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1. Atomic Structure and Properties

1.1 Moles and Molar Mass

- ☐☐☐ Calculate quantities of a substance or its relative number of particles using dimensional analysis and the mole concept.

1.2 Mass Spectra of Elements

- ☐☐☐ Explain the quantitative relationship between the mass spectrum of an element and the masses of the element's isotopes.

1.3 Elemental Composition of Pure Substances

- ☐☐☐ Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance.

1.4 Composition of Mixtures

- ☐☐☐ Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture.

1.5 Atomic Structure and Electron Configuration

- ☐☐☐ Represent the ground-state electron configuration of an atom of an element or its ions using the Aufbau principle.

1.6 Photoelectron Spectroscopy

- ☐☐☐ Explain the relationship between the photoelectron spectrum of an atom or ion and:

1.7 Periodic Trends

- ☐☐☐ Explain the relationship between trends in atomic properties of elements and electronic structure and periodicity.

1.8 Valence Electrons and Ionic Compounds

- ☐☐☐ Explain the relationship between trends in the reactivity of elements and periodicity.

2. Compound Structure and Properties

2.1 Types of Chemical Bonds

- ☐☐☐ Explain the relationship between the type of bonding and the properties of the elements participating in the bond.

2.2 Intramolecular Force and Potential Energy

- ☐☐☐ Represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength.

2.3 Structure of Ionic Solids

- ☐☐☐ Represent an ionic solid with a particulate model that is consistent with Coulomb's law and the properties of the constituent ions.

2.4 Structure of Metals and Alloys

- ☐☐☐ Represent a metallic solid and/or alloy using a model to show essential characteristics of the structure and interactions present in the substance.

2.5 Lewis Diagrams

- ☐☐☐ Represent a molecule with a Lewis diagram.

2.6 Resonance and Formal Charge

- ☐☐☐ Represent a molecule with a Lewis diagram that accounts for resonance between equivalent structures or that uses formal charge to select between nonequivalent structures.

2.7 VSEPR and Bond Hybridization

- ☐☐☐ Based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities:

3. Properties of Substances and Mixtures

3.1 Intermolecular and Interparticle Forces

- ☐☐☐ Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when:

3.2 Properties of Solids

- ☐☐☐ Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.

3.3 Solids, Liquids, and Gases

- ☐☐☐ Represent the differences between solid, liquid, and gas phases using a particulate-level model.

3.4 Ideal Gas Law

- ☐☐☐ Explain the relationship between the macroscopic properties of a sample of gas or mixture of gases using the ideal gas law.

3.5 Kinetic Molecular Theory

- ☐☐☐ Explain the relationship between the motion of particles and the macroscopic properties of gases with:

3.6 Deviation from Ideal Gas Law

- ☐☐☐ Explain the relationship among non-ideal behaviors of gases, interparticle forces, and/or volumes.

3.7 Solutions and Mixtures

- ☐☐☐ Calculate the number of solute particles, volume, or molarity of solutions.

3.8 Representations of Solutions

- ☐☐☐ Using particulate models for mixtures:

3.9 Separation of Solutions and Mixtures

- ☐☐☐ Explain the results of a separation experiment based on intermolecular interactions.

3.10 Solubility

- ☐☐☐ Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles.

3.11 Spectroscopy and the Electromagnetic Spectrum

- ☐☐☐ Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region.

3.12 Properties of Photons

- ☐☐☐ Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.

3.13 Beer-Lambert Law -

- ☐☐☐ Explain the amount of light absorbed by a solution of molecules or ions in relationship to the concentration, path length, and molar absorptivity.

4. Chemical Reactions

4.1 Introduction for Reactions

- ☐☐☐ Identify evidence of chemical and physical changes in matter.

4.2 Net Ionic Equations

- ☐☐☐ Represent changes in matter with a balanced chemical or net ionic equation:

4.3 Representations of Reactions

- ☐☐☐ Represent a given chemical reaction or physical process with a consistent particulate model.

4.4 Physical and Chemical Changes

- ☐☐☐ Explain the relationship between macroscopic characteristics and bond interactions for:

4.5 Stoichiometry

- ☐☐☐ Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process.

4.6 Introduction to Titration

- ☐☐☐ Identify the equivalence point in a titration based on the amounts of the titrant and analyte, assuming the titration reaction goes to completion.

4.7 Types of Chemical Reactions

- ☐☐☐ Identify a reaction as acid-base, oxidation-reduction, or precipitation.

4.8 Introduction to Acid-Base Reactions

- ☐☐☐ Identify species as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species.

4.9 Oxidation-Reduction (Redox) Reactions

- ☐☐☐ Represent a balanced redox reaction equation using half-reactions.

5. Kinetics

5.1 Reaction Rates

- ☐☐☐ Explain the relationship between the rate of a chemical reaction and experimental parameters.

5.2 Introduction to Rate Law

- ☐☐☐ Represent experimental data with a consistent rate law expression.

5.3 Concentration Changes Over Time

- ☐☐☐ Identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time.

5.4 Elementary Reactions

- ☐☐☐ Represent an elementary reaction as a rate law expression using stoichiometry.

5.5 Collision Model

- ☐☐☐ Explain the relationship between the rate of an elementary reaction and the frequency, energy, and orientation of particle collisions.

5.6 Reaction Energy Profile

- ☐☐☐ Represent the activation energy and overall energy change in an elementary reaction using a reaction energy profile.

5.7 Introduction to Reaction Mechanisms

- ☐☐☐ Identify the components of a reaction mechanism.

5.8 Reaction Mechanism and Rate Law

- ☐☐☐ Identify the rate law for a reaction from a mechanism in which the first step is rate limiting.

5.9 Pre-Equilibrium Approximation

- ☐☐☐ Identify the rate law for a reaction from a mechanism in which the first step is not rate limiting.

5.10 Multistep Reaction Energy Profile

- ☐☐☐ Represent the activation energy and overall energy change in a multistep reaction with a reaction energy profile.

5.11 Catalysis

- ☐☐☐ Explain the relationship between the effect of a catalyst on a reaction and changes in the reaction mechanism.

6. Thermochemistry

6.1 Endothermic and Exothermic Processes

- ☐☐☐ Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation.

6.2 Energy Diagrams

- ☐☐☐ Represent a chemical or physical transformation with an energy diagram.

6.3 Heat Transfer and Thermal Equilibrium

- ☐☐☐ Explain the relationship between the transfer of thermal energy and molecular collisions.

6.4 Heat Capacity and Calorimetry

- ☐☐☐ Calculate the heat q absorbed or released by a system undergoing heating/cooling based on the amount of the substance, the heat capacity, and the change in temperature.

6.5 Energy of Phase Changes

- ☐☐☐ Explain changes in the heat q absorbed or released by a system undergoing a phase transition based on the amount of the substance in moles and the molar enthalpy of the phase transition.

6.6 Introduction to Enthalpy of Reaction

- ☐☐☐ Calculate the heat q absorbed or released by a system undergoing a chemical reaction in relationship to the amount of the reacting substance in moles and the molar enthalpy of reaction.

6.7 Bond Enthalpies

- ☐☐☐ Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction.

6.8 Enthalpy of Formation

- ☐☐☐ Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation.

6.9 Hess's Law

- ☐☐☐ Represent a chemical or physical process as a sequence of steps.
- ☐☐☐ Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual steps.

7. Equilibrium

7.1 Introduction to Equilibrium

- ☐☐☐ Explain the relationship between the occurrence of a reversible chemical or physical process, and the establishment of equilibrium, to experimental observations.

7.2 Direction of Reversible Reactions

- ☐☐☐ Explain the relationship between the direction in which a reversible reaction proceeds and the relative rates of the forward and reverse reactions.

7.3 Reaction Quotient and Equilibrium Constant

- ☐☐☐ Represent the reaction quotient Q_c or Q_p , for a reversible reaction, and the corresponding equilibrium expressions $K_c = Q_c$ or $K_p = Q_p$.

7.4 Calculating the Equilibrium Constant

- ☐☐☐ Calculate K_c or K_p based on experimental observations of concentrations or pressures at equilibrium.

7.5 Magnitude of the Equilibrium Constant

- ☐☐☐ Explain the relationship between very large or very small values of K and the relative concentrations of chemical species at equilibrium.

7.6 Properties of the Equilibrium Constant

- ☐☐☐ Represent a multistep process with an overall equilibrium expression, using the constituent K expressions for each individual reaction.

7.7 Calculating Equilibrium Concentrations

- ☐☐☐ Identify the concentrations or partial pressures of chemical species at equilibrium based on the initial conditions and the equilibrium constant.

7.8 Representations of Equilibrium

- ☐☐☐ Represent a system undergoing a reversible reaction with a particulate model.

7.9 Introduction to Le Chatelier's Principle

- ☐☐☐ Identify the response of a system at equilibrium to an external stress, using Le Châtelier's principle.

7.10 Reaction Quotient and Le Chatelier's Principle

- ☐☐☐ Explain the relationships between Q , K , and the direction in which a reversible reaction will proceed to reach equilibrium.

7.11 Introduction to Solubility Equilibria

- ☐☐☐ Calculate the solubility of a salt based on the value of K_{sp} for the salt.

7.12 Common-Ion Effect

- ☐☐☐ Identify the solubility of a salt, and/or the value of K_{sp} for the salt, based on the concentration of a common ion already present in solution.

8. Acids and Bases

8.1 Introduction to Acids and Bases

- ☐☐☐ Calculate the values of pH and pOH, based on K_w and the concentration of all species present in a neutral solution of water.

8.2 pH and pOH of Strong Acids and Bases pH pOH

- ☐☐☐ Calculate pH and pOH based on concentrations of all species in a solution of a strong acid or a strong base.

8.3 Weak Acid and Base Equilibria

- ☐☐☐ Explain the relationship among pH, pOH, and concentrations of all species in a solution of a monoprotic weak acid or weak base.

8.4 Acid-Base Reactions and Buffers

- ☐☐☐ Explain the relationship among the concentrations of major species in a mixture of weak and strong acids and bases.

8.5 Acid-Base Titrations

- ☐☐☐ Explain results from the titration of a mono- or polyprotic acid or base solution, in relation to the properties of the solution and its components.

8.6 Molecular Structure of Acids and Bases

- ☐☐☐ Explain the relationship between the strength of an acid or base and the structure of the molecule or ion.

8.7 pH and pK_a pH pK_a

- ☐☐☐ Explain the relationship between the predominant form of a weak acid or base in solution at a given pH and the pK_a of the conjugate acid or the pK_b of the conjugate base.

8.8 Properties of Buffers

- ☐☐☐ Explain the relationship between the ability of a buffer to stabilize pH and the reactions that occur when an acid or a base is added to a buffered solution.

8.9 Henderson-Hasselbalch Equation -

- ☐☐☐ Identify the pH of a buffer solution based on the identity and concentrations of the conjugate acid-base pair used to create the buffer.

8.10 Buffer Capacity

- ☐☐☐ Explain the relationship between the buffer capacity of a solution and the relative concentrations of the conjugate acid and conjugate base components of the solution.

8.11 pH and Solubility pH

- ☐☐☐ Identify the qualitative effect of changes in pH on the solubility of a salt.

9. Thermodynamics and Electrochemistry

9.1 Introduction to Entropy

- ☐☐☐ Identify the sign and relative magnitude of the entropy change associated with chemical or physical processes.

9.2 Absolute Entropy and Entropy Change

- ☐☐☐ Calculate the standard entropy change for a chemical or physical process based on the absolute entropies (standard molar entropies) of the species involved in the process.

9.3 Gibbs Free Energy and Thermodynamic Favorability

- ☐☐☐ Explain whether a physical or chemical process is thermodynamically favored based on an evaluation of ΔG° .

9.4 Thermodynamic and Kinetic Control

- ☐☐☐ Explain, in terms of kinetics, why a thermodynamically favored reaction might not occur at a measurable rate.

9.5 Free Energy and Equilibrium

- ☐☐☐ Explain whether a process is thermodynamically favored using the relationships between K , ΔG° , and T .

9.6 Free Energy of Dissolution

- ☐☐☐ Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process.

9.7 Coupled Reactions

- ☐☐☐ Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes.

9.8 Galvanic (Voltaic) and Electrolytic Cells

- ☐☐☐ Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.

9.9 Cell Potential and Free Energy

- ☐☐☐ Explain whether an electrochemical cell is thermodynamically favored, based on its standard cell potential and the constituent half-reactions within the cell.

9.10 Cell Potential Under Nonstandard Conditions

- ☐☐☐ Explain the relationship between deviations from standard cell conditions and changes in the cell potential.

9.11 Electrolysis and Faraday's Law

- ☐☐☐ Calculate the amount of charge flow based on changes in the amounts of reactants and products in an electrochemical cell.