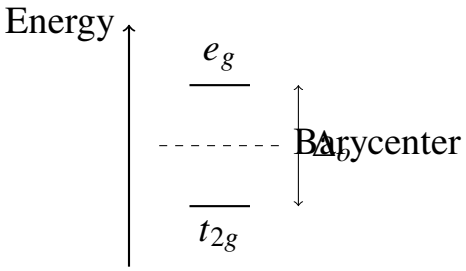
IISER Chemistry Sample Paper-2

Duration: 45 Minutes **Maximum Marks: 60**

Instructions

- This paper contains **15** Multiple Choice Questions (Single Correct).
- Each correct answer carries **+4 marks**.
- Each incorrect answer carries: **−1** marks.
- Unattempted questions carry **0** marks.
- Only one option is correct for each question.
- Use of mobile phones, smartwatches, calculators, or any electronic gadgets is strictly prohibited.

Q1. Consider the complex ion $[Co(NH_3)_6]^{3+}$. According to Crystal Field Theory (CFT), what is the Crystal Field Stabilization Energy (CFSE) and the number of unpaired electrons respectively? (Assume NH_3 is a strong field ligand).



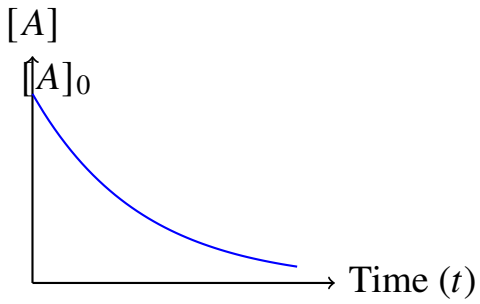
(A) $-2.4\Delta_o$, 0

(B) $-1.2\Delta_o$, 3

(C) $-0.4\Delta_o$, 4

(D) $-2.4\Delta_o$, 1

Q2. For a first-order reaction $A \rightarrow B$, the concentration of reactant A varies with time as shown in the graph below. If the initial concentration $[A]_0 = 0.8$ M and the concentration at $t = 20$ min is 0.2 M, what is the rate constant of the reaction?



(A) 0.0693 min^{-1}

(B) 0.0346 min^{-1}

(C) 0.1386 min^{-1}

(D) 0.0173 min^{-1}

Q3. Among the following carbocations, which one is stabilized by the most extensive resonance delocalization of the positive charge?

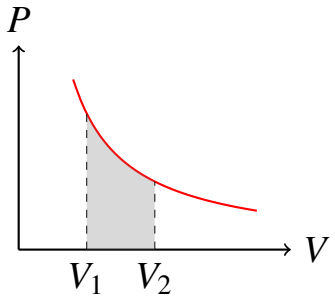
(A) Ethyl carbocation

(B) Isopropyl carbocation

(C) Benzyl carbocation

(D) Triphenylmethyl carbocation

Q4. One mole of an ideal gas expands isothermally from volume V_1 to V_2 at temperature T. If $V_2 = 2V_1$, what is the magnitude of work done by the gas?



(A) $RT \ln 2$

(B) RT

(C) $2RT$

(D) Zero

Q5. According to Molecular Orbital (MO) theory, which of the following diatomic molecules contains two unpaired electrons in its ground state?

(A) N_2

(B) O_2

(C) F_2

(D) C_2

Q6. Treatment of benzaldehyde with acetone in the presence of dilute aqueous sodium hydroxide followed by heating yields which of the following as the major organic product?

(A) 4-Phenylbut-3-en-2-one

(B) 1-Phenylbut-1-en-2-one

(C) Benzyl alcohol and sodium benzoate

(D) Cinnamic acid

Q7. Which property of glucose is NOT explained by its open-chain structure and led to the proposal of its cyclic hemiacetal form?

(A) Reduction by H_2/Ni to sorbitol.

(B) Reaction with NH_2OH to form an oxime.

(C) Absence of reaction with $NaHSO_3$.

(D) Oxidation by Bromine water to gluconic acid.

Q8. For the standard Hydrogen electrode (SHE), if the pressure of H_2 gas is increased from 1 atm to 100 atm at constant H^+ concentration ($1M$), the electrode potential at 298 K will become:

(A) +0.059 V

(B) −0.059 V

(C) +0.118 V

(D) −0.118 V

Q9. Which of the following phosphorus oxyacids is a monoprotic acid?

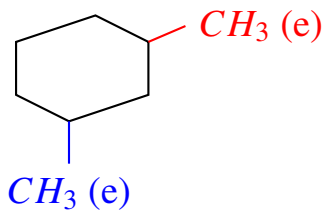
(A) H_3PO_4

(B) H_3PO_3

(C) H_3PO_2

(D) $H_4P_2O_7$

Q10. The most stable conformation of trans-1,2-dimethylcyclohexane is the one in which:



(A) Both methyl groups are axial.

(B) Both methyl groups are equatorial.

(C) One methyl is axial and one is equatorial.

(D) The molecule adopts a boat conformation.

Q11. For the decomposition of $N_2O_4(g) \rightleftharpoons 2NO_2(g)$, the degree of dissociation at equilibrium is α. If the total pressure is P, the equilibrium constant K_p is:

(A) $\frac{4\alpha^2 P}{1-\alpha^2}$

(B) $\frac{\alpha^2 P}{4(1-\alpha^2)}$

(C) $\frac{4\alpha P}{1-\alpha}$

(D) $\frac{\alpha^2 P}{1-\alpha}$

Q12. The number of geometric isomers possible for the square planar complex $[Pt(NH_3)(NH_2OH)(Py)(NO_2)]^+$ is:

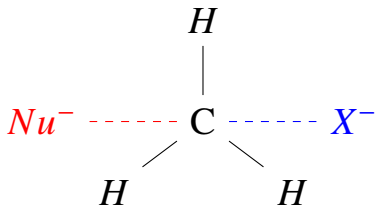
(A) 2

(B) 3

(C) 4

(D) 6

Q13. Which of the following alkyl halides undergoes S_N2 reaction at the fastest rate?



(A) CH_3Cl

(B) CH_3CH_2Cl

(C) $(CH_3)_2CHCl$

(D) $(CH_3)_3CCl$

Q14. Which of the following liquid pairs forms an ideal solution over the entire range of concentrations?

(A) Acetone and Chloroform

(B) Ethanol and Water

(C) Benzene and Toluene

(D) Nitric acid and Water

Q15. In the Cannizzaro reaction, an aldehyde without α-hydrogens undergoes:

(A) Oxidation only

(B) Reduction only

(C) Self-oxidation and reduction (disproportionation)

(D) Polymerization

Detailed Solutions

Q1.

Solution

Concept: Crystal Field Theory (CFT) states that strong field ligands like NH_3 cause a large crystal field splitting energy (Δ_o), forcing electrons to pair up in the lower-energy t_{2g} orbitals before entering the higher-energy e_g orbitals.

Solution:

(a) In $[Co(NH_3)_6]^{3+}$, Cobalt is in the +3 oxidation state. The electronic configuration of free Co^{3+} is $[Ar]3d^6$.

(b) Because NH_3 acts as a strong field ligand, the pairing energy (P) is lower than Δ_o. This induces a low-spin configuration where all six d-electrons pair up entirely within the t_{2g} subshell.

(c) The resulting orbital occupancy is $t_{2g}^6 e_g^0$. Because all electrons are paired, the number of unpaired electrons is exactly 0.

(d) The formula used to calculate Crystal Field Stabilization Energy (CFSE) for an octahedral environment is:

$$\text{CFSE} = (-0.4 \times n_{t_{2g}} + 0.6 \times n_{e_g})\Delta_o$$

Substituting the electron values gives:

$$\text{CFSE} = (-0.4 \times 6 + 0.6 \times 0)\Delta_o = -2.4\Delta_o$$

Final Answer: -2.4 Δ_o, 0

Answer: (A)

Go Back to Question 1

Q2.

Solution

Concept: For any first-order chemical reaction, the rate constant (k) is independent of the initial concentration and can be directly calculated using the integrated first-order rate law equation linking concentration and time.

Solution:

(a) The integrated rate equation for a first-order reaction is expressed as:

$$k = \frac{2.303}{t} \log\left(\frac{[A]_0}{[A]_t}\right)$$

(b) We are given the following experimental parameters from the problem context: initial concentration $[A]_0 = 0.8$ M, final concentration at the specified time $[A]_t = 0.2$ M, and time elapsed $t = 20$ min.

(c) Substituting these values directly into our first-order integrated rate expression yields:

$$k = \frac{2.303}{20} \log\left(\frac{0.8}{0.2}\right) = \frac{2.303}{20} \log(4)$$

(d) Using the identity $\log(4) \approx 0.6021$, the calculation simplifies to:

$$k = \frac{2.303 \times 0.6021}{20} = \frac{1.386}{20} = 0.0693 \text{ min}^{-1}$$

Final Answer: 0.0693 min^{-1}

Answer: (A)

Go Back to Question 2

Q3.

Solution

Concept: The thermodynamic stability of a carbocation intermediate is heavily enhanced by resonance effect. Greater delocalization of the positive charge over an extended system of conjugated double bonds lowers the potential energy.

Solution:

(a) Ethyl and isopropyl carbocations lack an adjacent conjugated π-system and are instead stabilized only by weaker inductive effects and hyperconjugation.

(b) The benzyl carbocation allows the vacant p-orbital containing the positive charge to conjugate with one aromatic ring, delocalizing the charge across four total resonant contributors.

(c) The triphenylmethyl carbocation (trityl cation) possesses three distinct phenyl rings directly attached to the electron-deficient central carbon atom.

(d) The positive charge is extensively delocalized throughout all three aromatic systems, generating a highly stable species with a large total number of major canonical structures.

Final Answer: Triphenylmethyl carbocation

Answer: (D)

Go Back to Question 3

Q4.

Solution

Concept: During an isothermal expansion of an ideal gas, the temperature remains constant, meaning the internal energy change is zero. The work done relates directly to the boundary change integrated across the pressure-volume curve.

Solution:

(a) The mathematical expression for the magnitude of work done during a reversible isothermal expansion of an ideal gas is derived from integration:

$$W = nRT \ln\left(\frac{V_2}{V_1}\right)$$

(b) The problem establishes that the quantity of gas $n = 1$ mole, and the final boundary condition satisfies the relationship $V_2 = 2V_1$.

(c) Substituting these specific variables into the classic thermodynamic equation gives:

$$W = (1)RT \ln\left(\frac{2V_1}{V_1}\right)$$

(d) Canceling out the common volume term simplifies the expression directly to $RT \ln 2$, matches the shaded geometric area beneath the P-V curve.

Final Answer: RT ln 2

Answer: (A)

Go Back to Question 4

Q5.

Solution

Concept: Molecular Orbital (MO) Theory determines magnetic properties by filling molecular orbitals in increasing order of energy. Unpaired electrons in the highest occupied molecular orbitals yield paramagnetic behavior.

Solution:

(a) The oxygen molecule (O_2) contains a total of 16 electrons. The ground-state molecular orbital electronic configuration is written as follows:

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

(b) According to Hund's Rule of maximum multiplicity, the final two valence electrons must enter the degenerate antibonding orbitals singly with parallel spins.

(c) This leaves O_2 with two unpaired electrons in its π^* antibonding orbitals, explaining its experimentally observed paramagnetism.

(d) In contrast, N_2, F_2, and C_2 feature completely paired electronic configurations within their ground state valence molecular orbitals.

Final Answer: O_2

Answer: (B)

Go Back to Question 5

Q6.

Solution

Concept: When an aldehyde without α-hydrogens reacts with a ketone containing α-hydrogens in a basic medium, a crossed Aldol condensation occurs, losing a water molecule upon heating to yield an α, β-unsaturated carbonyl compound.

Solution:

(a) Benzaldehyde (C_6H_5CHO) lacks α-hydrogens, whereas acetone (CH_3COCH_3) contains active α-hydrogens capable of deprotonation.

(b) Hydroxide ion abstracts a proton from acetone to generate a nucleophilic enolate anion: $^-CH_2COCH_3$.

(c) This enolate attacks the electrophilic carbonyl carbon of benzaldehyde to form a β-hydroxy ketone intermediate known as 4-hydroxy-4-phenylbutan-2-one.

(d) Upon subsequent heating, elimination of water occurs readily via an $E1cB$ pathway to generate the stable, highly conjugated α, β-unsaturated product named 4-Phenylbut-3-en-2-one.

Final Answer: 4-Phenylbut-3-en-2-one

Answer: (A)

Go Back to Question 6

Q7.

Solution

Concept: While many properties of glucose match an open-chain aldohexose structure, certain chemical anomalies point to a masked or cyclic hemiacetal form that exists in equilibrium with the open form.

Solution:

(a) The open-chain form possesses a free aldehyde group that readily reacts with hydroxylamine (NH_2OH) to yield an oxime and oxidizes with bromine water.

(b) However, glucose fails to form a bisulfite addition product when treated with sodium bisulfite ($NaHSO_3$), and it does not give a positive Schiff's test.

(c) This unexpected lack of reactivity indicates that the free aldehyde carbonyl group is not fully accessible in solution.

(d) This anomaly is resolved by the formation of an internal cyclic hemiacetal ring via intramolecular nucleophilic attack of the $C-5$ hydroxyl group on the $C-1$ carbonyl carbon.

Final Answer: Absence of reaction with $NaHSO_3$.

Answer: (C)

Go Back to Question 7

Q8.

Solution

Concept: The cell potential of a gas electrode under non-standard conditions is determined quantitatively using the Nernst equation, which correlates the reduction potential with temperature and the partial pressure or concentrations of the active species.

Solution:

(a) For the standard hydrogen electrode (SHE), the reduction half-reaction is given by:

$$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$$

(b) The corresponding Nernst equation for this reduction process at 298 K is written as:

$$E = E^\circ - \frac{0.0591}{2} \log\left(\frac{P_{H_2}}{[H^+]^2}\right)$$

(c) Since it is a standard hydrogen electrode, the standard reduction potential E° is by definition 0 V. The concentration of $[H^+]$ is held constant at 1 M.

(d) Substituting the initial and new conditions where the pressure of H_2 gas increases to 100 atm, the expression becomes:

$$E = 0 - \frac{0.0591}{2} \log\left(\frac{100}{(1)^2}\right)$$

(e) Since $\log(100) = 2$, substituting this value simplifies the reduction potential to:

$$E = -\frac{0.0591}{2} \times 2 = -0.0591 \text{ V}$$

Final Answer: -0.059 V

Answer: (B)

Go Back to Question 8

Q9.

Solution

Concept: The basicity or proticity of a phosphorus oxyacid depends exclusively on the number of hydroxyl ($-OH$) groups directly bonded to the central phosphorus atom, as only these hydrogen atoms can dissociate in aqueous solution.

Solution:

(a) Phosphorus oxyacids feature a tetrahedral geometry centered on the phosphorus atom, which always includes at least one stable $P = O$ double bond and one $P - OH$ bond.

(b) In hypophosphorous acid (H_3PO_2), the central phosphorus atom is bonded to one oxo group ($P = O$), two hydrogen atoms directly ($P - H$), and only one hydroxyl group ($P - OH$).

(c) The hydrogen atoms attached directly to the phosphorus atom via $P-H$ bonds are non-acidic because the electronegativity difference between phosphorus and hydrogen is negligible.

(d) Consequently, only the single hydrogen atom from the $P - OH$ group can be released as a proton, making H_3PO_2 a monoprotic (monobasic) acid.

Final Answer: H_3PO_2

Answer: (C)

Go Back to Question 9

Q10.

Solution

Concept: The relative stability of substituted cyclohexane chair conformations depends on minimizing steric strain. Bulky substituents experience destabilizing 1,3-diaxial interactions when forced into axial positions.

Solution:

(a) In a cyclohexane ring, substituents can adopt either vertical axial positions or outward-pointing equatorial positions.

(b) For a trans-1,2-disubstituted cyclohexane system, the two substituents must point to opposite faces of the ring (one up and one down).

(c) This spatial arrangement can be achieved either by placing both methyl groups in axial positions (1a, 2a) or by placing both methyl groups in equatorial positions (1e, 2e).

(d) The diequatorial conformation places the bulky methyl groups away from the ring system, completely avoiding unfavorable 1,3-diaxial steric interactions and maximizing thermodynamic stability.

Final Answer: Both methyl groups are equatorial.

Answer: (B)

Go Back to Question 10

Q11.

Solution

Concept: The equilibrium constant K_p for a gas-phase dissociation reaction can be derived using the initial moles, the degree of dissociation (α), Dalton's law of partial pressures, and the total equilibrium pressure.

Solution:

(a) Consider the equilibrium reaction starting with 1 mole of reactant:

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

At equilibrium, the moles of N_2O_4 remaining are $1 - \alpha$, and the moles of NO_2 produced are 2α.

(b) The total number of moles of gas present at equilibrium is calculated as:

$$\text{Total moles} = (1 - \alpha) + 2\alpha = 1 + \alpha$$

(c) The partial pressure of each gaseous component is determined by multiplying its respective mole fraction by the total pressure P:

$$p_{N_2O_4} = \left(\frac{1-\alpha}{1+\alpha}\right) P, \quad p_{NO_2} = \left(\frac{2\alpha}{1+\alpha}\right) P$$

(d) Substituting these values into the equilibrium constant expression gives:

$$K_p = \frac{(p_{NO_2})^2}{p_{N_2O_4}} = \frac{\left(\frac{2\alpha}{1+\alpha}P\right)^2}{\left(\frac{1-\alpha}{1+\alpha}\right)P} = \frac{4\alpha^2 P}{1-\alpha^2}$$

Final Answer: $4\alpha^2 P_{\overline{1-\alpha^2}}$

Answer: (A)

Go Back to Question 11

Q12.

Solution

Concept: Square planar complexes of the general formula $[Mabcd]$, where M is the central transition metal ion and a, b, c, d represent four distinct monodentate ligands, display geometric isomerism due to variations in spatial arrangement.

Solution:

(a) The complex ion $[Pt(NH_3)(NH_2OH)(Py)(NO_2)]^+$ represents a square planar system containing four completely different monodentate ligands.

(b) To systematically determine the total number of unique geometric isomers, we fix the position of one reference ligand, for instance, NH_3.

(c) We then systematically vary the ligand that sits directly opposite (trans to) the fixed reference ligand in the coordination sphere.

(d) The three distinct configurations arise when NH_3 is trans to NH_2OH, trans to Py, or trans to NO_2. Each unique trans arrangement constitutes a distinct geometric isomer.

Final Answer: 3

Answer: (B)

Go Back to Question 12

Q13.

Solution

Concept: The rate of a bimolecular nucleophilic substitution (S_N2) reaction depends heavily on steric hindrance around the electrophilic carbon atom, as the nucleophile must attack from the backside.

Solution:

(a) The mechanism of an S_N2 reaction involves a concerted single-step process where the incoming nucleophile attacks the substrate carbon from behind the leaving group.

(b) This mechanism proceeds through a crowded pentacoordinate transition state. The activation energy for this state increases rapidly with steric bulk.

(c) Methyl halides (CH_3Cl) present the absolute minimum steric hindrance because the central carbon is bonded only to tiny hydrogen atoms, allowing easy nucleophilic approach.

(d) Primary, secondary, and tertiary alkyl halides contain bulkier alkyl groups that physically block the backside approach, making the methyl halide react at the fastest rate.

Final Answer: CH_3Cl

Answer: (A)

Go Back to Question 13

Q14.

Solution

Concept: An ideal solution is formed when the intermolecular attractive forces between the components ($A - B$ interactions) are nearly identical to the forces within the pure liquids ($A - A$ and $B - B$ interactions).

Solution:

(a) Ideal solutions obey Raoult's law across the entire concentration range, exhibiting zero enthalpy change ($\Delta H_{\text{mix}} = 0$) and zero volume change ($\Delta V_{\text{mix}} = 0$) upon mixing.

(b) Components that form ideal solutions typically share very similar chemical structures, molecular sizes, polarities, and intermolecular bonding environments.

(c) Benzene (C_6H_6) and toluene ($C_6H_5CH_3$) are both non-polar aromatic hydrocarbons that interact almost exclusively via identical London dispersion forces.

(d) Other listed pairs exhibit significant deviations from Raoult's law due to strong hydrogen bonding changes or specific complex formation upon mixing.

Final Answer: Benzene and Toluene

Answer: (C)

Go Back to Question 14

Q15.

Solution

Concept: The Cannizzaro reaction is a base-induced organic transformation characteristic of non-enolizable aldehydes, which cannot undergo standard aldol condensation reactions due to the absence of α-hydrogens.

Solution:

(a) When an aldehyde without α-hydrogens is treated with a concentrated aqueous solution of a strong base, a nucleophilic addition of hydroxide to the carbonyl group takes place.

(b) The resulting intermediate undergoes a hydride shift, transferring a hydride ion (H^-) to a second molecule of the aldehyde.

(c) This concerted transfer acts simultaneously as an oxidation and a reduction process within the reacting mixture, commonly referred to as a disproportionation reaction.

(d) One molecule of the aldehyde is oxidized to form a carboxylic acid salt, while the second molecule is reduced to yield the corresponding primary alcohol.

Final Answer: Self-oxidation and reduction (disproportionation)

Answer: (C)

Go Back to Question 15

Answer Key

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