Fairfield Public Schools
Science Curriculum

Draft
Advanced Placement Chemistry
March 13, 2018

FAIRFIELD
PUBLIC SCHOOLS

AP Chemistry: Description

AP Chemistry is an introductory college-level chemistry course. Students cultivate their understanding of chemistry through inquiry-based investigations as they explore the following topics: matter, structure and arrangement of atoms, forces between atoms and molecules, changes in matter involving electrons, chemical reaction rates, thermodynamics, and bonding.

Standards for this course are taken from the *College Board Advanced Placement Chemistry course description* and are of three types:
Science Practices: The science practices enable students to establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena.

Big Ideas: The key concepts and related content that define the revised AP Biology course and exam are organized around a few underlying principles called the big ideas, which encompass the core scientific principles, theories and processes governing living organisms and biological systems.

Learning Objectives: Learning objectives provide clear and detailed articulation of what students should know and be able to do. Each learning objective is designed to help teachers integrate science practices with specific content, and to provide them with clear information about how students will be expected to demonstrate their knowledge and abilities.

AP Chemistry

Enduring Understandings

- All matter is made of atoms. There are a limited number of types of atoms; these are the elements.
- The atoms of each element have unique structures arising from interactions between electrons and nuclei.
- Elements display periodicity in their properties when the elements are organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of atoms. Periodicity is a useful principle for understanding properties and predicting trends in properties. Its modern-day uses range from examining the composition of materials to generating ideas for designing new materials.
- Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms
- Atoms are conserved in physical and chemical processes.
- Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.
- Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.
- The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
- The type of bonding in the solid state can be deduced from the properties of the solid state.
- Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.
- Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other. Classes of chemical reactions include synthesis, decomposition, acid-base, and oxidation-reduction reactions.
- Chemical and physical transformations may be observed in several ways and typically involve a change in energy.
- Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.
- Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.
- Many reactions proceed via a series of elementary reactions.
- Reaction rates may be increased by the presence of a catalyst.
- Two systems with different temperatures that are in thermal contact will exchange energy. The quantity of thermal energy transferred from one system to another is called heat.
- Energy is neither created nor destroyed, but only transformed from one form to another.

- Breaking bonds requires energy, and making bonds releases energy.
- Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.
- Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.
- Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.
- Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.
- Chemical equilibrium plays an important role in acid-base chemistry and in solubility.
- The equilibrium constant is related to temperature and the difference in Gibbs free energy between reactants and products.

Course Essential Questions

- How can all matter be understood in terms of arrangement of atoms, and how do these atoms retain their identity in chemical reactions?
- How can chemical and physical properties of materials be explained by the structure and arrangement of atoms, ions, or molecules and the forces between them?
- How do the rearrangement and/or reorganization of atoms and/or the transfer of electrons cause changes in matter?
- How are rates of chemical reactions determined by details of the molecular collisions?
- How do the laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter?
- How are the processes of bond forming and breaking in dynamic competition that are sensitive to initial conditions and external perturbations?

Course: Year-at-a Glance

Unit	Title	Unit Essential Questions (Enduring Understandings)
1	Atomic Structure	• What evidence do we have that the atoms of each element have unique structures arising from interactions between electrons and nuclei? • What is periodicity and why does it exist? • How do we use models to explain experimental data we collect about atoms? • What evidence do we have for the conservation of matter?
2	Chemical Bonding	• What determines the physical properties of different substances? • How do forces of attraction between particles determine how a substance behaves? • Why and how do substances bond?
3	Chemical Reactions	• How are chemical changes represented using models? • What is the role of stoichiometry in real world applications? • Why are there different types of chemical reactions? • What evidence do we have that a chemical reaction has occurred?
4	Kinetics	• Why do different factors influence the rate of chemical reactions? • What role do collisions play in reaction rates? • Do chemical reactions happen all at once or are there steps? • How do catalysts affect chemical reactions?
5	Thermodynamics	• Why and how does energy move? • Why is the total amount of energy in a closed system constant? • How are chemical processes distinguished from physical processes? • What influences thermodynamic processes?
6	Equilibrium	• What factors affect chemical equilibrium? • How can the relative strengths of acids and bases be determined given equilibrium concentrations? • What factors affect the equilibrium constant of a chemical reaction?

AP Science Practices

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
1.1 The student can create representations and models of natural or manmade phenomena and systems in the domain.
1.2 The student can describe representations and models of natural or manmade phenomena and systems in the domain.
1.3 The student can refine representations and models of natural or manmade phenomena and systems in the domain.
1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain.
Science Practice 2: The student can use mathematics appropriately
2.1 The student can justify the selection of a mathematical routine to solve problems.
2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
2.3 The student can estimate numerically quantities that describe natural phenomena.
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.
3.1 The student can pose scientific questions.
3.2 The student can refine scientific questions.
3.3 The student can evaluate scientific questions.
Science Practice 4: The student can plan and implement data collection strategies appropriate to a particular scientific question.
4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question.
4.2 The student can design a plan for collecting data to answer a particular scientific question.
4.3 The student can collect data to answer a particular scientific question.
4.4 The student can evaluate sources of data to answer a particular scientific question
Science Practice 5: The student can perform data analysis and evaluation of evidence.
5.1 The student can analyze data to identify patterns or relationships.
5.2 The student can refine observations and measurements based on data analysis.
5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question.
Science Practice 6: The student can work with scientific explanations and theories.
6.1 The student can justify claims with evidence.
6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
6.3 The student can articulate the reasons that scientific explanations and theories are refined or replaced.
6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
6.5 The student can evaluate alternative scientific explanations.
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.
7.1 The student can connect phenomena and models across spatial and temporal scales.
7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

Unit 1: Atomic Structure

Overview

The chemical elements are fundamental building materials of matter, and all matter can be understood in terms of arrangements of atoms. These atoms retain their identity in chemical reactions.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why: (Essential Knowledge)

- All matter is made of atoms. There are a limited number of types of atoms; these are the elements.
- The atoms of each element have unique structures arising from interactions between electrons and nuclei.
- Elements display periodicity in their properties when the elements are organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of atoms. Periodicity is a useful principle for understanding properties and predicting trends in properties. Its modern-day uses range from examining the composition of materials to generating ideas for designing new materials.
- Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.
- Atoms are conserved in physical and chemical processes.

Unit Essential Questions

- What evidence do we have that the atoms of each element have unique structures arising from interactions between electrons and nuclei?
- What is periodicity and why does it exist?
- How do we use models to explain experimental data we collect about atoms?
- What evidence do we have for the conservation of matter?

College Board Unit Standards

BIG IDEA:

Big Idea 1: The chemical elements are fundamental building materials of matter, all matter can be understood in terms of arrangements of atoms. These atoms retain their identity in chemical reactions.

LEARNING OBJECTIVES:

LO 1.1 The students 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 SP 6.1]

LO 1.2 The students is able to select and apply mathematical routines to mass data to identify or infer the composition of pure substances and/or mixtures. [See SP 2.2]

LO 1.3 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 SP 2.2, 6.1]

LO 1.4 The student is able to connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively [See SP 7.1]

LO 1.5 The student is able to explain the distribution of electrons in an atom or ion based upon data. **[**See SP 1.5, 6.2]

LO 1.6 The student is able to analyze data relating to electron energies for patterns and relationships [See SP 5.1]

LO 1.7 The students 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 SP 5.1, 6.2]

LO 1.8 The student is able to explain the distribution of electrons using Coulomb's law to analyze measured energies [See SP 6.2]

LO 1.9 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 SP 6.4]

LO 1.10 Students can justify with evidence the arrangement of the periodic table and can apply periodic properties to chemical reactivity. [See SP 6.1]

LO 1.11 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 SP 3.1, 5.1]

LO 1.12 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 with the quantum mechanical model. [See SP 6.3]

LO 1.13 Given information about a particular model of the atom, the student is able to determine if the model is consistent with specified evidence. [See SP 5.3]

LO 1.14 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 SP 1.4, 1.5]

LO 1.15 The student can justify the selection of a particular type of spectroscopy to measure properties associated with vibrational or electronic motions of molecules. [See SP 4.1, 6.4]

LO 1.16 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 SP 4.2, 5.1]

LO 1.17 The student is able to express the law of conservation of mass quantitatively and qualitatively using symbolic representations and particulate drawings. [See SP 1.5]

LO 1.18 The student is able to apply conservation of atoms to the rearrangement of atoms in various processes. **[**See SP 1.4]

LO 1.19 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 SP 4.2, 5.1, 6.4]
LO 1.20 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 SP 4.2, 5.1, 6.4]

Unit 2: Chemical Bonding

Overview

Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.
- Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.
- The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
- The type of bonding in the solid state can be deduced from the properties of the solid state.

Unit Essential Questions

- What determines the physical properties of different substances?
- How do forces of attraction between particles determine how a substance behaves?
- Why and how do substances bond?

College Board Unit Standards

BIG IDEA:
Big Idea 2: Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.

LEARNING OBJECTIVES:
LO 2.1 Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on

particle views. **[**See SP 6.4,7.1]

LO 2.2 The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. **[**See SP 7.2]

LO 2.3 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 SP 6.4, 7.1]

LO 2.4 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 SP 1.4, 6.4]

LO 2.5 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 SP 1.3, 6.4, 7.2]

LO 2.6 The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [See SP 2.2, 2.3]

LO 2.7 The student is able to explain how solutes can be separated by chromatography based on intermolecular interactions. [See SP 6.2]

LO 2.8 The student can draw and/or interpret representations of solutions that show the interactions between the solute and solvent. [See SP 1.1, 1.2, 6.4]

LO 2.9 The student is able to create or interpret representations that link the concept of molarity with particle views of solutions. [See SP 1.1, 1.4]

LO 2.10 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 SP 4.2, 5.1, 6.4]

LO 2.11 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 SP 6.2, 6.4]

LO 2.12 The student can qualitatively analyze data regarding real gases to identify deviations from ideal behavior and relate these to molecular interactions. [See SP 5.1, 6.5]

LO 2.13 The student is able to describe the relationships between the structural features of polar molecules and the forces of attraction between the particles. **[**See SP 1.4, 6.4]

LO 2.14 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 SP 1.4, 6.4]

LO 2.15 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 SP 1.4, 6.2]

LO 2.16 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 SP 6.2]

LO 2.17 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 SP 6.4]

LO 2.18 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 SP 6.1]

LO 2.19 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 SP 1.1, 1.4, 7.1]

LO 2.20 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 SP 6.2, 7.1]
LO 2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4]
LO 2.22 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 SP 4.2, 6.2]
LO 2.23 The student can create a representation of an ionic solid that shows essential characteristics of the structure and interactions present in the substance. **[**See SP 1.1]
LO 2.24 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 SP 1.1, 6.2, 7.1]
LO 2.25 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 SP 1.4, 7.2]
LO 2.26 Students can use the electron sea model of metallic bonding to predict or make claims about the macroscopic properties of metals or alloys. **[**See SP 6.4, 7.1]
LO 2.27 The student can create a representation of a metallic solid that shows essential characteristics of the structure and interactions present in the substance. **[**See SP 1.1]
LO 2.28 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 SP 1.1, 6.2, 7.1]
LO 2.29 The student can create a representation of a covalent solid that shows essential characteristics of the structure and interactions present in the substance. **[**See SP 1.1]
LO 2.30 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 SP 1.1, 6.2, 7.1]
LO 2.31 The student can create a representation of a molecular solid that shows essential characteristics of the structure and interactions present in the substance. **[**See SP 1.1]
LO 2.32 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 SP 1.1, 6.2, 7.1]

Unit 3: Chemical Reactions

Overview

Changes in matter involve the rearrangement and/or organization of atoms and/or the transfer of electrons.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.
- Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other. Classes of chemical reactions include synthesis, decomposition, acid-base, and oxidation-reduction reactions.
- Chemical and physical transformations may be observed in several ways and typically involve a change in energy.

Unit Essential Questions

- How are chemical changes represented using models?
- What is the role of stoichiometry in real world applications?
- Why are there different types of chemical reactions?
- What evidence do we have that a chemical reaction has occurred?

College Board Unit Standards

LO 3.1 Students can translate among macroscopic observations of change, chemical equations, and particle views. [See SP 1.5, 1.7]
LO 3.2 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 SP 1.5, 1.7]
LO 3.3 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 SP 2.2, 5.1]
LO 3.4 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 SP 2.2, 5.1, 6.4]
LO 3.5 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 SP 2.1, 4.2, 6.4]
LO 3.6 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 SP 2.2, 6.1]
LO 3.7 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 SP 6.1]
LO 3.8 The student is able to identify redox reactions and justify the identification in terms of electron transfer. **[**See SP 6.1]
LO 3.9 The student is able to design and/or interpret the results of an experiment involving a redox titration. [See SP 4.2, 5.1]
LO 3.10 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 SP 1.4, 6.1]
LO 3.11 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 SP 1.5, 4.4]
LO 3.12 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 SP 2.2, 2.3, 6.4]
LO 3.13 The student can analyze data regarding galvanic or electrolytic cells to identify properties of the underlying redox reactions. [See SP 5.1]

Unit 4: Kinetics

Overview

Rates of chemical reactions are determined by the details of the molecular collisions.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.
- Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.
- Many reactions proceed via a series of elementary reactions.
- Reaction rates may be increased by the presence of a catalyst.

Unit Essential Questions

- Why do different factors influence the rate of chemical reactions?
- What role do collisions play in reaction rates?
- Do chemical reactions happen all at once or are there steps?
- How do catalysts affect chemical reactions?

College Board Unit Standards

LO 4.1 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]

LO 4.2 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]

LO 4.3 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]

LO 4.4 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]

LO 4.5 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]
LO 4.6 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]
LO 4.7 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]
LO 4.8 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]
LO 4.9 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]

Unit 5: Thermodynamics

Overview

The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Two systems with different temperatures that are in thermal contact will exchange energy. The quantity of thermal energy transferred from one system to another is called heat.
- Energy is neither created nor destroyed, but only transformed from one form to another.
- Breaking bonds requires energy, and making bonds releases energy.
- Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.
- Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.

Unit Essential Questions

- Why and how does energy move?
- Why is the total amount of energy in a closed system constant?
- How are chemical processes distinguished from physical processes?
- What influences thermodynamic processes?

College Board Unit Standards

LO 5.1 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 SP 1.1, 1.4, 7.2,]
LO 5.2 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 SP 1.1, 1.4, 7.1]
LO 5.3 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 SP 7.1]
LO 5.4 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 SP 1.4, 2.2]
LO 5.5 The student is able to use conservation of energy to relate the magnitudes of the energy changes when two non-reacting substances are mixed or brought into contact with one another. [See SP 2.2]
LO 5.6 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 SP 2.2, 2.3]
LO 5.7 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 SP 4.2, 5.1]
LO 5.8 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 SP 2.3, 7.1, 7.2]
LO 5.9 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 SP 6.4]
LO 5.10 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 SP 5.1]
LO 5.11 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 SP 7.2]
LO 5.12 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 SP 1.4]
LO 5.13 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 $\Delta H°$ and $\Delta S°$, and calculation or estimation of $\Delta G°$ when needed. [See SP 2.2, 2.3, 6.4]
LO 5.14 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 SP 2.2]
LO 5.15 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 SP 6.2]
LO 5.16 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 SP 6.4]
LO 5.17 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 SP 6.4]
LO 5.18 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 SP 1.3, 7.2]

Unit 6: Equilibrium

Overview

Any bond or intermolecular attraction that can be formed can be broken. These two processes are a dynamic competition sensitive to initial conditions and external perturbations.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.
- Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.
- Chemical equilibrium plays an important role in acid-base chemistry and in solubility.
- The equilibrium constant is related to temperature and the difference in Gibbs free energy between reactants and products.

Unit Essential Questions

- What factors affect chemical equilibrium?
- How can the relative strengths of acids and bases be determined given equilibrium concentrations?
- What factors affect the equilibrium constant of a chemical reaction?

College Board Unit Standards

LO 6.1 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 SP 6.2]

LO 6.2 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 Q or K. [See SP 2.2]

LO 6.3 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 SP 7.2]

LO 6.4 The student can, given a set of initial conditions (concentrations or partial pressures) and the equilibrium constant, K, use the tendency of Q to approach K to predict and justify the prediction as to whether the reaction will proceed toward products or reactants as equilibrium is approached. [See SP 2.2, 6.4]

LO 6.5 The student can, given data (tabular, graphical, etc.) from which the state of a system at equilibrium can be obtained, calculate the equilibrium constant, K. [See SP 2.2; Essential knowledge 6.A.3]
LO 6.6 The student can, given a set of initial conditions (concentrations or partial pressures) and the equilibrium constant, K, use stoichiometric relationships and the law of mass action (Q equals K at equilibrium) to determine qualitatively and/or quantitatively the conditions at equilibrium for a system involving a single reversible reaction. [See SP 2.2, 6.4]
LO 6.7 The student is able, for a reversible reaction that has a large or small K, to determine which chemical species will have very large versus very small concentrations at equilibrium. [See SP 2.2, 2.3]
LO 6.8 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 SP 1.4, 6.4]
LO 6.9 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 SP 4.2]
LO 6.10 The student is able to connect LeChatelier's principle to the comparison of Q to K by explaining the effects of the stress on Q and K. [See SP 1.4, 7.2]
LO 6.11 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 SP 1.1, 1.4, 2.3]
LO 6.12 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 SP 1.4]
LO 6.13 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 pKa for a weak acid, or the pKb for a weak base. [See SP 5.1]
LO 6.14 The student can, based on the dependence of Kw on temperature, reason that neutrality requires [H+] = [OH–] as opposed to requiring pH = 7, including especially the applications to biological systems. [See SP 2.2, 6.2]
LO 6.15 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 SP 2.2, 2.3, 6.4]
LO 6.16 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 SP 2.2, 6.4]
LO 6.17 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 SP 6.4]
LO 6.18 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 SP 2.3, 4.2, 6.4]

LO 6.19 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 pKa associated with the labile proton. [See SP 2.3, 5.1, 6.4]
LO 6.20 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 SP 6.4]
LO 6.21 The student can predict the solubility of a salt, or rank the solubility of salts, given the relevant Ksp values. [See SP 2.2, 2.3, 6.4]
LO 6.22 The student can interpret data regarding solubility of salts to determine, or rank, the relevant Ksp values. [See SP 2.2, 2.3, 6.4]
LO 6.23 The student can interpret data regarding the relative solubility of salts in terms of factors (common ions, pH) that influence the solubility. [See SP 5.1]
LO 6.24 The student can analyze the enthalpic and entropic changes associated with the dissolution of a salt, using particulate level interactions and representations. [See SP 1.4, 7.1]
LO 6.25 The student is able to express the equilibrium constant in terms of $\Delta G°$ and RT and use this relationship to estimate the magnitude of K and, consequently, the thermodynamic favorability of the process. [See SP 2.3]