JEE Main Chemistry Sample Paper-13

Duration: 1 Hour **Maximum Marks: 100**

Instructions

- This paper contains TWO sections: **Section A** (MCQs) and **Section B** (Numerical).
- Section A contains 20 Multiple Choice Questions.
- Section B contains 5 Numerical Value Questions.
- Each correct answer carries **+4 marks**.
- Each incorrect answer carries **-1 mark**.
- No negative marking for unattempted questions.

Section A — Multiple Choice Questions

Q1. Which of the following compounds will show the highest rate of electrophilic aromatic substitution? [JEE Main 2023]

(A) Acetophenone

(B) Chlorobenzene

(C) Anisole

(D) Nitrobenzene

Q2. The number of structural isomers possible for a compound with molecular formula C_3H_6O is: [JEE Main 2022]

(A) 5

(B) 7

(C) 9

(D) 4

Q3. The major product formed when Ethyl bromide is treated with alcoholic KOH is: [JEE Main 2024]

(A) Ethanol

(B) Ethene

(C) Ethyne

(D) Diethyl ether

Q4. In the reaction of Phenol with Bromine water, the white precipitate formed is: [JEE Main 2021]

(A) 2-Bromophenol

(B) 4-Bromophenol

(C) 2,4,6-Tribromophenol

(D) 2,4-Dibromophenol

Q5. Which of the following ethers is most resistant to cleavage by concentrated HI? [JEE Main 2023]

(A) Diethyl ether

(B) Diphenyl ether

(C) Anisole

(D) Methyl t-butyl ether

Q6. The formation of Cyanohydrin from a Ketone is an example of: [JEE Main 2022]

(A) Electrophilic addition

(B) Nucleophilic addition

(C) Nucleophilic substitution

(D) Electrophilic substitution

Q7. Which carboxylic acid does not give the Hell-Volhard-Zelinsky (HVZ) reaction? [JEE Main 2024]

(A) CH_3COOH

(B) CH_3CH_2COOH

(C) $(CH_3)_3CCOOH$

(D) $(CH_3)_2CHCOOH$

Q8. The conversion of an Amide to a Primary Amine with one less carbon atom is known as: [JEE Main 2023]

(A) Gabriel Phthalimide synthesis

(B) Hoffmann Bromamide degradation

(C) Curtius rearrangement

(D) Stephen's reduction

Q9. Which of the following vitamins is water-soluble? [JEE Main 2022]

(A) Vitamin A

(B) Vitamin D

(C) Vitamin C

(D) Vitamin K

Q10. The bond order of O_2^+ is: [JEE Main 2024]

(A) 2

(B) 2.5

(C) 1.5

(D) 3

Q11. The hybridization of Central atom in I_3^- ion is: [JEE Main 2023]

(A) sp^3

(B) sp^3d

(C) sp^3d^2

(D) sp^2

Q12. Which molecule has the smallest bond angle? [JEE Main 2021]

(A) NH_3

(B) H_2O

(C) CH_4

(D) H_2S

Q13. The magnetic moment (spin-only) of $[NiCl_4]^{2-}$ is: [JEE Main 2024]

(A) 2.82 BM

(B) 1.73 BM

(C) 3.87 BM

(D) 4.90 BM

Q14. Which type of isomerism is shown by $[Co(NH_3)_5(NO_2)]Cl_2$? [JEE Main 2023]

(A) Geometrical isomerism

(B) Optical isomerism

(C) Linkage isomerism

(D) Coordination isomerism

Q15. The correct order of Electron Gain Enthalpy (with negative sign) for Halogens is: [JEE Main 2022]

(A) $F > Cl > Br > I$

(B) $Cl > F > Br > I$

(C) $I > Br > Cl > F$

(D) $Cl > Br > F > I$

Q16. Which of the following lanthanoid ions is diamagnetic? (Atomic numbers: Ce=58, Sm=62, Eu=63, Yb=70) [JEE Main 2024]

(A) Ce^{4+}

(B) Sm^{3+}

(C) Eu^{3+}

(D) Yb^{3+}

Q17. In the reaction of $KMnO_4$ with Oxalic acid in acidic medium, the change in oxidation state of Manganese is: [JEE Main 2023]

(A) +7 to +4

(B) +7 to +2

(C) +6 to +2

(D) +4 to +2

Q18. The unit of rate constant for a zero-order reaction is: [JEE Main 2021]

(A) s^{-1}

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

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

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

Q19. For a cell reaction to be spontaneous, the Gibbs free energy change (ΔG) must be: [JEE Main 2023]

(A) Positive

(B) Zero

(C) Negative

(D) Infinity

Q20. Isotonic solutions have the same: [JEE Main 2024]

(A) Vapor pressure

(B) Boiling point

(C) Osmotic pressure

(D) Freezing point

Section B — Numerical Questions

Q21. The total number of electrons present in all the completely filled subshells of an atom with atomic number 24 is: [JEE Main 2023]

Q22. The mass of CO_2 produced by the complete combustion of 24 g of Carbon is (in grams): [JEE Main 2022]

Q23. The equilibrium constant K_c for a reaction is 10. The value of ΔG° for the reaction at 300 K is $-X\ R \ln 10$. Find X. [JEE Main 2024]

Q24. A 5% (w/v) solution of cane sugar (mol. wt. 342) is isotonic with 1% (w/v) solution of a substance X. The molecular weight of X is: [JEE Main 2023]

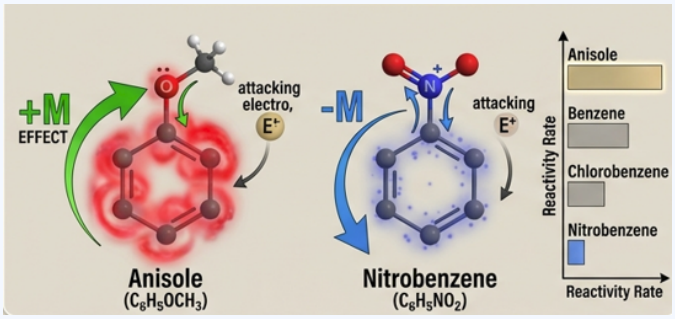
Q25. The work done (in Joules) during the isothermal reversible expansion of 1 mole of an ideal gas from 10 L to 100 L at 27°C is (Take $R = 8.314\ J/K/mol$ and $\ln 10 = 2.303$): [JEE Main 2024]

Detailed Solutions

Q1.

Solution

Concept: Electrophilic Aromatic Substitution (EAS) involves the attack of an electrophile (E^+) on the π-electron cloud of a benzene ring. The reaction rate depends on the electron density of the ring.



- **Activating Groups (+M/+I):** Increase electron density, making the ring more nucleophilic and faster-reacting.
- **Deactivating Groups (-M/-I):** Withdraw electron density, making the ring less nucleophilic and slower-reacting.

Solution: We analyze the electronic effect of the substituent on each molecule:

- **Anisole ($-OCH_3$):** The oxygen atom has lone pairs in direct conjugation with the ring. This creates a strong $+M$ **(Mesomeric) effect**, which outweighs its $-I$ effect. It highly activates the ring.
- **Chlorobenzene ($-Cl$):** While Chlorine has lone pairs ($+M$), its high electronegativity creates a dominant $-I$ **effect**, which makes it overall deactivating compared to benzene.
- **Acetophenone ($-COCH_3$):** The carbonyl group is electron-withdrawing through both $-M$ and $-I$ effects.
- **Nitrobenzene ($-NO_2$):** The nitro group is one of the strongest deactivating groups due to powerful $-M$ and $-I$ effects.

Therefore, Anisole, being the only strongly activated ring, reacts the fastest.

Answer: (C)

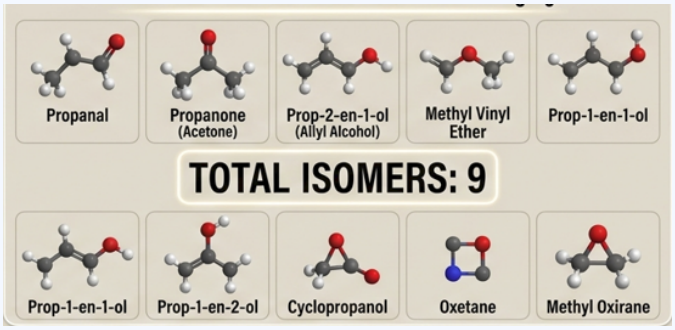
Q2.

Solution

Concept: Structural isomers are compounds with the same molecular formula but different connectivity. For C_3H_6O, we first calculate the **Degree of Unsaturation (DU)**:

$$DU = C + 1 - \frac{H}{2} = 3 + 1 - \frac{6}{2} = 1$$

A DU of 1 indicates either one double bond ($C = C$ or $C = O$) or one ring.



Solution: The possible structural isomers for C_3H_6O are:

(a) **Aldehyde:** Propanal (CH_3CH_2CHO)

(b) **Ketone:** Propanone (Acetone, CH_3COCH_3)

(c) **Enols/Unsaturated Alcohols:** Prop-2-en-1-ol, Prop-1-en-1-ol, Prop-1-en-2-ol.

(d) **Unsaturated Ether:** Methyl vinyl ether ($CH_3 - O - CH = CH_2$)

(e) **Cyclic Alcohols/Ethers:** Cyclopropanol, Oxetane, and Methyl oxirane.

Counting these distinct structural arrangements gives a total of 9.

Answer: (C)

Q3.

Solution

Concept: The reaction of an alkyl halide with **alcoholic KOH** promotes an **$E2$ elimination mechanism** (dehydrohalogenation).

Solution: In alcoholic KOH, the ethoxide ion ($C_2H_5O^-$) acts as a strong base. It attacks the β-hydrogen of Ethyl bromide while the Br^- leaving group departs simultaneously.

$$CH_3 - CH_2 - Br + KOH(alc.) \xrightarrow{\Delta} CH_2 = CH_2 + KBr + H_2O$$

The base abstracts a proton from the β-carbon, the $C - H$ electrons shift to form a $C = C$ bond, and the bromide ion leaves. The final product is Ethene.

Answer: (B)

Q4.

Solution

Concept: Phenol is a highly activated aromatic system due to the $+M$ effect of the $-OH$ group. In polar protic solvents like water, this activation is enhanced.
Solution: In **Bromine water** (Br_2/H_2O), Phenol ionizes into the **Phenoxide ion** ($C_6H_5O^-$), which is extremely reactive. Electrophilic substitution occurs rapidly at all ortho and para positions.

$$C_6H_5OH + 3Br_2 \xrightarrow{H_2O} \text{2,4,6-Tribromophenol} \downarrow + 3HBr$$

The resulting 2,4,6-Tribromophenol appears as a characteristic **white precipitate**.

Answer: (C)

Q5.

Solution

Concept: Ether cleavage by HI involves protonation followed by nucleophilic attack. Resistance depends on $C-O$ bond strength and stability of intermediates.
Solution: In **Diphenyl ether ($Ph-O-Ph$)**, the lone pairs on oxygen resonance with **both** benzene rings, giving the $C-O$ bonds significant **partial double bond character**.

- Double bonds are shorter and stronger than single bonds.
- I^- cannot perform an S_N2 attack on an sp^2 hybridized carbon of a benzene ring.
- S_N1 is impossible because the phenyl cation is highly unstable.

Thus, Diphenyl ether is exceptionally resistant to cleavage.

Answer: (B)

Q6.

Solution

Concept: Carbonyl carbons are electrophilic ($C^{\delta+}$). The reaction type is determined by what species attacks the carbon first.
Solution: The formation of a cyanohydrin involves the attack of a cyanide ion (CN^-) on the carbonyl group.

(a) **Nucleophilic Attack:** CN^- (the nucleophile) attacks the electrophilic carbon, breaking the π-bond.

(b) **Protonation:** The resulting oxygen anion is protonated to form $-OH$.

Since the rate-determining step involves the addition of a nucleophile to a double bond, it is a **Nucleophilic Addition**.

Answer: (B)

Q7.

Solution

Concept: The **Hell-Volhard-Zelinsky (HVZ)** reaction halogenates the α-carbon of a carboxylic acid and requires at least one **α-hydrogen**.
Solution: We examine the α-carbon (the carbon next to the $-COOH$ group):

- CH_3COOH: 3 α-H atoms.
- CH_3CH_2COOH: 2 α-H atoms.
- $(CH_3)_2CHCOOH$: 1 α-H atom.
- $(CH_3)_3CCOOH$ **(Pivalic acid):** The α-carbon is bonded to three methyl groups. It has **zero α-hydrogens**.

Without an α-hydrogen, the necessary enol intermediate cannot form, so no reaction occurs.

Answer: (C)

Q8.

Solution

Concept: Specific organic name reactions often involve the rearrangement of the carbon skeleton or the loss of specific functional groups.
Solution: The **Hoffmann Bromamide Degradation** treats a primary amide with Br_2 and KOH.

$$R - CONH_2 + Br_2 + 4KOH \rightarrow R - NH_2 + K_2CO_3 + 2KBr + 2H_2O$$

The mechanism involves the migration of the R group to the nitrogen atom and the subsequent loss of the carbonyl carbon as a carbonate ion (CO_3^{2-}). This results in an amine with one less carbon than the original amide.

Answer: (B)

Q9.

Solution

Concept: Solubility depends on molecular polarity. Water-soluble vitamins are polar, while fat-soluble vitamins (A, D, E, K) are largely non-polar.
Solution:

- **Vitamin C (Ascorbic Acid):** Contains multiple polar hydroxyl ($-OH$) groups that form extensive hydrogen bonds with water.
- **Vitamins A, D, and K:** These are long-chain hydrocarbons or ring systems with minimal polarity, making them fat-soluble.

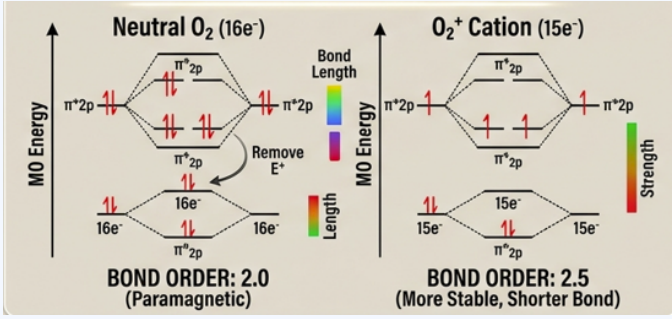
Because Vitamin C is water-soluble, it cannot be stored in the body's fat reserves and must be consumed daily.

Answer: (C)

Q10.

Solution

Concept: Bond Order (B.O.) is calculated using Molecular Orbital Theory: $B.O. = \frac{1}{2}(N_b - N_a)$.



Solution: 1. **O_2 (16e):** Configuration includes 10 bonding and 6 antibonding electrons ($\pi^*2p_x^1, \pi^*2p_y^1$). $B.O. = \frac{10-6}{2} = 2$. 2. **$O_2^+$ (15e):** One electron is removed from the **antibonding** π^* orbital.

$$B.O. = \frac{10-5}{2} = \mathbf{2.5}$$

Removing an electron from an antibonding orbital increases the bond order and makes the bond stronger.

Answer: (B)

Q11.

Solution

Concept: Hybridization depends on the Steric Number (SN): SN = Lone Pairs + Sigma Bonds.

Solution: In I_3^-, the central Iodine atom:

- Valence electrons = 7. Add 1 for the negative charge = 8.
- Sigma bonds to 2 other Iodine atoms = 2.
- Remaining electrons = $8 - 2 = 6$, which means **3 lone pairs**.
- $SN = 2$ bonds + 3 LPs = 5.

$SN = 5$ corresponds to **sp^3d** hybridization. The molecule is linear because the 3 lone pairs occupy equatorial positions to minimize repulsion.

Answer: (B)

Q12.

Solution

Concept: Bond angles are dictated by hybridization and electron repulsion. For hydrides of heavier elements, Drago's Rule explains the lack of hybridization.

Solution:

- CH_4 (sp^3): 109.5°.
- NH_3 (sp^3): 107° (due to 1 LP).
- H_2O (sp^3): 104.5° (due to 2 LPs).
- **H_2S:** Sulfur is a 3rd-period element. In H_2S, there is no significant hybridization; bonding occurs through nearly pure p-orbitals. The angle is approximately **92°**.

Answer: (D)

Q13.

Solution

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

Solution: 1. In $[NiCl_4]^{2-}$, Ni is in the **+2** oxidation state. 2. Ni^{2+} electronic configuration is **$[Ar]3d^8$**. 3. Cl^- is a **Weak Field Ligand**, so no pairing occurs in the tetrahedral geometry. 4. $3d^8$ with WFL has **$n = 2$** unpaired electrons ($t_2^4e^4$ or $e^4t_2^4$). 5. $\mu = \sqrt{2(2+2)} = \sqrt{8} \approx \mathbf{2.82}$ BM.

Answer: (A)

Q14.

Solution

Concept: This isomerism occurs when an **ambidentate ligand** can bind through different donor atoms.

Solution: The ligand NO_2^- (nitro) can coordinate to Cobalt via:

- **Nitrogen:** $[Co(NH_3)_5(\mathbf{N}O_2)]Cl_2$ (Nitro isomer)
- **Oxygen:** $[Co(NH_3)_5(\mathbf{O}NO)]Cl_2$ (Nitrito isomer)

Since the difference lies in the linkage of the ligand, it is **Linkage Isomerism**.

Answer: (C)

Q15.

Solution

Concept: Electron Gain Enthalpy is the energy change for adding an electron. Small size can lead to high inter-electronic repulsion.

Solution: While Fluorine is more electronegative, it is extremely small. Adding an electron to the compact $2p$ subshell of F causes significant repulsion. **Chlorine (Cl)** has a larger $3p$ subshell which accommodates the extra electron more easily. Thus, Cl releases more energy. The order is: $**Cl > F > Br > I**$.

Answer: (B)

Q16.

Solution

Concept: Diamagnetism occurs when all electrons are paired (f^0 or f^{14} configuration).

Solution:

- $**Ce^{4+}:**$ Cerium ($Z = 58$) is $[Xe]4f^15d^16s^2$. Ce^{4+} is $**[Xe]4f^0**$. With no electrons in the f-orbital, it is diamagnetic.
- Sm^{3+} ($4f^5$), Eu^{3+} ($4f^6$), and Yb^{3+} ($4f^{13}$) all have unpaired electrons and are paramagnetic.

Answer: (A)

Q17.

Solution

Concept: $KMnO_4$ is an oxidizer; its reduction product varies by pH.

Solution: In **acidic medium**, the reduction half-reaction is:

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

- Oxidation state of Mn in MnO_4^- is $**+7**$.
- Oxidation state of Mn in the product Mn^{2+} is $**+2**$.

The change is from $+7$ to $+2$.

Answer: (B)

Q18.

Solution

Concept: The units of k for a reaction of order n are $(mol\ L^{-1})^{1-n}s^{-1}$.
Solution: For a **zero-order reaction** ($n = 0$):

$$\text{Units} = (mol\ L^{-1})^{1-0}s^{-1} = \mathbf{mol\ L^{-1}\ s^{-1}}$$

In zero-order reactions, the rate is constant and equal to the rate constant k, regardless of concentration.

Answer: (C)

Q19.

Solution

Concept: Thermodynamic spontaneity at constant T and P is determined by the Gibbs Free Energy change.
Solution: For any process to be spontaneous, the change in Gibbs Free Energy (**ΔG**) must be **negative**.

- $\Delta G < 0$: Spontaneous.
- $\Delta G = 0$: Equilibrium.
- $\Delta G > 0$: Non-spontaneous.

In electrochemical cells, this corresponds to a positive cell potential (E_{cell}).

Answer: (C)

Q20.

Solution

Concept: Colligative properties depend on the concentration of solute particles. Isotonicity refers specifically to pressure balance.
Solution: By definition, **isotonic solutions** have the **same osmotic pressure** (π) at a given temperature. If two solutions have the same osmotic pressure, there is no net flow of solvent across a semi-permeable membrane separating them.

Answer: (C)

Q21.

Solution

Concept: We identify the configuration and count only subshells that have reached their maximum capacity (s^2, p^6, d^{10}).
Solution: Chromium ($Z = 24$): $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, 3d^5$.

- Filled subshells: $1s(2), 2s(2), 2p(6), 3s(2), 3p(6)$.
- Not filled: $4s(1)$ and $3d(5)$ are half-filled.

Total electrons in filled subshells $= 2 + 2 + 6 + 2 + 6 =$ **18**.

Answer: (18)

Q22.

Solution

Concept: Stoichiometry based on the equation: $C + O_2 \rightarrow CO_2$.
Solution: 1. 1 mole of C (12 g) produces 1 mole of CO_2 (44 g). 2. Moles of C provided = 24 g/12 g/mol = **2** moles. 3. Mass of CO_2 produced = 2 moles $\times$ 44 g/mol = **88** grams.

Answer: (88)

Q23.

Solution

Concept: ΔG° and K_c are related by: $\Delta G^\circ = -RT \ln K_c$.
Solution: Given $K_c = 10$ and $T = 300$ K:

$$\Delta G^\circ = -(R) \times (300) \times \ln(10) = -300\ R \ln 10$$

Comparing this with the form $-X\ R \ln 10$, we find $X =$ **300**.

Answer: (300)

Q24.

Solution

Concept: Isotonic non-electrolytes have equal molarity: $W_1/(M_1V_1) = W_2/(M_2V_2)$.
Solution: 1. Cane sugar: 5 g/(342 $\times$ 0.1 L). 2. Substance X: 1 g/($M_x \times$ 0.1 L). Setting them equal: $5/342 = 1/M_x$.

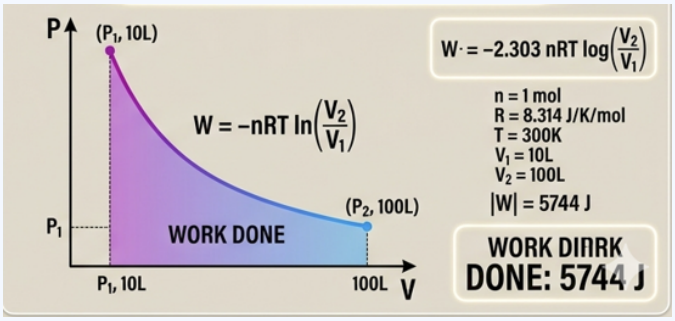
$$M_x = 342/5 = \mathbf{68.4}$$

Answer: (68.4)

Q25.

Solution

Concept: Isothermal reversible work: $W = -2.303\, nRT \log(V_2/V_1)$.



Solution: $n = 1, R = 8.314, T = 300$ K, $V_1 = 10, V_2 = 100$.

$$W = -2.303 \times 1 \times 8.314 \times 300 \times \log(100/10)$$

$$W = -2.303 \times 8.314 \times 300 \times 1 \approx -5744.14 \text{ J}$$

The magnitude is **5744**.

Answer: (5744)

Answer Key — Section A

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

Answer Key — Section B

Q	Ans	Q	Ans
21	18	22	88
23	300	24	68.4
25	5744		