NIOS Class 12 Chemistry Sample Paper – 4

Duration: 180 Minutes **Maximum Marks: 80**

Instructions

- This paper contains **43** Questions. The paper is divided into two sections: **Section A – 40** marks, **Section B – 40** marks.
- **Section A** consists of
  - **Q.No. 1 to 16** – Multiple Choice type questions (MCQs) carrying 1 mark each. Select and write the most appropriate option out of the four options given in each of these questions. An internal choice has been provided in some of these questions. You have to attempt only one of the given choices in such questions.
  - **Q. No. 17 to 28** – Objective type questions. Q. No. 17 to 28 carry 02 marks each (with 2 sub- parts of 1 mark each). Attempt these questions as per the instructions given for each of the questions 17 –28.
- **Section B** consists of
  - **Q.No. 29 to 37** – Very Short questions carrying 02 marks each to be answered in the range of 30 to 50 words.
  - **Q.No. 38 to 41** – Short Answer type questions carrying 03 marks each to be answered in the range of 50 to 80 words.
  - **Q.No. 42 and 43** – Long Answer type questions carrying 05 marks each to be answered in the range of 80 to 120 words.
- There is **No Negative marking**.
- Use of mobile phones, smartwatches, calculators, or any electronic gadgets is strictly prohibited.

Section: A

Q1. An organic compound contains 40% carbon, 6.7% hydrogen and 53.3% oxygen by mass. Its empirical formula is: **(1)**

(A) CH_2O

(B) CHO

(C) C_2H_4O

(D) CH_3O

Q2. The number of radial nodes for a $3p$ orbital is: **(1)**

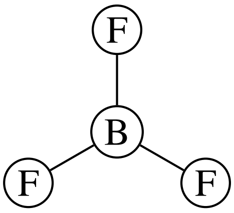
(A) 0

(B) 1

(C) 2

(D) 3

Q3. Which of the following molecules has a net dipole moment of zero? **(1)**



BF_3 Structure

(A) NH_3

(B) H_2O

(C) BF_3

(D) $CHCl_3$

Q4. The solubility of a gas in a liquid is directly proportional to the partial pressure of the gas above the liquid. This is known as: **(1)**

(A) Raoult's Law

(B) Henry's Law

(C) Boyle's Law

(D) Charles's Law

Q5. Which of the following is an intensive property? **(1)**

(A) Enthalpy

(B) Entropy

(C) Specific heat capacity

(D) Internal energy

Q6. A reaction has a rate constant $k = 2.5 \times 10^{-4}$ L mol^{-1} s^{-1}. The order of the reaction is: **(1)**

(A) Zero

(B) First

(C) Second

(D) Third

Q7. If the standard reduction potential of an electrode is positive, it means: **(1)**

(A) It is a weaker oxidizing agent than H^+

(B) It is a stronger oxidizing agent than H^+

(C) It acts as an anode when coupled with SHE

(D) It easily loses electrons

Q8. The conjugate acid of ammonia (NH_3) is: **(1)**

(A) NH_2^-

(B) NH_4^+

(C) N_3^-

(D) NH_2OH

Q9. Which of the following halogens does not exhibit a positive oxidation state? **(1)**

(A) Chlorine

(B) Bromine

(C) Iodine

(D) Fluorine

Q10. Which of the following ions is diamagnetic in nature? **(1)**

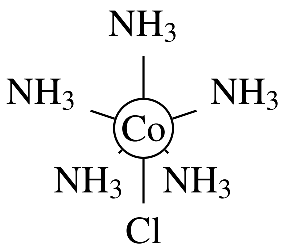
(A) Cu^{2+}

(B) Ni^{2+}

(C) Zn^{2+}

(D) Co^{2+}

Q11. The oxidation state of cobalt in the complex $[Co(NH_3)_5Cl]^{2+}$ shown below is: **(1)**



(A) +1

(B) +2

(C) +3

(D) +4

Q12. Which of the following compounds is chiral? **(1)**

(A) 1-Chlorobutane

(B) 2-Chlorobutane

(C) 1-Chloropropane

(D) 2-Chloropropane

Q13. Which of the following is the most acidic? **(1)**

(A) Ethanol

(B) Phenol

(C) p-Nitrophenol

(D) p-Methoxyphenol

Q14. The correct order of reactivity towards nucleophilic addition reaction is: **(1)**

(A) Methanal > Ethanal > Propanone

(B) Propanone > Ethanal > Methanal

(C) Ethanal > Methanal > Propanone

(D) Propanone > Methanal > Ethanal

Q15. In aqueous solution, the most basic amine among the following is: **(1)**

(A) Ammonia

(B) Methylamine

(C) Dimethylamine

(D) Trimethylamine

Q16. Deficiency of Vitamin C causes: **(1)**

(A) Scurvy

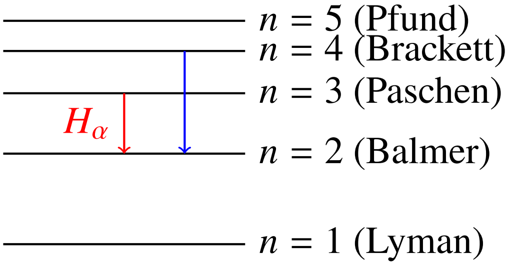
(B) Beri-Beri

(C) Night blindness

(D) Rickets

Note: Q. No. 17 to 28 are the objective type questions of 2 marks each.

Q17. Read the passage given below and answer the following questions:
The emission spectrum of hydrogen consists of several series of lines. The Balmer series appears in the visible region. Electrons transition between various energy levels as shown in the diagram. **(2)**



1. Which transition corresponds to the H_α line of the Balmer series?

2. What is the lowest energy level n for the Paschen series?

Q18. Fill in the blanks: **(2)**

1. The temperature above which a gas cannot be liquefied no matter how much pressure is applied is called . . . .
2. The vapor pressure of a solution containing a non-volatile solute is than that of the pure solvent.

Q19. Write TRUE (T) for the correct statement and FALSE (F) for the incorrect statement: **(2)**

1. The entropy of a perfectly crystalline substance at absolute zero is zero.
2. An endothermic reaction is always non-spontaneous at all temperatures.

Q20. Complete the following by using the options given below:
(activation energy, threshold energy, collision frequency, effective collision) **(2)**

1. The minimum energy that reacting molecules must possess for a collision to result in a chemical reaction is called . . . .
2. The number of collisions per second per unit volume of the reaction mixture is known as . . . .

Q21. Complete the following by using the options given below:
(paramagnetic, diamagnetic, V_2O_5, Fe_2O_3) **(2)**

1. In the Contact process for the manufacture of sulphuric acid, the catalyst used is . . . .
2. Oxygen molecule (O_2) is in nature according to Molecular Orbital Theory.

Q22. Read the passage given below and answer the following questions:
Transition metals form a large number of alloys because their atomic radii are very similar. Alloys are generally harder and have higher melting points than pure metals. **(2)**

1. Why do transition metals readily form alloys?

2. Name an alloy of copper and zinc.

Q23. Read the passage given below and answer the following questions:
Ambidentate ligands have two different donor atoms and can coordinate to a metal ion through either of them, giving rise to linkage isomerism in coordination compounds. **(2)**

1. Give one example of an ambidentate ligand.
2. What type of isomerism is shown by $[Co(NH_3)_5(NO_2)]Cl_2$ and $[Co(NH_3)_5(ONO)]Cl_2$?

Q24. Match the items given in Column I with the most appropriate items in Column II: **(2)**

Column I	**Column II**
(a) Carbylamine test	(i) Alcohols
(b) Iodoform test	(ii) Unsaturation
(c) Bromine water test	(iii) Methyl ketones
(d) Lucas test	(iv) Primary amines

Q25. Complete the following reaction equations: **(2)**

1. $C_6H_5CHO + H_2N-NH_2 \xrightarrow{H^+}$
2. $CH_3CN \xrightarrow{H_2O/H^+}$

Q26. Read the passage given below and answer the following questions:
Enzymes are highly specific biological catalysts. They are globular proteins that lower the activation energy of biochemical reactions, enabling them to proceed at physiological temperatures. **(2)**

1. What is the chemical nature of enzymes?
2. Name the enzyme that converts glucose into ethanol and carbon dioxide.

Q27. Write TRUE (T) for the correct statement and FALSE (F) for the incorrect statement: **(2)**

1. Tranquilizers are chemical compounds used for the treatment of stress and mental diseases.
2. Broad-spectrum antibiotics are effective against only a single specific organism.

Q28. Read the passage given below and answer the questions given below:
Food preservatives prevent spoilage of food due to microbial growth. The most commonly used preservatives are table salt, sugar, vegetable oils, and sodium benzoate. **(2)**

1. What is the primary function of a food preservative?
2. Name one chemical substance used as a food preservative other than salt or sugar.

Section: B

Q29. (i) State Heisenberg's Uncertainty Principle.

OR

(ii) What are degenerate orbitals? Give an example. **(2)**

Q30. Distinguish between a sigma (σ) bond and a pi (π) bond. (Any two points). **(2)**

Q31. (i) What is meant by the dual nature of matter? Write de Broglie's equation.

OR

(ii) Explain why the radius of a cation is smaller than its parent atom. **(2)**

Q32. (i) State Raoult's law for a solution containing volatile liquids.

OR

(ii) What are azeotropes? Give one example of a minimum boiling azeotrope. **(2)**

Q33. Define Kohlrausch's law of independent migration of ions. **(2)**

Q34. Why does PCl_5 exist but NCl_5 does not? **(2)**

Q35. (i) Write the balanced chemical equation for the reaction of chlorine with cold and dilute NaOH.

OR

(ii) Draw the structure of $XeOF_4$. **(2)**

Q36. What is Williamson's ether synthesis? Give an example. **(2)**

Q37. Convert the following: **(2)**

(a) Benzene to Chlorobenzene

(b) Propene to Propan-2-ol

Q38. An organic compound on analysis gave the following percentage composition: C = 54.5%, H = 9.1%, O = 36.4%. Find the empirical formula of the compound. (Atomic masses: C=12, H=1, O=16). **(3)**

Q39. (i) 18 g of glucose ($C_6H_{12}O_6$) is dissolved in 1 kg of water. At what temperature will this solution boil? (K_b for water is 0.52 K kg mol^{-1}, boiling point of pure water is 373.15 K).

OR

(ii) A solution is prepared by dissolving 5.85 g of NaCl in 500 mL of water. Calculate the molarity of the solution. (Molar mass of NaCl = 58.5 g/mol). **(3)**

Q40. Calculate the standard enthalpy of formation of methane (CH_4) given that the standard enthalpies of combustion of Carbon, Hydrogen and Methane are −393.5 kJ/mol, −285.8 kJ/mol and −890.3 kJ/mol respectively. **(3)**

Q41. (i) Explain the mechanism of nucleophilic addition of HCN to a carbonyl compound.

OR

(ii) Write short notes on:

(a) Reimer-Tiemann reaction

(b) Hofmann bromamide degradation reaction. **(3)**

Q42. (i) Answer the following:

A. State Faraday's second law of electrolysis.

B. The rate constant of a first-order reaction is $1.15 \times 10^{-3}\ \mathrm{s}^{-1}$. How long will 5 g of this reactant take to reduce to 3 g?

OR

(ii) Answer the following:

A. Define molar conductivity. How does it vary with dilution for a weak electrolyte?

B. Represent the galvanic cell in which the reaction

$\mathrm{Zn(s)} + \mathrm{Cu^{2+}(aq)} \rightarrow \mathrm{Zn^{2+}(aq)} + \mathrm{Cu(s)}$ takes place. What is the direction of flow of electrons? **(5)**

Q43. (i) Answer the following:

A. Describe the preparation of potassium dichromate ($K_2Cr_2O_7$) from chromite ore.

B. Why do transition elements show variable oxidation states?

OR

(ii) Answer the following:

A. Give the IUPAC name of $[\mathrm{Pt(NH_3)_2Cl(NO_2)}]$.

B. On the basis of Crystal Field Theory, write the electronic configuration for d^4 ion if $\Delta_o < P$.

C. What are interstitial compounds? Give one example. **(5)**

Detailed Solutions

Q1.

Solution

Concept: The empirical formula represents the simplest whole-number ratio of atoms of each element present in a chemical compound. Unlike the molecular formula, which gives the actual number of atoms, the empirical formula is derived directly from experimental composition data. We calculate this by finding the relative number of moles for each element, which normalizes the mass values against their respective atomic weights.

Step 1 — Assuming a 100 g sample of the compound makes the math straightforward, as percentages convert directly to masses. Therefore, we have 40 g of Carbon (C), 6.7 g of Hydrogen (H), and 53.3 g of Oxygen (O).

Step 2 — Calculate the number of moles of each element by dividing the given mass by its corresponding molar mass (C = 12 g/mol, H = 1 g/mol, O = 16 g/mol): Moles of C = $40/12 = 3.33$ mol Moles of H = $6.7/1 = 6.70$ mol Moles of O = $53.3/16 = 3.33$ mol

Step 3 — To determine the simplest integer ratio, divide each calculated mole value by the smallest mole value obtained in the previous step, which is 3.33: For C: $3.33/3.33 = 1$ For H: $6.70/3.33 \approx 2$ For O: $3.33/3.33 = 1$ The resulting whole-number ratio for C, H, and O is 1 : 2 : 1.

Step 4 — Combining these elemental ratios gives us the final empirical formula, which is CH_2O. This formula indicates that for every carbon atom, there are two hydrogen atoms and one oxygen atom.

Final Answer: CH_2O

Answer: (A)

Go Back to Question 1

Q2.

Solution

Concept: The spatial distribution of an electron in an atom is described by quantum mechanical wave functions. Nodes are regions in space around the nucleus where the probability of finding an electron is exactly zero. Nodes are categorized into two types: angular nodes and radial nodes. The number of radial (or spherical) nodes for any atomic orbital depends on its energy state and is calculated using the formula $n - l - 1$, where n represents the principal quantum number (indicating the energy level or shell) and l represents the azimuthal (or orbital angular momentum) quantum number (indicating the subshell shape).

Step 1 — For a $3p$ orbital, the number preceding the subshell letter denotes the main energy level. Therefore, the principal quantum number is $n = 3$.

Step 2 — The azimuthal quantum number l is defined by the type of orbital. The values are $l = 0$ for s, $l = 1$ for p, $l = 2$ for d, and $l = 3$ for f. For a p orbital, we find that $l = 1$.

Step 3 — Substitute these specific quantum values into the node formula: Number of radial nodes = $n - l - 1 = 3 - 1 - 1 = 1$. This means the $3p$ orbital contains exactly one spherical surface where electron density drops to zero.

Final Answer: 1

Answer: (B)

Go Back to Question 2

Q3.

Solution

Concept: Molecular polarity is dictated by both individual bond dipoles and molecular geometry. A bond dipole arises from electronegativity differences between bonded atoms. However, a molecule will have a net dipole moment of zero ($\mu = 0$) if it possesses a highly symmetrical geometry. In such cases, the individual bond dipole moment vectors point in opposite directions and cancel each other out completely.

Step 1 — Consider NH_3 and H_2O. The presence of non-bonding lone pairs on the central atoms distorts the geometry according to VSEPR theory, leading to asymmetric structures (trigonal pyramidal for ammonia and bent for water). Because of this asymmetry, individual bond dipoles reinforce one another rather than cancelling out, resulting in a net dipole moment.

Step 2 — In chloroform ($CHCl_3$), the central carbon is bonded to three highly electronegative chlorine atoms and one hydrogen atom. The tetrahedral geometry is asymmetric because the pulling force of the $C - Cl$ bonds is structurally different from the $C - H$ bond, preventing any total vector cancellation.

Step 3 — Boron trifluoride (BF_3) features a central boron atom bonded to three fluorine atoms. It utilizes sp^2 hybridization and has no lone pairs on the central atom, creating a perfectly symmetrical trigonal planar geometry with 120° bond angles. The three identical $B - F$ bond dipoles point outward symmetrically, summing vectorially to zero.

Final Answer: BF_3

Answer: (C)

Go Back to Question 3

Q4.

Solution

Concept: The behavior, solubility, and phase properties of gases are governed by specific named gas laws that describe relationships between pressure, volume, temperature, and quantity. When evaluating how a gas dissolves in a liquid solvent, the relationship between gas solubility and external pressure is described by a fundamental law of physical chemistry.

Step 1 — Let us analyze the alternative gas and solution laws. Boyle's Law states that the volume of a gas is inversely proportional to its pressure at a constant temperature. Charles's Law establishes that gas volume is directly proportional to absolute temperature under constant pressure. Raoult's Law relates the vapor pressure of a solution component to its mole fraction in the liquid phase, focusing primarily on volatile liquids rather than gas dissolution.

Step 2 — Henry's Law specifically addresses gas-liquid mixtures. It states that at a constant temperature, the mass or solubility of a gas dissolved in a given volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with the liquid. Mathematically, it is written as $C = k \cdot P$, where C is solubility, k is Henry's constant, and P is partial pressure. This law explains real-world phenomena such as the carbonation in soft drinks and decompression sickness in deep-sea divers.

Final Answer: Henry's Law

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

Go Back to Question 4

Q5.

Solution

Concept: In thermodynamics, the properties of a system are classified into two categories based on how they respond to changes in the size or mass of the system: intensive properties and extensive properties. An intensive property is an inherent characteristic of the substance that remains completely independent of the total amount of matter present. Conversely, an extensive property changes proportionally with the quantity of substance in the system.

Step 1 — Properties like enthalpy (H), entropy (S), and internal energy (U) represent the total energy content or molecular disorder of a system. If you double the mass of the substance, you double its total internal energy, total heat content, and total entropy. Because these values scale directly with the mass or quantity of matter, they are classified as extensive properties.

Step 2 — Heat capacity is the amount of heat required to raise the temperature of an entire object by one degree, making it extensive. However, specific heat capacity (c) is defined as the heat required to raise the temperature of exactly one unit mass (such as one gram or one kilogram) of a substance by one degree Celsius or Kelvin. Because it is calculated per unit mass, it becomes a fixed characteristic of the material itself. One drop of water and a whole swimming pool of water share identical specific heat capacities. Thus, it is an intensive property.

Final Answer: Specific heat capacity

Answer: (C)

Go Back to Question 5

Q6.

Solution

Concept: In chemical kinetics, the order of a reaction represents the relationship between the rate of the chemical reaction and the concentrations of the reacting species. While the rate of a reaction always has the unit mol L^{-1} s^{-1}, the units of the rate constant k vary depending on the overall reaction order (n). The general dimensional formula for determining the unit of a rate constant is expressed as $(\text{mol L}^{-1})^{1-n}\text{s}^{-1}$. By evaluating the given units, we can solve for n.

Step 1 — The problem states that the experimental unit of the rate constant k is L mol^{-1} s^{-1}.

Step 2 — To align this with our general formula, we can algebraically rearrange L mol^{-1} s^{-1}. Since L mol^{-1} is the reciprocal of concentration (mol L^{-1}), we can rewrite the given unit as $(\text{mol L}^{-1})^{-1}\text{s}^{-1}$.

Step 3 — Now, equate the exponents of the concentration term from the general formula and our rewritten unit: $1 - n = -1$ Rearranging the equation to solve for n, we get: $n = 1 - (-1) = 2$ Because $n = 2$, the process follows second-order kinetics, meaning the rate depends on the product of two concentrations.

Final Answer: Second

Answer: (C)

Go Back to Question 6

Q7.

Solution

Concept: Standard reduction potential ($E°$) is an intensive electrochemical property that measures the thermodynamic tendency of a chemical species to gain electrons and undergo reduction under standard conditions (298 K, 1 atm, 1 M). All standard reduction potentials are measured relative to the Standard Hydrogen Electrode (SHE), which serves as the universal reference point and is assigned an arbitrary potential of exactly $E° = 0.00$ V for the reaction $2H^+ + 2e^- \longrightarrow H_2$.

Step 1 — A positive standard reduction potential ($E° > 0$ V) indicates that the forward reduction reaction is thermodynamically favorable when paired with a SHE. It signifies that the chemical species has a significantly higher affinity for electrons than a hydrogen ion (H^+).

Step 2 — An oxidizing agent is a substance that oxidizes other species by gaining electrons itself; thus, a good oxidizing agent is a substance that is easily reduced.

Step 3 — Since a positive $E°$ indicates a strong tendency to capture electrons and undergo reduction, the species will readily pull electrons away from other substances. Therefore, a positive standard reduction potential directly implies that the chemical species acts as a stronger oxidizing agent than the reference H^+ ion.

Final Answer: It is a stronger oxidizing agent than H^+

Answer: (B)

Go Back to Question 7

Q8.

Solution

Concept: According to the Brønsted-Lowry acid-base theory, acid-base reactions involve the transfer of a hydrogen ion (a proton, or H^+) from one reactant to another. Within this framework, a base is defined as a proton acceptor, while an acid is a proton donor. When a Brønsted-Lowry base accepts a proton, it transforms into its conjugate acid. The base and its corresponding conjugate acid differ structurally by exactly one single proton (H^+).

Step 1 — Ammonia (NH_3) possesses a lone pair of electrons on its central nitrogen atom. This high electron density allows it to attract and form a coordinate covalent bond with a positively charged hydrogen ion, meaning it behaves fundamentally as a Brønsted-Lowry base.

Step 2 — When ammonia accepts a proton (H^+) from an acid source in a chemical environment, it undergoes protonation. The balanced chemical equation representing this fundamental acid-base step is: $NH_3 + H^+ \rightarrow NH_4^+$

Step 3 — The product formed from this reaction is the ammonium ion (NH_4^+). Because the ammonium ion can reverse this reaction by donating a proton back to a base, it acts as the conjugate acid of ammonia.

Final Answer: NH_4^+

Answer: (B)

Go Back to Question 8

Q9.

Solution

Concept: The oxidation state or oxidation number reflects the hypothetical charge an atom would carry if all bonds to atoms of different elements were 100% ionic. This assignment depends fundamentally on the relative electronegativities of the bonded atoms. The more electronegative atom in a bond is assigned the negative electrons, while the less electronegative atom is assigned a positive value.

Step 1 — Halogens such as chlorine (Cl), bromine (Br), and iodine (I) belong to group 17 and typically display an oxidation state of -1. However, when they bind to elements that are more electronegative than themselves, such as oxygen or fluorine, they lose electron density and can exhibit a variety of positive oxidation states ranging from $+1, +3, +5$, up to $+7$ (as seen in perchlorates or interhalogen compounds).

Step 2 — Fluorine (F) occupies the top right position of the reactive periodic table. It is established as the most electronegative element across the entire periodic table, possessing an electronegativity value of 4.0 on the Pauling scale. Because no element can pull electron density away from fluorine, it can never lose electrons in a chemical bond.

Step 3 — Consequently, fluorine exclusively exhibits a negative oxidation state of -1 in all its chemical compounds. It only shows an oxidation state of 0 when bonded to itself in elemental fluorine gas (F_2). It is chemically impossible for fluorine to exhibit a positive oxidation state.

Final Answer: Fluorine

Answer: (D)

Go Back to Question 9

Q10.

Solution

Concept: The magnetic properties of transition metal complexes and ions are determined by their electronic configurations. According to electronic principles, a chemical species is classified as diamagnetic if all of its electrons are completely paired within their respective atomic or molecular orbitals. Diamagnetic substances are weakly repelled by external magnetic fields. Conversely, if a species contains one or more unpaired electrons, it is classified as paramagnetic and is attracted to magnetic fields.

Step 1 — Let us determine the valence electron configurations for the given transition metal divalent cations by removing two electrons from their neutral ground states: Cu^{2+} (Atomic number 29): $[Ar]3d^9$ → Contains 1 unpaired electron (Paramagnetic). Ni^{2+} (Atomic number 28): $[Ar]3d^8$ → Contains 2 unpaired electrons (Paramagnetic). Co^{2+} (Atomic number 27): $[Ar]3d^7$ → Contains 3 unpaired electrons (Paramagnetic).

Step 2 — Now evaluate the zinc ion. The atomic number of neutral Zinc (Zn) is 30, and its ground state configuration is $[Ar]3d^{10}4s^2$. When forming a Zn^{2+} cation, the two valence electrons are lost from the outermost $4s$ subshell.

Step 3 — This results in an electronic configuration of $[Ar]3d^{10}$ for Zn^{2+}. The five $3d$ orbitals are completely filled with ten electrons, meaning every single electron is paired up. The absence of unpaired electrons makes Zn^{2+} diamagnetic.

Final Answer: Zn^{2+}

Answer: (C)

Go Back to Question 10

Q11.

Solution

Concept: Coordination compounds feature a central metal atom or ion bonded to surrounding molecules or ions known as ligands. The overall charge carried by a complex coordination entity is the algebraic sum of the oxidation states of its constituent parts. By assigning known characteristic charges to the coordinated ligands, we can set up a simple linear algebraic equation to calculate the unknown oxidation state of the central transition metal ion.

Step 1 — Let us represent the variable oxidation state of the central Cobalt (Co) atom with the placeholder variable x.

Step 2 — Ammonia (NH_3) functions as an ammine ligand. Because it is a stable, neutral molecular compound with no net charge, its contribution to the total oxidation state expression is exactly 0. The complex contain 5 identical ammine ligands, contributing a combined value of $5 \times 0 = 0$.

Step 3 — The chloride ion (Cl^-) acts as an anionic chlorido ligand inside the coordination sphere. Since it belongs to the halogen group and carries a single negative charge, its oxidation state value is -1.

Step 4 — The entire complex ion bears an explicit overall charge of +2. Setting up the charge balance equation: $x + 5(0) + (-1) = +2$ Simplifying the expression gives: $x - 1 = 2 \implies x = +3$. Thus, Cobalt exists in the +3 oxidation state, written as Co(III).

Final Answer: +3

Answer: (C)

Go Back to Question 11

Q12.

Solution

Concept: In stereochemistry, molecular chirality is responsible for optical activity, enabling a molecule to rotate plane-polarized light. A molecule is considered structurally chiral if it cannot be superimposed onto its mirror image. This property typically arises when the molecule lacks internal planes or centers of symmetry, commonly due to the presence of an asymmetric carbon atom, also known as a stereocenter or chiral center. A chiral center is defined as a tetrahedral carbon atom covalently bonded to four chemically distinct groups.

Step 1 — Let us examine the structural formula of 2-chlorobutane, which can be drawn explicitly as $CH_3 - C^*H(Cl) - CH_2 - CH_3$.

Step 2 — Focus on the second carbon atom (marked as C^*) along the principal alkane chain. By inspecting its tetrahedral valency, we observe that it is directly bonded to four entirely different functional groups or atomic arrangements: a hydrogen atom ($-H$), a chlorine atom ($-Cl$), a methyl group ($-CH_3$), and an ethyl group ($-CH_2CH_3$).

Step 3 — Because all four substituents are unique, this specific carbon represents a genuine chiral center. The molecule exhibits optical isomerism with non-superimposable *R* and *S* enantiomers. The remaining choices contain carbons bonded to matching pairs of alkyl groups or hydrogens, lacking any asymmetric center.

Final Answer: 2-Chlorobutane

Answer: (B)

Go Back to Question 12

Q13.

Solution

Concept: The relative acidity of organic hydroxyl compounds is determined by the thermodynamic stability of the conjugate base formed upon deprotonation. When an acid loses a proton (H^+), it forms a negatively charged ion. Any structural feature that disperses or stabilizes this negative charge will drive the equilibrium forward, enhancing acidity. Substituents affect the electron density of an aromatic system via inductive effects ($-I$ or $+I$) and resonance or mesomeric effects ($-R$ or $+R$).

Step 1 — Ethanol (CH_3CH_2OH) is an aliphatic alcohol. Its deprotonated conjugate base, the ethoxide ion ($CH_3CH_2O^-$), experiences the electron-donating $+I$ effect of the ethyl group, which destabilizes the oxygen atom's negative charge. Furthermore, it lacks resonance stabilization, making ethanol significantly less acidic than any aromatic phenol.

Step 2 — In p-nitrophenol, the nitro group ($-NO_2$) attached at the para position is a powerful electron-withdrawing group via both $-I$ and $-R$ pathways. Upon deprotonation, the negative charge on the phenoxide oxygen can be delocalized directly onto the oxygen atoms of the nitro group. This extensive resonance stabilization vastly lowers the potential energy of the conjugate base.

Step 3 — Conversely, the methoxy group ($-OCH_3$) in p-methoxyphenol exerts an electron-donating $+R$ effect due to lone pairs on its oxygen, which pumps electron density into the ring, destabilizing the phenoxide ion. Hence, p-nitrophenol is the most acidic.

Final Answer: p-Nitrophenol

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

Go Back to Question 13

Q14.

Solution

Concept: Carbonyl compounds (aldehydes and ketones) typically undergo nucleophilic addition reactions because the carbonyl group is highly polarized due to the electronegativity difference between carbon and oxygen ($C^{\delta+} = O^{\delta-}$). The reactivity of this carbonyl carbon towards a nucleophile is governed by two main factors: steric hindrance and electronic effects. Bulky substituents physically block the approaching nucleophile, while electron-donating alkyl groups reduce the partial positive charge ($\delta+$) on the carbon via the inductive ($+I$) effect, making it less electrophilic.

Step 1 — Methanal (HCHO, formaldehyde) contains a carbonyl carbon bonded only to two tiny hydrogen atoms. It features minimal steric hindrance, and because hydrogen has a negligible inductive effect, the carbonyl carbon remains highly positive, electrophilic, and reactive.

Step 2 — Ethanal (CH_3CHO, acetaldehyde) has one hydrogen replaced by a bulkier methyl group. This methyl group exerts an electron-donating $+I$ effect, which partially neutralizes the positive charge on the carbonyl carbon and increases steric crowding, rendering it less reactive than methanal.

Step 3 — Propanone (CH_3COCH_3, acetone) possesses two methyl groups surrounding the carbonyl center. These two groups offer substantial steric resistance and donate electron density from both sides, significantly lowering its electrophilic nature. Therefore, the order decreases as Methanal > Ethanal > Propanone.

Final Answer: Methanal > Ethanal > Propanone

Answer: (A)

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Q15.

Solution

Concept: The basic strength of an amine is defined by its ability to donate its lone pair of electrons to a proton. In the gaseous phase, basicity simply follows the electronic inductive ($+I$) effect of alkyl groups: tertiary (3°) > secondary (2°) > primary (1°) amines, because more alkyl groups increase electron density on the nitrogen. However, in an aqueous solution, the trend becomes complicated due to the competing interactions of three distinct factors: the $+I$ effect, steric hindrance, and hydration or solvation energy.

Step 1 — Based purely on the inductive effect, tertiary amines should be the most basic. Alkyl groups continually push electron density toward the nitrogen atom, enhancing its lone-pair availability.

Step 2 — When dissolved in water, the resulting substituted ammonium cation must be stabilized via hydrogen bonding with water molecules (hydration). Smaller ions with more available hydrogens ($-NH_3^+$ or $-NH_2^+$) form stronger hydrogen bonds. Tertiary ammonium ions are heavily crowded and have only one hydrogen, leading to poor hydration stability due to steric hindrance.

Step 3 — For methyl-substituted amines, the unique structural interplay of these opposing trends peaks at the secondary amine. Dimethylamine, $(CH_3)_2NH$, strikes the perfect thermodynamic balance, making it the strongest base in an aqueous medium.

Final Answer: Dimethylamine

Answer: (C)

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Q16.

Solution

Concept: Vitamins are organic compounds required in minute quantities to maintain normal metabolic functions and cellular biochemistry within living organisms. Since the human body cannot synthesize most vitamins in sufficient amounts, they must be obtained through dietary sources. Vitamins are classified based on their solubility as either fat-soluble or water-soluble. A prolonged lack of any specific vitamin halts critical biochemical pathways, resulting in distinct nutritional deficiency diseases.

Step 1 — Vitamin C, chemically identified as ascorbic acid, is a essential water-soluble vitamin found abundantly in citrus fruits. It acts as a powerful antioxidant and a necessary cofactor for the enzyme prolyl hydroxylase, which is responsible for the post-translational modification and stabilization of collagen triple helices.

Step 2 — When an individual suffers from a severe deficiency of Vitamin C, defective collagen synthesis disrupts connective tissues throughout the body. This pathological state leads to Scurvy, a disease characterized by fragile blood vessels, bleeding gums, subcutaneous hemorrhaging, and significantly delayed wound healing.

Step 3 — For comparative clarity, Beri-Beri is a neurological and cardiovascular disorder caused by Vitamin B1 (thiamine) deficiency. Night blindness is caused by a lack of Vitamin A, and Rickets is a bone-softening condition linked to Vitamin D deficiency.

Final Answer: Scurvy

Answer: (A)

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Q17.

Solution

Concept: The atomic hydrogen emission spectrum provides experimental validation for the quantized nature of electronic energy levels in atoms. According to the Bohr model, when an excited electron falls from a higher principle energy level (n_2) to a lower energy level (n_1), it releases a photon of a specific frequency. The resulting spectral lines are grouped into distinct families or series named after their discoverers, where each series is uniquely defined by its final landing energy level (n_1).

Step 1 — The first part asks about the Balmer series transitions. The Balmer series comprises lines emitted when electrons drop down to the second energy shell ($n_1 = 2$), producing transitions that fall within the visible light spectrum. The first line of this series, known as the H_α line, represents the lowest energy and longest wavelength transition, which originates from the immediate next energy level, $n_2 = 3$. Therefore, the transition is from $n = 3$ to $n = 2$.

Step 2 — The second part addresses the Paschen series. The Paschen series contains infrared emission lines that are produced when electrons fall from various outer shells down to the third main energy level. Thus, the lowest or destination energy level for all Paschen spectral lines is fixed at $n = 3$.

Final Answer: 1. $n = 3$ to $n = 2$; 2. $n = 3$

Answer: (See above)

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Q18.

Solution

Concept: This question addresses two separate areas of physical chemistry: the liquefaction properties of real gases and the behavior of solutions containing non-volatile solutes, described by colligative properties. Understanding these physical attributes allows us to predict how systems change under variations in temperature, pressure, and chemical composition.

Step 1 — The first prompt concerns the boundary conditions of gas liquefaction. Every real gas is governed by intermolecular forces that can be overcome by thermal kinetic energy. The specific maximum temperature above which a gas can no longer be compressed into a liquid phase—regardless of how much external pressure is applied—is defined as the critical temperature (T_c). Above this thermal threshold, the substance exists as a supercritical fluid, where gas and liquid phases become indistinguishable.

Step 2 — The second prompt deals with Raoult's Law and colligative effects. When a non-volatile solute is added to a volatile pure solvent, the solute particles occupy space at the liquid-gas interface. This structural block decreases the number of solvent molecules capable of escaping into the vapor phase per unit time. Consequently, the equilibrium vapor pressure of the solution is lower than that of the pure solvent at any given temperature.

Final Answer: 1. Critical temperature; 2. Lower

Answer: (See above)

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Q19.

Solution

Concept: Thermodynamics evaluates the macroproperties of systems, focusing on energy conservation, entropy changes, and reaction spontaneity. Determining whether chemical statements are true or false requires evaluating fundamental thermodynamic definitions and the mathematical relationship governing free energy.

Step 1 — The first statement refers to the third law of thermodynamics. This law establishes an absolute reference scale for entropy. It states that the entropy (S) of a perfectly pure, flawless crystalline substance approaches a value of absolute zero as its thermodynamic temperature drops to absolute zero Kelvin (0 K). At this absolute thermal floor, all molecular motion and vibrational disorder cease completely. Therefore, this assertion is true (T).

Step 2 — The second statement discusses the driving forces of spontaneity. The absolute criterion for a reaction to proceed spontaneously is a negative change in Gibbs free energy ($\Delta G < 0$), calculated using the equation $\Delta G = \Delta H - T\Delta S$. An endothermic reaction has a positive enthalpy change ($\Delta H > 0$). However, if the reaction results in a large increase in disorder, making the entropy change positive ($\Delta S > 0$), the negative $-T\Delta S$ term can outweigh ΔH at a sufficiently high temperature (T), yielding a negative ΔG. Thus, the claim that endothermic reactions can never be spontaneous is false (F).

Final Answer: 1. True (T); 2. False (F)

Answer: (See above)

Go Back to Question 19

Q20.

Solution

Concept: The collision theory of chemical kinetics provides a physical model for understanding how chemical reactions occur and why reaction rates vary. According to this theory, a chemical reaction can take place only when reacting gas molecules physically collide with each other. However, a collision will only lead to the formation of products if the colliding particles possess a certain minimum energy and collide in the correct spatial orientation.

Step 1 — The first part addresses the energetic barrier of a reaction. Reacting molecules must possess a minimum amount of energy to successfully break their existing intramolecular bonds upon impact. The absolute minimum total energy that the colliding molecules must have to undergo a productive chemical transformation is defined as the threshold energy. If the kinetic energy of the collision is lower than this threshold value, the molecules simply bounce apart elastically without reacting.

Step 2 — The second part deals with the rate of impacts. To calculate the total number of encounters, kinetics defines a specific spatial metric. The total number of collisions that occur between reacting molecules per second within one unit volume of the reaction mixture is formally designated as the collision frequency, typically represented by the symbol Z.

Final Answer: 1. Threshold energy; 2. Collision frequency

Answer: (See above)

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Q21.

Solution

Concept: Industrial chemical processes and Molecular Orbital Theory.

Step 1 — The Contact process is the modern, highly efficient industrial method used to manufacture concentrated sulfuric acid (H_2SO_4). The central, rate-determining chemical step in this production line involves the exothermic catalytic oxidation of sulfur dioxide gas (SO_2) into sulfur trioxide gas (SO_3) using atmospheric oxygen. To maximize reaction rates at optimal temperatures, vanadium pentoxide (V_2O_5) is utilized as a heterogeneous catalyst. It offers an alternative reaction pathway with a lower activation energy, replacing older platinum catalysts due to its high resistance to chemical poisoning.

Step 2 — Molecular Orbital (MO) Theory provides a comprehensive quantum mechanical model for homonuclear diatomic molecules. When drawing the molecular orbital diagram for dioxygen (O_2), sixteen total electrons are filled into molecular orbitals according to the Aufbau principle and Hund's rule. The highest occupied molecular orbitals are the doubly degenerate antibonding pi orbitals ($\pi^*_{2p_x}$ and $\pi^*_{2p_y}$). Following Hund's rule, the final two valence electrons occupy these separate, degenerate orbitals individually with parallel spins. Because the molecule contains these two unpaired electrons, O_2 exhibits a net magnetic moment and is classified as paramagnetic.

Final Answer: 1. V_2O_5; 2. Paramagnetic

Answer: (See above)

Go Back to Question 21

Q22.

Solution

Concept: Physical properties of d-block transition metals leading to solid-state alloy formation.

Step 1 — Transition metals located in the d-block of the periodic table exhibit unique metallic properties, including high tensile strength, malleability, and a remarkable capacity to form alloys. Alloys are homogeneous solid mixtures composed of two or more metals. The ease with which transition elements form alloys is attributed to their atomic radii. Due to the shielding effect of inner d-electrons combined with increasing nuclear charge, transition elements within the same period possess remarkably similar atomic sizes. When a molten mixture of two such metals cools, atoms of one transition metal can easily replace atoms of another metal inside the metallic crystal lattice without causing significant lattice strain, generating a stable substitution alloy solid solution.

Step 2 — Brass is a widely known, practically useful substitution alloy. It is composed primarily of copper (Cu) acting as the host crystal matrix, mixed with zinc (Zn) acting as the solute element. Because copper and zinc are adjacent transition elements, their similar metallic radii allow them to blend seamlessly, resulting in a material with enhanced corrosion resistance and superior mechanical machinability compared to pure copper.

Final Answer: 1. Because their atomic radii are very similar; 2. Brass

Answer: (See above)

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Q23.

Solution

Concept: Structural isomerism and coordination chemistry of ambidentate ligands.

Step 1 — In coordination chemistry, structural isomerism arises when isomers possess identical chemical formulas but differ in their internal atom-to-atom bonding connections. A specific sub-type known as linkage isomerism occurs exclusively when a coordination complex contains an ambidentate ligand. An ambidentate ligand is a coordinating species that possesses two or more distinct donor atoms through which it can potentially bind to a central transition metal ion, though it only coordinates via one donor atom at a time. Classic examples include the nitrite ion (NO_2^-), which can bind via nitrogen or oxygen, and the thiocyanate ion (SCN^-), which coordinates via sulfur or nitrogen.

Step 2 — Consider the two coordination compounds: $[Co(NH_3)_5(NO_2)]Cl_2$ and $[Co(NH_3)_5(ONO)]Cl_2$. In the first complex, the nitro ligand ($-NO_2$) is bonded to the cobalt core directly through its nitrogen atom, forming a nitro isomer. In the second complex, the nitrito ligand ($-ONO$) binds to the cobalt core through a single oxygen atom, forming a nitrito isomer. This structural variation modifies physical properties like color and stability, exemplifying linkage isomerism.

Final Answer: 1. NO_2^- or SCN^-; 2. Linkage isomerism

Answer: (See above)

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Q24.

Solution

Concept: Analytical organic chemistry and qualitative functional group chemical tests.

Step 1 — The Carbylamine test is a highly sensitive diagnostic test used exclusively for detecting primary aliphatic and aromatic amines. When a primary amine is heated with chloroform ($CHCl_3$) and ethanolic potassium hydroxide (KOH), it undergoes an alpha-elimination mechanism to form a foul-smelling isocyanide or carbylamine product, mapping perfectly to item (a-iv).

Step 2 — The Iodoform test identifies the presence of compounds containing a specific methyl carbonyl group ($CH_3C = O$) or secondary alcohols capable of being oxidized to a methyl carbonyl unit ($CH_3CH(OH)-$). Reacting these with iodine and sodium hydroxide yields a characteristic bright yellow precipitate of iodoform (CHI_3), matching item (b-iii).

Step 3 — The bromine water test is a rapid diagnostic tool used to detect carbon-carbon unsaturation. When an alkene or alkyne is treated with an aqueous bromine solution, an electrophilic addition reaction occurs across the multiple bonds, resulting in the immediate decolorization of the characteristic reddish-brown bromine solution, matching item (c-ii).

Step 4 — The Lucas test differentiates primary, secondary, and tertiary alcohols based on their rate of reaction with Lucas reagent (a mixture of concentrated HCl and anhydrous $ZnCl_2$). Tertiary alcohols react instantly to form an insoluble alkyl chloride, creating turbidity, matching item (d-i).

Final Answer: a-iv, b-iii, c-ii, d-i

Answer: (See above)

Go Back to Question 24

Q25.

Solution

Concept: Nucleophilic addition-elimination mechanisms of carbonyl groups and the acid-catalyzed hydrolysis of nitriles.

Step 1 — Benzaldehyde (C_6H_5CHO) features an electrophilic carbonyl carbon that readily reacts with nitrogenous nucleophiles. When treated with hydrazine ($H_2N - NH_2$) in a weakly acidic environment, the reaction proceeds via a nucleophilic addition of the amino group to the carbonyl carbon, followed by the rapid elimination of a water molecule (H_2O). This condensation reaction establishes a carbon-nitrogen double bond, yielding benzaldehyde hydrazone as the organic product. The balanced chemical transformation is represented by the equation: $C_6H_5CHO + H_2N - NH_2 \xrightarrow{H^+} C_6H_5CH = N - NH_2 + H_2O$.

Step 2 — Nitriles contain a highly polarized carbon-nitrogen triple bond ($-C \equiv N$). When ethanenitrile (CH_3CN, acetonitrile) undergoes complete chemical hydrolysis by heating it in an aqueous acidic medium, water molecules act as nucleophiles to attack the nitrile carbon sequentially. This pathway shifts the compound through an amide intermediate, ultimately cleaving the carbon-nitrogen bond entirely to produce ethanoic acid (CH_3COOH, acetic acid) while generating an ammonium byproduct. The complete stoichiometric chemical equation is: $CH_3CN + 2H_2O + H^+ \rightarrow CH_3COOH + NH_4^+$.

Final Answer: 1. $C_6H_5CH = N - NH_2 + H_2O$; 2. $CH_3COOH + NH_3$

Answer: (See above)

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Q26.

Solution

Concept: Biochemical kinetics and the properties of highly specific biological enzymes.

Step 1 — Enzymes represent a class of highly specialized biocatalysts that accelerate metabolic reactions in living systems by many orders of magnitude. Morphologically, nearly all known enzymes are globular proteins. They are constructed from complex, precisely folded polypeptide chains that twist into a unique three-dimensional conformation. This intricate folding pattern forms a localized spatial pocket known as the active site, which binds specific substrate molecules. Apart from a minor class of catalytic RNA molecules termed ribozymes, proteins serve as the fundamental structural blueprint for the body's entire enzymatic machinery.

Step 2 — Fermentation is an anaerobic metabolic pathway that breaks down complex carbohydrates into simpler organic compounds. The biochemical conversion of simple hexose sugars like glucose into ethanol and carbon dioxide gas is driven by a complex mixture of enzymes known collectively as zymase. Zymase is produced naturally by active yeast cells (*Saccharomyces cerevisiae*). In this industrial process, the zymase complex catalyzes the sequential cleavage of carbon-carbon bonds, converting glucose into ethyl alcohol.

Final Answer: 1. Proteins; 2. Zymase

Answer: (See above)

Go Back to Question 26

Q27.

Solution

Concept: Medicinal chemistry, neuropharmacology, and classification of antibacterial chemotherapeutic agents.

Step 1 — Tranquilizers comprise a chemically diverse group of psychoactive therapeutic drugs designed to manage psychological disorders. These pharmaceutical compounds act on the central nervous system (CNS) by modulating neurotransmitter activity, particularly targeting receptors like GABA or serotonin. By altering synaptic transmission, tranquilizers alleviate acute anxiety, stress, tension, and mild or severe psychoneurotic states without inducing deep sleep or cognitive blocks. Consequently, the assertion that tranquilizers function to relieve anxiety and mental diseases is completely true (T).

Step 2 — Antibiotics are chemical substances used to treat bacterial infections. Clinically, they are categorized based on their range of activity. A narrow-spectrum antibiotic is formulated to target only a specific, limited group of bacteria. In contrast, a broad-spectrum antibiotic refers to a drug that is effective against a vast range of pathogenic micro-organisms, successfully inhibiting both Gram-positive and Gram-negative bacterial strains simultaneously. Because the second statement incorrectly defines broad-spectrum antibiotics as targeting only a single specific organism, the claim is false (F).

Final Answer: 1. True (T); 2. False (F)

Answer: (See above)

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Q28.

Solution

Concept: Chemistry of food preservation and inhibiting microbial spoilage pathways.

Step 1 — Food preservation encompasses a variety of chemical and physical techniques designed to extend the shelf-life of consumable products. The fundamental biological objective of adding a chemical preservative to food items is to prevent spoilage. Spoilage is primarily driven by the metabolic growth and proliferation of microscopic organisms, such as bacteria, yeasts, and molds, which decompose nutrients and generate toxic waste products. Chemical preservatives interfere with the cellular membranes, enzymatic pathways, or internal genetic material of these microbes, effectively halting their reproduction and keeping the food safe for consumption over extended periods.

Step 2 — While traditional preservation relies on high concentrations of natural ingredients like sodium chloride (common salt), sucrose (sugar), and vegetable oils to induce osmotic pressure, modern industrial food science utilizes synthetic chemical additives. A widely used organic chemical preservative is sodium benzoate (C_6H_5COONa). When added to acidic food products like fruit juices, carbonated beverages, sauces, and pickles, it converts into benzoic acid, which easily penetrates microbial cell walls to inhibit intracellular fermentation.

Final Answer: 1. To prevent spoilage due to microbes; 2. Sodium benzoate

Answer: (See above)

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Q29.

Solution

Concept: Postulates of quantum mechanics, subatomic properties, and wave-particle duality.

Step 1 — Alternative (i): Heisenberg's Uncertainty Principle is a foundational tenet of quantum mechanics formulated by Werner Heisenberg. It states that it is physically impossible to determine simultaneously and with absolute precision both the exact position (Δx) and the exact momentum (Δp) of a microscopic subatomic particle like an electron. This limitation is an inherent wave property of quantum systems, not a flaw in measurement technology. Mathematically, this physical law is expressed by the inequality:

$$\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$$

Step 2 — Alternative (ii): Degenerate orbitals are defined as an organized group of atomic or molecular orbitals that share the exact same principal energy level. In an isolated atom free from external influences, orbitals within a given subshell exhibit identical energy states.

Step 3 — For example, the three distinct p-orbitals (p_x, p_y, and p_z) belonging to the second principal shell ($n = 2$) possess identical energy levels. They only split into different energy states when exposed to an asymmetrical external magnetic or electric field, a phenomenon known as the Zeeman or Stark effect.

Final Answer: Stated definitions for Uncertainty Principle or Degenerate orbitals with example.

Answer: (See above)

Go Back to Question 29

Q30.

Solution

Concept: Chemical bonding based on the directional overlap of valence atomic orbitals.

Step 1 — Covalent chemical bonds are classified into sigma (σ) and pi (π) bonds depending on the spatial orientation and overlap geometry of the participating atomic orbitals. A sigma bond is established via the direct, head-on, or axial overlap of atomic orbitals (such as $s - s$, $s - p$, or axial $p - p$ orbitals) along the shared internuclear axis. This configuration focuses maximum electron density directly between the two nuclei. Conversely, a pi bond is formed via the lateral, sideways, or parallel overlap of two adjacent p-orbitals, distributing electron density in two distinct lobes located strictly above and below the plane of the internuclear axis.

Step 2 — This geometric distinction dictates the relative thermodynamic stability of the bonds. A sigma bond is significantly stronger than a pi bond because the axial approach allows a much greater extent of orbital overlap. A pi bond is weaker due to poorer lateral overlap.

Step 3 — Furthermore, the symmetrical distribution of a single sigma bond allows for completely unrestricted free rotation of the bonded atoms around the axis. In contrast, a pi bond locks the atoms in place, restricting rotation because twisting the bond would disrupt the parallel alignment of the p-orbitals.

Final Answer: Sigma is axial overlap and stronger; Pi is lateral overlap and weaker.

Answer: (See above)

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Q31.

Solution

Concept: Quantum mechanics introduces wave-particle duality, while nuclear chemistry dictates periodic trends like ionic radius variations across the table.

Step 1 — Alternative (i): The dual nature of matter, originally postulated by Louis de Broglie, fundamentally asserts that all moving macroscopic and microscopic particles possess both particle-like momentum and wave-like characteristics. This concept bridges classical mechanics and quantum theory. The mathematical relation defining this phenomenon is known as the de Broglie equation:

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

where λ represents the de Broglie wavelength, h is Planck's constant (6.626×10^{-34} J s), m signifies the mass of the moving subatomic or atomic particle, and v is its instantaneous velocity vector.

Step 2 — Alternative (ii): A cation is a positively charged chemical species that forms when a neutral atom undergoes oxidation, losing one or more valence electrons from its outermost electron shell.

Step 3 — Following the loss of valence electrons, the total number of protons within the nucleus remains identical, but the size of the surrounding electron cloud decreases. Consequently, the net positive nuclear charge is distributed over fewer remaining electrons. This significantly increases the effective nuclear charge (Z_{eff}) experienced by each remaining electron, pulling the orbital shells closer to the core and reducing the total ionic radius. Thus, a cation is always smaller than its parent atom.

Final Answer: Stated explanations depending on the alternative chosen.

Answer: (See above)

Go Back to Question 31

Q32.

Solution

Concept: Physical properties of multi-component liquid solutions are governed by thermodynamic mixing laws and non-ideal behaviors.

Step 1 — Alternative (i): Raoult's law provides a quantitative baseline for ideal liquid mixtures. It states that for a solution composed of volatile liquids, the partial vapor pressure (p_i) exerted by each individual volatile component in the gas phase at a specific temperature is directly proportional to its respective mole fraction (x_i) in the liquid solution phase. Mathematically, it is written as $p_i = p_i^\circ \cdot x_i$, where p_i° represents the vapor pressure of that pure, isolated component at the identical temperature.

Step 2 — Alternative (ii): Azeotropes (or constant-boiling mixtures) represent specialized binary liquid mixtures that show severe deviations from Raoult's law. These unique liquid mixtures possess identical chemical compositions in both the liquid phase and the coexisting vapor phase at equilibrium. Because of this structural composition identity, the mixture boils at a single fixed temperature, distilling over completely without undergoing any change in concentration.

Step 3 — A classic example of a minimum-boiling azeotrope is a mixture of ethanol and water containing approximately 95% ethanol by volume. This mixture exhibits positive deviation from ideal behavior, generating a maximum vapor pressure and a minimum boiling point below that of either pure component.

Final Answer: Definitions stated for Raoult's law or Azeotropes depending on choice.

Answer: (See above)

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Q33.

Solution

Concept: Electrochemical transport properties of ionic solutes are analyzed using rules of infinite dilution, specifically Kohlrausch's law.

Step 1 — Friedrich Kohlrausch formulated the law of independent migration of ions to explain the behavior of electrolytes at infinite dilution (concentration $\rightarrow 0$). The law states that when a solution is diluted infinitely, the intermolecular forces between ions vanish completely, ensuring that dissociation is 100% complete. Under these idealized conditions, each individual ion migrates independently through the solvent and makes a fixed, definite contribution to the overall molar conductivity of the electrolyte. This specific ion transport contribution remains completely constant, irrespective of the chemical nature of the opposing ion with which it is paired in the formula unit.

Step 2 — Mathematically, the limiting molar conductivity (Λ_m°) of any salt or compound can be expressed as the simple algebraic sum of the limiting ionic conductivities of its constituent cations (λ_+°) and anions (λ_-°), each multiplied by the stoichiometric coefficient representing the number of ions generated per formula unit:

$$\Lambda_m^\circ = \nu_+\lambda_+^\circ + \nu_-\lambda_-^\circ$$

Here, ν_+ and ν_- denote the number of moles of cations and anions produced upon complete dissociation. This framework allows electrochemists to accurately determine the limiting molar conductivity values for weak electrolytes, which cannot be measured directly through extrapolation.

Final Answer: Limiting molar conductivity of an electrolyte is the sum of individual ionic contributions.

Answer: (See above)

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Q34.

Solution

Concept: The structural geometry and bonding limits of main-group p-block elements are determined by their principal quantum number and valence orbital configurations.

Step 1 — Phosphorus (P) is located in Period 3, Group 15 of the periodic table. Its ground-state electron configuration is $[\text{Ne}]3s^2 3p^3$. Because its principal quantum number is $n = 3$, its valence shell contains not only the filled $3s$ and half-filled $3p$ subshells but also empty, energetically accessible $3d$ orbitals. Upon absorbing excitation energy, an electron can be promoted from the $3s$ orbital into a vacant $3d$ orbital. This generates five unpaired electrons, allowing the phosphorus atom to undergo sp^3d hybridization and form five covalent bonds, stabilizing the hypervalent compound PCl_5 by expanding its valence shell to accommodate ten electrons.

Step 2 — Nitrogen (N) is a congener located directly above phosphorus in Period 2, Group 15, with an electronic configuration of $1s^2 2s^2 2p^3$. For the principal quantum level $n = 2$, the only mathematically allowed values for the azimuthal quantum number are $l = 0$ and $l = 1$, corresponding to the $2s$ and $2p$ subshells. There is no such thing as a $2d$ orbital in atomic structures.

Step 3 — Due to the absolute absence of low-energy vacant d-orbitals in its valence shell, nitrogen has no mechanism to excite electrons or expand its octet beyond eight electrons. It is restricted to a maximum covalency of four. Thus, NCl_5 cannot exist under standard chemical conditions.

Final Answer: Phosphorus has vacant d-orbitals to expand its octet; nitrogen does not.

Answer: (See above)

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Q35.

Solution

Concept: This problem covers the redox chemistry of halogens in basic media and the architectural modeling of noble gas molecules via VSEPR theory.

Step 1 — Alternative (i): Elemental chlorine (Cl_2) undergoes a classic disproportionation reaction when treated with a cold, dilute aqueous solution of sodium hydroxide (NaOH). In this single process, chlorine atoms simultaneously function as both the oxidizing and reducing agents. A portion of the zero-valent chlorine gas is reduced to the -1 oxidation state to form sodium chloride (NaCl), while another portion is oxidized to the $+1$ state to yield sodium hypochlorite (NaOCl). The balanced molecular chemical equation for this redox reaction is:

$$\mathrm{Cl_2 + 2NaOH(dil., cold) \rightarrow NaCl + NaOCl + H_2O}$$

Step 2 — Alternative (ii): Xenon oxytetrafluoride ($XeOF_4$) can be modeled using Valence Shell Electron Pair Repulsion (VSEPR) theory. The central xenon (Xe) atom contributes 8 valence electrons. It forms four single covalent bonds with the fluorine atoms and one double bond with the oxygen atom, utilizing a total of 6 valence electrons for bonding. This leaves 2 non-bonding valence electrons, which form exactly 1 stereochemically active lone pair on the xenon atom.

Step 3 — The total steric number counts six electron domains (5 bonding regions $+1$ lone pair), which dictates an octahedral electron-pair geometry. To minimize electron repulsion between the lone pair and the highly electronegative oxygen atom, the lone pair occupies an axial position opposite the $Xe = O$ double bond. The remaining four equatorial fluorine atoms create a planar base, resulting in a square pyramidal molecular shape.

Final Answer: Chemical equation or XeOF4 structure as chosen.

Answer: (See above)

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Q36.

Solution

Concept: Williamson ether synthesis is a fundamental substitution reaction in organic chemistry used to create ether linkages.

Step 1 — The Williamson ether synthesis is an industrial and laboratory method used to produce both symmetrical and unsymmetrical ethers. Mechanistically, this reaction follows an S_N2 (Substitution Nucleophilic Bimolecular) pathway. The reaction is initiated by heating a primary alkyl halide with a strongly basic sodium or potassium alkoxide. The alkoxide ion ($R' - O^-$) acts as a strong nucleophile, attacking the electrophilic carbon atom of the alkyl halide from the backside. This single-step, concerted process forms the new carbon-oxygen ether bond while simultaneously displacing the halide leaving group.

Step 2 — The general structural equation illustrating this bimolecular nucleophilic substitution can be written as:

$$R - X + R' - ONa \rightarrow R - O - R' + NaX$$

To achieve high chemical yields, the alkyl halide ($R - X$) must be sterically unhindered, preferably a primary or methyl halide. If a secondary or tertiary alkyl halide is used, the alkoxide acts as a strong base instead, shifting the pathway toward an E2 elimination reaction to yield an alkene.

Step 3 — As an example, treating bromoethane (ethyl bromide) with sodium methoxide yields ethyl methyl ether (methoxyethane) along with a sodium bromide byproduct:

$$CH_3CH_2Br + CH_3ONa \rightarrow CH_3CH_2 - O - CH_3 + NaBr$$

Final Answer: Reaction of alkyl halide with sodium alkoxide; e.g. formation of ethyl methyl ether.

Answer: (See above)

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Q37.

Solution

Concept: Functional group transformations involve altering aromatic systems via electrophilic substitution and altering unsaturated alkenes via regioselective electrophilic additions.

Step 1 — (a) Benzene (C_6H_6) is a highly stable aromatic hydrocarbon that resists addition reactions to preserve its resonance stabilization energy. To synthesize chlorobenzene (C_6H_5Cl), benzene must undergo an electrophilic aromatic substitution (S_EAr) reaction. This is achieved by reacting benzene with chlorine gas (Cl_2) at room temperature in the presence of an anhydrous Lewis acid catalyst, such as iron(III) chloride ($FeCl_3$) or aluminum chloride ($AlCl_3$). The Lewis acid coordinates with a chlorine molecule to polarize the bond and generate a highly reactive, electrophilic chloronium ion (Cl^+). The benzene ring attacks this electrophile, forming a sigma complex intermediate that rapidly eliminates a proton to restore aromaticity. The balanced chemical equation is:

$$C_6H_6 + Cl_2 \xrightarrow{FeCl_3} C_6H_5Cl + HCl$$

Step 2 — (b) Propene ($CH_3 - CH = CH_2$) is an unsymmetrical alkene containing a reactive pi bond. It can be converted into propan-2-ol (isopropyl alcohol) via acid-catalyzed hydration. In this process, the alkene is treated with water in the presence of a strong mineral acid catalyst, such as sulfuric acid (H_2SO_4). Mechanistically, the alkene's pi electrons attack a hydronium ion, generating a more stable secondary carbocation intermediate ($CH_3 - CH^+ - CH_3$) rather than a less stable primary carbocation. This pathway follows Markovnikov's rule, where the electrophilic hydrogen adds to the carbon with more hydrogen atoms, and the nucleophilic water molecule subsequently attacks the carbocation center. After deprotonation, propan-2-ol is formed:

$$CH_3 - CH = CH_2 + H_2O \xrightarrow{H^+} CH_3 - CH(OH) - CH_3$$

Final Answer: (a) Reaction with Cl2 and FeCl3. (b) Acid-catalyzed hydration.

Answer: (See above)

Go Back to Question 37

Q38.

Solution

Concept: Analytical empirical formula determinations use percentage composition by mass to resolve the simplest atomic ratios within a compound.

Step 1 — To find the empirical formula of an organic compound from its element percentages, it is mathematically convenient to assume a total sample mass of exactly 100 g. This assumption allows us to convert mass percentages directly into mass values in grams. For this sample, we have 54.5 g of Carbon (C), 9.1 g of Hydrogen (H), and 36.4 g of Oxygen (O).

Step 2 — Next, convert these mass values into chemical amounts in moles by dividing each element's mass by its respective molar mass (C = 12 g/mol, H = 1 g/mol, O = 16 g/mol):

$$\text{Moles of C} = \frac{54.5\text{ g}}{12\text{ g/mol}} = 4.54\text{ mol}$$

$$\text{Moles of H} = \frac{9.1\text{ g}}{1\text{ g/mol}} = 9.10\text{ mol}$$

$$\text{Moles of O} = \frac{36.4\text{ g}}{16\text{ g/mol}} = 2.275\text{ mol}$$

Step 3 — To determine the simplest atomic ratio, divide each calculated value by the smallest value among them, which is 2.275 mol:

$$\text{Ratio of C} = \frac{4.54}{2.275} \approx 2$$

$$\text{Ratio of H} = \frac{9.10}{2.275} \approx 4$$

$$\text{Ratio of O} = \frac{2.275}{2.275} = 1$$

Step 4 — The calculated numbers form a whole-number ratio of 2 : 4 : 1 for the constituent atoms C, H, and O. Combining these stoichiometric ratios yields the empirical formula C_2H_4O, which corresponds to a base structure like ethanal.

Final Answer: C_2H_4O

Answer: (See above)

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Q39.

Solution

Concept: This problem involves solving for solution properties like the colligative elevation of boiling point and concentration expressions like molarity.

Step 1 — Alternative (i): First, calculate the molality (m) of the glucose solution. The molecular formula of glucose is $C_6H_{12}O_6$, giving a molar mass of 180 g/mol. Calculate the moles of glucose solute added to the solvent:

$$\text{Moles of glucose} = \frac{18\text{ g}}{180\text{ g/mol}} = 0.1\text{ mol}$$

The mass of the solvent (water) is given as 1 kg. Using the definition of molality:

$$m = \frac{\text{moles of solute}}{\text{mass of solvent in kg}} = \frac{0.1\text{ mol}}{1\text{ kg}} = 0.1\text{ mol/kg}$$

Step 2 — Apply the boiling point elevation formula, $\Delta T_b = K_b \times m$, where K_b for water is $0.52\text{ K kg mol}^{-1}$:

$$\Delta T_b = 0.52 \times 0.1 = 0.052\text{ K}$$

The normal boiling point of pure water is 373.15 K. Adding a non-volatile solute elevates this temperature, so the final boiling point of the solution is:

$$T_b = 373.15\text{ K} + 0.052\text{ K} = 373.202\text{ K}$$

Step 3 — Alternative (ii): To calculate the molarity (M) of the sodium chloride solution, find the moles of NaCl solute using its molar mass (58.5 g/mol):

$$\text{Moles of NaCl} = \frac{5.85\text{ g}}{58.5\text{ g/mol}} = 0.1\text{ mol}$$

Convert the total solution volume from milliliters into liters: 500 mL = 0.5 L. Molarity is defined as moles of solute per liter of total solution:

$$M = \frac{0.1\text{ mol}}{0.5\text{ L}} = 0.2\text{ M}$$

Final Answer: Alternative (i): 373.202 K; Alternative (ii): 0.2 M

Answer: (See above)

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Q40.

Solution

Concept: Hess's Law of Constant Heat Summation states that the total enthalpy change for a chemical reaction is identical whether the process occurs in a single step or through a series of intermediate stages.

Step 1 — We need to determine the standard enthalpy of formation (ΔH_f°) for methane gas (CH_4), which represents the enthalpy change for synthesizing one mole of methane from its constituent elements in their standard reference states:

$$\mathrm{C(s)} + 2\mathrm{H_2(g)} \longrightarrow \mathrm{CH_4(g)} \quad (\Delta H_f^\circ = ?)$$

Step 2 — Write the thermochemical equations for the given standard combustion processes:

$$(1)\ \mathrm{C(s)} + \mathrm{O_2(g)} \longrightarrow \mathrm{CO_2(g)} \quad \Delta H_1 = -393.5\ \text{kJ/mol}$$

$$(2)\ \mathrm{H_2(g)} + \frac{1}{2}\mathrm{O_2(g)} \longrightarrow \mathrm{H_2O(l)} \quad \Delta H_2 = -285.8\ \text{kJ/mol}$$

$$(3)\ \mathrm{CH_4(g)} + 2\mathrm{O_2(g)} \longrightarrow \mathrm{CO_2(g)} + 2\mathrm{H_2O(l)} \quad \Delta H_3 = -890.3\ \text{kJ/mol}$$

Step 3 — Algebraically manipulate these equations to reconstruct our target formation reaction. Keep Equation (1) as written to supply one mole of solid graphite. Multiply Equation (2) by a factor of 2 to provide the required two moles of diatomic hydrogen gas:

$$2\mathrm{H_2(g)} + \mathrm{O_2(g)} \longrightarrow 2\mathrm{H_2O(l)} \quad \Delta H_{2,\text{new}} = 2 \times (-285.8) = -571.6\ \text{kJ/mol}$$

Finally, reverse the combustion of methane in Equation (3) to place $CH_4(g)$ on the product side, which inverts the algebraic sign of its enthalpy change:

$$\mathrm{CO_2(g)} + 2\mathrm{H_2O(l)} \longrightarrow \mathrm{CH_4(g)} + 2\mathrm{O_2(g)} \quad \Delta H_{3,\text{new}} = +890.3\ \text{kJ/mol}$$

Step 4 — Summing these three modified equations cancels out the intermediate molecules (CO_2, H_2O, and O_2), leaving the target reaction. Summing their corresponding enthalpy values yields:

$$\Delta H_f^\circ = (-393.5) + (-571.6) + (+890.3) = -965.1 + 890.3 = -74.8\ \text{kJ/mol}$$

Final Answer: -74.8 kJ/mol

Answer: (See above)

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Q41.

Solution

Concept: Mechanistic details of carbonyl addition and named organic reactions.

Step 1 — Alternative (i): The nucleophilic addition of HCN to carbonyls is catalyzed by a base. The base removes a proton from HCN to generate a strong nucleophile, the cyanide ion (CN^-). The CN^- attacks the electrophilic carbonyl carbon, breaking the π bond and pushing electrons onto oxygen to form a tetrahedral alkoxide intermediate. Finally, protonation of the alkoxide yields cyanohydrin.

Step 2 — Alternative (ii) (a): Reimer-Tiemann reaction: Heating phenol with chloroform ($CHCl_3$) in the presence of aqueous sodium hydroxide introduces an aldehyde group at the ortho position of the benzene ring, resulting in salicylaldehyde as the major product.

Step 3 — Alternative (ii) (b): Hofmann bromamide reaction: An amide is treated with bromine in an aqueous or ethanolic solution of NaOH. It results in the degradation of the amide to a primary amine containing one carbon atom less than the original amide.

Final Answer: Explanations provided per chosen alternative.

Answer: (See above)

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Q42.

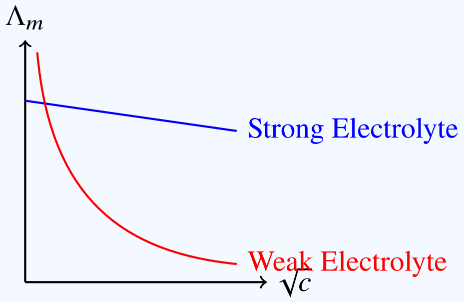
Solution

Concept: Electrolysis laws, first-order kinetics, and conductivity properties of electrolytes.

Step 1 — Alternative (i) A: Faraday's second law states that when the same quantity of electricity is passed through solutions of different electrolytes connected in series, the masses of the substances produced at the electrodes are directly proportional to their equivalent weights.

Step 2 — Alternative (i) B: For a first-order reaction, $t = \frac{2.303}{k}\log\left(\frac{[R]_0}{[R]}\right)$. Substitute values: $t = \frac{2.303}{1.15\times10^{-3}}\log\left(\frac{5}{3}\right) = 2002.6 \times 0.2218 \approx 444.2$ s.

Step 3 — Alternative (ii) A: Molar conductivity (Λ_m) is the conductance of a volume of solution containing one mole of electrolyte placed between two electrodes unit distance apart. For weak electrolytes, Λ_m increases steeply on dilution because the degree of dissociation increases significantly, producing more ions.



Step 4 — Alternative (ii) B: Cell representation: $Zn(s)|Zn^{2+}(aq)||Cu^{2+}(aq)|Cu(s)$. Electrons flow from the Zinc electrode (anode) to the Copper electrode (cathode) through the external circuit.

Final Answer: Explanations and graph/calculations matching the chosen option.

$\boxed{\textbf{Answer: (See above)}}$

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Q43.

Solution

Concept: Preparation of d-block compounds, coordination nomenclature, and crystal field theory.

Step 1 — Alternative (i) A: Preparation of $K_2Cr_2O_7$: Chromite ore ($FeCr_2O_4$) is fused with Na_2CO_3 in excess air to yield sodium chromate (Na_2CrO_4). The yellow solution is acidified with H_2SO_4 to give sodium dichromate ($Na_2Cr_2O_7$). This is treated with KCl to crystallize the less soluble potassium dichromate ($K_2Cr_2O_7$).

Step 2 — Alternative (i) B: Transition elements show variable oxidation states because the energy difference between their $(n-1)d$ and ns orbitals is very small. Both sets of electrons can participate in bond formation.

Step 3 — Alternative (ii) A: The IUPAC name of $[Pt(NH_3)_2Cl(NO_2)]$ is Diamminechloridonitrito-N-platinum(II).

Step 4 — Alternative (ii) B: For a d^4 ion, if the crystal field splitting energy is less than the pairing energy ($\Delta_o < P$), it behaves as a weak field case. The fourth electron enters the e_g orbital. The configuration is $t_{2g}^3 e_g^1$.

Step 5 — Alternative (ii) C: Interstitial compounds are formed when small atoms (like H, C, or N) get trapped inside the interstitial spaces of the metal crystal lattice. Example: Steel or Cast iron.

Final Answer: Detailed textual description as per the alternative chosen.

Answer: (See above)

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Answer Key

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