) The total summation of the distribution fractions for all three interconverting carbon-containing species ($\alpha_{H_2A} + \alpha_{HA^-} + \alpha_{A^{2-}}$) at any single isolated pH value along the timeline must strictly equate to 1.0.

Q17. The commercial synthesis of anhydrous ammonia (NH_3) via the classical Haber-Bosch configuration relies deeply on applying Le Chatelier's equilibrium principles. Choose all the valid engineering parameters or conditions that are correct for maximizing the industrial reactor output profile:

(A) Continuous condensation and removal of liquid ammonia from the reaction zone drives the equilibrium state forward.

(B) Because the formation of ammonia gas is exothermic, operating at extremely high temperature zones (> 2000°C) maximizes the net equilibrium yield constant.

(C) Increasing the operational pressure values up to 200 atm shifts the system toward the product side due to volume contraction.

(D) The incorporation of a finely divided iron (Fe) catalyst containing molybdenum (Mo) as a promoter alters the net overall enthalpy (ΔH) value of the synthesis.

Q18. Consider the chemical kinetic behaviors and stereochemical features of a tertiary alkyl halide substrate undergoing substitution and elimination pathways in a strongly basic alcoholic matrix. Which of the following statements are true?

(A) The substitution reaction proceeds via a two-step S_N1 mechanism involving a planar carbocation intermediate.

(B) A higher concentration of a strong nucleophile directly speeds up the rate of an S_N1 pathway.

(C) The competitive E2 elimination mechanism requires a strict anti-periplanar spatial relationship between the leaving halogen atom and the beta-proton.

(D) Choosing a polar protic solvent layout selectively stabilizes the intermediate ionic states, accelerating the initial ionization rate.

Q19. Which of the following quantum statements or structural selection limits regarding electron setups and wave functions within multielectron systems are theoretically sound?

(A) The Pauli Exclusion Principle mandates that an asymmetric total electronic wave function must invert its mathematical sign upon exchanging any pair of coordinates.

(B) The total number of angular nodes for any specific atomic orbital solution is determined solely by its azimuthal quantum number l.

(C) Chromium ($Z = 24$) and Copper ($Z = 29$) exhibit anomalous ground-state electron distributions due to the extra exchange energy stability associated with symmetric half-filled and fully-filled subshell configurations.

(D) The principal quantum number n defines the precise number of angular node surfaces generated within the electron cloud.

Q20. An aqueous buffer matrix is formulated by mixing a weak base with its conjugate acid salt. Which of the given assertions accurately specify the operational constraints or performance profiles of this buffer system?

(A) The pH value of a basic buffer solution remains practically unchanged upon minor dilutions because the ratio of salt concentration to weak base concentration stays constant.

(B) The maximum buffering capacity is reached when the solution pH becomes numerically equal to the operating pK_b value of the base.

(C) Adding a small quantity of a strong mineral acid to this system converts the active buffering components, altering the net system pH only minimally.

(D) The operational buffer range of a chemical system is widely accepted to span a total window defined by pK_a ± 1.

Detailed Solutions

Q1.

Solution

Concept: The number of nodes in a hydrogenic orbital determines its quantum state. The total number of radial nodes is mathematically defined as $n - l - 1$, and the number of angular nodes equals the azimuthal quantum number l. The energy or frequency of the emitted photon during an electronic transition within a hydrogenic ion is given by the Rydberg formula adjusted for atomic number Z:

$$\nu = R_\infty c Z^2 \left(\frac{1}{n_{\text{final}}^2} - \frac{1}{n_{\text{initial}}^2} \right)$$

Solution:

1. **Determine the initial principal quantum number (n_{initial}):** Given that the number of angular nodes is 1, we have $l = 1$. The number of radial nodes is given as 3:

$$\text{Radial Nodes} = n_{\text{initial}} - l - 1 = 3 \implies n_{\text{initial}} - 1 - 1 = 3 \implies n_{\text{initial}} = 5$$

2. **Identify transition states and parameters:** * Initial state: $n_{\text{initial}} = 5$ * Final ground state: $n_{\text{final}} = 1$ * For highly ionized Lithium ($Z = 3$ since it is a hydrogenic element with $Z = 3$)

3. **Calculate the emission photon frequency (ν):**

$$\nu = R_\infty c (3)^2 \left(\frac{1}{1^2} - \frac{1}{5^2} \right) = 9 R_\infty c \left(1 - \frac{1}{25} \right)$$

$$\nu = 9 R_\infty c \left(\frac{24}{25} \right) = \frac{216}{25} R_\infty c$$

Final Answer: $\boxed{\frac{216}{25} R_\infty c}$

Answer: (A)

Go Back to Question 1

Q2.

Solution

Concept: The equilibrium constant K_c of a net chemical reaction composed of multiple individual acid-base steps can be expressed as a ratio of the corresponding ionization constants (K_a) by checking the algebraic combination of their reactions.

Solution:

1. **Break down the individual chemical reactions:** * The acid dissociation equilibrium of HA is given by:

$$\mathrm{HA(aq)} \rightleftharpoons \mathrm{H^+(aq)} + \mathrm{A^-(aq)} \quad K_a(\mathrm{HA}) = \frac{[\mathrm{H^+}][\mathrm{A^-}]}{[\mathrm{HA}]} = 1.0 \times 10^{-5}$$

* The acid dissociation equilibrium of HB is given by:

$$\mathrm{HB(aq)} \rightleftharpoons \mathrm{H^+(aq)} + \mathrm{B^-(aq)} \quad K_a(\mathrm{HB}) = \frac{[\mathrm{H^+}][\mathrm{B^-}]}{[\mathrm{HB}]} = 4.0 \times 10^{-6}$$

2. **Combine to find the competitive proton exchange target reaction:**

$$\mathrm{A^-(aq)} + \mathrm{HB(aq)} \rightleftharpoons \mathrm{HA(aq)} + \mathrm{B^-(aq)}$$

Notice that this targeted equation can be obtained by adding the dissociation of HB to the reverse dissociation reaction of HA:

$$K_c = \frac{[\mathrm{HA}][\mathrm{B^-}]}{[\mathrm{A^-}][\mathrm{HB}]} = \frac{K_a(\mathrm{HB})}{K_a(\mathrm{HA})}$$

3. **Substitute numerical values into the expression:**

$$K_c = \frac{4.0 \times 10^{-6}}{1.0 \times 10^{-5}} = 0.40$$

Final Answer: $\boxed{0.40}$

$\boxed{\textbf{Answer: (A)}}$

Go Back to Question 2

Q3.

Solution

Concept: The electric potential E_{cell} of a concentration cell consisting of identical metal electrodes immersed in different concentration pools of the same metal ion is modeled by the Nernst Equation. At 298 K, for a standard n-electron process with an assumed ideal activity coefficient ($\gamma = 1$), the equation is:

$$E_{\text{cell}} = E^{\circ}_{\text{cell}} - \frac{0.0591}{n} \log \frac{[\mathrm{M}^{n+}]_{\text{anode}}}{[\mathrm{M}^{n+}]_{\text{cathode}}}$$

Solution:

1. **Identify cell parameters:** * The standard cell potential for any concentration cell is identically zero ($E^{\circ}_{\text{cell}} = 0\,\mathrm{V}$). * The electrochemical reduction half-reaction involves copper ions: $\mathrm{Cu}^{2+} + 2e^{-} \rightarrow \mathrm{Cu}$, hence $n = 2$. * Electrode-1 serves as the Anode: $[\mathrm{Cu}^{2+}]_1 = 0.1\,\mathrm{M}$. * Electrode-2 serves as the Cathode: $[\mathrm{Cu}^{2+}]_2 = 0.001\,\mathrm{M}$.
2. **Calculate the potential value using the Nernst Equation:**

$$E_{\text{cell}} = 0 - \frac{0.0591}{2} \log \frac{0.1}{0.001}$$

$$E_{\text{cell}} = -\frac{0.0591}{2} \log(100) = -\frac{0.0591}{2} \times 2 = -0.0591\ \mathrm{V}$$

Final Answer: $\boxed{-0.0591\ \mathrm{V}}$

Answer: (B)

Go Back to Question 3

Q4.

Solution

Concept: Copper concentrates extracted via pyrometallurgy generally contain high fractions of iron sulfide (FeS) impurities. During smelting operations in a reverberatory furnace, silica ($\mathrm{SiO_2}$) is intentionally introduced as an acidic fluxing agent to chemically combine with basic iron(II) oxide (FeO) intermediates to separate them as a low-density liquid slag layer.

Solution:

1. **Trace the chemistry inside the furnace room:** * Iron sulfide is oxidized to form iron(II) oxide:

$$2\mathrm{FeS(s)} + 3\mathrm{O_2(g)} \rightarrow 2\mathrm{FeO(s)} + 2\mathrm{SO_2(g)}$$

* The basic impurity oxide (FeO) then reacts with the added acidic flux, silica ($\mathrm{SiO_2}$):

$$\mathrm{FeO(s)} + \mathrm{SiO_2(s)} \rightarrow \mathrm{FeSiO_3(l)} \quad \text{(Slag)}$$

2. **Match with choices:** The chemical identity of the added flux is silica ($\mathrm{SiO_2}$), and the corresponding composition of the fusible liquid slag layer is iron(II) silicate ($\mathrm{FeSiO_3}$).

Final Answer: $\boxed{\text{Silica } (\mathrm{SiO_2}),\ \mathrm{FeSiO_3}}$

Answer: (B)

Go Back to Question 4

Q5.

Solution

Concept: The nomenclature rules defined by IUPAC require identifying the principal functional group to establish seniority ranking, followed by selecting the longest continuous carbon chain containing maximum unsaturation and numbering it to give the main group the lowest locant number.

Solution:

1. **Analyze functional group seniority rankings:** * The molecule contains an aldehyde group ($-CHO$), a hydroxyl group ($-OH$), an alkene ($= CH-$), and an alkyne ($-C \equiv C-$). * The senior principal functional group is the aldehyde ($-CHO$), which defines the suffix as "-nal" and establishes position C1.

2. **Number the main carbon chain path:** Expanding the formula $\overset{7\,6}{HC} \equiv \overset{5}{C} - \overset{4}{C}(CH_3) = \overset{3}{CH} - \overset{2}{CH}(OH) - \overset{1}{CH_2} - CHO$: * Carbon-1: $-CHO$ (Aldehyde carbon) * Carbon-2: Contains $-OH$ substituent → 2-hydroxy (Wait, let's recount based on structure: $HC \equiv C - C(CH_3) = CH - CH(OH) - CH_2 - CHO$). * Let's layout carefully from right to left:

$$\text{C1: CHO}, \quad \text{C2: CH}_2, \quad \text{C3: CH(OH)}, \quad \text{C4: CH} = \text{C}, \quad \text{C5: C(CH}_3), \quad \text{C6: C} \equiv, \quad \text{C7: CH}$$

* Let's check substituents based on this correct numbering order: * A hydroxyl ($-OH$) group is located at C3 → 3-Hydroxy * A methyl group ($-CH_3$) is located at C5 → 5-Methyl * Double bond is at position C4 → 4-en * Triple bond is at position C6 → 6-yn

3. **Assemble the full name systematically:** Combining the parts alphabetically (Hydroxy before Methyl): 3-Hydroxy-5-methylhept-4-en-6-ynal. This matches Option D.

Final Answer: $\boxed{\text{3-Hydroxy-5-methylhept-4-en-6-ynal}}$

$\boxed{\textbf{Answer: (D)}}$

Go Back to Question 5

Q6.

Solution

Concept: Active halogen radical species like chlorine ($Cl^\bullet$) and chlorine monoxide ($ClO^\bullet$) cause catalytic breakdown cycles of ozone in the stratospheric layer. Atmospheric reservoir sinks trap these highly active radicals into stable, temporarily inactive chemical species, slowing down ozone depletion.

Solution:

The primary global chemical reservoir states that safely store active chlorine components in the lower stratosphere are:

(a) **Hydrogen chloride (HCl):** Formed when chlorine radicals abstract a hydrogen atom from methane:

$$Cl^\bullet + CH_4 \rightarrow HCl + CH_3^\bullet$$

(b) **Chlorine nitrate ($ClONO_2$):** Formed by the combination of chlorine monoxide with nitrogen dioxide:

$$ClO^\bullet + NO_2 \rightarrow ClONO_2$$

These reservoir species do not directly destroy ozone but can later react on the surface of Polar Stratospheric Clouds (PSCs) to release active chlorine gas. This matches Option A.

Final Answer: $\boxed{\text{HCl and ClONO}_2}$

$\boxed{\textbf{Answer: (A)}}$

Go Back to Question 6

Q7.

Solution

Concept: The spatial geometry and configuration parameters of a polyatomic molecule or coordinate ion are evaluated by counting the central nucleus valence shell electron pairs (Steric Number, SN):

$$SN = \frac{1}{2}\,[\text{Valence electrons of central atom} + \text{Number of monovalent ligands} - \text{Charge}]$$

Solution:

1. **Calculate the Steric Number for XeF_5^-:** * Central atom Xenon (Xe) has 8 valence electrons. * Number of monovalent Fluorine (F) ligands = 5. * Net anionic charge = -1.

$$SN = \frac{8+5-(-1)}{2} = \frac{14}{2} = 7$$

2. **Determine Hybridization and Spatial Geometry:** * A steric number of 7 indicates sp^3d^3 orbital hybridization, which natively generates a pentagonal bipyramidal core geometry framework. * Out of the 7 electron pairs, 5 are bonding pairs ($Xe - F$) and 2 are non-bonding lone pairs. * To minimize lone pair-lone pair electrostatic repulsion according to VSEPR theory, the 2 lone pairs take positions opposite to one another along the collinear axial vertices (180° apart), forcing the 5 Fluorine atoms into a perfectly flat equatorial configuration. * Therefore, the resulting molecular shape is planar pentagonal with 2 axial lone pairs.

Final Answer: $\boxed{\text{sp}^3\text{d}^3\text{, Planar Pentagonal with 2 axial lone pairs}}$

$\boxed{\textbf{Answer: (A)}}$

Go Back to Question 7

Q8.

Solution

Concept: An acid-base indicator HIn acts as a weak organic acid that exhibits a pH-dependent dissociation equilibrium:

$$\mathrm{HIn(aq)} \rightleftharpoons \mathrm{H^+(aq)} + \mathrm{In^-(aq)} \quad K_a = \frac{[\mathrm{H^+}][\mathrm{In^-}]}{[\mathrm{HIn}]}$$

Taking the negative logarithm yields the Henderson-Hasselbalch indicator equation: $\mathrm{pH} = \mathrm{p}K_a + \log \frac{[\mathrm{In^-}]}{[\mathrm{HIn}]}$.

Solution:

1. **Analyze the crossing point condition from the graph:** At the point where the fraction curves intersect, the relative distribution concentrations are exactly equal:

$$\alpha_{\mathrm{In^-}} = \alpha_{\mathrm{HIn}} \implies [\mathrm{In^-}] = [\mathrm{HIn}]$$

2. **Relate pH to pK_a:** Substituting this equality into the indicator buffer model:

$$\mathrm{pH} = \mathrm{p}K_a + \log(1) \implies \mathrm{pH} = \mathrm{p}K_a$$

From the graphical intersection metric, this equivalence threshold occurs at pH = 5.4. Therefore, $\mathrm{p}K_a = 5.4$.

3. **Convert pK_a to the acid ionization constant K_a:**

$$K_a = 10^{-\mathrm{p}K_a} = 10^{-5.4} = 3.98 \times 10^{-6}$$

Final Answer: $\boxed{3.98 \times 10^{-6}}$

Answer: (A)

Go Back to Question 8

Q9.

Solution

Concept: Electrolysis of an aqueous solution containing a metal salt with inert platinum electrodes involves competitive redox discharges. The mass or moles of substances reacted are determined by Faraday's Laws of Electrolysis: Moles of electrons $(n_e) = \frac{I \cdot t}{F}$.

Solution:

1. **Identify the electrochemical half-reactions occurring at the electrodes:** * At the Cathode: Nickel ions are reduced to solid nickel: $\text{Ni}^{2+}(\text{aq}) + 2e^- \longrightarrow \text{Ni(s)}$ * At the Anode: Water is preferentially oxidized over sulfate ions, releasing oxygen gas and generating hydronium ions:

$$2\text{H}_2\text{O(l)} \longrightarrow \text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4e^-$$

2. **Calculate the total chemical equivalents of charge passed (n_e):** Given $I = 9.65\,\text{A}$, $t = 1000\,\text{s}$, and $F = 96500\,\text{C/mol}$:

$$n_e = \frac{9.65 \times 1000}{96500} = \frac{9650}{96500} = 0.1 \text{ mol of electrons}$$

3. **Determine the amount of generated H^+ ions and the resulting pH:** From the anode stoichiometry, the generation of 4 mol e^- corresponds to the production of 4 mol of H^+ ions. Thus, the moles of H^+ produced match the moles of electrons passed:

$$n(\text{H}^+) = n_e = 0.1 \text{ mol}$$

Since the volume of the solution pool is exactly $1.0\,\text{L}$, the concentration of hydronium ions is:

$$[\text{H}^+] = \frac{0.1 \text{ mol}}{1.0\,\text{L}} = 0.1\,\text{M} = 10^{-1}\,\text{M}$$

$$\text{pH} = -\log[\text{H}^+] = -\log(10^{-1}) = 1.00$$

Final Answer: $\boxed{1.00}$

Answer: (A)

Go Back to Question 9

Q10.

Solution

Concept: The shift in chemical equilibrium positions and reaction rates under changing pressure parameters is governed respectively by Le Chatelier's Principle and the Collision Theory of gas kinetics.

Solution:

Let us analyze the impacts of changing the operational pressure from 2 atm to 10 atm:

(a) **Equilibrium position and SO_3 Yield:** The given oxidation reaction is:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The total number of gaseous reactant moles is 3, while the product gaseous moles is 2. Increasing the external pressure shifts the equilibrium toward the side with fewer gas moles (the forward direction) to minimize the pressure stress. Consequently, the equilibrium yield of SO_3 scales up.

(b) **Reaction Rate Kinetics:** Boosting the total operating pressure increases the number of gas molecules per unit volume. This shortens the mean free path, increasing the collision frequency between SO_2 and O_2 molecules, which accelerates the forward reaction rate.

Thus, both the SO_3 yield and the reaction rate scale up. This corresponds to Option B.

Final Answer: $\boxed{SO_3 \text{ yield scales up; reaction rate scales up}}$

$\boxed{\textbf{Answer: (B)}}$

Go Back to Question 10

Q11.

Solution

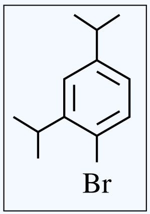
Concept: Electrophilic Aromatic Substitution (EAS) of multi-substituted benzene rings is guided by the electronic directing properties of the existing groups and steric hindrance. Alkyl groups like the *tert*-butyl group are ortho/para-directing via inductive effect and hyperconjugation.

Solution:

1. **Evaluate directing positions on 1,3-di-tert-butylbenzene:** * The two bulky *tert*-butyl groups are located meta to each other (positions C1 and C3). * Position C2 is located between both *tert*-butyl groups. * Positions C4 and C6 are equivalent and are ortho to one group and para to the other. * Position C5 is meta to both groups.

2. **Analyze competitive electronic vs. steric constraints:** * Carbon-2 is highly activated electronically because it is ortho to both activating *tert*-butyl groups. However, a *tert*-butyl group is extremely bulky. The steric hindrance at C2 is so severe that the incoming bulky bromonium ion (Br^+) cannot attack here. * Carbon-4 (or C6) is ortho to one *tert*-butyl group and para to the other. This position is highly activated electronically and offers much less steric resistance compared to C2. * Attack at C4 yields **4-bromo-1,3-di-tert-butylbenzene** as the principal isolated regioisomer product. This matches the drawing in Option A.

Final Answer:



Final Answer: $\boxed{\text{A}}$

$\boxed{\textbf{Answer: (A)}}$

Go Back to Question 11

Q12.

Solution

Concept: The ratio of the 5-day Biochemical Oxygen Demand to the Chemical Oxygen Demand (BOD_5/COD) serves as an indicator of the biodegradability profile of wastewater streams.

Solution:

1. **Interpret the ratio thresholds:** * A BOD_5/COD ratio ≥ 0.5 means the wastewater is highly biodegradable and easily treated via conventional biological methods. * A low ratio value (≤ 0.3) indicates that a large portion of the chemical compounds cannot be broken down biologically by microbes.

2. **Apply to the given stream state:** The measured ratio value is 0.15, which is significantly below 0.3. This demonstrates that the effluent stream contains a large fraction of non-biodegradable organic matter or toxic chemical pollutants. Consequently, standard biological treatment will fail, and advanced chemical oxidation processes are required to treat the waste stream. This aligns with Option B.

Final Answer: The water contains a massive fraction of non-biodegradable toxic chemical pollutants.

Answer: (B)

Go Back to Question 12

Q13.

Solution

Concept: Molecular Orbital Theory explains the electronic structure of heteronuclear diatomic molecules like nitric oxide (NO, 15 valence/total electrons) by mixing atomic orbitals of differing electronegativities.

Solution:

1. **Determine the molecular orbital filling blueprint for NO:** The 15 electrons of the NO molecule populate the molecular orbitals in the following order:

$$\sigma_{1s}^2\,\sigma_{1s}^{*2}\,\sigma_{2s}^2\,\sigma_{2s}^{*2}\,\sigma_{2p_z}^2\,(\pi_{2p_x}^2=\pi_{2p_y}^2)\,(\pi_{2p_x}^{*1}=\pi_{2p_y}^{*0})$$

2. **Identify the position of the unpaired electron:** The first 14 electrons completely fill all bonding and antibonding levels up through the π_{2p} bonding manifold. The 15th unpaired electron is placed into the next available higher-energy state, which is the degenerate antibonding π_{2p}^* molecular orbital. This matches Option C.

Final Answer: It is localized within an antibonding π_{2p}^* molecular orbital

Answer: (C)

Go Back to Question 13

Q14.

Solution

Concept: A polyprotic acid titration curve exhibits multiple distinct buffer zones and equivalence points. For a triprotic acid (H_3A), the titration progress sequentially neutralizes protons across separate distinct flat plateaus.

Solution:

1. **Map the ionization steps to the graphical regions:** * **Zone-A:** Corresponds to the first buffer plateau. Here, the first proton is being partially neutralized, establishing an equilibrium between remaining weak acid H_3A and its conjugate base H_2A^-. The governing model is:

$$\text{pH} = \text{p}K_{a1} + \log \frac{[H_2A^-]}{[H_3A]}$$

* The first sharp vertical jump represents the first equivalence point where H_3A has been completely converted to H_2A^-. * **Zone-B:** Corresponds to the second flat stabilization plateau. In this region, the second acidic proton is being neutralized, creating a secondary buffer system consisting of the weak acid species H_2A^- and its conjugate base product HA^{2-}.

2. **Formulate the equation for Zone-B:** The Henderson-Hasselbalch representation governing this second chemical buffer domain utilizes the second ionization constant $\text{p}K_{a2}$:

$$\text{pH} = \text{p}K_{a2} + \log \frac{[HA^{2-}]}{[H_2A^-]}$$

This matches Option B.

Final Answer: $\boxed{\text{pH} = \text{p}K_{a2} + \log \frac{[HA^{2-}]}{[H_2A^-]}}$

Answer: (B)

Go Back to Question 14

Q15.

Solution

Concept: In industrial municipal water softening, cold lime-soda processes chemically precipitate hardness ions as $CaCO_3$ and $Mg(OH)_2$. Alum ($Al_2(SO_4)_3$) is added as a coagulant to neutralize charges and bind these fine colloidal precipitates into larger flocs.

Solution:

1. **Analyze the structural layout zones of the reactor basin:** * **Zone I (Primary Mixing):** This chamber handles the initial introduction and rapid mechanical mixing of raw hard water feed with lime and soda chemicals. * **Zone II (Coagulation & Flocculation):** After primary mixing, the fluid enters this larger chamber. As shown in the diagram, the Alum Feed directly enters this zone. Alum hydrolyzes to form gelatinous $Al(OH)_3$ precipitates, which trap and aggregate the fine suspended $CaCO_3$ and $Mg(OH)_2$ particles into large flocs.
2. **Conclusion:** The flocculation process is completed within **Zone II (Coagulation & Flocculation)** before the aggregated sludge settles into the discharge base and clear water passes through the filter bed. This matches Option B.

Final Answer: $\boxed{\text{Zone II (Coagulation \& Flocculation)}}$

$\boxed{\textbf{Answer: (B)}}$

Go Back to Question 15

Q16.

Solution

Concept: The distribution profile of a polyprotic acid system is mapped by tracking the concentration fractions (α) of its conjugate species as a function of pH. The step-wise equilibria are dictated by the acid dissociation constants (K_{a1}, K_{a2}) and their thermodynamic interrelationship with salt hydrolysis constants (K_h).

Solution:

Let us systematically evaluate each analytical speciation declaration:

(A) **Intersection Thresholds:** From the Henderson-Hasselbalch equation for the first and second ionization stages:

$$\text{pH} = \text{p}K_{a1} + \log\frac{[\text{HA}^-]}{[\text{H}_2\text{A}]} \quad \text{and} \quad \text{pH} = \text{p}K_{a2} + \log\frac{[\text{A}^{2-}]}{[\text{HA}^-]}$$

At the crossover point thresholds where fractions are equal ($\alpha_{\text{H}_2\text{A}} = \alpha_{\text{HA}^-}$ and $\alpha_{\text{HA}^-} = \alpha_{\text{A}^{2-}}$), the log terms reduce to zero, meaning pH $=$ pK_{a1} and pH $=$ pK_{a2} respectively. This confirms Statement A is correct.

(B) **First-Stage Hydrolysis Constant Relationship:** For a dibasic salt (Na_2A), the first-stage hydrolysis involving the most basic dianion particle is:

$$\text{A}^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HA}^-(\text{aq}) + \text{OH}^-(\text{aq}) \quad K_{h1} = \frac{[\text{HA}^-][\text{OH}^-]}{[\text{A}^{2-}]}$$

Multiplying the numerator and denominator by $[\text{H}^+]$ reveals that K_{h1} relates to the *second* acid dissociation constant of the parent acid: $K_{h1} = \frac{K_w}{K_{a2}}$, not K_{a1}. Thus, Statement B is incorrect.

(C) **Amphiprotic Intermediate pH Approximation:** The intermediate species HA^- undergoes simultaneous acid dissociation and hydrolysis. The rigorous proton-balance equation can be approximated by the expression pH $= \frac{\text{p}K_{a1}+\text{p}K_{a2}}{2}$ as long as the analytical concentration is significantly greater than K_{a1} and autoionization of water is negligible. This confirms Statement C is correct.

(D) **Mass Balance Conservation Limits:** Since the parent acid can only exist in one of these three interconverting forms, the sum of their individual distribution fractions must satisfy the mass balance constraint at any given coordinate: $\alpha_{\text{H}_2\text{A}} + \alpha_{\text{HA}^-} + \alpha_{\text{A}^{2-}} = 1.0$. This confirms Statement D is correct.

Final Answers: $\boxed{\text{A, C, and D}}$

$\boxed{\textbf{Answer: (A, C, D)}}$

Go Back to Question 16

Q17.

Solution

Concept: The synthesis of ammonia via the Haber-Bosch process is governed by Le Chatelier's principle and chemical kinetics:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92.4\,\text{kJ/mol}$$

Solution:
Let us evaluate each engineering parameter optimization parameter:

(A) **Continuous Product Removal:** Continuously condensing and removing NH_3 out of the reaction stream keeps the reaction quotient Q_p below the equilibrium constant K_p, shifting the equilibrium position forward. This confirms Statement A is correct.

(B) **Temperature Effects:** Because the forward synthesis is highly exothermic ($\Delta H < 0$), an increase in temperature shifts the equilibrium backward, decreasing the equilibrium yield. High industrial operating temperatures ($\sim 400 - 450°\text{C}$) are a kinetic compromise to ensure catalyst activity, but extremely high values ($> 2000°\text{C}$) would eliminate the yield entirely. Thus, Statement B is incorrect.

(C) **Pressure Effects:** The forward reaction results in a net reduction of gaseous moles ($\Delta n_g = 2 - 4 = -2$). According to Le Chatelier's principle, operating at elevated pressures (200 atm) shifts the system towards the side with fewer gas moles (the product side). This confirms Statement C is correct.

(D) **Catalyst Role Functions:** The implementation of a finely divided iron (Fe) catalyst with a molybdenum (Mo) promoter increases the rate at which equilibrium is reached by lowering the activation energy barrier (E_a). It does not alter state functions such as the overall enthalpy change (ΔH) of the reaction. Thus, Statement B is incorrect.

Final Answers: $\boxed{\text{A and C}}$

$\boxed{\textbf{Answer: (A, C)}}$

Go Back to Question 17

Q18.

Solution

Concept: Tertiary alkyl halides placed under strongly basic and highly polar reaction environments participate in competing unimolecular (S_N1, E1) and bimolecular (S_N2, E2) mechanistic path channels.

Solution:

Let us test the validity of each substitution and elimination assertion:

(A) **S_N1 Carbocation Steps:** Substitution of highly hindered tertiary alkyl substrates undergoes a two-step S_N1 path. The initial slow rate-determining step releases the halogen leaving group to generate a flat, planar carbocation intermediate. This confirms Statement A is correct.

(B) **Kinetic Rate Dependence:** The rate law of an S_N1 pathway depends exclusively on the concentration of the alkyl halide substrate (Rate $= k[\text{R-X}]$). Increasing the strength or concentration of an external nucleophile has no impact on this rate. Thus, Statement B is incorrect.

(C) **Stereochemical Core Constraints of E2:** A concerted bimolecular elimination (E2) pathway requires a strict anti-periplanar spatial alignment (dihedral angle $\theta = 180°$) between the breaking $C_\beta - H$ bond and the $C_\alpha - X$ bond to allow efficient orbital alignment for π-bond formation. This confirms Statement C is correct.

(D) **Solvent Ionization Stabilization:** Polar protic solvents possess high dielectric constants and stabilize the developing charge separation in the transition state and the resulting carbocation/leaving group ions via solvation, lowering the activation energy for the initial ionization step. This confirms Statement D is correct.

Final Answers: $\boxed{\text{A, C, and D}}$

$\boxed{\textbf{Answer: (A, C, D)}}$

Go Back to Question 18

Q19.

Solution

Concept: The structural features and electronic setups within multielectron systems are restricted by core wave-mechanical constraints and quantum number selection limits.

Solution:

Let us assess each quantum mechanical assertion:

(A) **Pauli Exclusion Principle Wave Formulation:** In quantum mechanics, electrons are identical fermions. The Pauli Exclusion Principle mandates that the total electronic wave function must be antisymmetric, meaning it changes its mathematical sign upon swapping the spatial and spin coordinates of any two electrons. This confirms Statement A is correct.

(B) **Angular Node Quantization:** The total number of angular node surfaces (planes or cones) generated within an orbital is exactly equal to the azimuthal quantum number l. This confirms Statement B is correct.

(C) **Anomalous Electron Shell Configurations:** Chromium ($Z = 24$: $[\mathrm{Ar}]3d^5 4s^1$) and Copper ($Z = 29$: $[\mathrm{Ar}]3d^{10} 4s^1$) deviate from the regular Aufbau filling order because shifting an electron from the $4s$ to the $3d$ subshell yields half-filled and fully-filled $3d$ configurations. These derive extra stability from maximum exchange energy and increased spherical symmetry. This confirms Statement C is correct.

(D) **Principal Quantum Number Meaning:** The principal quantum number n defines the primary energy level and shell size, determining the *total* number of nodes ($n - 1$). The number of angular nodes depends solely on l, whereas the number of radial nodes is $n - l - 1$. Thus, Statement D is incorrect.

Final Answers: $\boxed{\text{A, B, and C}}$

$\boxed{\textbf{Answer: (A, B, C)}}$

Go Back to Question 19

Q20.

Solution

Concept: An aqueous basic buffer solution consists of a weak base and its conjugate acid salt. Its operating characteristics are modeled using the Henderson-Hasselbalch equation:

$$\text{pOH} = \text{p}K_b + \log \frac{[\text{Conjugate Acid}]}{[\text{Weak Base}]}$$

Solution:
Let us test the validity of each buffer performance profile:

(A) **Dilution Effects on Matrix:** Upon minor dilution, the volume changes identically for both components, meaning the ratio of salt concentration to weak base concentration remains fixed. Consequently, the pOH (and thus the pH) stays practically unchanged. This confirms Statement A is correct.

(B) **Maximum Buffering Capacity:** Maximum buffering capacity is achieved when the concentration of the weak base equals its conjugate acid, reducing the log term to zero. This occurs when $\text{pOH} = \text{p}K_b$, which translates to a pH of $14 - \text{p}K_b$, not $\text{pH} = \text{p}K_b$. Thus, Statement B is incorrect.

(C) **Acid Neutralization Resistance:** When a small amount of strong mineral acid (H^+) is introduced, it is neutralized by the weak base component to form the conjugate acid. Because this merely shifts the component ratio slightly within the log term, the net change in system pH is minimal. This confirms Statement C is correct.

(D) **Operational Buffer Range:** A buffer maintains adequate stabilization capacity when the component ratio stays within a range of 0.1 to 10. This translates to an operational window defined by $\text{pH} = \text{p}K_a \pm 1$ (where $\text{p}K_a$ is the acid dissociation constant of the conjugate acid). This confirms Statement D is correct.

Final Answers: $\boxed{\text{A, C, and D}}$

Answer: (A, C, D)

Go Back to Question 20

Answer Key

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