HS AP Chemistry

Grade 11-12

Unit 1
Atomic Structure and Properties

Essential Questions

These questions guide the student experience throughout the unit and are open-ended and enduring.

- How can the same element be used in nuclear fuel rods and fake diamonds?
- How can large quantities of objects be counted by weighing?
- If atoms are too small to be observed directly, how is their structure known?
- Why does the periodic table have the shape that it does?

Unit Summary

This summary provides high-level information about the main learning outcomes within this unit.

This first unit sets the foundation for the course by examining the atomic theory of matter, the fundamental premise of chemistry. Although atoms represent the foundational level of chemistry, observations of chemical properties are made on collections of atoms. Macroscopic systems involve such large numbers of particles that they require the units of moles to translate between this and the particulate scale. The organization of the periodic table reflects the periodicity of element properties as a function of atomic number. The electronic structure of an atom can be described by an electron configuration that provides a method for describing the distribution of electrons in an atom or ion. In subsequent units, students will apply their understanding of atomic structure to models and representations of chemical phenomena to explain changes and interactions of chemical substances.

Guiding Questions

At the end of this unit, students should be able to respond to these questions as they demonstrate understanding of key concepts, skills and relevance to their own lives.

Content

- How do you make a connection between the masses of substances reacting and the actual number of particles undergoing chemical changes?
- How do you explain how the mass spectrum of a sample containing a single element can be used to determine the identity of the isotopes of that element and the relative abundance of each isotope in nature?
- How do you explain how some pure substances are composed of individual molecules, while others consist of atoms or ions held together in fixed proportions as described by a formula unit?
- How do you explain how elemental analysis can be used to determine the relative numbers of atoms in a substance and to determine its purity?
- How is electron configuration is explained by quantum mechanics, as delineated in the Aufbau principle and exemplified in the periodic table of the elements?
- How do you determine the energies of the electrons in a given shell that are measured experimentally with photoelectron spectroscopy (PES)?
- How do you explain how trends in atomic properties within the periodic table (periodicity) can be predicted by the position of the element on the periodic table and qualitatively understood using Coulomb's law?
- How do you explain the likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of elements.

Process

- How do you identify an appropriate theory, definition, or mathematical relationship to solve a problem?
- How do you identify information presented graphically to solve a problem?
- How do you identify a testable scientific question based on an observation, data, or a model.
- How do you identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs or tables)?
- How do you describe the components of and quantitative information from models and representations that illustrate particulate-level properties?
- How do you explain whether a model is consistent with chemical theories?
- How do you explain chemical properties or phenomena using given chemical theories, models and representations?
- How do you explain the connection between particulate-level and

macroscopic properties of a substance using models and representations?

Reflective

- Why do we wear a lead apron when we get an x-ray?
- If you were Mendeleev, how would you organize the elements?
- Think about each family of the periodic table, do you agree with the name?

Power Standards

These state standards have been identified as critical to students' long-term learning progression in this discipline. They are assessed within the scope of this unit.

- 1.1.A Calculate quantities of a substance or its relative number of particles using dimensional analysis and the mole concept.
- 1.2.A Explain the quantitative relationship between the mass spectrum of an element and the masses of the element's isotopes.
- 1.3.A Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance.
- 1.4.A Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture.
- 1.5.A Represent the ground-state electron configuration of an atom of an element or its ions using the Aufbau principle.
- 1.6.A Explain the relationship between the photoelectron spectrum of an atom or ion and electron configuration.
- 1.7.A Explain the relationship between trends in atomic properties of elements and electronic structure and periodicity.
- 1.8.A Explain how the periodic table shows patterns in electronic structure and trends in atomic properties.

Unit 2
Compound Structure and Properties

Essential Questions

These questions guide the student experience throughout the unit and is open-ended and enduring.

- How are molecular compounds arranged?
- Why are some bonds easier to break than others?
- In what ways does a diagram drawn on paper accurately reflect the structure of a molecule?
- In what ways does it not accurately reflect the structure?

Unit Summary

This summary provides high-level information about the main learning outcomes within this unit.

In Unit 2, students apply their knowledge of atomic structure at the particulate level and connect it to the macroscopic properties of a substance. Both the chemical and physical properties of materials can be explained by the structure and arrangement of atoms, ions, or molecules and the forces between them. These forces, called chemical bonds, are distinct from typical intermolecular interactions. Electronegativity can be used to make predictions about the type of bonding present between two atoms. In subsequent units, students will use the periodic table and the atomic properties to predict the type of bonding present between two atoms based on position.

Guiding Questions

At the end of this unit, students should be able to respond to these questions as they demonstrate understanding of key concepts, skills and relevance to their own lives.

Content

- How do you explain how valence electrons shared between atoms of unequal electronegativity constitute a polar covalent bond?
- How do you explain how a graph of potential energy versus the distance between atoms (internuclear distance) is a useful representation for describing the interactions between atoms?
- How do you explain how the cations and anions in an ionic crystal are arranged in a systematic, 3-D array that maximizes the attractive forces among cations and anions while minimizing the repulsive forces?
- How do you explain how metallic bonding can be represented as an array of positive metal ions surrounded by delocalized valence electrons?

- How do you demonstrate how Lewis diagrams can be constructed according to an established set of principles?
- How do you explain, in cases where more than one equivalent Lewis structure can be constructed, how resonance must be included as a refinement to the Lewis structure?
- How do you explain how VSEPR theory uses the Coulombic repulsion between electrons as a basis for predicting the arrangement of electron pairs around a central atom?

Process

- How do you represent chemical phenomena using appropriate graphing techniques, including scale and units?
- How do you represent chemical substances or phenomena with appropriate diagrams or models (e.g. electron configuration)?
- How do you explain the connection between particulate and macroscopic properties using models and representations?
- How do you make a scientific claim?
- How do you support a claim with evidence from scientific data?
- How do you support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules?

Reflective

- How do the bonds in an item you can't live without relate to its importance?
- How do manufacturers choose the material they use for new products?
- How would our world be different if electrons were positively charged?

Power Standards

These state standards have been identified as critical to students' long-term learning progression in this discipline. They are assessed within the scope of this unit.

- 2.1.A Explain the relationship between the type of bonding and the properties of the elements participating in the bond.
- 2.2.A Represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength.
- 2.3.A Represent an ionic solid with a particulate model that is consistent with Coulomb's law and the properties of the constituent ions.
- 2.4.A 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.A Represent a molecule or ion using a Lewis diagram.
- 2.6.A 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.A Represent a molecule with a Lewis diagram that accounts for resonance between equivalent structures or that uses formal charge to select between nonequivalent structures.

Unit 3
Properties of Substances and Mixtures

Essential Questions

These questions guide the student experience throughout the unit and are open-ended and enduring.

- How do interactions between particles influence the properties of pure substances and mixtures?
- Why does the smell of perfume only last for a short time?
- Why can you swim in water, but you can't walk through a wall?
- How does the spacing and motion of particles relate to a substance's state of matter and the properties of gases?
- How can you determine the structure and concentration of a chemical species in a mixture?

Unit Summary

Transformations of matter can be observed in ways that are generally categorized as either a chemical or physical change. The shapes of the particles involved and the space between them are key factors in determining the nature of physical changes. The properties of solids, liquids, and gases reflect the relative orderliness of the arrangement of particles in those states, their relative freedom of motion, and the nature and strength of the interactions between them. There is a relationship between the macroscopic properties of solids, liquids, and gases, as well as the structure of the constituent particles of those materials on the molecular and atomic scale. In subsequent units, students will explore chemical transformations of matter.

Guiding Questions

At the end of this unit, students should be able to respond to these questions as they demonstrate understanding of key concepts, skills and relevance to their own lives.

Content

- How do you explain that In large biomolecules, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule?
- How do you explain how many properties of liquids and solids are determined by the strengths and types of intermolecular forces present?
- How do you explain how solids can be crystalline, where the particles are

arranged in regular three-dimensional structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement?
- How do you explain how the macroscopic properties of ideal gases are related through the ideal gas law: EQN: PV = nRT?
- How do you explain how the kinetic molecular theory (KMT) relates the macroscopic properties of gases to motions of the particles in the gas?
- How do you explain how deviations from the ideal gas law may result from interparticle attractions among gas molecules, particularly at conditions that are close to those resulting in condensation?
- How do you explain how solution composition can be expressed in a variety of ways in the laboratory?
- How do you explain how particulate representations of solutions communicate the structure and properties of solutions?
- How do you explain how the components of a liquid solution cannot be separated by filtration?
- How do you explain how substances with similar intermolecular interactions tend to be miscible or soluble in one another?
- How do you explain how the differences in absorption or emission of photons in different spectral regions are related to the different types of molecular motion or electronic transition?
- How do you explain how the wavelength of the electromagnetic wave is related to its frequency and the speed of light by the equation: EQN: $c = \lambda\nu$?
- How do you explain how the Beer-Lambert Law relates the absorption of light by a solution to three variables according to the equation: EQN: $A = \varepsilon bc$?

Process

- How do you explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties?
- How do you explain the connection between particulate-level and macroscopic properties of a substance using models and representations?
- How do you visually represent the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic)?
- How do you explain the relationship between variables within an equation when one variable changes?
- How do you provide reasoning to justify a claim using connections between

particulate and macroscopic scales or levels?
- How do you identify experimental procedures that are aligned to the question (which may include a sketch of a lab setup)?

Reflective

- How do pollutants affect our water supply?
- Could your cell phone work without intermolecular forces?
- Why is it better to drink milk than water when eating spicy food?
- What could we have done to make this unit more environmentally friendly?
- What evidence do we have that particles have interactions?

Power Standards

These state standards have been identified as critical to students' long-term learning progression in this discipline. They are assessed within the scope of this unit.

- 3.1.A Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when, 1) the molecules are of the same chemical species and 2) the molecules are of two different chemical species.
- 3.2.A 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.A Represent differences between solid, liquid and gas phases using a particulate-level model.
- 3.4.A Explain the relationship between the macroscopic properties of a sample of gas or mixture of gases using the ideal gas law.
- 3.5.A Explain the relationship between the motion of particles and macroscopic properties of gases, the KMT, a particulate model, or a graphical representation.
- 3.6.A Explain the relationship among non-ideal behaviors of gases, interparticle forces and/or volume.
- 3.7.A Calculate the number of solute particles, the volume, or the molarity of solutions.
- 3.8.A Using particulate models for mixtures, represent the interactions between components and their concentrations.
- 3.9.A Explain the results of the separation experiment based on intermolecular interactions.

- 3.10.A Explain the relationship between the solubility of ionic and molecular compounds in aqueous and non-aqueous solvents, and the IMFs between particles.
- 3.11.A Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region.
- 3.12.A Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.
- 3.13.A Explain the amount of light absorbed by a solution of molecules or ions in relationship to the concentration, path length, and molar absorptivity.

Unit 4
Chemical Reactions

Essential Questions

These questions guide the student experience throughout the unit and are open-ended and enduring.

- What makes fireworks explode?
- In what ways can a chemical change be described and documented?
- How can you predict that a chemical reaction will generate enough product?

Unit Summary

This unit explores chemical transformations of matter by building on the physical transformations studied in Unit 3. Chemical changes involve the making and breaking of chemical bonds. Many properties of a chemical system can be understood using the concepts of varying strengths of chemical bonds and weaker intermolecular interactions. When chemical changes occur, the new substances formed have properties that are distinguishable from the initial substance or substances. Chemical reactions are the primary means by which transformations in matter occur. Chemical equations are a representation of the rearrangement of atoms that occur during a chemical reaction. In subsequent units, students will explore rates at which chemical changes occur.

Guiding Questions

At the end of this unit, students should be able to respond to these questions as they demonstrate understanding of key concepts, skills and relevance to their own lives.

Content

- How do you explain the difference between a physical change that occurs when a substance undergoes a change in properties but not a change in composition?
- How do you explain the difference between balanced molecular, complete ionic, and net ionic equations?
- How do you explain how balanced chemical equations in their various forms can be translated into symbolic particulate representations?
- How do you explain how processes that involve the breaking and/or formation of chemical bonds are typically classified as chemical processes?
- How do you explain how it is possible to calculate product amounts by using known reactant amounts, or to calculate reactant amounts given known

product amounts?
- How do you explain how titrations may be used to determine the amount of an analyte in solution?
- How do you explain how acid-base reactions involve transfer of one or more protons (H+ ions) between chemical species?
- How do you explain how precipitation reactions frequently involve mixing ions in aqueous solution to produce an insoluble or sparingly soluble ionic compound?
- How do you explain when an acid or base ionizes in water, the conjugate acid-base pairs can be identified and their relative strengths compared?
- How do you explain how balanced chemical equations for redox reactions can be constructed from half-reactions?

Process

- How do you formulate a hypothesis or predict the results of an experiment?
- How do you determine a balanced chemical equation for a given chemical phenomena?
- How do you represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration)?
- How do you support a claim with evidence from experimental data?
- How do you explain the relationship between variables within an equation when one variable changes?
- How do you represent chemical phenomena using appropriate graphing techniques, including correct scale and units?
- How do you describe the components of and quantitative information from models and representations that illustrate both particulate level and macroscopic-level properties?

Reflective

- How do reactions play a role in car engines or home heating systems?
- What are the environmental and health impacts of redox reactions?
- How do acid-base reactions influence household cleaning processes?
- How do displacement reactions apply to batteries or corrosion prevention?

Power Standards

These state standards have been identified as critical to students' long-term learning progression in this discipline. They are assessed within the scope of this unit.

- 4.1.A Identify evidence of chemical and physical changes in matter.
- 4.2.A Represent changes in matter with a balanced chemical or net ionic equation: 1) For physical changes. 2) For given information about the identity of the reactants and/or product. 3) For ions in a given chemical reaction.
- 4.3.A Represent a given chemical reaction or physical process with a consistent particulate model.
- 4.4.A Explain the relationship between macroscopic characteristics and bond interactions for: 1) Chemical processes. 2) Physical processes.
- 4.5.A Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process.
- 4.6.A 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.A Identify are action as acid-base, oxidation-reduction, or precipitation.
- 4.8.A Identify species as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species.
- 4.9.A Represent a balanced redox reaction equation using half-reactions.

Unit 5
Kinetics

Essential Questions

These questions guide the student experience throughout the unit and are open-ended and enduring.

- Why are some reactions faster than other reactions?
- Why are some medications taken every 8 hours and other's once a day?
- Why is food stored in a refrigerator, but bread dough is kept in a warm place to rise?
- How can the speed of a reaction be controlled by understanding the collisions that occur on the particle level?

Unit Summary

Unit 4 focused on chemical changes; in Unit 5 students will develop an understanding of the rates at which chemical changes occur and the factors that influence the rates. Those factors include the concentration of reactants, temperature, catalysts, and other environmental factors. Chemical changes are represented by chemical reactions, and the rates of chemical reactions are determined by the details of the molecular collisions. Rates of change in chemical reactions are observable and measurable. When measuring rates of change, students are measuring the concentration of reactant or product species as a function of time. These chemical processes may be observed in a variety of ways and often involve changes in energy as well. In subsequent units, students will describe the role of energy in changes in matter.

Guiding Questions

At the end of this unit, students should be able to respond to these questions as they demonstrate understanding of key concepts, skills and relevance to their own lives.

Content

- How do you explain how the kinetics of a chemical reaction is defined as the rate at which an amount of reactants is converted to products per unit of time?
- How do you explain how experimental methods can be used to monitor the amounts of reactants and/or products of a reaction over time and to determine the rate of the reaction?
- How do you explain how the slopes of the concentration versus time data for zeroth, first, and second order reactions can be used to determine the rate constant for the reaction?
- How do you explain how the rate law of an elementary reaction can be inferred from the stoichiometry of the particles participating in a collision?

- How do you explain how, in most reactions, only a small fraction of the collisions leads to a reaction?
- How do you explain how elementary reactions typically involve the breaking of some bonds and the forming of new ones?
- How do you explain how a reaction mechanism consists of a series of elementary reactions, or steps, that occur in sequence?
- How do you explain that for a reaction mechanism, the rate law of the reaction is set by the molecularity of the slowest elementary step?
- How do you explain how approximations (such as pre-equilibrium)must be made to determine a rate law expression?
- How do you explain how knowledge of the energetics of each elementary reaction in a mechanism allows for the construction of an energy profile for a multistep reaction?
- How do you explain that in order for a catalyst to increase the rate of a reaction, the addition of the catalyst must increase the number of effective collisions and/or provide a reaction path with a lower activation energy?

Process

- How do you provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels?
- How do you explain the relationship between variables within an equation when one variable changes?
- How do you identify an appropriate theory, definition, or mathematical relationship to solve a problem?
- How do you determine a balanced chemical equation for a given chemical phenomena?
- How do you provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels?
- How do you represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration)?
- How do you describe the components of and quantity information from models and representations that illustrate both particle-level and macroscopic-level properties?

Reflective

- How does the temperature of food affect the rate of cooking?

- Why does a sliced apple or banana turn brown over time?
- What factors impact the speed of a chemical reaction?
- Why does the reaction between baking soda and vinegar happen quickly?

Power Standards

These state standards have been identified as critical to students' long-term learning progression in this discipline. They are assessed within the scope of this unit.

- 5.1.A Explain the relationship between the rate of a chemical reaction and experimental parameters.
- 5.2.A Represent experimental data with a consistent rate law expression.
- 5.3.A Identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time.
- 5.4.A Represent an elementary reaction as a rate law expression using stoichiometry.
- 5.5.A Explain the relationship between the rate of an elementary reaction and the frequency, energy, and orientation of particle collisions.
- 5.6.A Represent the activation energy and overall energy change in an elementary reaction using a reaction energy profile.
- 5.7.A Identify the components of a reaction mechanism.
- 5.8.A Identify the rate law for a reaction from a mechanism in which the first steps rate limiting.
- 5.9.A Identify the rate law for a reaction from a mechanism in which the first step snot rate limiting.
- 5.10.A Represent the activation energy and overall energy change in a multistep reaction with a reaction energy profile.
- 5.11.A Explain the relationship between the effect of a catalyst on a reaction and changes in the reaction mechanism.

Unit 6
Thermochemistry

Essential Questions

These questions guide the student experience throughout the unit and are open-ended and enduring.

- Why is energy released when liquid water becomes an ice cube?
- Why does your skin feel cold when water evaporates off of it?
- How does a thermal energy transfer affect temperature, states of matter, and chemical bonds?
- How can energy changes be tracked and measured when energy can't be seen?
- Why do combustion reactions that form carbon dioxide release energy?

Unit Summary

The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter. The availability or disposition of energy plays a role in virtually all observed chemical processes. Thermochemistry provides tools for understanding this key role, particularly the conservation of energy, including energy transfer in the forms of heat and work. Chemical bonding is central to chemistry. A key concept to know is that the breaking of a chemical bond inherently requires an energy input, and because bond formation is the reverse process, it will release energy. In subsequent units, the application of thermodynamics will determine the favorability of a reaction occurring.

Guiding Questions

At the end of this unit, students should be able to respond to these questions as they demonstrate understanding of key concepts, skills and relevance to their own lives.

Content

- How do you explain how energy changes in a system can be described as endothermic and exothermic processes such as the heating or cooling of a substance, phase changes, or chemical transformations?
- How do you explain how a physical or chemical process can be described with an energy diagram that shows the endothermic or exothermic nature of that process?
- How do you explain how the particles in a warmer body have a greater average kinetic energy than those in a cooler body?

- How do you explain how the amount of heat transferred between two bodies may be quantified by the heat transfer equation: EQN: $q = mc\Delta T$?
- How do you explain how the energy absorbed during a phase change is equal to the energy released during a complementary phase change in the opposite direction?
- How do you explain how the enthalpy change of a reaction gives the amount of heat energy released (for negative values) or absorbed (for positive values) by a chemical reaction at constant pressure?
- How do you explain how during a chemical reaction, bonds are broken and/or formed, and these events change the potential energy of the system?
- How do you explain how tables of standard enthalpies of formation can be used to calculate the standard enthalpies of reactions?
- How do you explain how many processes can be broken down into a series of steps?

Process

- How do you provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels?
- How do you provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification?
- How do you represent chemical phenomena using appropriate graphing techniques, including correct scale and units?
- How do you calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)?
- How do you identify quantities needed to solve a problem from given information (e.g.,text, mathematical expressions, graphs, or tables)?

Reflective

- How does energy released/absorbed in a reaction affect the surroundings?
- What changes molecularly with temperature changes in a reaction?
- How do enthalpy/entropy explain why reactions happen spontaneously?
- How can understanding heat changes help us optimize energy usage?

Power Standards

These state standards have been identified as critical to students' long-term learning progression in this discipline. They are assessed within the scope of this unit.

- 6.1.A Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation.
- 6.2.A Represent a chemical or physical transformation with an energy diagram.
- 6.3.A Explain the relationship between the transfer of thermal energy and molecular collisions.
- 6.4.A 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.A 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.A 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.A Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction.
- 6.8.A Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation.
- 6.9.A Represent a chemical or physical process as a sequence of steps.
- 6.9.B Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual steps.

Unit 7
Equilibrium

Essential Questions

These questions guide the student experience throughout the unit and are open-ended and enduring.

- How are reaction rates related to the direction that a reaction proceeds?
- How can the composition of a mixture at equilibrium be predicted?
- How can an equilibrium system be manipulated to maximize product yield?
- Why do medics administer pure O_2 to people with carbon monoxide poisoning?
- What factors influence the degree to which a salt will dissolve?

Unit Summary

Chemical equilibrium is a dynamic state in which opposing processes occur at the same rate. In this unit, students learn that any bond or intermolecular attraction that can be formed can be broken. These two processes are in a dynamic competition, sensitive to initial conditions and external perturbations. A change in conditions, such as addition of a chemical species, change in temperature, or change in volume, can cause the rate of the forward and reverse reactions to fall out of balance. Le Châtelier's principle provides a means to reason qualitatively about the direction of the shift in an equilibrium system resulting from various possible stresses. The expression for the equilibrium constant, K, is a mathematical expression that describes the equilibrium state associated with a chemical change. An analogous expression for the reaction quotient, Q, describes a chemical reaction at any point, enabling a comparison to the equilibrium state. The dissolution of a solid in a solvent can also be understood by applying the principles of chemical equilibrium because it is a reversible reaction. The relationships between salt solubility, pH, and free energy will be encountered in subsequent units. Subsequent units will also explore equilibrium constants that arise from acid-base chemistry.

Guiding Questions

At the end of this unit, students should be able to respond to these questions as they demonstrate understanding of key concepts, skills and relevance to their own lives.

Content

- How do you explain how the equilibrium state is dynamic? The forward and reverse processes continue to occur at equal rates, resulting in no net

observable change.

- How do you explain: 1) If the rate of the forward reaction is greater than the reverse reaction, then there is a net conversion of reactants to products; and 2) If the rate of the reverse reaction is greater than that of the forward reaction, then there is a net conversion of products to reactants?
- How do you explain how the reaction quotient Qc describes the relative concentrations of reaction species at any time?
- How do you explain how equilibrium constants can be determined from experimental measurements of the concentrations or partial pressures of the reactants and products at equilibrium?
- How do you explain how some equilibrium reactions have very large K values and proceed essentially to completion, while others have very small K values and barely proceed at all?
- How do you explain how the stoichiometric coefficients of a reaction are multiplied by a factor x, K is raised to the power x?
- How do you explain how the concentrations or partial pressures of species at equilibrium can be predicted given the balanced reaction, initial concentrations, and the appropriate K?
- How do you explain how particulate representations can be used to describe the relative numbers of reactant and product particles present prior to and at equilibrium, and the value of the equilibrium constant?
- How do you explain how Le Châtelier's principle can be used to predict the effect that stress will have on experimentally measurable properties such as pH, temperature, and color of a solution?
- How do you explain how a disturbance to a system at equilibrium causes Q to differ from K, thereby taking the system out of equilibrium?
- How do you explain how the dissolution of a salt is a reversible process whose extent can be described by K sp, the solubility-product constant?
- How do you explain how the solubility of a salt is reduced when it is dissolved into a solution that already contains one of the ions present in the salt?

Process

- How do you provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification?
- How do you explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties?

- How do you represent chemical phenomena using appropriate graphing techniques, including correct scale and units?
- How do you explain the relationship between variables within an equation when one variable changes?
- How do you identify quantities needed to solve a problem from given information(e.g., text, mathematical expressions, graphs, or tables)?
- How do you visually represent the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic)?
- How do you explain the connection between experimental results and chemical concepts, processes, or theories?
- How do you calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)?
- How do you identify an appropriate theory, definition, or mathematical relationship to solve a problem?
- How do you explain how modifications to an experimental procedure will alter results?

Reflective

- How do processes, like CO_2 levels in a soda or the fragrance of a perfume, seem to stay constant over time?
- How can chemical equilibrium explain how the body regulates blood pH?
- How does chemical equilibrium control reactions in industrial processes, like in the production of fertilizers?
- What role does Le Chatelier's principle play in everyday situations, such as adjusting the temperature or pressure in a pressure cooker?

Power Standards

These state standards have been identified as critical to students' long-term learning progression in this discipline. They are assessed within the scope of this unit.

- 7.1.A Explain the relationship between the occurrence of a reversible chemical or physical process, and the establishment of equilibrium, to experimental observations.
- 7.2.A Explain the relationship between the direction in which a reversible reaction proceeds and the relative rates of the forward and reverse reactions.
- 7.3.A Represent the reaction quotient Qc or Qp , for a reversible reaction, and the corresponding equilibrium expressions Kc = Qc or K p = Qp .
- 7.4.A Calculate Kc or Kp based on experimental observations of concentrations or pressures at equilibrium.
- 7.5.A Explain the relationship between very large or very small values of K and the relative concentrations of chemical species at equilibrium.
- 7.6.A Represent a multistep process with an overall equilibrium expression, using the constituent K expressions for each individual reaction.
- 7.7.A Identify the concentrations or partial pressures of chemical species at equilibrium based on the initial conditions and the equilibrium constant.
- 7.8.A Represent a system undergoing a reversible reaction with a particulate model.
- 7.9.A Identify the response of a system at equilibrium to an external stress, using Le Châtelier's principle.
- 7.10.A Explain the relationships between Q, K, and the direction in which a reversible reaction will proceed to reach equilibrium.
- 7.11.A Calculate the solubility of a salt based on the value of Ksp for the salt.
- 7.12.A Identify the solubility of a salt, and/or the value of Ksp for the salt, based on the concentration of a common ion already present in solution.

Unit 8
Acids & Bases

Essential Questions

These questions guide the student experience throughout the unit and are open-ended and enduring.

- How is pH related to the concentration and strength of an acid, a base, or a mixture of them?
- How does acid or base strength relate to the concentrations of reactants and products when a system reaches equilibrium?
- Why are some acids stronger than others?
- How does your body maintain pH balance?

Unit Summary

This unit builds on the content about chemical equilibrium studied in Unit 7. Chemical equilibrium plays an important role in acid-base chemistry and solubility. The proton-exchange reactions of acid-base chemistry are reversible reactions that reach equilibrium quickly, and much of acid-base chemistry can be understood by applying the principles of chemical equilibrium. Most acid-base reactions have either large or small values of K, which means qualitative conclusions regarding equilibrium state can often be drawn without extensive computations. In the final unit, the equilibrium constant is related to temperature and the difference in Gibbs free energy between the reactants and products.

Guiding Questions

At the end of this unit, students should be able to respond to these questions as they demonstrate understanding of key concepts, skills and relevance to their own lives.

Content

- How do you explain how the concentrations of hydronium ion and hydroxide ion are often reported as pH and pOH, respectively?
- How do you explain how 1) Molecules of a strong acid (e.g., HCl, HBr, HI, $HClO_4$, H_2SO4 , and HNO_3) will completely ionize in aqueous solution to produce hydronium ions; 2) Strong bases (e.g., group I and II hydroxides) completely dissociate to produce hydroxide ions?
- How do you explain how 1) Weak acids react with water to produce hydronium ions. However, only a small percentage of molecules of a weak acid will ionize in this way; 2) Weak bases react with water to produce

hydroxide ions in solution. However, ordinarily just a small percentage of the molecules of a weak base in solution will ionize this way?

- How do you explain how a solution of a weak base involves equilibrium between an un-ionized base and its conjugate acid?
- How do you explain when a strong acid and a strong base are mixed, they react quantitatively in a reaction represented by the equation: H^+ (aq) + OH^- (aq) H_2O(l)?
- How do you explain when a weak base and a strong acid are mixed, they will react quantitatively in a reaction represented by the equation: B(aq) + H_3O^+ (aq) HB^+ (aq) + H_2O(l)?
- How do you explain how an acid-base reaction can be carried out under controlled conditions in a titration?
- How do you explain how the protons on a molecule that will participate in acid-base reactions, and the relative strength of these protons, can be inferred from the molecular structure?
- How do you explain how the protonation state of an acid or base (i.e., the relative concentrations of HA and A^-) can be predicted by comparing the pH of a solution to the pKa of the acid in that solution?
- How do you explain how a buffer solution contains a large concentration of both members in a conjugate acid-base pair?
- How do you explain how the pH of the buffer is related to the pKa the acid and the concentration ratio of the conjugate acid-base pair?
- How do you explain how Increasing the concentration of the buffer components keeps the pH of the buffer the same but increases the capacity of the buffer to neutralize added acid or base?
- How do you explain how the solubility of a salt is pH sensitive when one of the constituent ions is a weak acid, a weak base, or the hydroxide ion?

Process

- How do you identify an appropriate theory, definition, or mathematical relationship to solve a problem?
- How do you explain the relationship between variables within an equation when one variable changes?
- How do you calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending

to significant figures)?
- How do you identify information presented graphically to solve a problem?
- How do you support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules?
- How do you make observations or collect data from representations of laboratory set ups or results, while attending to precision where appropriate?
- How do you provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification?
- How do you explain how potential sources of experimental error may affect the experimental results?

Reflective

- How do acids and bases play a role in household cleaning products?
- How does the pH level of the food we eat affect our health?
- In what ways do buffers in our body help maintain homeostasis?
- How do acids and bases affect the environment, such as acid rain?

Power Standards

These state standards have been identified as critical to students' long-term learning progression in this discipline. They are assessed within the scope of this unit.

- 8.1.A Calculate the values of pH and pOH, based on Kw and the concentration of all species present in a neutral solution of water.
- 8.2.A Calculate pH and pOH based on concentrations of all species in a solution of a strong acid or a strong base.
- 8.3.A Explain the relationship among pH, pOH, and concentrations of all species in a solution of a monoprotic weak acid or weak base.
- 8.4.A Explain the relationship among the concentrations of major species in a mixture of weak and strong acids and bases.
- 8.5.A 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.A Explain the relationship between the strength of an acid or base and the structure of the molecule or ion.
- 8.7.A Explain the relationship between the predominant form of a weak acid or base in solution at a given pH and the pKa of the conjugate acid or the pKb of the conjugate base.
- 8.8.A 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.A Identify the pH of buffer solution based on the identity and concentrations of the conjugate acid-base pair used to create the buffer.
- 8.10.A 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.A Identify the qualitative effect of changes in pH on the solubility of a salt.

Annually PLCs are able to add 1-3 additional priority standards, as needed, based on their students' achievement and growth data.

Supporting Standards

These state standards are included in the student learning experiences for this unit and may be assessed.

- Bulleted list with standards notation

Unit 9
Thermodynamics & Electrochemistry

Essential Questions

These questions guide the student experience throughout the unit and are open-ended and enduring.

- Why do some chemical reactions occur without intervention, but others require the input of energy?
- How can we determine the conditions under which a chemical or physical transformation is likely to occur?
- How is electrical energy generated using chemical reactions?

Unit Summary

This unit allows students to connect principles and calculations across Units 1–8. The thermodynamics of a chemical reaction is connected to both the structural aspects of the reaction and the macroscopic outcomes of the reaction. All changes in matter involve some form of energy change. One key determinant of chemical transformations is the change in potential energy that results from changes in electrostatic forces. Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions. Applying the laws of thermodynamics will allow students to describe the essential role of energy and explain and predict the direction of changes in matter.

Guiding Questions

At the end of this unit, students should be able to respond to these questions as they demonstrate understanding of key concepts, skills and relevance to their own lives.

Content

- How do you explain how entropy increases when matter becomes more dispersed?
- How do you explain how the entropy change for a process can be calculated from the absolute entropies of the species involved before and after the process occurs?
- How do you explain how the standard Gibbs free energy change for a chemical or physical process is a measure of thermodynamic favorability?
- How do you explain how processes that are thermodynamically favored do not occur to any measurable extent, or they occur at extremely slow rates?
- How do you explain how the phrase “thermodynamically favored” means that

the products are favored at equilibrium under standard conditions?
- How do you explain how the free energy change (ΔG^o) for the dissolution of a substance reflects a number of factors?
- How do you explain how an external source of energy can be used to make a thermodynamically unfavorable process occur?
- How do you explain how each component of an electrochemical cell plays a specific role in the overall functioning of the cell?
- How do you explain how electrochemistry encompasses the study of redox reactions that occur within electrochemical cells?
- How do you explain how In a real system under nonstandard conditions, the cell potential will vary depending on the concentrations of the active species?
- How do you explain how Faraday's laws can be used to determine the stoichiometry of the redox reaction occurring in an electrochemical cell?

Process

- How do you support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules?
- How do you calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision?
- How do you provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels?
- How do you provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification?
- How do you explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties?
- How do you explain how modifications to an experimental procedure will alter results?
- How do you identify an appropriate theory, definition, or mathematical relationship to solve a problem?

Reflective

- How does thermodynamics explain why the rusting of iron happens?
- What role do redox reactions play in batteries or fuel cells?

- How does electrochemistry help make devices efficient and long-lasting?
- How does free energy explain why ice forms at certain temperatures?
- How can we use free energy to control processes in industry?
- How does electrochemistry affect water treatment or pollution reduction?
- How can we apply electrochemistry to develop more sustainable solutions?

Power Standards

These state standards have been identified as critical to students' long-term learning progression in this discipline. They are assessed within the scope of this unit.

- 9.1.A Identify the sign and relative magnitude of the entropy change associated with chemical or physical processes.
- 9.2.A 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.A Explain whether a physical or chemical process is thermodynamically favored based on an evaluation of ΔG°.
- 9.4.A Explain, in terms of kinetics, why a thermodynamically favored reaction might not occur at a measurable rate.
- 9.5.A Explain whether a process is thermodynamically favored using the relationships between K, ΔG° , and T.
- 9.6.A Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process.
- 9.7.A Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes.
- 9.8.A Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.
- 9.9.A Explain whether an electrochemical cell is thermodynamically favored, based on its standard cell potential and the constituent half-reactions within the cell.
- 9.10.A Explain the relationship between deviations from standard cell conditions and changes in the cell potential.

Annually PLCs are able to add 1-3 additional priority standards, as needed, based on their students' achievement and growth data.

Supporting Standards

These state standards are included in the student learning experiences for this unit and may be assessed.

- Bulleted list with standards notation