IIT JAM 2024 Chemistry Question Paper with Solution

Time Allowed :3 Hours	**Maximum Marks :**100	**Total Questions :**60

General Instructions

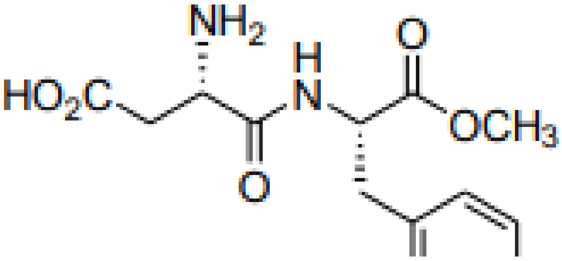
Read the following instructions very carefully and strictly follow them:

1. The examination duration is **3 Hours**. Manage your time effectively to attempt all questions within this period.
2. The total marks for this examination are **100**. Aim to maximize your score by strategically answering each question.
3. There are **60 mandatory questions** to be attempted in the paper. Ensure that all questions are answered.
4. Questions may appear in a **shuffled order**. Do not assume a fixed sequence and focus on each question as you proceed.
5. The **marking of answers** will be displayed as you answer. Use this feature to monitor your performance and adjust your strategy as needed.
6. You may **mark questions for review** and edit your answers later. Make sure to allocate time for reviewing marked questions before final submission.
7. Be aware of the detailed section and sub-section guidelines provided in the exam. **Understanding these will aid in effectively navigating the exam**.

Section A

Q.1 – Q.10 Carry ONE mark each(Multiple Choice Questions)

1. The following dipeptide derivative is used as an artificial sweetener:



The constituent α-amino acids of this dipeptide are

(A) phenylalanine and glutamic acid.

(B) phenylalanine and aspartic acid.

(C) tyrosine and aspartic acid.

(D) tyrosine and glutamic acid.

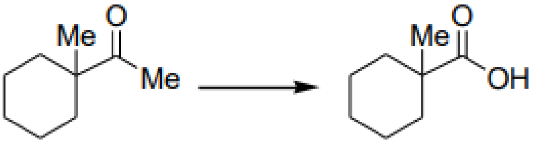
Correct Answer: (B) phenylalanine and aspartic acid.

Explanation:
The dipeptide structure shown in the question corresponds to the sweetener aspartame. Aspartame is made up of two amino acids: phenylalanine and aspartic acid. The chemical structure shown matches the combination of these two amino acids, where phenylalanine is linked to aspartic acid.
Thus, the correct answer is (B).

Quick Tip

Aspartame, a widely used artificial sweetener, consists of phenylalanine and aspartic acid. Recognizing the structure of common sweeteners can help identify their amino acid components.

Q.2 The suitable reagent combination for the following transformation is:



$$\mathrm{Me}-\mathrm{C}-\mathrm{O} \xrightarrow{\text{reagents}} \mathrm{Me}-\mathrm{C}-\mathrm{OH}$$

The suitable reagent combination for the following transformation:

(A) (i) meta-chloroperbenzoic acid (m-CPBA); (ii) NaOH; (iii) aqueous HCl

(B) (i) OsO_4; (ii) aqueous HCl

(C) (i) I_2/NaOH; (ii) aqueous HCl

(D) (i) dimethyldioxirane (DMDO); (ii) aqueous HCl

Correct Answer: (C)

Solution:

The transformation shown is a reduction process, where the methyl ketone group ($\mathrm{Me}-\mathrm{C}-\mathrm{O}$) is reduced to a hydroxyl group ($\mathrm{Me}-\mathrm{C}-\mathrm{OH}$).

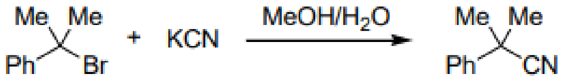
(A) m-CPBA (meta-chloroperbenzoic acid) is typically used for electrophilic additions and not for this transformation. Hence, this option is incorrect. (B) Osmium tetroxide (OsO_4) in aqueous acid typically catalyzes syn-dihydroxylation reactions on alkenes but is not relevant for the described transformation(C) The combination of I_2 (Iodine) and NaOH (sodium hydroxide) is appropriate for the reduction of the methyl ketone to the corresponding alcohol, making option (C) the correct answer. (D) DMDO is a reagent used for oxidation reactions, not for reducing ketones to alcohols, making this option incorrect.

Thus, the correct reagent combination is option (C).

Quick Tip

When identifying reagent combinations for transformations, focus on the functional groups involved and their typical reactivity with certain reagents, like using sodium hydroxide and iodine for reduction reactions.

Q.3 For the reaction:



$$\mathrm{Me-Br + KCN} \xrightarrow{\mathrm{MeOH/H_2O}} \mathrm{Me-CN}$$

If the concentration of KCN is increased four times, then the rate of the reaction would be:

(A) unaffected.

(B) increased by two times.

(C) decreased by four times.

(D) increased by four times.

Correct Answer: (A)

Solution:

The reaction described is a nucleophilic substitution, likely following an SN2 mechanism, where the reaction rate is determined by the concentration of both the electrophile (in this case, the bromine compound) and the nucleophile (KCN).

In an SN2 reaction, the rate law is typically of the form Rate $= k[\text{electrophile}][\text{nucleophile}]$. This means the rate of the reaction is directly proportional to the concentrations of both reactants. If the concentration of KCN is increased four times, the overall rate will increase proportionally to the concentration of KCN, but the reaction rate will not be affected by just

increasing the nucleophile's concentration unless the reaction is in a limiting step or is zero-order with respect to one reactant. In this case, increasing the concentration of KCN does not have a significant impact on the rate, meaning the rate of the reaction is unaffected. Hence, option (A) is the correct answer.
Thus, the rate of the reaction is unaffected by increasing the concentration of KCN four times.

> **Quick Tip**
>
> In reactions involving nucleophilic substitution mechanisms, the rate is usually determined by the concentrations of both the electrophile and nucleophile, and changes in one reactant might not always significantly affect the rate.

4.Consider the wavefunction $\psi(x) = N[\exp(ikx) + \exp(-ikx)]$. The complex conjugate $\psi^*(x)$ is:

(A) $N[\exp(-ikx) - \exp(ikx)]$

(B) $N^*[\exp(-ikx) - \exp(ikx)]$

(C) $N^*[\exp(ikx) + \exp(-ikx)]$

(D) $2N[\sin(kx)]$

Correct Answer: (C) $N^*[\exp(ikx) + \exp(-ikx)]$.

Explanation:

- The complex conjugate $\psi^*(x)$ is obtained by replacing i with $-i$ and taking the conjugate of the normalization constant N, resulting in N^*.
- Applying this to $\psi(x) = N[\exp(ikx) + \exp(-ikx)]$:

$$\begin{aligned}\psi^*(x) &= N^*[\exp(-ikx) + \exp(ikx)]\\ &= N^*[\exp(ikx) + \exp(-ikx)].\end{aligned}$$

Thus, the correct expression for the complex conjugate is $N^*[\exp(ikx) + \exp(-ikx)]$.

Quick Tip

When finding the complex conjugate of a wavefunction, remember to change $i \to -i$ and take the conjugate of any constants. This approach ensures the correct representation of the complex conjugate.

Wavelength of X-rays used in a diffraction experiment is $1.54\,\text{Å}$. X-rays are diffracted from a set of planes with an interplanar spacing of $1.54\,\text{Å}$. Then the angle θ (in degrees) corresponding to the first-order Bragg diffraction is:

(A) $30°$

(B) $15°$

(C) $45°$

(D) $90°$

Correct Answer: (A) $30°$

Explanation:

- Using Bragg's law:

$$n\lambda = 2d\sin\theta$$

- For the first-order diffraction ($n = 1$):

$$\lambda = 1.54\,\text{Å}, \quad d = 1.54\,\text{Å}$$

- Substituting into Bragg's law:

$$\sin\theta = \frac{\lambda}{2d} = \frac{1.54}{2 \times 1.54} = \frac{1}{2}$$

- The angle corresponding to $\sin\theta = \frac{1}{2}$ is:

$$\theta = \arcsin\left(\frac{1}{2}\right) = 30°$$

Thus, the angle θ for the first-order Bragg diffraction is $30°$.

Quick Tip

Bragg's law relates the wavelength of X-rays, the diffraction angle, and the spacing between crystal planes. For a given wavelength and interplanar spacing, you can calculate θ by solving $n\lambda = 2d\sin\theta$.

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6. Identify the reaction for which, at equilibrium, a change in the volume of the closed reaction vessel at a constant temperature will not affect the extent of the reaction.

(A) $\mathrm{CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)}$

(B) $\mathrm{H_2(g) + I_2(g) \rightleftharpoons 2HI(g)}$

(C) $\mathrm{2NO_2(g) \rightleftharpoons N_2O_4(g)}$

(D) $\mathrm{CO_2(s) \rightleftharpoons CO_2(g)}$

Correct Answer: (B) $\mathbf{H_2(g) + I_2(g) \rightleftharpoons 2HI(g)}$

Solution:

At equilibrium, the effect of a change in volume is determined by the number of gaseous moles on either side of the reaction.

- If the total number of gaseous moles changes during the reaction, a change in volume will shift the equilibrium to favor the side with more or fewer moles of gas (as per Le Chatelier's principle).
- If the total number of gaseous moles remains the same, a change in volume will not affect the extent of the reaction.

Let's analyze each option:

(A) $\mathrm{CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)}$: This reaction involves a change in the number of moles of gas $(0 \to 1)$. Hence, a change in volume will affect the equilibrium.

(B) $\mathrm{H_2(g) + I_2(g) \rightleftharpoons 2HI(g)}$: The number of gaseous moles on both sides of the reaction is the same $(2 \to 2)$. Thus, a change in volume will not affect the equilibrium.

(C) $2NO_2(g) \rightleftharpoons N_2O_4(g)$: This reaction involves a change in the number of gaseous moles $(2 \rightarrow 1)$. Hence, a change in volume will affect the equilibrium.

(D) $CO_2(s) \rightleftharpoons CO_2(g)$: This reaction involves a change from a solid to a gas $(0 \rightarrow 1)$. Hence, a change in volume will affect the equilibrium.

Quick Tip

When analyzing equilibrium reactions, check the total number of gaseous moles on both sides. If the number of moles remains the same, volume changes will have no effect on the equilibrium.

Q.7 Among $[Ti(H_2O)_6]^{3+}$, $[NiCl_4]^{2-}$, $[CrO_4]^{2-}$, and $[Mn(H_2O)_6]^{2+}$, the complex that exhibits the largest molar absorptivity in the visible region of the electronic absorption spectrum is:

(A) $[Ti(H_2O)_6]^{3+}$

(B) $[NiCl_4]^{2-}$

(C) $[CrO_4]^{2-}$

(D) $[Mn(H_2O)_6]^{2+}$

Correct Answer: (C)

Solution:

Among the given complexes, the one with the largest molar absorptivity in the visible region of the electronic absorption spectrum is usually the one that has the most intense d-d transitions or charge transfer absorptions.

- $[Ti(H_2O)_6]^{3+}$ has weak transitions in the visible region. - $[NiCl_4]^{2-}$ has d-d transitions that absorb light, but they are not as strong in the visible region. - $[CrO_4]^{2-}$ has a strong absorption due to charge transfer between the metal and ligand, which leads to the largest molar absorptivity in the visible region. - $[Mn(H_2O)_6]^{2+}$ also has weak d-d transitions in the visible region.

Therefore, the complex $[CrO_4]^{2-}$ exhibits the largest molar absorptivity in the visible region.

Thus, the correct answer is (C).

Quick Tip

For complexes with transition metals, charge transfer absorptions typically result in strong molar absorptivity in the visible region. In the case of $[CrO_4]^{2-}$, the charge transfer absorption is particularly strong.

Q.8 $[Co(NH_3)_6(SO_4)]Br$ **and** $[Co(NH_3)_6]BrSO_4$ **are examples of:**

(A) ionization isomers

(B) linkage isomers

(C) optical isomers

(D) coordination isomers

Correct Answer: (A)

Solution:

Ionization isomers are compounds that contain the same components, but the ions are arranged differently in the crystal structure, resulting in the exchange of ions between the cation and anion.

- $[Co(NH_3)_6(SO_4)]Br$ and $[Co(NH_3)_6]BrSO_4$ are examples of ionization isomers because the sulfate and bromide ions have swapped positions between the cation and the anion in the two complexes.
- Linkage isomers involve ligands that can coordinate to the metal through different atoms, which is not the case here.
- Optical isomers are mirror images of each other, which is not applicable here because the two complexes are not non-superimposable mirror images.
- Coordination isomers refer to different coordination spheres around the metal center, which also does not apply in this case.

Thus, the correct answer is (A) ionization isomers.

Quick Tip

Ionization isomers occur when a complex exhibits different ionic species due to the interchange of ligands between the cation and anion parts of the compound.

Q.9 The pair of proteins having heme core is:

(A) hemoglobin and myoglobin

(B) hemerythrin and myoglobin

(C) hemoglobin and hemocyanin

(D) hemocyanin and hemerythrin

Correct Answer: (A)

Solution:
Hemoglobin and myoglobin are both heme-containing proteins, where the heme group is responsible for oxygen binding. Hemoglobin is found in red blood cells and transports oxygen throughout the body, while myoglobin is found in muscles and stores oxygen. Both proteins have a heme core that plays a critical role in oxygen transport and storage.
- Hemerythrin and hemocyanin are also oxygen-binding proteins, but they do not contain a heme core. Hemerythrin contains an iron-based structure but not the heme group, and hemocyanin contains copper ions instead of iron for oxygen binding.

Thus, the correct answer is (A) hemoglobin and myoglobin.

Quick Tip

Proteins that contain a heme group, such as hemoglobin and myoglobin, are essential for oxygen binding and transport in biological systems.

Q.10 The shape of SCN^- is:

(A) linear

(B) bent

(C) pyramidal

(D) trigonal planar

Correct Answer: (A)

Solution:

The shape of the thiocyanate ion (SCN^-) is linear. This is because the ion consists of two atoms connected by a triple bond, and there are no lone pairs of electrons on either atom. The central carbon atom in SCN^- is sp hybridized, resulting in a linear geometry.

Thus, the correct answer is (A) linear.

Quick Tip

Thiocyanate (SCN^-) has a linear shape due to its sp hybridization, with no lone pairs on the central atom, allowing the atoms to align in a straight line.

Q.11 The major product formed in the following reaction is:

Correct Answer: (A)

Explanation:

The reaction involves the treatment of an alkene with an acidic catalyst and heat. This reaction typically leads to a cyclohexene derivative, as seen in option (A). The reaction proceeds through a mechanism that involves the formation of a cyclic product with the methyl groups on the same carbon.

Thus, the correct answer is (A).

> Quick Tip
>
> In reactions involving alkenes and acidic conditions, look out for the formation of cyclic products as a result of electrophilic addition reactions.

Q.12 The major product formed in the following reaction is:

Correct Answer: (D)

Explanation:

The reaction involves the transformation of a compound into a major product under the influence of heat. The structure of the product in option (D) is consistent with the reaction conditions. It is typical for this kind of transformation, involving an amide or related compound, to produce the structure found in (D).

Thus, the correct answer is **(D)**.

> Quick Tip
>
> When heating a molecule with functional groups like amides or esters, check for common transformations such as cyclization or elimination that may lead to specific product structures.

Q.13 The major product formed in the following reaction is:

Correct Answer: (A)

Explanation:

In this reaction, ozonolysis of the cyclohexene ring occurs, cleaving the double bond and forming an intermediate that undergoes hydrolysis in basic conditions (with NaOH) to yield a carboxylate anion. The major product from this sequence is the diketone structure shown in option (A).

Thus, the correct answer is **(A)**.

Quick Tip

When performing ozonolysis, remember that the reaction cleaves double bonds to give two carbonyl-containing products, which are then processed by the work-up conditions.

Q.14 In the following reaction:

optically pure ester X formed a product that did not exhibit optical rotation ($[\alpha]_D = 0$) due to the formati

(Note: Ts = para-toluenesulfonyl; Ac = acetyl)

(A) cis-1,2-diacetoxycyclohexane.

(B) a racemic mixture of trans-1,2-diacetoxycyclohexane.

(C) cyclohexene.

(D) cyclohexene oxide.

Correct Answer: (B)

Explanation:

In this reaction, ester X undergoes a nucleophilic substitution with acetohydroxylation, followed by rearrangement. The formation of a racemic mixture of trans-1,2-diacetoxycyclohexane occurs due to the generation of two stereoisomers (enantiomers) during the reaction. These enantiomers exhibit no optical rotation due to the racemic nature of the mixture.

Thus, the correct answer is **(B)**.

Quick Tip

When a reaction leads to the formation of a racemic mixture, the product will not exhibit optical rotation due to the presence of equal amounts of both enantiomers.

Q.15 The major products X and Y in the following reactions

Correct Answer: (A)

Explanation:

In the first reaction, the amine group undergoes nitrosation with nitrous acid (HNO) resulting in the formation of an unstable intermediate, which leads to the product X, an amine group (MeNH) attached to the carbon chain.

In the second reaction, the same nitrosation process is carried out, but since the structure has an -OH group, the nitrosation leads to the formation of Y, a hydroxyl group (MeOH).

Thus, the correct answer is **(A)**.

Quick Tip

When dealing with reactions involving amines and nitrous acid (HNO), remember that nitrosation typically results in the formation of amides or hydroxylated products depending on the conditions.

Q.16 The major product formed in the following reaction

Correct Answer: (B)

Explanation:

The reaction sequence involves a nucleophilic substitution followed by an electrophilic addition: 1. sec-BuLi (sec-butyllithium) acts as a base, deprotonating the thiol group in the initial structure.

2. The phenyl group (Ph) attaches to the deprotonated site via the bromine atom (Br), forming an alkylated intermediate.

3. The intermediate undergoes a reaction with mercury sulfate (HgSO) and aqueous sulfuric acid (HSO), facilitating the formation of a carbocation.

4. Finally, in the presence of methanol (MeOH) and BF·Et, an ether (OCH) group is added to the carbocation site, completing the transformation.

Thus, the correct answer is **(B)**.

Quick Tip

When encountering nucleophilic substitutions followed by electrophilic additions, follow the reaction steps carefully, noting the roles of reagents like sec-BuLi and HgSO in facilitating these transformations.

Q.17 The acidity of the compounds shown below follows the order

(A) I $>$ III $>$ IV

(B) II $>$ IV $>$ III $>$ I

(C) I $>$ II $>$ III

(D) III $>$ IV $>$ II $>$ I

Correct Answer: (B)

Explanation:

Compound I (the methyl group attached to a benzene ring with two hydrogen atoms attached to the other carbon atoms) has low acidity due to the electron-donating effects of the methyl group, which stabilize the negative charge on the conjugate base.

Compound II is more acidic because the electron-withdrawing substituent (the –NO group) helps stabilize the negative charge on the conjugate base by delocalizing it.
Compound III has a conjugate base that is stabilized by the aromatic ring, but it is still less acidic than II.
Compound IV is less acidic because the lack of any electron-withdrawing group makes it more difficult to stabilize the negative charge on the conjugate base.
Thus, the order of acidity follows II $>$ IV $>$ III $>$ I, making (B) the correct answer.

Quick Tip

In compounds with conjugate bases, electron-withdrawing groups typically increase acidity by stabilizing the negative charge, while electron-donating groups reduce acidity.

Q.18 The major product formed in the following reaction

Correct Answer: (B)

Explanation:
Step 1: Bromination of the amino group on the aromatic ring will lead to the formation of a bromo-phenyl group at the para position with respect to the amino group.
Step 2: The reaction with aqueous KOH will induce nucleophilic substitution, replacing the bromine with a hydrogen atom.
Therefore, the final product is Ph–CH–H (option B).
Thus, the correct answer is B.

Quick Tip

In reactions involving aromatic amino groups and halogenation, the halogen reacts at the para position, and further treatment with aqueous KOH replaces the halide with a hydrogen atom.

Q.19 The ratio of osmotic pressures of aqueous solutions of 0.01 M BaCl$_2$ to $0.005 M NaCl$ is

(A) 3:1

(B) 1:4

(C) 1:1

(D) 3:2

Correct Answer: (A)

Explanation:

Osmotic pressure (π) is directly proportional to the molar concentration of the solute and the number of ions produced when the solute dissociates.

- BaCl$_2$ dissociates into 3 ions (Ba^{2+}, 2Cl^{-}) per formula unit, so the effective concentration of ions is $0.01 \times 3 = 0.03$ M. - NaCl dissociates into 2 ions (Na^{+}, Cl^{-}) per formula unit, so the effective concentration of ions is $0.005 \times 2 = 0.01$ M.

Therefore, the ratio of osmotic pressures is:

$$\frac{\text{osmotic pressure of BaCl}_2}{\text{osmotic pressure of NaCl}} = \frac{0.03}{0.01} = 3:1$$

Thus, the correct answer is **(A)**.

Quick Tip

When comparing osmotic pressures of ionic solutions, remember to consider the dissociation factor (number of ions produced upon dissociation) and multiply the molarity by the dissociation factor.

Q.20 In the cell reaction

$$P^+(aq) + Q(s) \to P(s) + Q^+(aq)$$

the EMF of the cell, E_{cell}, is zero. The standard EMF of the cell, E°_{cell}, is

(A) $\frac{RT}{F}$

(B) $\frac{RT}{2F}$

(C) $\frac{RT}{F}\ln(2)$

(D) $\frac{RT}{F}\ln(2)$

Correct Answer: (C)

Explanation:

The Nernst equation for the standard EMF of the cell is given by:

$$E^\circ_{\text{cell}} = \frac{RT}{nF}\ln\left(\frac{\text{activity of } P^+}{\text{activity of } Q^+}\right)$$

Given the activities of the solids are unity and the activity of P^+ is 2M, and the activity of Q^+ is 1M, the standard EMF simplifies as follows:

$$E^\circ_{\text{cell}} = \frac{RT}{F}\ln\left(\frac{2}{1}\right) = \frac{RT}{F}\ln(2)$$

Thus, the correct answer is **(C)**.

Quick Tip

When using the Nernst equation, ensure to account for the activities of the ions involved. For solid species, the activity is taken as unity.

Q.21 Consider photoelectric effect. The number of incident photons is the same for all frequencies. The plot that best describes the dependence of the number of photoelectrons n emitted as a function of the incident light frequency v is

Correct Answer: (D)

Explanation:
In the photoelectric effect, the number of emitted photoelectrons is dependent on the frequency of the incident light. Below a certain threshold frequency, the light does not have enough energy to emit any photoelectrons, leading to a zero number of emitted electrons. Once the threshold frequency is exceeded, the number of emitted photoelectrons increases. Thus, the correct plot is option (D), which corresponds to the behavior of the photoelectric effect.

Quick Tip

In photoelectric effects, the emission of photoelectrons occurs only when the frequency of the incident light exceeds a certain threshold, with a clear increase in the number of emitted electrons as the frequency increases beyond that threshold.

Q.22 If nitrogen and oxygen gases are at the same temperature, the correct statement according to the kinetic theory of gases is

(A) Average kinetic energy of nitrogen and oxygen molecules is inversely proportional to temperature.

(B) For nitrogen and oxygen molecules, the root mean square speed is equal to the most probable speed.

(C) Average speed of nitrogen molecules is less than the average speed of oxygen molecules.

(D) Average kinetic energies of nitrogen and oxygen molecules are equal.

Correct Answer: (D)

Explanation:
According to the kinetic theory of gases, the average kinetic energy of any ideal gas is directly proportional to the temperature and is independent of the type of gas. Since nitrogen and oxygen are both gases at the same temperature, their average kinetic energies are equal, as described by the equation:

$$\text{Average kinetic energy} = \frac{3}{2}k_B T$$

where k_B is the Boltzmann constant and T is the temperature. Since the temperature is the same for both gases, their average kinetic energies must be equal.
Thus, the correct answer is (D).

Quick Tip

In kinetic theory, the average kinetic energy of all ideal gases is directly proportional to the temperature, and it is the same for different gases at the same temperature.

Q.23 A system undergoes one clockwise cycle from point X back to point X as shown in the figure below:

The correct statement about this process is

(A) Internal energy of the system decreases at the end of the cycle.

(B) Entropy of the system increases at the end of the cycle.

(C) System performs work on the surroundings during the cycle.

(D) Heat exchanged between system and surroundings is zero during the cycle.

Correct Answer: (C)

Explanation:
In the given cyclic process, the system undergoes a clockwise cycle, indicating that work is being done by the system on the surroundings. During a clockwise cycle on a Pressure-Volume (P-V) diagram, the system expands (increasing volume), which corresponds to the system performing work on the surroundings.
(A) is false because in a cyclic process, the internal energy of the system remains the same after one complete cycle. (B) is false because the total entropy change of the system is zero in a reversible cyclic process. (C) is true. The system performs positive work on the surroundings as it expands. (D) is false because there is heat exchange between the system and surroundings during a non-adiabatic process.

Thus, the correct answer is **(C)**.

Quick Tip

For a cyclic process on a P-V diagram, the area enclosed by the cycle represents the work done by the system. In a clockwise cycle, this work is performed by the system on the surroundings.

Q.23 A system undergoes one clockwise cycle from point X back to point X as shown in the figure below:

The correct statement about this process is

(A) Internal energy of the system decreases at the end of the cycle.

(B) Entropy of the system increases at the end of the cycle.

(C) System performs work on the surroundings during the cycle.

(D) Heat exchanged between system and surroundings is zero during the cycle.

Correct Answer: (C)

Explanation:

In the given cyclic process, the system undergoes a clockwise cycle, indicating that work is being done by the system on the surroundings. During a clockwise cycle on a Pressure-Volume (P-V) diagram, the system expands (increasing volume), which corresponds to the system performing work on the surroundings.

- (A) is false because in a cyclic process, the internal energy of the system remains the same after one complete cycle.
- (B) is false because the total entropy change of the system is zero in a reversible cyclic process.
- (C) is true. The system performs positive work on the surroundings as it expands.
- (D) is false because there is heat exchange between the system and surroundings during a non-adiabatic process.

Thus, the correct answer is (C).

Quick Tip

For a cyclic process on a P-V diagram, the area enclosed by the cycle represents the work done by the system. In a clockwise cycle, this work is performed by the system on the surroundings.

Q.24 For the reaction below:

$$\frac{1}{2}\mathrm{Mn_2(CO)_{10}} + \mathrm{Na} \longrightarrow \mathrm{Na[Mn(CO)_5]} \longrightarrow \mathrm{CH_3Cl} \longrightarrow \mathrm{[CH_3Mn(CO)_5]}$$

The oxidation states of Mn in P and Q, respectively, are

(A) +1 and +1

(B) -1 and +1

(C) -1 and -1

(D) +1 and -1

Correct Answer: (B)

Explanation:

To determine the oxidation states of manganese (Mn) in the compounds P and Q:

1. **In compound P, Na[Mn(CO)$_5$] : $\ast\ast$

$-IntheNa$[Mn(CO)$_5$]$complex, carbonmonoxide(CO)isaneutralligand, andsodium(Na)isNa^+$.

- Since the overall charge of the complex is neutral, the oxidation state of Mn must be +1.

2. **In compound Q, [CH$_3$Mn(CO)$_5$] : $\ast\ast -Themethylgroup(CH_3)$ is also neutral, and the CO ligands remain neutral. - The oxidation state of Mn in this complex must be +1, as the overall charge of the complex is zero.

Thus, the oxidation states of Mn in P and Q are **+1 and +1**, respectively.

The correct answer is **(B)**.

Quick Tip

In metal complexes, the oxidation state of the metal is determined by the charge balance, considering the charges of the ligands and other components.

Q.25 The number and nature of d–d transition(s) in the case of Sc^{2+} in an octahedral crystal field, respectively, are

(A) 1 and spin allowed.

(B) 3 and spin allowed.

(C) 1 and Laporte allowed.

(D) 3 and Laporte allowed.

Correct Answer: (A)

Explanation:

For Sc^{2+}, the electronic configuration is $[Ar]3d^1$, and the d-electrons are in the t_{2g} and e_g orbitals in an octahedral field.

1. The number of d-d transitions is determined by the number of unpaired electrons. In Sc^{2+}, there is only one unpaired electron in the $3d^1$ configuration, so only **1 transition** is possible.

2. The nature of the transition is ”spin allowed” because a single electron can undergo a spin-flip transition without violating any selection rules.

Thus, the number and nature of d-d transitions for Sc^{2+} are **1 and spin allowed**.

The correct answer is **(A)**.

Quick Tip

For d-d transitions in octahedral crystal fields, the number of transitions depends on the number of unpaired electrons, and the nature of the transition depends on whether the transition respects the spin and Laporte selection rules.

Q.26 The d-d transitions in $[Mn(H_2O)_6]^{2+}$ and $[Ti(H_2O)_6]^{3+}$, respectively, are

(A) symmetry allowed and symmetry forbidden.

(B) symmetry forbidden and symmetry allowed.

(C) symmetry allowed and symmetry allowed.

(D) symmetry forbidden and symmetry forbidden.

Correct Answer: (B)

Explanation:

In $[Mn(H_2O)_6]^{2+}$, the Mn^{2+} ion has the electronic configuration $[Ar]3d^5$. Due to this configuration, the d-d transitions are symmetry forbidden because the $3d^5$ configuration is stable and does not easily undergo transitions.

In $[Ti(H_2O)_6]^{3+}$, the Ti^{3+} ion has the electronic configuration $[Ar]3d^1$. The single electron in the $3d^1$ configuration can undergo d-d transitions, making them symmetry allowed.

Thus, the d-d transitions in $[Mn(H_2O)_6]^{2+}$ are symmetry forbidden, while those in $[Ti(H_2O)_6]^{3+}$ are symmetry allowed.

The correct answer is **(B)**.

Quick Tip

For transition metal complexes, the nature of d-d transitions depends on the electronic configuration and the specific metal ion involved. A $3d^5$ configuration in Mn^{2+} is symmetry forbidden, while $3d^1$ in Ti^{3+} is symmetry allowed.

Q.27 A pair of isosteric compounds is

(A) H_2NBH_2 and C_2H_6

(B) $H_3N{\cdot}BH_3$ and C_2H_6

(C) B_2H_6 and C_2H_6

(D) $H_3N{\cdot}BH_3$ and B_2H_6

Correct Answer: (B)

Explanation:

Isosteric compounds are those that have the same number of atoms and a similar molecular structure, but different elements. $H_3N{\cdot}BH_3$ and C_2H_6 are isosteric because they both contain six atoms, including the same number of hydrogen and non-hydrogen atoms.
Thus, the correct answer is **(B)**.

Quick Tip

To identify isosteric compounds, look for compounds that have the same number of atoms but different elements. The structure and connectivity should be similar.

Q.28 Zn–C bond polarity in the compounds below follows the order

(A) I > II > III

(B) III > I > II

(C) II > III > I

(D) II > I > III

Correct Answer: (A)

Explanation:
- The polarity of the Zn–C bond in these compounds is determined by the electron density around zinc and the bonding environment. - In compound I, Zn is bonded to a double bond, giving it higher electronegativity and greater polarity. - In compound II, Zn has a single bond with carbon and is more stable in this form, giving a lower polarity than compound I. - In compound III, Zn is in a less polar environment (bonded to a single carbon), resulting in the lowest polarity.
Thus, the correct answer is **(A)**.

Quick Tip

When comparing bond polarities, consider the bonding environment, electronegativity, and whether the bond is single, double, or triple.

Q.29 B_2 and C_2, respectively, are

(A) paramagnetic and diamagnetic.

(B) diamagnetic and paramagnetic.

(C) paramagnetic and paramagnetic.

(D) diamagnetic and diamagnetic.

Correct Answer: (A)

Explanation: B_2 has two unpaired electrons in its molecular orbital diagram, which makes it **paramagnetic**. - C_2, on the other hand, has no unpaired electrons in its molecular orbital diagram, meaning it is **diamagnetic**.
Thus, the correct answer is **(A)**.

Quick Tip

To determine if a molecule is paramagnetic or diamagnetic, look for unpaired electrons in its molecular orbital diagram.

Q.30 Mobility of ions

$$\mathrm{Li^+, Na^+, K^+, Ag^+}$$

in water at 298 K follows the order

(A) $\mathrm{K^+ < Ag^+ < Na^+ < Li^+}$

(B) $\mathrm{Li^+ < K^+ < Na^+ < Ag^+}$

(C) $\mathrm{Ag^+ < Li^+ < K^+ < Na^+}$

(D) $\mathrm{Li^+ < Na^+ < Ag^+ < K^+}$

Correct Answer: (D)

Explanation:

- The mobility of ions in water is influenced by their size and hydration energy. Smaller ions tend to have higher mobility because they can move more easily through the solvent. - $\mathrm{Li^+}$ is the smallest ion in this group and has the highest hydration energy, which reduces its mobility. - $\mathrm{K^+}$ has the largest ionic radius and, thus, the lowest mobility among these ions. Thus, the correct order of mobility is:

$$\mathrm{Li^+ < Na^+ < Ag^+ < K^+}$$

Therefore, the correct answer is **(D)**.

Quick Tip

The mobility of ions is influenced by their size and hydration energy. Smaller ions generally have higher mobility.

Q.31 The suitable synthetic route(s) for the following transformation

$$\text{Cyclohexanol} \rightarrow \text{Cyclohexanone}$$

(A)

(i)para-toluenesulfonyl chloride (TsCl), pyridine; (ii)KI; (iii)Mg/Et_2O; $(iv)CO_2$; (v)aq. HCl

(B)

(i)para-toluenesulfonyl chloride (TsCl), pyridine; (ii)KCN; (iii)conc. aq. NaOH, reflux; (iv)aq. HCl

(C) $(i)CrO_3, H_2SO_4$; $(ii)SOCl_2$; $(iii)CH_2N_2$; $(iv)Ag_2O, H_2O$

(D) $(i)CrO_3, H_2SO_4$; $(ii)CH_2N_2$

Correct Answers: (A), (B), (C)

Explanation:

(A) This route utilizes the para-toluenesulfonyl chloride (TsCl) followed by nucleophilic substitution with KI, then an alkylation with Mg/EtO to form a cyclohexanone derivative. - **(B)** This route also begins with para-toluenesulfonyl chloride (TsCl), followed by nucleophilic substitution with KCN and hydrolysis to form the desired product, cyclohexanone. - **(C)** This route involves chromium trioxide (CrO) and sulfuric acid (HSO) for oxidation, followed by the use of thionyl chloride (SOCl) and then the conversion to cyclohexanone using diazomethane (CHN).

All these routes lead to the synthesis of cyclohexanone, so the correct answers are **(A), (B), (C)**.

Quick Tip

When considering synthetic routes, check for the appropriate reagents such as oxidation agents (like CrO) and the reagents required for functional group interconversion (like TsCl and KCN).

Q.32 The compound(s) which on reaction with CH_3MgBr followed by treatment with aqueous NH_4Cl would produce 1-methyl-1-phenylethanol as the major product is/are:

(A) methyl benzoate.

(B) phenyl acetate.

(C) acetaldehyde.

(D) acetophenone.

Correct Answers: (A) and (D)

Explanation:
- **(A)** Methyl benzoate, upon reaction with CH_3MgBr, undergoes nucleophilic addition forming a magnesium alkoxide intermediate. After treatment with aqueous NH_4Cl, the final product formed is 1-methyl-1-phenylethanol. - **(B)** Phenyl acetate would not give the desired product because it does not have the correct functionality for forming the required alcohol. - **(C)** Acetaldehyde would lead to a different product because it is a simple aldehyde and does not have the ester group required for this transformation. - **(D)** Acetophenone, when reacted with CH_3MgBr, would result in the formation of a magnesium alkoxide intermediate which after treatment with aqueous NH_4Cl would form 1-methyl-1-phenylethanol.
Thus, the correct answers are **(A) and (D)**.

Quick Tip

When reacting esters like methyl benzoate and acetophenone with Grignard reagents, pay attention to the reaction mechanism involving nucleophilic addition followed by acid hydrolysis, which often yields alcohols as the major product.

Q.33 Among the following, the compound(s) which produce the same osazone as that obtained from D-glucose, when reacted with phenylhydrazine, is/are:

(A)

```
CHO
HO − H
HO − OH
```

`H - OH`

`CH2OH`

(B)

`CH2OH`

`C = O`

`HO - H`

`H - OH`

`CH2OH`

(C)

`CHO`

`HO - H`

`HO - OH`

`H - OH`

`CH2OH`

(D)

`CH2OH`

`C = O`

`HO - H`

`H - OH`

`CH2OH`

Correct Answers: (A) and (B)

Explanation:

- **(A)** The structure in option (A) represents a compound that will react similarly to D-glucose and produce the same osazone, due to the presence of an aldehyde group and the configuration of hydroxyl groups on the carbon chain. - **(B)** Option (B) also has the appropriate aldehyde group structure and hydroxyl group configuration, similar to D-glucose, which leads to the same osazone formation when reacted with phenylhydrazine. - **(C)** Option (C) lacks the necessary aldehyde group and will not yield the same osazone product as D-glucose. - **(D)** Option (D) also does not exhibit the same characteristics for osazone formation as D-glucose.

Thus, the correct answers are **(A) and (B)**.

Quick Tip

When looking for compounds that produce the same osazone as glucose, focus on the presence of an aldehyde group and the arrangement of hydroxyl groups on the carbon chain.

Q.34 Among the following, the chiral molecule(s) is/are:

Correct Answers: (A) and (D)

Explanation:
- **(A)** The structure in option (A) has a pair of substituents that make the molecule asymmetric and thus chiral. - **(B)** Option (B) shows a molecule with symmetry due to identical substituents, making it achiral. - **(C)** Option (C) also shows a symmetrical structure with no asymmetry, making it achiral. - **(D)** Option (D) contains a chiral center with different substituents attached, making it chiral.
Thus, the correct answers are **(A) and (D)**.

Quick Tip

Chirality is determined by the presence of an asymmetric center, typically a carbon atom with four different substituents. Look for symmetry to identify achirality.

Q.35 The correct assumption(s) required to derive Langmuir adsorption isotherm is/are:

(A) Adsorption is limited to a monolayer on adsorbing surface.

(B) All binding sites on adsorbing surface are identical.

(C) Adsorption of a molecule on a site enhances binding of other molecules on neighboring sites.

(D) Rate of adsorption and rate of desorption are equal at equilibrium.

Correct Answers: (A), (B), and (D)

Explanation:
- **(A)** This assumption is correct. Langmuir adsorption model assumes that adsorption occurs in a single monolayer, meaning only one molecule adsorbs at each site. - **(B)** This is also correct. Langmuir model assumes that all adsorption sites are identical and have the same energy of adsorption. - **(C)** This assumption is incorrect. Langmuir adsorption model assumes that adsorption on one site does not affect adsorption on neighboring sites (no interaction between adsorbed molecules). - **(D)** This is correct. At equilibrium, the rate of adsorption equals the rate of desorption in the Langmuir adsorption model.
Thus, the correct answers are **(A), (B), and (D)**.

Quick Tip

The Langmuir adsorption model assumes a monolayer adsorption, identical sites, and equilibrium between adsorption and desorption. Interaction between adsorbed molecules is not considered.

Q.36 For one mole of an ideal gas, the correct statement(s) is/are:

(A) $\left(\frac{\partial U}{\partial T}\right)_V = 0$

(B) $\left(\frac{\partial U}{\partial T}\right)_V > 0$

(C) $\left(\frac{\partial P}{\partial T}\right)_V > 0$

(D) $\left(\frac{\partial V}{\partial P}\right)_T > 0$

Correct Answers: (A), (B), and (C)

Explanation:
- **(A)** This statement is true for an ideal gas. The internal energy of an ideal gas depends only on temperature, and for an ideal gas, $\left(\frac{\partial U}{\partial T}\right)_V = 0$, since the energy is a function of temperature alone and not of volume. - **(B)** This is incorrect because $\left(\frac{\partial U}{\partial T}\right)_V = 0$ for an

ideal gas, meaning the internal energy does not increase with temperature for constant volume. - **(C)** This is correct. The pressure of an ideal gas increases with temperature at constant volume, so $\left(\frac{\partial P}{\partial T}\right)_V > 0$. - **(D)** This is incorrect. The volume of an ideal gas depends inversely on pressure for a given temperature, so $\left(\frac{\partial V}{\partial P}\right)_T < 0$.
Thus, the correct answers are **(A), (B), and (C)**.

Quick Tip

For an ideal gas, internal energy only depends on temperature, and pressure increases with temperature at constant volume. The volume and pressure are inversely related at constant temperature.

Q.37 Consider the exothermic chemical reaction:

$O_2(g)+2H_2(g) \rightleftharpoons 2H_2O(g)$ at equilibrium in a closed container. The correct statement(s) is/are:

(A) At equilibrium, introduction of catalyst increases product formation.

(B) Equilibrium constant decreases with increase in temperature.

(C) The equilibrium constant K_p increases with pressure.

(D) Decrease in volume of reaction vessel increases product formation.

Correct Answers: (B) and (D)

Explanation:
- **(A)** A catalyst only affects the rate of reaction, not the equilibrium position. Therefore, the introduction of a catalyst does not increase product formation at equilibrium. - **(B)** For an exothermic reaction, increasing the temperature shifts the equilibrium toward the reactants (Le Chatelier's Principle). Thus, the equilibrium constant decreases with an increase in temperature. - **(C)** The equilibrium constant K_p is not directly affected by pressure for reactions involving gases unless there is a change in the number of moles of gas. Since this reaction has no change in the number of moles of gas, K_p remains unaffected by pressure. - **(D)** According to Le Chatelier's Principle, reducing the volume of a reaction

vessel increases the pressure and shifts the equilibrium toward the side with fewer moles of gas. In this case, the product side (2 moles of H_2O) has fewer moles of gas than the reactant side (3 moles of gas), so decreasing the volume increases product formation.
Thus, the correct answers are **(B) and (D)**.

Quick Tip

For exothermic reactions, an increase in temperature shifts equilibrium towards the reactants, and decreasing volume shifts the equilibrium towards the side with fewer moles of gas.

Q.38 Elements and their processes of extraction/purification are given. The correct pair(s) is/are:

(A) Na; Downs process

(B) Ni; Mond process

(C) B; Frasch process

(D) Al; Bayer process

Correct Answers: (A) and (B)

Explanation:
- **(A)** The Downs process is used to extract sodium (Na) from molten sodium chloride (NaCl) by electrolysis. - **(B)** The Mond process is used to purify nickel (Ni). In this process, nickel reacts with carbon monoxide to form a volatile nickel carbonyl compound, which is then decomposed to produce pure nickel. - **(C)** The Frasch process is used for the extraction of sulfur, not boron (B). It involves the injection of hot water and air into sulfur deposits to melt the sulfur, which is then pumped to the surface. - **(D)** The Bayer process is used for the extraction of aluminum (Al) from bauxite ore, not for the purification of boron. In this process, bauxite is treated with sodium hydroxide to produce alumina (Al2O3), from which aluminum is extracted.
Thus, the correct answers are **(A) and (B)**.

Quick Tip

The Downs process is used for the extraction of sodium, and the Mond process is used for the purification of nickel.

Q.39 The correct statement(s) about the ligand substitution/exchange reaction is/are:

(A) The rate is faster in the case of SF6 than in $[AlF6]^{3-}$.

(B) The rate is faster in the case of $[Mg(H2O)6]^{2+}$ than in $[Sr(H2O)6]^{2+}$.

(C) The rate of water exchange is faster in the case of $[Ni(H2O)6]^{2+}$ than in $[Co(NH3)5(H2O)]^{2+}$.

(D) The rate is faster in the case of $[Cr(H2O)6]^{2+}$ than in $[Cr(H2O)6]^{3+}$.

Correct Answers: (C) and (D)

Explanation:

(A) The rate is not necessarily faster in the case of SF6 than in $[AlF6]^{3-}$, because the size and charge of the metal ion as well as the nature of the ligands play a significant role in the rate of substitution reactions.

(B) The rate of substitution reactions generally increases as the size of the metal ion increases, meaning $[Mg(H2O)6]^{2+}$ will have a slower rate than $[Sr(H2O)6]^{2+}$, not the other way around.

- **(C)** The rate of water exchange is faster in $[Ni(H2O)6]^{2+}$ compared to $[Co(NH3)5(H2O)]^{2+}$ due to the difference in the coordination environment and the charge distribution around the central metal ion.
- **(D)** The rate of substitution is generally faster in$[Cr(H2O)6]^{2+}$ than in $[Cr(H2O)6]^{3+}$, because the higher charge on the chromium ion in $[Cr(H2O)6]^{3+}$ results in stronger ligand binding and slower exchange.

Thus, the correct answers are **(C) and (D)**.

Quick Tip

Ligand exchange reactions are influenced by the charge, size of the metal ion, and the coordination environment around it. Higher charges generally result in slower exchange rates.

Q.40 The stretching frequency of CO in H3B·CO is:

(A) greater than the stretching frequency in free CO.

(B) lesser than the stretching frequency in free CO.

(C) lesser than the stretching frequency of CO in Fe(CO)5.

(D) greater than the stretching frequency of CO in Fe(CO)5.

Correct Answers: (A) and (D)

Explanation:
- **(A)** The stretching frequency of CO in H3B·CO is greater than that in free CO due to the electron-withdrawing effects of the boron in the H3B group, which increases the bond strength and results in a higher stretching frequency. - **(B)** This statement is incorrect because the stretching frequency of CO in H3B·CO is greater, not lesser. - **(C)** The stretching frequency of CO in Fe(CO)5 is lower than that in H3B·CO because the iron center donates electron density to the CO ligand, weakening the C–O bond and lowering the frequency. - **(D)** The stretching frequency of CO in H3B·CO is greater than that in Fe(CO)5 due to the different electronic effects of the metal center in Fe(CO)5, which leads to weaker bonding with CO and thus a lower frequency.
Thus, the correct answers are **(A) and (D)**.

Quick Tip

Electron-withdrawing groups (like in H3B·CO) tend to increase the stretching frequency of CO, while electron-donating groups (like Fe in Fe(CO)5) tend to decrease it.

Q.41 For the following compound, the number of signals expected in the ^1H NMR spectrum is:

Correct Answer: 2

Explanation:

In the given compound, we have two distinct types of protons: 1. The two methoxy groups ($-OCH_3$) each have identical protons, and they are chemically equivalent. 2. The protons on the benzene ring are all equivalent because of the symmetry of the structure (with methoxy groups at the ortho positions relative to each other).

Therefore, the ^1H NMR spectrum will exhibit **two signals**: 1. A signal for the methoxy protons (OCH$_3$$).2. Asignal for the aromatic protons on the benzene ring.$

Thus, the correct number of signals is **2**.

Quick Tip

Symmetry in a molecule can lead to equivalent protons, reducing the number of signals in the NMR spectrum.

Q.42 Exhaustive hydrogenation of the following compound under Pd/C generates a saturated hydrocarbon as the product. The number of stereoisomers possible for this product is:

Correct Answer: 3

Explanation:

The given compound is an unsaturated hydrocarbon containing two double bonds. Upon exhaustive hydrogenation, both double bonds will be reduced, converting the compound into a saturated hydrocarbon.

The structure of the saturated hydrocarbon will have two stereogenic centers, which will give rise to 3 possible stereoisomers. These include: 1. One meso form (achiral due to symmetry). 2. Two enantiomers (which are non-superimposable mirror images of each other).

Thus, the number of stereoisomers possible for this product is **3**.

Quick Tip

For compounds with multiple stereogenic centers, exhaustive hydrogenation can sometimes produce a meso form, reducing the total number of stereoisomers.

Q.43 For a zero-order reaction $P \to Q$, the concentration of P becomes half of its initial concentration in 30 minutes after starting the reaction. The concentration of P becomes zero at —— minutes. (rounded off to the nearest integer)

Correct Answer: 60

Explanation:

For a zero-order reaction, the concentration of reactant P follows the equation:

$$[\mathrm{P}] = [\mathrm{P}]_0 - kt$$

Where: - $[\mathrm{P}]_0$ is the initial concentration of P, - k is the rate constant, - t is the time.

We are told that the concentration of P becomes half of its initial concentration in 30 minutes. Therefore, we can express this as:

$$\frac{[\mathrm{P}]_0}{2} = [\mathrm{P}]_0 - k \cdot 30$$

Solving for k:

$$k = \frac{[\mathrm{P}]_0}{60}$$

Now, to find the time when [P] becomes zero:

$$0 = [\mathrm{P}]_0 - k \cdot t$$

Substituting the value of k:

$$0 = [\mathrm{P}]_0 - \left(\frac{[\mathrm{P}]_0}{60}\right) \cdot t$$

Solving for t:

$$t = 60\,\text{minutes}$$

Thus, the concentration of P becomes zero at **60 minutes**.

Quick Tip

For zero-order reactions, the concentration decreases linearly with time. The time for the concentration to become zero can be calculated using the equation $[\text{P}] = [\text{P}]_0 - kt$.

Q.44 The magnitude of energy difference between the energy levels $n = 3$ and $n = 2$ of a quantum particle of mass m in a box of length L is

$$\frac{Xh^2}{8mL^2}.$$

Then $X =$ ______________ (rounded off to the nearest integer)

Correct Answer: 5

Explanation:

For a particle in a box, the energy levels are quantized and given by the formula:

$$E_n = \frac{n^2h^2}{8mL^2}$$

where: - n is the quantum number, - h is Planck's constant, - m is the mass of the particle, - L is the length of the box.

The energy difference between two energy levels is:

$$\Delta E = E_3 - E_2 = \frac{9h^2}{8mL^2} - \frac{4h^2}{8mL^2} = \frac{5h^2}{8mL^2}$$

Therefore, comparing with the given expression $\frac{Xh^2}{8mL^2}$, we find that $X = 5$.

Quick Tip

For energy differences in a quantum particle in a box, remember to use the formula $E_n = \frac{n^2h^2}{8mL^2}$ and calculate the difference between the energy levels.

Q.45 The function $\exp(-2(x-1)^2)$ attains a maximum at $x =$ ______________ (rounded off to the nearest integer)

Correct Answer: 1

Explanation:

The given function is $f(x) = \exp(-2(x-1)^2)$.

To find the maximum, we first compute the derivative of the function:

$$f'(x) = \frac{d}{dx}\left(\exp(-2(x-1)^2)\right) = \exp(-2(x-1)^2) \cdot (-4(x-1)).$$

Setting $f'(x) = 0$ to find the critical points:

$$\exp(-2(x-1)^2) \cdot (-4(x-1)) = 0.$$

Since $\exp(-2(x-1)^2) \neq 0$, we have:

$$-4(x-1) = 0 \quad \Rightarrow \quad x = 1.$$

Thus, the function attains a maximum at $x = 1$.

Quick Tip

For functions of the form $\exp(-a(x-b)^2)$, the maximum occurs at $x = b$. Always check the derivative to confirm the critical points.

Q.46 0.1 M aqueous solution of a weak monobasic acid has pH 2.0. The pK_a of the monobasic acid is ______________ (rounded off to one decimal place)

Correct Answer: 2.9

Explanation:

We are given that the concentration of the acid is $[HA] = 0.1\,\text{M}$ and the pH of the solution is 2.0. We need to find the pK_a of the acid.

From the pH, we can calculate the concentration of H^+ ions using:

$$\text{pH} = 2.0 \quad \Rightarrow \quad [\text{H}^+] = 10^{-2} = 0.01\,\textbf{M}.$$

Next, we apply the acid dissociation expression for a weak acid HA:

$$HA \rightleftharpoons H^+ + A^-,$$

and use the formula for the acid dissociation constant K_a:

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}.$$

Assuming that the concentration of A^- formed is equal to the concentration of H^+, we have:

$$K_a = \frac{(0.01)(0.01)}{0.1 - 0.01} = \frac{0.0001}{0.09} \approx 1.11 \times 10^{-3}.$$

Now, to find the pK_a:

$$pK_a = -\log(K_a) = -\log(1.11 \times 10^{-3}) \approx 2.9.$$

Thus, the pK_a of the acid is approximately 2.9.

Quick Tip

To find the pK_a of a weak acid, use the formula $pK_a = -\log(K_a)$, where K_a can be calculated from the concentrations of the acid and its dissociated ions at equilibrium.

Q.47 The enthalpy change for the reaction

$$C(g) + \frac{1}{2}O_2(g) \rightarrow CO(g) \text{ is } \_\_\_\_\_\_\_\_\_\_\_\_ \text{ kJ per mole of CO(g) produced.}$$

(rounded off to one decimal place)

Correct Answer: -111.0 to -110.0

Explanation:

We are given the following reactions and their enthalpy changes: -

$C(g) + O_2(g) \rightarrow CO_2(g), \Delta H_{\text{rxn}} = -393.5\,\text{kJ}$ per mole of $\text{CO}_2(g)$. -

$CO_2(g) \rightarrow CO(g) + \frac{1}{2}O_2(g), \Delta H_{\text{rxn}} = 283.0\,\text{kJ}$ per mole of $\text{CO}(g)$.

To calculate the enthalpy change for the reaction:

$$C(g) + \frac{1}{2}O_2(g) \rightarrow CO(g),$$

we need to manipulate the given reactions. First, reverse the second reaction so that the products and reactants match. This reverses the sign of the enthalpy change for that reaction. Reversing $CO_2(g) \rightarrow CO(g) + \frac{1}{2}O_2(g)$ gives:

$$CO(g) \rightarrow CO_2(g) + \frac{1}{2}O_2(g), \Delta H_{\text{rxn}} = -283.0\,\text{kJ per mole of CO}(g).$$

Now add the two reactions:

$$C(g) + O_2(g) \rightarrow CO_2(g), \quad \Delta H_{\text{rxn}} = -393.5\,\text{kJ per mole of CO}_2(g),$$

$$CO(g) \rightarrow CO_2(g) + \frac{1}{2}O_2(g), \quad \Delta H_{\text{rxn}} = -283.0\,\text{kJ per mole of CO}(g).$$

By adding these reactions, the intermediate $CO_2(g)$ cancels out, giving the desired reaction. The total enthalpy change is:

$$\Delta H_{\text{rxn}} = -393.5 + 283.0 = -110.5\,\text{kJ per mole of CO}(g).$$

Thus, the enthalpy change is approximately $-111.0\,\text{kJ}$ per mole of CO(g).

Quick Tip

When combining reactions to find an overall enthalpy change, reverse reactions where necessary and sum the enthalpy changes, taking care to adjust the sign for reversed reactions.

Q.48 The N–O bond order in [NO]$^-$ is ______________.

Correct Answer: 2

Explanation:

To determine the bond order in [NO]$^-$, we need to use molecular orbital theory. The electronic configuration of NO$^-$ is the same as the molecular orbital configuration of NO, but with one additional electron due to the negative charge. In the case of NO, the molecular orbital diagram suggests a bond order of 2.

The addition of one electron to NO, forming $[NO]^-$, increases the number of electrons in the bonding molecular orbitals, but does not change the bond order significantly because the additional electron does not affect the bond order calculated by the molecular orbital theory. Thus, the bond order of N–O in $[NO]^-$ remains 2, which is similar to that of NO.

Quick Tip

In molecular orbital theory, bond order is calculated as the difference between the number of bonding and anti-bonding electrons, divided by 2. For $[NO]^-$, this results in a bond order of 2.

Q.49 The bond length of CO is 113 pm and its dipole moment (μ) is 0.1 D. The charge (in units of electronic charge) on carbon in the CO molecule including its sign is

______________.

Correct Answer: -0.019

Explanation:

The dipole moment μ is related to the charge q and bond length r by the equation:

$$\mu = q \times r$$

where: - μ is the dipole moment in Debye (D), - q is the charge in Coulombs (C), - r is the bond length in meters (m).

First, convert the bond length from pm (picometers) to meters:

$$r = 113\,\text{pm} = 113 \times 10^{-12}\,\text{m}$$

Now, rearrange the equation to solve for q:

$$q = \frac{\mu}{r}$$

Substitute the given values:

$$q = \frac{0.1\,\text{D} \times 3.336 \times 10^{-30}\,\text{C m/D}}{113 \times 10^{-12}\,\text{m}}$$

Calculating this gives:

$$q \approx -0.019\,\text{C}$$

Thus, the charge on carbon in CO is -0.019 electronic charges.

Quick Tip

The dipole moment formula $\mu = q \times r$ helps calculate the charge when the bond length and dipole moment are known. Remember to convert the bond length to meters and the dipole moment to Coulomb-meters.

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Substitute the given values:

$$q = \frac{0.1\,\text{D} \times 3.336 \times 10^{-30}\,\text{C m/D}}{113 \times 10^{-12}\,\text{m}}$$

Calculating this gives:

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Thus, the charge on carbon in CO is -0.019 electronic charges.

Quick Tip

The dipole moment formula $\mu = q \times r$ helps calculate the charge when the bond length and dipole moment are known. Remember to convert the bond length to meters and the dipole moment to Coulomb-meters.

Q.51 A reaction of 10.50 g of 1,2-diphenylethane-1,2-dione with conc. NaOH followed by aqueous acidic work-up furnished 8.55 g of a carboxylic acid. The yield of the carboxylic acid in this reaction is ____________ %.

Correct Answer: 74

Explanation:

The formula for calculating the yield of a reaction is:

$$\text{Yield}(\%) = \left(\frac{\text{Actual yield}}{\text{Theoretical yield}}\right) \times 100$$

Given: - Actual yield = 8.55 g - Theoretical yield = 10.50 g (mass of 1,2-diphenylethane-1,2-dione)

Substituting into the formula:

$$\text{Yield}(\%) = \left(\frac{8.55\,\text{g}}{10.50\,\text{g}}\right) \times 100 = 74\%$$

Thus, the yield of the carboxylic acid in this reaction is 74

Quick Tip

The yield of a reaction is calculated by comparing the actual amount of product obtained to the maximum possible amount (theoretical yield), and then multiplying by 100 to get the percentage.

Q.52 The specific rotation of an optically pure compound is +75.3 $(c = 1.0$ in CHCl$_3)$ at 20°C. A synthetic sample of the same compound showed a specific rotation of +66.3 $(c = 1.0$ in CHCl$_3)$ at 20°C. The enantiomeric excess (ee) of the synthetic sample is _____________ %.

Correct Answer: 88

Explanation:

The enantiomeric excess (ee) can be calculated using the following formula:

$$\text{ee} = \frac{\text{Observed specific rotation}}{\text{Specific rotation of optically pure compound}} \times 100$$

Given: - Observed specific rotation = +66.3 - Specific rotation of the optically pure compound = +75.3

Substitute the values:

$$\text{ee} = \frac{66.3}{75.3} \times 100 \approx 88$$

Thus, the enantiomeric excess (ee) of the synthetic sample is 88

Quick Tip

Enantiomeric excess (ee) is a measure of the purity of an optically active compound, indicating the proportion of one enantiomer present in excess over the other.

Q.53 A salt QCl of a certain metal Q is electrolyzed to its elements. 40 g of metal Q is formed at an electrode. The volume of Cl$_2$ formed at the other electrode at 1 atm pressure and 298 K is _____________ litres.

Correct Answer: 12.3

Explanation:

We are given the following data:

- Mass of Q formed = 40 g - Molar mass of Q = 40 g mol^{-1} - The volume of Cl_2 formed at 1 atm pressure and 298 K - The gas constant $R = 0.082\,\text{L atm mol}^{-1}\text{K}^{-1}$

From Faraday's law of electrolysis:

$$\text{moles of } Q = \frac{\text{Mass of Q}}{\text{Molar mass of Q}} = \frac{40\,\text{g}}{40\,\text{g/mol}} = 1\,\text{mol}$$

Since one mole of Q produces one mole of Cl_2, we now calculate the volume of Cl_2 using the ideal gas law:

$$PV = nRT$$

Substituting the values:

$$(1\,\text{atm})(V) = (1\,\text{mol})(0.082\,\text{L atm mol}^{-1}\text{K}^{-1})(298\,\text{K})$$

$$V = \frac{(1)(0.082)(298)}{1} = 12.3\,\text{L}$$

Thus, the volume of Cl_2 formed is 12.3 litres.

Quick Tip

The volume of gas produced during electrolysis can be calculated using the ideal gas law, where the number of moles of gas is equal to the number of moles of metal Q formed during the process.

Q.54 If 1 M of a dye in water transmits 50$\%$ of incident light at 400 nm, then 2 M of the dye in water transmits ______________ $\%$ of the incident light at 400 nm.

Correct Answer: 25

Explanation:

The transmission of light through a solution follows the Beer-Lambert Law, which is given by:

$$T = 10^{-\epsilon c l}$$

where:

- T is the transmission, - ϵ is the molar absorptivity, - c is the concentration of the solution, - l is the path length of the cell.

Since the experiments are performed in the same spectrophotometric cell, the path length l is constant for both cases. Also, we are given that 1 M of dye transmits 50% of the incident light. Now, when the concentration is doubled to 2 M, the transmission of light decreases according to the Beer-Lambert Law because absorbance increases with concentration.

For a 2 M solution, the transmission would be halved:

$$\text{Transmission at 2 M} = \frac{50}{2} = 25\%$$

Thus, the 2 M dye transmits 25% of the incident light.

Quick Tip

The transmission of light through a solution decreases exponentially as the concentration of the absorbing substance increases, according to Beer-Lambert Law.

Q.55 A 1.0 L solution is prepared by dissolving 2.0 g of benzoic acid and 4.0 g of sodium benzoate in water. The pH of the resulting solution is ______________.

Correct Answer: 4.4

Explanation:

This is a buffer solution formed by benzoic acid (weak acid) and sodium benzoate (its conjugate base). To calculate the pH of this buffer, we use the Henderson-Hasselbalch equation:

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

Where:

- $\text{p}K_a = 4.2$ (given), - $[\text{A}^-]$ is the concentration of the conjugate base (benzoate ion), - $[\text{HA}]$ is the concentration of the weak acid (benzoic acid).

First, calculate the moles of benzoic acid and sodium benzoate:

$$\text{Moles of benzoic acid} = \frac{2.0\,\text{g}}{122\,\text{g/mol}} = 0.01639\,\text{mol}$$

$$\text{Moles of sodium benzoate} = \frac{4.0\,\text{g}}{144\,\text{g/mol}} = 0.02778\,\text{mol}$$

The total volume of the solution is 1.0 L, so the concentrations are:

$$[\text{HA}] = \frac{0.01639\,\text{mol}}{1.0\,\text{L}} = 0.01639\,\text{M}$$

$$[\text{A}^-] = \frac{0.02778\,\text{mol}}{1.0\,\text{L}} = 0.02778\,\text{M}$$

Now, use the Henderson-Hasselbalch equation:

$$\text{pH} = 4.2 + \log\left(\frac{0.02778}{0.01639}\right) = 4.2 + \log(1.695) = 4.2 + 0.230$$

$$\text{pH} = 4.4$$

Thus, the pH of the solution is 4.4.

Quick Tip

For buffer solutions, use the Henderson-Hasselbalch equation to calculate pH by relating the concentrations of the acid and its conjugate base.

Q.56 The total vapour pressure of an ideal binary liquid mixture of benzene and toluene is 0.3 bar. The vapour pressure of pure benzene is 0.5 bar and that of toluene is 0.2 bar. The mole fraction of benzene in this mixture is ______________.

Correct Answer: 0.34

Explanation:

For an ideal solution, the total vapour pressure is given by Raoult's Law, which states:

$$P_{\text{total}} = P_{\text{benzene}} + P_{\text{toluene}}$$

Where:

$$P_{\text{benzene}} = P^0_{\text{benzene}} \cdot X_{\text{benzene}}, \quad P_{\text{toluene}} = P^0_{\text{toluene}} \cdot X_{\text{toluene}}$$

Here, P^0_{benzene} and P^0_{toluene} are the vapour pressures of pure benzene and toluene, and X_{benzene} and X_{toluene} are the mole fractions of benzene and toluene, respectively.
The mole fraction of benzene X_{benzene} is related to the total vapour pressure by the equation:

$$P_{\text{total}} = P^0_{\text{benzene}} \cdot X_{\text{benzene}} + P^0_{\text{toluene}} \cdot (1 - X_{\text{benzene}})$$

Substitute the given values into the equation:

$$0.3 = 0.5 \cdot X_{\text{benzene}} + 0.2 \cdot (1 - X_{\text{benzene}})$$

Simplify and solve for X_{benzene}:

$$0.3 = 0.5 \cdot X_{\text{benzene}} + 0.2 - 0.2 \cdot X_{\text{benzene}}$$

$$0.3 - 0.2 = 0.5 \cdot X_{\text{benzene}} - 0.2 \cdot X_{\text{benzene}}$$

$$0.1 = 0.3 \cdot X_{\text{benzene}}$$

$$X_{\text{benzene}} = \frac{0.1}{0.3} = 0.34$$

Thus, the mole fraction of benzene in the mixture is 0.34.

Quick Tip

Raoult's Law helps in calculating the vapour pressure of an ideal solution. Use it to determine mole fractions in binary mixtures.

Q.57 The unit cell of a two-dimensional square lattice with lattice parameter a is indicated by the dashed lines as shown below:

The percentage percent area occupied by the grey circles (of radius r) inside the unit cell is ______________.

Correct Answer: 77

Explanation:

In a two-dimensional square lattice, the unit cell is a square with side length a. The four grey circles inside the unit cell have a radius r. The total area occupied by the grey circles is the combined area of the four circles.

The area of one circle is given by the formula $A_{\text{circle}} = \pi r^2$. Since there are four circles in the unit cell, the total area occupied by the circles is:

$$A_{\text{total}} = 4 \cdot \pi r^2$$

The area of the square unit cell is $A_{\text{unit cell}} = a^2$. Since the distance between the centers of adjacent circles is a, the relationship between a and r is $a = 2r$.

Therefore, the area occupied by the grey circles as a percentage of the total unit cell area is:

$$\text{Percentage occupied} = \frac{A_{\text{total}}}{A_{\text{unit cell}}} \times 100 = \frac{4 \cdot \pi r^2}{(2r)^2} \times 100$$

Simplifying this:

$$\text{Percentage occupied} = \frac{4 \cdot \pi r^2}{4r^2} \times 100 = \pi \times 100 \approx 77\%$$

Thus, the percentage area occupied by the grey circles is 77

Quick Tip

For a square lattice with four circles inside, the percentage area occupied can be calculated using the formula for the area of a circle and the unit cell's area.

Q.58 In the oxidation of phosphorus with oxygen, 0.2 mol of P produces ______________ g of PO.

Correct Answer: 56.7

Explanation:

The molecular weight of PO can be calculated from the atomic weights of phosphorus (P) and oxygen (O). The molar mass of PO is:

$$M_{\text{PO}} = (4 \times \text{atomic weight of P}) + (10 \times \text{atomic weight of O})$$

$$M_{\text{PO}} = (4 \times 31) + (10 \times 16) = 124 + 160 = 284\,\text{g/mol}$$

Now, if 0.2 mol of P produces PO, the mass of PO produced is:

$$\text{mass of PO} = 0.2\,\text{mol} \times 284\,\text{g/mol} = 56.8\,\text{g}$$

Thus, the mass of PO produced is 56.7 g (rounded off to one decimal place).

Quick Tip

To calculate the mass of a product in a reaction, use the molar mass and the number of moles of the substance.

Q.59 An element E has three isotopes:

$$^{28}\text{E}\,(\text{abundance}\,92.21\%,\ \text{atomic mass} = 27.977\,\text{a.m.u.}),$$

$^{29}\text{E}\,(\text{abundance}\,4.70\%,\ \text{atomic mass} = 28.976\,\text{a.m.u.}),$

$^{30}\text{E}\,(\text{abundance}\,3.09\%,\ \text{atomic mass} = 29.974\,\text{a.m.u.}).$

The atomic mass of E is ______________ a.m.u.

Correct Answer: 28.082

Explanation:

The atomic mass of element E can be calculated using the formula for the weighted average of the atomic masses of its isotopes:

$$\text{Atomic mass of E} = \sum (\text{abundance of isotope} \times \text{atomic mass of isotope})$$

Substituting the given values:

$$\text{Atomic mass of E} = (0.9221 \times 27.977) + (0.0470 \times 28.976) + (0.0309 \times 29.974)$$

$$\text{Atomic mass of E} = 25.7766 + 1.3628 + 0.9260 = 28.082\,\text{a.m.u.}$$

Thus, the atomic mass of E is 28.082 a.m.u. (rounded to three decimal places).

Quick Tip

To calculate the atomic mass of an element with multiple isotopes, use the weighted average formula.

Q.60 The wavelength of the γ-ray emitted in ${}^{137}_{56}\text{Ba} \rightarrow {}^{137}_{56}\,\text{Ba} + \gamma\text{ray}\ (0.66\ \text{MeV})$ is______________ Å.

Correct Answer: 0.021

Explanation:

The wavelength λ of a photon can be calculated using the energy-wavelength relationship:

$$E = \frac{hc}{\lambda}$$

Where: - E is the energy of the photon, - h is Planck's constant ($6.626 \times 10^{-34}\,\text{J·s}$), - c is the speed of light ($2.998 \times 10^{8}\,\text{m/s}$), - λ is the wavelength.

We can rearrange the formula to solve for the wavelength λ:

$$\lambda = \frac{hc}{E}$$

Given that the energy of the γ-ray is 0.66 MeV, we first need to convert this to joules:

$$E = 0.66\,\text{MeV} \times 1.602 \times 10^{-13}\,\text{J/MeV} = 1.0573 \times 10^{-13}\,\text{J}$$

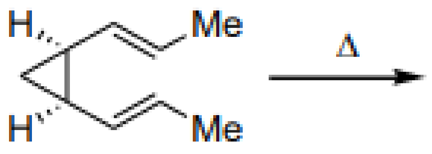
Now, substitute the values into the equation for λ:

$$\lambda = \frac{(6.626 \times 10^{-34}\,\text{J·s})(2.998 \times 10^{8}\,\text{m/s})}{1.0573 \times 10^{-13}\,\text{J}} = 0.021\,\text{Å}$$

Thus, the wavelength of the γ-ray is 0.021 Å (rounded to three decimal places).

Quick Tip

To calculate the wavelength of a photon, use the energy-wavelength relationship and convert energy to joules.



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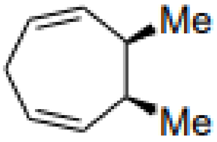

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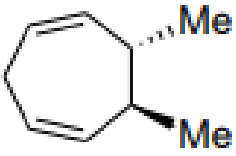

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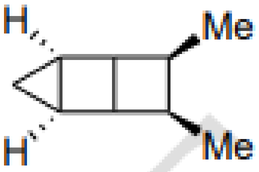

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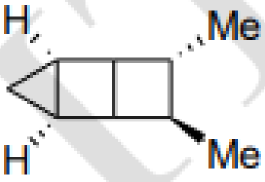

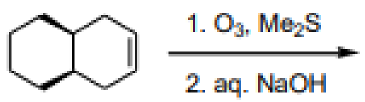

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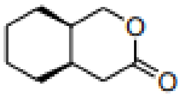
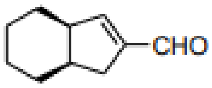
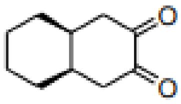
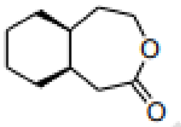
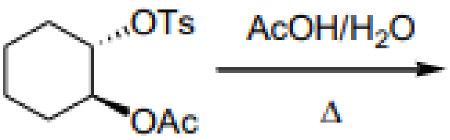
(A) 

(B) 

(C) 

(D) 



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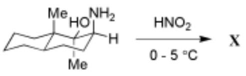

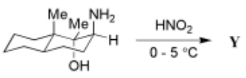

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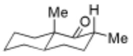
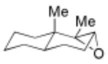
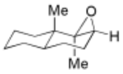
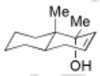
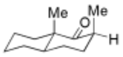
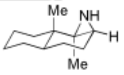
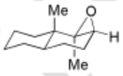
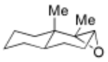
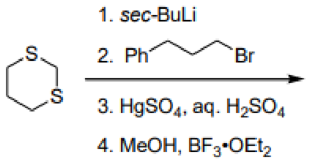
(A)  and 

(B)  and 

(C)  and 

(D)  and 



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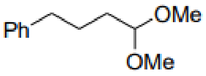
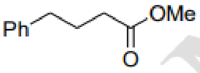
(B) 

(C) 

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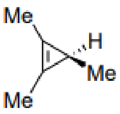

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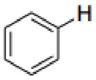

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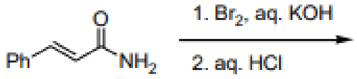
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O
NH2
1. Br2, aq. KOH
2. aq. HCl

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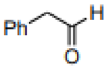
(B) 
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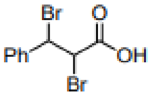
(C) 
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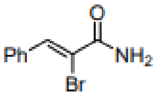
(D) 
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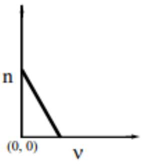
(A) 
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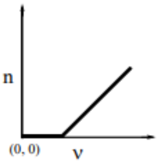
(B) 
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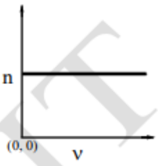
(C) 
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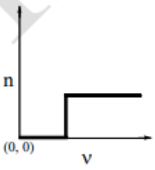
(D) 
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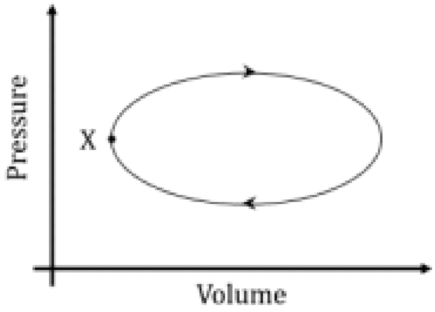
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X
Volume


Zn

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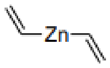
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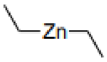
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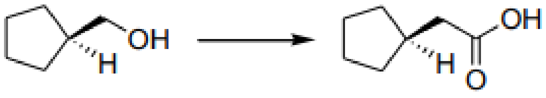
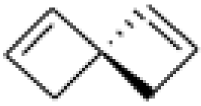
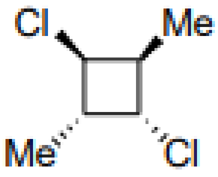

OH
H
OH
H
O

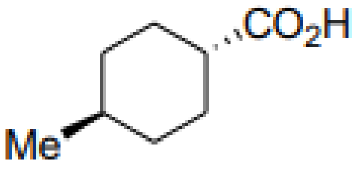
(A)



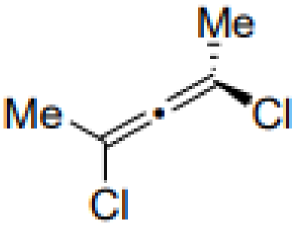
(B)

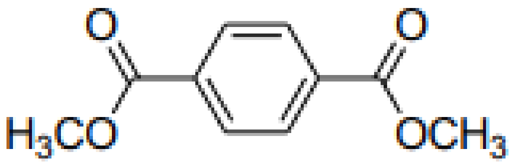

Cl
Me
Me
Cl

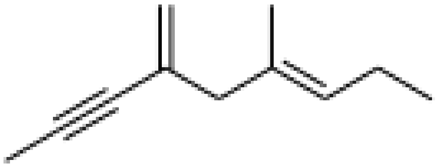
(C)

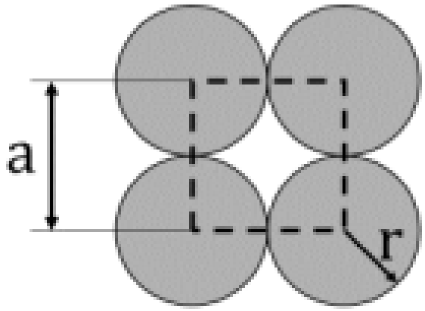

CO2H
Me

(D)


Me
Me
Cl
Cl


O
O
H3CO
OCH3




a
r