



Structure of Matter		
Mole Concept: Empirical Formula, Percent Composition, Stoichiometry	<p><b>Learning objective 1.1</b> The student can justify the observation that the ratio of the masses of the constituent elements in any pure sample of that compound is always identical on the basis of the atomic molecular theory. [See <b>SP 6.1</b>; <b>Essential knowledge 1.A.1</b>]</p>	
	<p><b>Learning objective 1.2</b> The student is able to select and apply mathematical routines to mass data to identify or infer the composition of pure substances and/or mixtures. [See <b>SP 2.2</b>; <b>Essential knowledge 1.A.2</b>]</p>	
	<p><b>Learning objective 1.3</b> The student is able to select and apply mathematical relationships to mass data in order to justify a claim regarding the identity and/or estimated purity of a substance. [See <b>SP 2.2, 6.1</b>; <b>Essential knowledge 1.A.2</b>]</p>	
	<p><b>Learning objective 1.4</b> The student is able to connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively. [See <b>SP 7.1</b>; <b>Essential knowledge 1.A.3</b>]</p>	
Analyzing Data to Determine Electron Configurations, PES, IE, Coulomb's Law	<p><b>Learning objective 1.5</b> The student is able to explain the distribution of electrons in an atom or ion based upon data. [See <b>SP 1.5, 6.2</b>; <b>Essential knowledge 1.B.1</b>]</p>	
	<p><b>Learning objective 1.6</b> The student is able to analyze data relating to electron energies for patterns and relationships. [See <b>SP 5.1</b>; <b>Essential knowledge 1.B.1</b>]</p>	
	<p><b>Learning objective 1.7</b> The student is able to describe the electronic structure of the atom, using PES data, ionization energy data, and/or Coulomb's law to construct explanations of how the energies of electrons within shells in atoms vary. [See <b>SP 5.1, 6.2</b>; <b>Essential knowledge 1.B.2</b>]</p>	
	<p><b>Learning objective 1.8</b> The student is able to explain the distribution of electrons using Coulomb's law to analyze measured energies. [See <b>SP 6.2</b>; <b>Essential knowledge 1.B.2</b>]</p>	
Periodicity	<p><b>Learning objective 1.9</b> The student is able to predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model. [See <b>SP 6.4</b>; <b>Essential knowledge 1.C.1</b>]</p>	
	<p><b>Learning objective 1.10</b> Students can justify with evidence the arrangement of the periodic table and can apply periodic properties to chemical reactivity. [See <b>SP 6.1</b>; <b>Essential knowledge 1.C.1</b>]</p>	
	<p><b>Learning objective 1.11</b> The student can analyze data, based on periodicity and the properties of binary compounds, to identify patterns and generate hypotheses related to the molecular design of compounds for which data are not supplied. [See <b>SP 3.1, 5.1</b>; <b>Essential knowledge 1.C.1</b>]</p>	

Atomic Structure: Mass Spectroscopy & Shell vs. Quantum Model	<p><b>Learning objective 1.12</b> The student is able to explain why a given set of data suggests, or does not suggest, the need to refine the atomic model from a classical shell model with the quantum mechanical model. [See <b>SP 6.3; Essential knowledge 1.C.2</b>]</p>	
	<p><b>Learning objective 1.13</b> Given information about a particular model of the atom, the student is able to determine if the model is consistent with specified evidence. [See <b>SP 5.3; Essential knowledge 1.D.1</b>]</p>	
	<p><b>Learning objective 1.14</b> The student is able to use data from mass spectrometry to identify the elements and the masses of individual atoms of a specific element. [See <b>SP 1.4, 1.5; Essential knowledge 1.D.2</b>]</p>	
	<p><b>Learning objective 1.15</b> The student can justify the selection of a particular type of spectroscopy to measure properties associated with vibrational or electronic motions of molecules. [See <b>SP 4.1, 6.4; Essential knowledge 1.D.3</b>]</p>	
LAB: Beers Law (Colorimetry)	<p><b>Learning objective 1.16</b> The student can design and/or interpret the results of an experiment regarding the absorption of light to determine the concentration of an absorbing species in a solution. [See <b>SP 4.2, 5.1; Essential knowledge 1.D.3</b>]</p>	
Law of Conservation of Matter	<p><b>Learning objective 1.17</b> The student is able to express the law of conservation of mass quantitatively and qualitatively using symbolic representations and particulate drawings. [See <b>SP 1.5; Essential knowledge 1.E.1</b>]</p>	
	<p><b>Learning objective 1.18</b> The student is able to apply conservation of atoms to the rearrangement of atoms in various processes. [See <b>SP 1.4; Essential knowledge 1.E.2</b>]</p>	
LAB: Gravimetric Analysis & Titration (Redox)	<p><b>Learning objective 1.19</b> The student can design, and/or interpret data from, an experiment that uses gravimetric analysis to determine the concentration of an analyte in a solution. [See <b>SP 4.2, 5.1, 6.4; Essential knowledge 1.E.2</b>]</p>	
	<p><b>Learning objective 1.20</b> The student can design, and/or interpret data from, an experiment that uses titration to determine the concentration of an analyte in a solution. [See <b>SP 4.2, 5.1, 6.4; Essential knowledge 1.E.2</b>]</p>	



Properties of Matter		
Bonding : Ionic, Covalent, Metallic	<p><b>Learning objective 2.1</b> Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See <b>SP 6.4, 7.1</b>; <b>Essential knowledge components of 2.A–2.D</b>]</p>	
	<p><b>Learning objective 2.2</b> The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See <b>SP 7.2</b>, <i>connects to Big Idea 5, Big Idea 6</i>; <b>Essential knowledge components of 2.A–2.D</b>]</p>	
	<p><b>Learning objective 2.17</b> The student can predict the type of bonding present between two atoms in a binary compound based on position in the periodic table and the electronegativity of the elements. [See <b>SP 6.4</b>; <b>Essential knowledge components of 2.C</b>]</p>	
	<p><b>Learning objective 2.18</b> The student is able to rank and justify the ranking of bond polarity on the basis of the locations of the bonded atoms in the periodic table. [See <b>SP 6.1</b>; <b>Essential knowledge 2.C.1</b>]</p>	
	<p><b>Learning objective 2.19</b> The student can create visual representations of ionic substances that connect the microscopic structure to macroscopic properties, and/or use representations to connect the microscopic structure to macroscopic properties (e.g., boiling point, solubility, hardness, brittleness, low volatility, lack of malleability, ductility, or conductivity). [See <b>SP 1.1, 1.4, 7.1</b>; <b>Essential knowledge 2.C.2</b>, <i>connects to 2.D.1, 2.D.2</i>]</p>	
	<p><b>Learning objective 2.20</b> The student is able to explain how a bonding model involving delocalized electrons is consistent with macroscopic properties of metals (e.g., conductivity, malleability, ductility, and low volatility) and the shell model of the atom. [See <b>SP 6.2, 7.1</b>; <b>Essential knowledge 2.C.3</b>, <i>connects to 2.D.2</i>]</p>	
	<p><b>Learning objective 2.26</b> Students can use the electron sea model of metallic bonding to predict or make claims about the macroscopic properties of metals or alloys. [See <b>SP 6.4, 7.1</b>; <b>Essential knowledge 2.D.2</b>]</p>	
Molecular Structure	<p><b>Learning objective 2.21</b> The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See <b>SP 1.4</b>; <b>Essential knowledge 2.C.4</b>]</p>	
LAB: Bond Types	<p><b>Learning objective 2.22</b> The student is able to design or evaluate a plan to collect and/or interpret data needed to deduce the type of bonding in a sample of a solid. [See <b>SP 4.2, 6.4</b>; <b>Essential knowledge components of 2.D</b>]</p>	

Liquids and Solids	<p><b>Learning objective 2.3</b> The student is able to use aspects of particulate models (i.e., particle spacing, motion, and forces of attraction) to reason about observed differences between solid and liquid phases and among solid and liquid materials. [See <b>SP 6.4, 7.1; Essential knowledge 2.A.1</b>]</p>	
Gases and KMT	<p><b>Learning objective 2.4</b> The student is able to use KMT and concepts of intermolecular forces to make predictions about the macroscopic properties of gases, including both ideal and nonideal behaviors. [See <b>SP 1.4, 6.4; Essential knowledge 2.A.2</b>]</p>	
	<p><b>Learning objective 2.5</b> The student is able to refine multiple representations of a sample of matter in the gas phase to accurately represent the effect of changes in macroscopic properties on the sample. [See <b>SP 1.3, 6.4, 7.2; Essential knowledge 2.A.2</b>]</p>	
	<p><b>Learning objective 2.6</b> The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [See <b>SP 2.2, 2.3; Essential knowledge 2.A.2</b>]</p>	
	<p><b>Learning objective 2.12</b> The student can qualitatively analyze data regarding real gases to identify deviations from ideal behavior and relate these to molecular interactions. [See <b>SP 5.1, 6.5; Essential knowledge 2.B.2, connects to 2.A.2</b>]</p>	
LAB: Chromatography	<p><b>Learning objective 2.7</b> The student is able to explain how solutes can be separated by chromatography based on intermolecular interactions. [See <b>SP 6.2; Essential knowledge 2.A.3</b>]</p>	
Solution Formation: Particle Interactions, Molarity, Solubility	<p><b>Learning objective 2.8</b> The student can draw and/or interpret representations of solutions that show the interactions between the solute and solvent. [See <b>SP 1.1, 1.2, 6.4; Essential knowledge 2.A.3</b>]</p>	
	<p><b>Learning objective 2.9</b> The student is able to create or interpret representations that link the concept of molarity with particle views of solutions. [See <b>SP 1.1, 1.4; Essential knowledge 2.A.3</b>]</p>	
	<p><b>Learning objective 2.14</b> The student is able to apply Coulomb's law qualitatively (including using representations) to describe the interactions of ions, and the attractions between ions and solvents to explain the factors that contribute to the solubility of ionic compounds. [See <b>SP 1.4, 6.4; Essential knowledge 2.B.2</b>]</p>	
	<p><b>Learning objective 2.15</b> The student is able to explain observations regarding the solubility of ionic solids and molecules in water and other solvents on the basis of particle views that include intermolecular interactions and entropic effects. [See <b>SP 1.4, 6.2; Essential knowledge 2.B.3, connects to 5.E.1</b>]</p>	
LAB: Separation Techniques	<p><b>Learning objective 2.10</b> The student can design and/or interpret the results of a separation experiment (filtration, paper chromatography, column chromatography, or distillation) in terms of the relative strength of interactions among and between the components. [See <b>SP 4.2, 5.1, 6.4; Essential knowledge 2.A.3</b>]</p>	

Intermolecular Forces	<b>Learning objective 2.11</b> The student is able to explain the trends in properties and/or predict properties of samples consisting of particles with no permanent dipole on the basis of London dispersion forces. [See <b>SP 6.2, 6.4; Essential knowledge 2.B.1</b> ]	
	<b>Learning objective 2.13</b> The student is able to describe the relationships between the structural features of polar molecules and the forces of attraction between the particles. [See <b>SP 1.4, 6.4; Essential knowledge 2.B.2</b> ]	
	<b>Learning objective 2.16</b> The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces. [See <b>SP 6.2; Essential knowledge 2.B.3</b> ]	
Ionic Solids	<b>Learning objective 2.23</b> The student can create a representation of an ionic solid that shows essential characteristics of the structure and interactions present in the substance. [See <b>SP 1.1; Essential knowledge 2.D.1</b> ]	
	<b>Learning objective 2.24</b> The student is able to explain a representation that connects properties of an ionic solid to its structural attributes and to the interactions present at the atomic level. [See <b>SP 1.1, 6.2, 7.1; Essential knowledge 2.D.1</b> ]	
Metallic Solids	<b>Learning objective 2.25</b> The student is able to compare the properties of metal alloys with their constituent elements to determine if an alloy has formed, identify the type of alloy formed, and explain the differences in properties using particulate level reasoning. [See <b>SP 1.4, 7.2; Essential knowledge 2.D.2</b> ]	
	<b>Learning objective 2.27</b> The student can create a representation of a metallic solid that shows essential characteristics of the structure and interactions present in the substance. [See <b>SP 1.1; Essential knowledge 2.D.2</b> ]	
	<b>Learning objective 2.28</b> The student is able to explain a representation that connects properties of a metallic solid to its structural attributes and to the interactions present at the atomic level. [See <b>SP 1.1, 6.2, 7.1; Essential knowledge 2.D.2</b> ]	
Covalent (Network) Solids	<b>Learning objective 2.29</b> The student can create a representation of a covalent solid that shows essential characteristics of the structure and interactions present in the substance. [See <b>SP 1.1; Essential knowledge 2.D.3</b> ]	
	<b>Learning objective 2.30</b> The student is able to explain a representation that connects properties of a covalent solid to its structural attributes and to the interactions present at the atomic level. [See <b>SP 1.1, 6.2, 7.1; Essential knowledge 2.D.3</b> ]	
Molecular Solids	<b>Learning objective 2.31</b> The student can create a representation of a molecular solid that shows essential characteristics of the structure and interactions present in the substance. [See <b>SP 1.1; Essential knowledge 2.D.4</b> ]	
	<b>Learning objective 2.32</b> The student is able to explain a representation that connects properties of a molecular solid to its structural attributes and to the interactions present at the atomic level. [See <b>SP 1.1, 6.2, 7.1; Essential knowledge 2.D.4</b> ]	



Chemical Reactions		
Representing Chemical Reactions; Molecular, Ionic, Net Ionic Equations	<p><b>Learning objective 3.1</b> Students can translate among macroscopic observations of change, chemical equations, and particle views. [See <b>SP 1.5, 7.1; Essential knowledge components of 3.A–3.C</b>]</p>	
	<p><b>Learning objective 3.2</b> The student can translate an observed chemical change into a balanced chemical equation and justify the choice of equation type (molecular, ionic, or net ionic) in terms of utility for the given circumstances. [See <b>SP 1.5, 7.1; Essential knowledge 3.A.1</b>]</p>	
Stoichiometry and Limiting Reactants	<p><b>Learning objective 3.3</b> The student is able to use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results. [See <b>SP 2.2, 5.1; Essential knowledge 3.A.2</b>]</p>	
	<p><b>Learning objective 3.4</b> The student is able to relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion. [See <b>SP 2.2, 5.1, 6.4; Essential knowledge 3.A.2</b>]</p>	
LAB: Laws of Conservation of Matter and Definite Proportions	<p><b>Learning objective 3.5</b> The student is able to design a plan in order to collect data on the synthesis or decomposition of a compound to confirm the conservation of matter and the law of definite proportions. [See <b>SP 2.1, 4.2, 6.4; Essential knowledge 3.B.1</b>]</p>	
	<p><b>Learning objective 3.6</b> The student is able to use data from synthesis or decomposition of a compound to confirm the conservation of matter and the law of definite proportions. [See <b>SP 2.2, 6.1; Essential knowledge 3.B.1</b>]</p>	
Identifying Acid-Base and Redox Reactions	<p><b>Learning objective 3.7</b> The student is able to identify compounds as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, using proton-transfer reactions to justify the identification. [See <b>SP 6.1; Essential knowledge 3.B.2</b>]</p>	
	<p><b>Learning objective 3.8</b> The student is able to identify redox reactions and justify the identification in terms of electron transfer. [See <b>SP 6.1; Essential knowledge 3.B.3</b>]</p>	
LAB: Redox Titration	<p><b>Learning objective 3.9</b> The student is able to design and/or interpret the results of an experiment involving a redox titration. [See <b>SP 4.2, 5.1; Essential knowledge 3.B.3</b>]</p>	

Physical vs. Chemical Changes	<p><b>Learning objective 3.10</b> The student is able to evaluate the classification of a process as a physical change, chemical change, or ambiguous change based on both macroscopic observations and the distinction between rearrangement of covalent interactions and noncovalent interactions. [See <b>SP 1.4, 6.1; Essential knowledge 3.C.1</b>, connects to <b>5.D.2</b>]</p>	
Energy Changes in Reactions	<p><b>Learning objective 3.11</b> The student is able to interpret observations regarding macroscopic energy changes associated with a reaction or process to generate a relevant symbolic and/or graphical representation of the energy changes. [See <b>SP 1.5, 4.4; Essential knowledge 3.C.2</b>]</p>	
Electrochemistry: Galvanic and Electrolytic	<p><b>Learning objective 3.12</b> The student can make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faraday's laws. [See <b>SP 2.2, 2.3, 6.4; Essential knowledge 3.C.3</b>]</p>	
	<p><b>Learning objective 3.13</b> The student can analyze data regarding galvanic or electrolytic cells to identify properties of the underlying redox reactions. [See <b>SP 5.1; Essential knowledge 3.C.3</b>]</p>	



## Big Idea 4: Kinetics

### Learning Objective Check List

Kinetics		
Lab: Factors Affecting Rate	<b>Learning objective 4.1</b> The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., temperature, concentration, surface area) that may influence the rate of a reaction. [See SP 4.2, 5.1; <b>Essential knowledge 4.A.1</b> ]	
Rate Laws	<b>Learning objective 4.2</b> The student is able to analyze concentration vs. time data to determine the rate law for a zeroth-, first-, or second-order reaction. [See SP 5.1; <b>Essential knowledge 4.A.2</b> , <i>connects to 4.A.3</i> ]	
Half Life	<b>Learning objective 4.3</b> The student is able to connect the half-life of a reaction to the rate constant of a first-order reaction and justify the use of this relation in terms of the reaction being a first-order reaction. [See SP 2.1, 2.2; <b>Essential knowledge 4.A.3</b> ]	
Collision Theory	<b>Learning objective 4.4</b> The student is able to connect the rate law for an elementary reaction to the frequency and success of molecular collisions, including connecting the frequency and success to the order and rate constant, respectively. [See SP 7.1; <b>Essential knowledge 4.B.1</b> , <i>connects to 4.A.3, 4.B.2</i> ]	
	<b>Learning objective 4.5</b> The student is able to explain the difference between collisions that convert reactants to products and those that do not in terms of energy distributions and molecular orientation. [See SP 6.2; <b>Essential knowledge 4.B.2</b> ]	
Energy Profile Graphs	<b>Learning objective 4.6</b> The student is able to use representations of the energy profile for an elementary reaction (from the reactants, through the transition state, to the products) to make qualitative predictions regarding the relative temperature dependence of the reaction rate. [See SP 1.4, 6.4; <b>Essential knowledge 4.B.3</b> ]	
	<b>Learning objective 4.8</b> The student can translate among reaction energy profile representations, particulate representations, and symbolic representations (chemical equations) of a chemical reaction occurring in the presence and absence of a catalyst. [See SP 1.5; <b>Essential knowledge 4.D.1</b> ]	
Mechanisms	<b>Learning objective 4.7</b> The student is able to evaluate alternative explanations, as expressed by reaction mechanisms, to determine which are consistent with data regarding the overall rate of a reaction, and data that can be used to infer the presence of a reaction intermediate. [See SP 6.5; <i>connects to</i> <b>Essential knowledge 4.C.1, 4.C.2, 4.C.3</b> ]	
Catalysts	<b>Learning objective 4.9</b> The student is able to explain changes in reaction rates arising from the use of acid-base catalysts, surface catalysts, or enzyme catalysts, including selecting appropriate mechanisms with or without the catalyst present. [See SP 6.2, 7.2; <b>Essential knowledge 4.D.2</b> ]	



## Big Idea 5: Thermochemistry & Thermodynamics

### Learning Objective Check List

Thermochemistry	
Graphical Representations	<b>Learning objective 5.1</b> The student is able to create or use graphical representations in order to connect the dependence of potential energy to the distance between atoms and factors, such as bond order (for covalent interactions) and polarity (for intermolecular interactions), which influence the interaction strength. [See <b>SP 1.1, 1.4, 7.2</b> , connects to <b>Big Idea 2</b> ; <b>Essential knowledge components of 5.A-5.E</b> ]
Temperature and Energy Transfers	<b>Learning objective 5.2</b> The student is able to relate temperature to the motions of particles, either via particulate representations, such as drawings of particles with arrows indicating velocities, and/or via representations of average kinetic energy and distribution of kinetic energies of the particles, such as plots of the Maxwell-Boltzmann distribution. [See <b>SP 1.1, 1.4, 7.1</b> ; <b>Essential knowledge 5.A.1</b> ]
	<b>Learning objective 5.3</b> The student can generate explanations or make predictions about the transfer of thermal energy between systems based on this transfer being due to a kinetic energy transfer between systems arising from molecular collisions. [See <b>SP 7.1</b> ; <b>Essential knowledge 5.A.2</b> ]
Conservation of Energy	<b>Learning objective 5.4</b> The student is able to use conservation of energy to relate the magnitudes of the energy changes occurring in two or more interacting systems, including identification of the systems, the type (heat versus work), or the direction of energy flow. [See <b>SP 1.4, 2.2</b> , connects to <b>Essential knowledge 5.B.1, 5.B.2</b> ]
	<b>Learning objective 5.5</b> The student is able to use conservation of energy to relate the magnitudes of the energy changes when two nonreacting substances are mixed or brought into contact with one another. [See <b>SP 2.2</b> , connects to <b>Essential knowledge 5.B.1, 5.B.2</b> ]
Calorimetry Calculations	<b>Learning objective 5.6</b> The student is able to use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to $P\Delta V$ work. [See <b>SP 2.2, 2.3</b> ; <b>Essential knowledge 5.B.3</b> ]
LAB: Calorimetry	<b>Learning objective 5.7</b> The student is able to design and/or interpret the results of an experiment in which calorimetry is used to determine the change in enthalpy of a chemical process (heating/cooling, phase transition, or chemical reaction) at constant pressure. [See <b>SP 4.2, 5.1</b> ; <b>Essential knowledge 5.B.4</b> ]
Enthalpy and Bond Energies	<b>Learning objective 5.8</b> The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds. [See <b>SP 2.3, 7.1, 7.2</b> ; <b>Essential knowledge 5.C.2</b> ]
Intramolecular and Intermolecular Forces	<b>Learning objective 5.9</b> The student is able to make claims and/or predictions regarding relative magnitudes of the forces acting within collections of interacting molecules based on the distribution of electrons within the molecules and the types of intermolecular forces through which the molecules interact. [See <b>SP 6.4</b> ; <b>Essential knowledge 5.D.1</b> ]
	<b>Learning objective 5.10</b> The student can support the claim about whether a process is a chemical or physical change (or may be classified as both) based on whether the process involves changes in intramolecular versus intermolecular interactions. [See <b>SP 5.1</b> ; <b>Essential knowledge 5.D.2</b> ]
	<b>Learning objective 5.11</b> The student is able to identify the noncovalent interactions within and between large molecules, and/or connect the shape and function of the large molecule to the presence and magnitude of these interactions. [See <b>SP 7.2</b> ; <b>Essential knowledge 5.D.3</b> ]

## Thermodynamics

<b><math>\Delta H^\circ</math>; <math>\Delta S^\circ</math>; <math>\Delta G^\circ</math>; Coupled Reactions</b>	<p><b>Learning objective 5.12</b> The student is able to use representations and models to predict the sign and relative magnitude of the entropy change associated with chemical or physical processes. [See <b>SP 1.4; Essential knowledge 5.E.1</b>]</p>	
	<p><b>Learning objective 5.13</b> The student is able to predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both <math>\Delta H^\circ</math> and <math>\Delta S^\circ</math>, and calculation or estimation of <math>\Delta G^\circ</math> when needed. [See <b>SP 2.2, 2.3, 6.4; Essential knowledge 5.E.2, connects to 5.E.3</b>]</p>	
	<p><b>Learning objective 5.14</b> The student is able to determine whether a chemical or physical process is thermodynamically favorable by calculating the change in standard Gibbs free energy. [See <b>SP 2.2; Essential knowledge 5.E.3, connects to 5.E.2</b>]</p>	
	<p><b>Learning objective 5.15</b> The student is able to explain how the application of external energy sources or the coupling of favorable with unfavorable reactions can be used to cause processes that are not thermodynamically favorable to become favorable. [See <b>SP 6.2; Essential knowledge 5.E.4</b>]</p>	
<b>Connections to Equilibrium and Kinetics</b>	<p><b>Learning objective 5.16</b> The student can use LeChatelier's principle to make qualitative predictions for systems in which coupled reactions that share a common intermediate drive formation of a product. [See <b>SP 6.4; Essential knowledge 5.E.4, connects to 6.B.1</b>]</p>	
	<p><b>Learning objective 5.17</b> The student can make quantitative predictions for systems involving coupled reactions that share a common intermediate, based on the equilibrium constant for the combined reaction. [See <b>SP 6.4; Essential knowledge 5.E.4, connects to 6.A.2</b>]</p>	
	<p><b>Learning objective 5.18</b> The student can explain why a thermodynamically favored chemical reaction may not produce large amounts of product (based on consideration of both initial conditions and kinetic effects), or why a thermodynamically unfavored chemical reaction can produce large amounts of product for certain sets of initial conditions. [See <b>SP 1.3, 7.2; Essential knowledge 5.E.5, connects to 6.D.1</b>]</p>	

## Big Idea 6: Equilibrium

### Learning Objective Check List

General Equilibrium		
Equilibrium Concept	<p><b>Learning objective 6.1</b> The student is able to, given a set of experimental observations regarding physical, chemical, biological, or environmental processes that are reversible, construct an explanation that connects the observations to the reversibility of the underlying chemical reactions or processes. [See <b>SP 6.2; Essential knowledge 6.A.1</b>]</p>	
	<p><b>Learning objective 6.2</b> The student can, given a manipulation of a chemical reaction or set of reactions (e.g., reversal of reaction or addition of two reactions), determine the effects of that manipulation on <math>Q</math> or <math>K</math>. [See <b>SP 2.2; Essential knowledge 6.A.2</b>]</p>	
	<p><b>Learning objective 6.3</b> The student can connect kinetics to equilibrium by using reasoning about equilibrium, such as LeChatelier's principle, to infer the relative rates of the forward and reverse reactions. [See <b>SP 7.2; Essential knowledge 6.A.3</b>]</p>	
Calculating and Interpreting Equilibrium Constants	<p><b>Learning objective 6.4</b> The student can, given a set of initial conditions (concentrations or partial pressures) and the equilibrium constant, <math>K</math>, use the tendency of <math>Q</math> to approach <math>K</math> to predict and justify the prediction as to whether the reaction will proceed toward products or reactants as equilibrium is approached. [See <b>SP 2.2, 6.4; Essential knowledge 6.A.3</b>]</p>	
	<p><b>Learning objective 6.5</b> The student can, given data (tabular, graphical, etc.) from which the state of a system at equilibrium can be obtained, calculate the equilibrium constant, <math>K</math>. [See <b>SP 2.2; Essential knowledge 6.A.3</b>]</p>	
	<p><b>Learning objective 6.6</b> The student can, given a set of initial conditions (concentrations or partial pressures) and the equilibrium constant, <math>K</math>, use stoichiometric relationships and the law of mass action (<math>Q</math> equals <math>K</math> at equilibrium) to determine qualitatively and/or quantitatively the conditions at equilibrium for a system involving a single reversible reaction. [See <b>SP 2.2, 6.4; Essential knowledge 6.A.3</b>]</p>	
	<p><b>Learning objective 6.7</b> The student is able, for a reversible reaction that has a large or small <math>K</math>, to determine which chemical species will have very large versus very small concentrations at equilibrium. [See <b>SP 2.2, 2.3; Essential knowledge 6.A.4</b>]</p>	
LeChatelier's Principle	<p><b>Learning objective 6.8</b> The student is able to use LeChatelier's principle to predict the direction of the shift resulting from various possible stresses on a system at chemical equilibrium. [See <b>SP 1.4, 6.4; Essential knowledge 6.B.1</b>]</p>	
	<p><b>Learning objective 6.9</b> The student is able to use LeChatelier's principle to design a set of conditions that will optimize a desired outcome, such as product yield. [See <b>SP 4.2; Essential knowledge 6.B.1</b>]</p>	
	<p><b>Learning objective 6.10</b> The student is able to connect LeChatelier's principle to the comparison of <math>Q</math> to <math>K</math> by explaining the effects of the stress on <math>Q</math> and <math>K</math>. [See <b>SP 1.4, 7.2; Essential knowledge 6.B.2</b>]</p>	

Acid Base Equilibrium		
Acid-Base Concept; Strong vs. Weak	<b>Learning objective 6.11</b> The student can generate or use a particulate representation of an acid (strong or weak or polyprotic) and a strong base to explain the species that will have large versus small concentrations at equilibrium. [See <b>SP 1.1, 1.4, 2.3; Essential knowledge 6.C.1</b> ]	
	<b>Learning objective 6.12</b> The student can reason about the distinction between strong and weak acid solutions with similar values of pH, including the percent ionization of the acids, the concentrations needed to achieve the same pH, and the amount of base needed to reach the equivalence point in a titration. [See <b>SP 1.4; Essential knowledge 6.C.1, connects to 1.E.2</b> ]	
Titration	<b>Learning objective 6.13</b> The student can interpret titration data for monoprotic or polyprotic acids involving titration of a weak or strong acid by a strong base (or a weak or strong base by a strong acid) to determine the concentration of the titrant and the $pK_a$ for a weak acid, or the $pK_b$ for a weak base. [See <b>SP 5.1; Essential knowledge 6.C.1, connects to 1.E.2</b> ]	
pH Concept and Calculations	<b>Learning objective 6.14</b> The student can, based on the dependence of $K_w$ on temperature, reason that neutrality requires $[H^+] = [OH^-]$ as opposed to requiring $pH = 7$ , including especially the applications to biological systems. [See <b>SP 2.2, 6.2; Essential knowledge 6.C.1</b> ]	
	<b>Learning objective 6.15</b> The student can identify a given solution as containing a mixture of strong acids and/or bases and calculate or estimate the pH (and concentrations of all chemical species) in the resulting solution. [See <b>SP 2.2, 2.3, 6.4; Essential knowledge 6.C.1</b> ]	
	<b>Learning objective 6.16</b> The student can identify a given solution as being the solution of a monoprotic weak acid or base (including salts in which one ion is a weak acid or base), calculate the pH and concentration of all species in the solution, and/or infer the relative strengths of the weak acids or bases from given equilibrium concentrations. [See <b>SP 2.2, 6.4; Essential knowledge 6.C.1</b> ]	
Equilibrium Mixtures	<b>Learning objective 6.17</b> The student can, given an arbitrary mixture of weak and strong acids and bases (including polyprotic systems), determine which species will react strongly with one another (i.e., with $K > 1$ ) and what species will be present in large concentrations at equilibrium. [See <b>SP 6.4; Essential knowledge 6.C.1</b> ]	
Buffers		
Buffer pH and Capacity	<b>Learning objective 6.18</b> The student can design a buffer solution with a target pH and buffer capacity by selecting an appropriate conjugate acid-base pair and estimating the concentrations needed to achieve the desired capacity. [See <b>SP 2.3, 4.2, 6.4; Essential knowledge 6.C.2</b> ]	
pH and $pK_a$ of weak acids	<b>Learning objective 6.19</b> The student can relate the predominant form of a chemical species involving a labile proton (i.e., protonated/deprotonated form of a weak acid) to the pH of a solution and the $pK_a$ associated with the labile proton. [See <b>SP 2.3, 5.1, 6.4; Essential knowledge 6.C.2</b> ]	
Buffer Mechanisms	<b>Learning objective 6.20</b> The student can identify a solution as being a buffer solution and explain the buffer mechanism in terms of the reactions that would occur on addition of acid or base. [See <b>SP 6.4; Essential knowledge 6.C.2</b> ]	

## Solubility Equilibria

<b>K<sub>sp</sub> Concept</b>	<b>Learning objective 6.21</b> The student can predict the solubility of a salt, or rank the solubility of salts, given the relevant $K_{sp}$ values. [See <b>SP 2.2, 2.3, 6.4; Essential knowledge 6.C.3</b> ]	
	<b>Learning objective 6.22</b> The student can interpret data regarding solubility of salts to determine, or rank, the relevant $K_{sp}$ values. [See <b>SP 2.2, 2.3, 6.4; Essential knowledge 6.C.3</b> ]	
<b>Common Ions</b>	<b>Learning objective 6.23</b> The student can interpret data regarding the relative solubility of salts in terms of factors (common ions, pH) that influence the solubility. [See <b>SP 5.1; Essential knowledge 6.C.3</b> ]	
<b>Connections to Thermodynamics</b>		
<b>Heat of Solution</b>	<b>Learning objective 6.24</b> The student can analyze the enthalpic and entropic changes associated with the dissolution of a salt, using particulate level interactions and representations. [See <b>SP 1.4, 7.1; Essential knowledge 6.C.3, connects to 5.E</b> ]	
<b>Relating K to <math>\Delta G^\circ</math></b>	<b>Learning objective 6.25</b> The student is able to express the equilibrium constant in terms of $\Delta G^\circ$ and $RT$ and use this relationship to estimate the magnitude of $K$ and, consequently, the thermodynamic favorability of the process. [See <b>SP 2.3; Essential knowledge 6.D.1</b> ]	