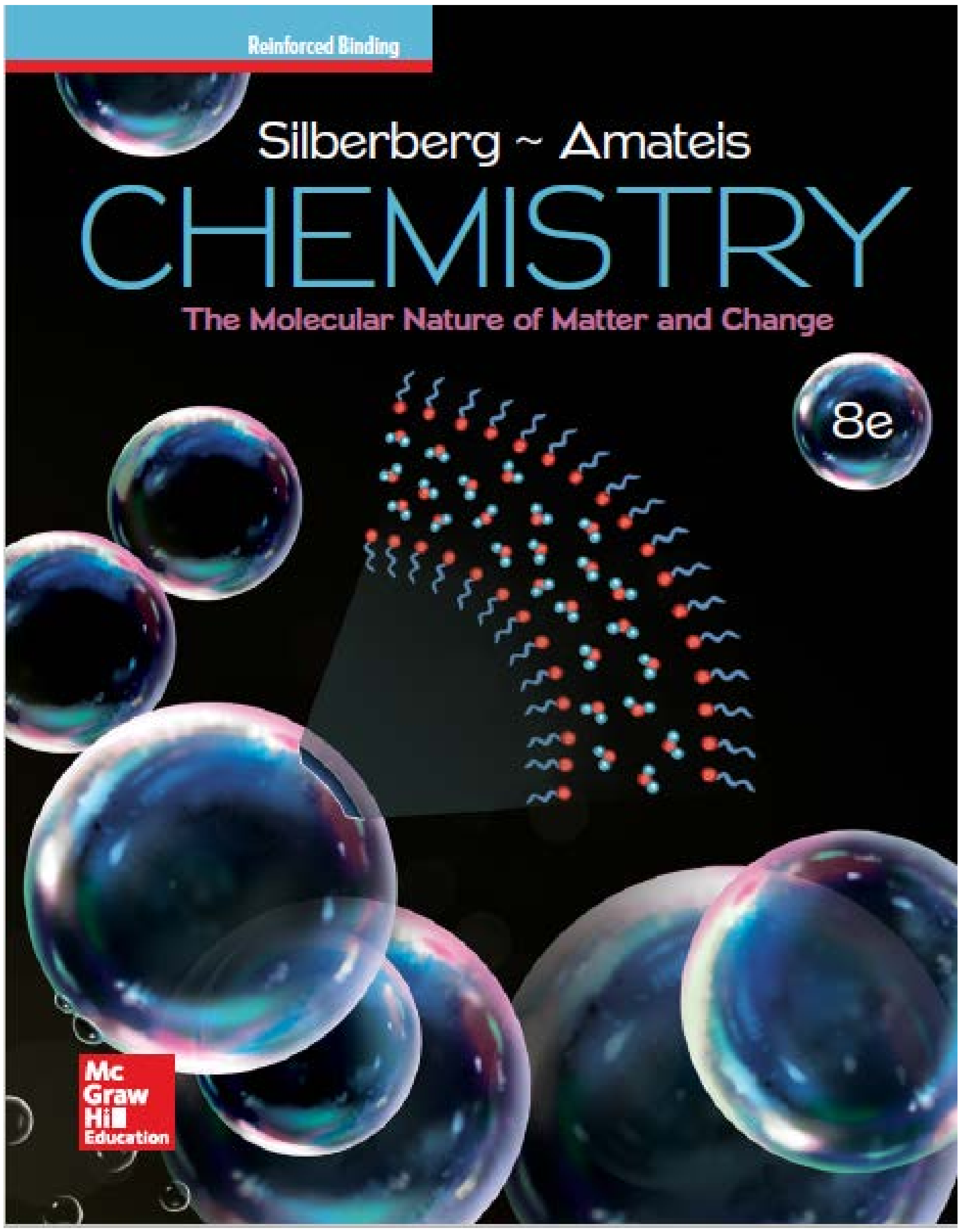
AP Chemistry

CORRELATION

for *Chemistry: The Molecular Nature of Matter and Change*



By Martin S. Silberberg & Patricia G. Amateis

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Big Idea 1: 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	
Enduring Understanding 1.A. All matter is made of atoms. There are a limited number of types of atoms; these are the elements.	
Essential Knowledge (EK) or Learning Objective (LO) (EK) 1.A.1. Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.	
Essential Knowledge Component	Reference
a. The average mass of any large number of atoms of a given element is always the same for a given element.	44
b. A pure sample contains particles (or units) of one specific atom or molecule; a mixture contains particles (or units) of more than one specific atom or molecule.	44-45
c. Because the molecules of a particular compound are always composed of the identical combination of atoms in a specific ratio, the ratio of the masses of the constituent elements in any pure sample of that compound is always the same.	44
d. Pairs of elements that form more than one type of molecule are nonetheless limited by their atomic nature to combine in whole number ratios. This discrete nature can be confirmed by calculating the difference in mass percent ratios between such types of molecules.	49-50

Big Idea 1: 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.	
Enduring Understanding 1.A. All matter is made of atoms. There are a limited number of types of atoms; these are the elements.	
Learning Objective	Reference
(LO) 1.1. 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 SP 6.1]**	44, 87 Concept Review Question 2.14-2.20

Big Idea 1: 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.	
Enduring Understanding 1.A. All matter is made of atoms. There are a limited number of types of atoms; these are the elements.	
Essential Knowledge 1.A.2. Chemical analysis provides a method for determining the relative number of atoms in a substance, which can be used to identify the substance or determine its purity.	
Essential Knowledge Component	Reference
a. Because compounds are composed of atoms with known masses, there is a correspondence between the mass percent of the elements in a	102-104

compound and the relative number of atoms of each element.	
b. An empirical formula is the lowest whole number ratio of atoms in a compound. Two molecules of the same elements with identical mass percent of their constituent atoms will have identical empirical formulas.	104-106
c. Because pure compounds have a specific mass percent of each element, experimental measurements of mass percents can be used to verify the purity of compounds.	106-109
Big Idea 1: 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.	
Enduring Understanding 1.A. All matter is made of atoms. There are a limited number of types of atoms; these are the elements.	
Learning Objective	**Reference**
(LO) 1.2. 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 SP 2.2]**	106-109; 137, Skill-Building Exercise 3.42
(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]**	102-104; 137, Problems in Context 3.48
Big Idea 1: 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.	
Enduring Understanding 1.A. All matter is made of atoms. There are a limited number of types of atoms; these are the elements.	
Essential Knowledge 1.A.3. The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.	
Essential Knowledge Component	**Reference**
a. Atoms and molecules interact with one another on the atomic level. Balanced chemical equations give the number of particles that react and the number of particles produced. Because of this, expressing the amount of a substance in terms of the number of particles, or moles of particles, is essential to understanding chemical processes.	95-102
b. Expressing the mass of an individual atom or molecule in atomic mass unit (amu) is useful because the average mass in amu of one particle (atom or molecule) of a substance will always be numerically equal to the molar mass of that substance in grams.	95-98
c. Avogadro's number provides the connection between the number of moles in a pure sample	95-96

of a substance and the number of constituent particles (or units) of that substance.	
d. Thus, for any sample of a pure substance, there is a specific numerical relationship between the molar mass of the substance, the mass of the sample, and the number of particles (or units) present.	95-102

Big Idea 1: 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.	
Enduring Understanding 1.A. All matter is made of atoms. There are a limited number of types of atoms; these are the elements.	
Learning Objective	**Reference**
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]**	95-102; 136, Problems in Context 3.25

Big Idea 1: 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.	
Enduring Understanding 1.B. The atoms of each element have unique structures arising from interactions between electrons and nuclei.	
Essential Knowledge 1.B.1. The atom is composed of negatively charged electrons, which can leave the atom, and a positively charged nucleus that is made of protons and neutrons. The attraction of the electrons to the nucleus is the basis of the structure of the atom. Coulomb's law is qualitatively useful for understanding the structure of the atom.	
Essential Knowledge Component	**Reference**
a. Based on Coulomb's law, the force between two charged particles is proportional to the magnitude of each of the two charges (q1 and q2), and inversely proportional to the square of the distance, r, between them. (Potential energy is proportional to q1q2/r. If the two charges are of opposite sign, the force between them is attractive; if they are of the same sign, the force is repulsive.	64-66
b. The first ionization energy is the minimum energy needed to remove the least tightly held electron from an atom or ion. In general, the ionization energy of any electron in an atom or ion is the minimum energy needed to remove that electron from the atom or ion.	348-350
c. The relative magnitude of the ionization energy can be estimated through qualitative application of Coulomb's law. The farther an electron is from the nucleus, the lower its ionization energy. When comparing two species with the same arrangement of electrons, the higher the nuclear charge, the higher the ionization energy of an electron in a given subshell.	348-350

d. Photoelectron spectroscopy (PES) provides a useful means to engage students in the use of quantum mechanics to interpret spectroscopic data and extract information on atomic structure from such data. In particular, low-resolution PES of atoms provides direct evidence for the shell model. Light consists of photons, each of which has energy E =hv , where h is Planck's constant and v is the frequency of the light. In the photoelectric effect, incident light ejects electrons from a material. This requires the photon to have sufficient energy to eject the electron. Photoelectron spectroscopy determines the energy needed to eject electrons from the material. Measurement of these energies provides a method to deduce the shell structure of an atom. The intensity of the photoelectron signal at a given energy is a measure of the number of electrons in that energy level.	WebQuest 1
e. The electronic structure of atoms with multiple electrons can be inferred from evidence provided by PES. For instance, both electrons in He are identical, and they are both roughly the same distance from the nucleus as in H, while there are two shells of electrons in Li, and the outermost electron is further from the nucleus than in H.	WebQuest 1
Big Idea 1: 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.	
Enduring Understanding 1.B. The atoms of each element have unique structures arising from interactions between electrons and nuclei.	
Learning Objective	Reference
(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]**	348-351; 364-365 Concept Review Questions 8.48
(LO) 1.6. The student is able to analyze data relating to electron energies for patterns and relationships. **[See SP 5.1]**	348-351; 365 Concept Review Question 8.55

Big Idea 1: 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.	
Enduring Understanding 1.B The atoms of each element have unique structures arising from interactions between electrons and nuclei.	
Essential Knowledge 1.B.2. The electronic structure of the atom can be described using an electron configuration that reflects the concept of electrons in quantized energy levels or shells; the energetics of the electrons in the atom can be understood by consideration of Coulomb's law.	
Essential Knowledge Component	**Reference**
a. Electron configurations provide a method for describing the distribution of electrons in an atom or ion.	335-345
b. Each electron in an atom has a different ionization energy, which can be qualitatively explained through Coulomb's law.	333
c. In multielectron atoms and ions, the electrons can be thought of as being in "shells" and "subshells," as indicated by the relatively close ionization energies associated with some groups of electrons. Inner electrons are called core electrons, and outer electrons are called valence electrons.	342
d. Core electrons are generally closer to the nucleus than valence electrons, and they are considered to "shield" the valence electrons from the full electrostatic attraction of the nucleus. This phenomenon can be used in conjunction with Coulomb's law to explain/rationalize/predict relative ionization energies. Differences in electron-electron repulsion are responsible for the differences in energy between electrons in different orbitals in the same shell.	333-334

Big Idea 1: 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.	
Enduring Understanding 1.B. The atoms of each element have unique structures arising from interactions between electrons and nuclei.	
Learning Outcomes	**Reference**
(LO) 1.7. 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 SP 5.1, 6.2]**	333-334; 348-351; 365, Concept Review Questions 8.49
(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]**	333; 350-351; 366, Comprehensive Problems 8.92

Big Idea 1: 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.	
Enduring Understanding 1.C. 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.	
Essential Knowledge 1.C.1. Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.	
Essential Knowledge Component	**Reference**
a. The structure of the periodic table is a consequence of the pattern of electron configurations and the presence of shells (and subshells) of electrons in atoms.	343-344
b. Ignoring the few exceptions, the electron configuration for an atom can be deduced from the element's position in the periodic table.	340-344
c. For many atomic properties, trends within the periodic table (and relative values for different atoms and ions) can be qualitatively understood and explained using Coulomb's law, the shell model, and the concept of shielding/effective nuclear charge. These properties include: 1. First ionization energy 2. Atomic and ionic radii 3. Electronegativity 4. Typical ionic charges	345-352
d. Periodicity is a useful tool when designing new molecules or materials, since replacing an element of one group with another of the same group may lead to a new substance with similar properties. For instance, since SiO2 can be a ceramic, SnO2 may be as well.	WebQuest 2

Big Idea 1: 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.	
Enduring Understanding 1.C. 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.	
Learning Objective	**Reference**
(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]**	345-352; 365, Concept Review Questions 8.49
(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]**	345-352

(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]**	353-355; 440, Comprehensive Problem 10.84

Big Idea 1: 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.
Enduring Understanding 1.C. 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.
Essential Knowledge 1.C.2. The currently accepted best model of the atom is based on the quantum mechanical model.

Essential Knowledge Component	Reference
a. Coulomb's law is the basis for describing the energy of interaction between protons and electrons.	64-66
b. Electrons are not considered to follow specific orbits. Chemists refer to the region of space in which an electron is found as an orbital.	314-315
c. Electrons in atoms have an intrinsic property known as spin that can result in atoms having a magnetic moment. There can be at most two electrons in any orbital, and these electrons must have opposite spin.	332-333
d. The quantum mechanical (QM) model addresses known problems with the classical shell model and is also consistent with atomic electronic structures that correspond with the periodic table.	310-312
e. The QM model can be approximately solved using computers and serves as the basis for software that calculates the structure and reactivity of molecules.	WebQuest 3

Big Idea 1: 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.
Enduring Understanding 1.C. 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.

Learning Objective	Reference
(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 model with the quantum mechanical model. **[See SP 6.3]**	310-312; 88 Concept Review Questions 2.30 and 2.35

Big Idea 1: 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.	
Enduring Understanding 1.D. Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.	
Essential Knowledge 1.D.1. As is the case with all scientific models, any model of the atom is subject to refinement and change in response to new experimental results. In that sense, an atomic model is not regarded as an exact description of the atom, but rather a theoretical construct that fits a set of experimental data.	
Essential Knowledge Component	References
a. Scientists use experimental results to test scientific models. When experimental results are not consistent with the predictions of a scientific model, the model must be revised or replaced with a new model that is able to predict/explain the new experimental results. A robust scientific model is one that can be used to explain/predict numerous results over a wide range of experimental circumstances.	12-13
b. The construction of a shell model of the atom through ionization energy information provides an opportunity to show how a model can be refined and changed as additional information is considered.	WebQuest 4

Big Idea 1: 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.	
Enduring Understanding 1.D. Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.	
Learning Objective	Reference
(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]**	12-13; 88 Concept Review Question 2.35

Big Idea 1: 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.	
Enduring Understanding 1.D. Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.	
Essential Knowledge 1.D.2. An early model of the atom stated that all atoms of an element are identical. Mass spectrometry data demonstrate evidence that contradicts this early model.	
Essential Knowledge Component	Reference
a. Data from mass spectrometry demonstrate evidence that an early model of the atom (Dalton's model) is incorrect; these data then require a modification of that model.	58-61
b. Data from mass spectrometry also demonstrate direct evidence of different isotopes from the same element.	58
c. The average atomic mass can be estimated from mass spectra.	60

Big Idea 1: 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.	
Enduring Understanding 1.D Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.	
Learning Objective	**Reference**
(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]**	58; 88 Concept Review Questions 2.48

Big Idea 1: 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.	
Enduring Understanding 1.D. Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.	
Essential Knowledge 1.D.3. The interaction of electromagnetic waves or light with matter is a powerful means to probe the structure of atoms and molecules, and to measure their concentration.	
Essential Knowledge Component	**Reference**
a. The energy of a photon is related to the frequency of the electromagnetic wave through Planck's equation (E=hv). When a photon is absorbed (or emitted) by a molecule, the energy of the molecule is increased (or decreased) by an amount equal to the energy of the photon.	300
b. Different types of molecular motion lead to absorption or emission of photons in different spectral regions. Infrared radiation is associated with transitions in molecular vibrations and so can be used to detect the presence of different types of bonds. Ultraviolet/visible radiation is associated with transitions in electronic energy levels and so can be used to probe electronic structure.	308-309; 384-385
c. The amount of light absorbed by a solution can be used to determine the concentration of the absorbing molecules in that solution, via the Beer-Lambert law.	309; Design Your Own Lab: Beer's Law and the Rate of Reaction

Big Idea 1: 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.	
Enduring Understanding 1.D. Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.	
Learning Objective	**Reference**
(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]**	384-385; 309, Problem B7.2
(LO) 1.16. The student can design and/or interpret the results of an experiment	308; 309 Problem B7.1

regarding the absorption of light to determine the concentration of an absorbing species in a solution. **[See SP 4.2, 5.1]**	
Big Idea 1: 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.	
Enduring Understanding 1.E. Atoms are conserved in physical and chemical processes.	
Essential Knowledge 1.E.1. Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.	
Essential Knowledge Component	**Reference**
a. Various types of representations can be used to show that matter is conserved during chemical and physical processes. 1. Symbolic representations 2. Particulate drawings	46-47
b. Because atoms must be conserved during a chemical process, it is possible to calculate product masses given known reactant masses, or to calculate reactant masses given product masses.	46-47
c. The concept of conservation of atoms plays an important role in the interpretation and analysis of many chemical processes on the macroscopic scale. Conservation of atoms should be related to how nonradioactive atoms are neither lost nor gained as they cycle among land, water, atmosphere, and living organisms.	46-47
Big Idea 1: 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.	
Enduring Understanding 1.E. Atoms are conserved in physical and chemical processes.	
Learning Objective	**Reference**
(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]**	46-47; 141, Comprehensive Problem 3.115
Big Idea 1. 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.	
Enduring Understanding 1.E. Atoms are conserved in physical and chemical processes	
Essential Knowledge 1.E.2. Conservation of atoms makes it possible to compute the masses of substances involved in physical and chemical processes. Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation.	
Essential Knowledge Component	**Reference**
a. The number of atoms, molecules, or formula units in a given mass of substance can be calculated.	98-102
b. The subscripts in a chemical formula represent the number of atoms of each type in a molecule.	68-70
c. The coefficients in a balanced chemical	111-113

equation represent the relative numbers of particles that are consumed and created when the process occurs.	
d. The concept of conservation of atoms plays an important role in the interpretation and analysis of many chemical processes on the macroscopic scale.	111-113
e. In gravimetric analysis, a substance is added to a solution that reacts specifically with a dissolved analyte (the chemical species that is the target of the analysis) to form a solid. The mass of solid formed can be used to infer the concentration of the analyte in the initial sample.	162-164
f. Titrations may be used to determine the concentration of an analyte in a solution. The titrant has a known concentration of a species that reacts specifically with the analyte. The equivalence of the titration occurs when the analyte is totally consumed by the reacting species in the titrant. The equivalence point is often indicated by a change in a property (such as color) that occurs when the equivalence point is reached. This observable event is called the end point of the titration.	172-174
Big Idea 1: 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.	
Enduring Understanding 1.E. Atoms are conserved in physical and chemical processes.	
Learning Objective	**Reference**
(LO) 1.18. The student is able to apply conservation of atoms to the rearrangement of atoms in various processes. **[See SP 1.4]**	157-164; 139 Skill Building Exercises 3.79
(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]**	162-164; 198 Problems in Context 4.47
(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]**	172-173; 198, Problems in Context, 4.55

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.	
Enduring Understanding 2.A. 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.	
Essential Knowledge 2.A.1. The different properties of solids and liquids can be explained by differences in their structures, both at the particulate level and in their supramolecular structures.	
Essential Knowledge Component	**Reference**
a. Solids can be crystalline, where the particles are arranged in a regular 3-D structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. In both cases, the motion of the individual particles is limited, and the particles do not undergo any overall translation with respect to each other. Interparticle interactions and the ability to pack the particles together provide the main criteria for the structures of solids.	495-498
b. The constituent particles in liquids are very close to each other, and they are continually moving and colliding. The particles are able to undergo translation with respect to each other and their arrangement, and movement is influenced by the nature and strength of the intermolecular forces that are present.	4, 490-492
c . The solid and liquid phases for a particular substance generally have relatively small differences in molar volume because in both cases the constituent particles are very close to each other at all times.	4
d. The differences in other properties, such as viscosity, surface tension, and volumes of mixing (for liquids), and hardness and macroscopic crystal structure (for solids), can be explained by differences in the strength of attraction between the particles and/or their overall organization	484-493; 495-501
e. Heating and cooling curves for pure substances provide insight into the energetics of liquid/solid phase changes.	475-477

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.	
Enduring Understanding 2.A. 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.	
Learning Objective	**Reference**
(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]**	475

(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, connects to Big Idea 5, Big Idea 6]**	816-818; 834, Concept Review Question 18.4
(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]**	475; 525, Concept Review Questions 12.2
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.	
Enduring Understanding 2.A 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.	
Enduring Understanding 2.A.2. The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.	
Essential Knowledge Component	Reference
a. Ideal gases exhibit specific mathematical relationships among the number of particles present, the temperature, the pressure, and the volume.	216
b. In a mixture of ideal gases, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the total pressure is the sum of the partial pressures.	225-226
c. Graphical representations of the relationships between P, V, and T are useful to describe gas behavior.	211-212
d. Kinetic molecular theory combined with a qualitative use of the Maxwell-Boltzmann distribution provides a robust model for qualitative explanations of these mathematical relationships.	231-236
e. Some real gases exhibit ideal or near-ideal behavior under typical laboratory conditions. Laboratory data can be used to generate or investigate the relationships in 2.A.2.a and to estimate absolute zero on the Celsius scale.	212-214; 241-243
f. All real gases are observed to deviate from ideal behavior, particularly under conditions that are close to those resulting in condensation. Except at extremely high pressures that are not typically seen in the laboratory, deviations from ideal behavior are the result of intermolecular attractions among gas molecules. These forces are strongly distance-dependent, so they are most significant during collisions.	241-243

g. Observed deviations from ideal gas behavior can be explained through an understanding of the structure of atoms and molecules and their intermolecular interactions.	241-243
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.	
Enduring Understanding 2.A. 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.	
Learning Objective	**Reference**
(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]**	241-243; Test Bank Chapter 10, Question 10-1
(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]**	210-215; 232-234; 255, Comprehensive Problem 5.142
(LO) 2.6. The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases**. [See SP 2.2, 2.3]**	217-231; 249, Skill Building Exercises 5.20
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.	
Enduring Understanding 2.A. 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.	
Essential Knowledge: 2.A.3. Solutions are homogenous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of the solutes and solvent.	
Essential Knowledge Component	**Reference**
a. In a solution (homogeneous mixture), the macroscopic properties do not vary throughout the sample. This is in contrast to a heterogeneous mixture in which the macroscopic properties depend upon the location in the mixture. The distinction between heterogeneous and homogeneous depends on the length scale of interest. As an example, colloids may be heterogeneous on the scale of micrometers, but homogeneous on the scale of centimeters.	81
b. Solutions come in the form of solids, liquids, and gases.	81
c. For liquid solutions, the solute may be a gas, a liquid, or a solid.	81
d. Based on the reflections of their structure on the microscopic scale, liquid solutions exhibit several general properties: 1. The components cannot be separated by	81-83

using filter paper. 2. There are no components large enough to scatter visible light. 3. The components can be separated using processes that are a result of the intermolecular interactions between and among the components.	
e. Chromatography (paper and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components.	83
f. Distillation is used to separate chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components and the effects these interactions have on the vapor pressures of the components in the mixture.	83
g. The formation of a solution may be an exothermic or endothermic process, depending on the relative strengths of intermolecular/interparticle interactions before and after the dissolution process.	544-549
h. Generally, when ionic compounds are dissolved in water, the component ions are separated and dispersed. The presence of ions in a solution can be detected by use of conductivity measurements.	146-147
i. Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory. Molarity is defined as the number of moles of solute per liter of solution.	150
j. Understanding how to prepare solutions of specified molarity through direct mixing of the components, through use of volumetric glassware, and by dilution of a solution of known molarity with additional solvent is important for performing laboratory work in chemistry.	152-153
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.	
Enduring Understanding 2.A. 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.	
Learning Objective	Reference
(LO) 2.7. The student is able to explain how solutes can be separated by chromatography based on intermolecular interactions. [**See SP 6.2**]	83, Problem B2.3; Lab 1: Using Paper Chromatography to Separate a Mixture
(LO) 2.8. The student can draw and/or interpret representations of solutions that	152-153; 580, Comprehensive Problems 13.124

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]**	150; 579, Comprehensive Problems 13.119
(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**	83; 579, Concept Review Questions 13.83; Test Bank, Chapter 2 Question 2-10; Lab 1: Using Paper Chromatography to Separate a Mixture, Questions 1-3

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.

Enduring Understanding 2.B. 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.

Enduring Understanding 2.B.1. London dispersion forces are attractive forces present between all atoms and molecules. London dispersion forces are often the strongest net intermolecular force between large molecules.

Essential Knowledge Component	Reference
a. A temporary, instantaneous dipole may be created by an uneven distribution of electrons around the nucleus (nuclei) of an atom (molecule).	488-489
b. London dispersion forces arise due to the Coulombic interaction of the temporary dipole with the electron distribution in neighboring atoms and molecules.	488-489
c. Dispersion forces increase with contact area between molecules and with increasing polarizability of the molecules. The polarizability of a molecule increases with the number of electrons in the molecule, and is enhanced by the presence of pi bonding.	488-489

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.

Enduring Understanding 2.B. 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.

Learning Objective	Reference
(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]**	488-489
(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]**	488-489; p. 841, Comprehensive Problems 18.186
(LO) 2.11. The student is able to explain the trends in properties and/or predict	488-489; 527, Skill Building Exercises 12.53

properties of samples consisting of particles with no permanent dipole on the basis of London dispersion forces. **[See SP 6.2, 6.4]**	
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.	
Enduring Understanding 2.B. 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.	
Enduring Understanding 2.B.2. Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force that exists when very electronegative atoms (N, O, and F) are involved.	
Essential Knowledge Component	**Reference**
a. Molecules with dipole moments experience Coulombic interactions that result in a net attractive interaction when they are near each other. 1. Intermolecular dipole-dipole forces are weaker than ionic forces or covalent bonds. 2. Interactions between polar molecules are typically greater than between nonpolar molecules of comparable size because these interactions act in addition to London dispersion forces. 3. Dipole-dipole attractions can be represented by diagrams of attraction between the positive and negative ends of polar molecules trying to maximize attractions and minimize repulsions in the liquid or solid state. 4. Dipole-induced dipole interactions are present between a polar and nonpolar molecule. The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule.	484-489
b. Hydrogen bonding is a relatively strong type of intermolecular interaction that exists when hydrogen atoms that are covalently bonded to the highly electronegative atoms (N, O, and F) are also attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a different molecule, or a different part of the same molecule. When hydrogen bonding is present, even small molecules may have strong intermolecular attractions.	486-487
c. Hydrogen bonding between molecules, or between different parts of a single molecule, may be represented by diagrams of molecules with hydrogen bonding and indications of location of hydrogen bonding.	486-487
d. Ionic interactions with dipoles are important in the solubility of ionic compounds in polar solvents.	485

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.	
Enduring Understanding 2.B. 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.	
Learning Objective	**Reference**
(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, connects to 2.A.2]**	241-244; 251, Skill Building Exercises 5.84
(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]**	484-489; 527, Concept Review Questions 12.33
(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]**	484-489; 576, Skill Building Exercises 13.7; Test Bank Chapter 9, Question 9-10

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.	
Enduring Understanding 2.B. 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.	
Enduring Understanding 2.B.3. Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.	
Essential Knowledge Component	**Reference**
a. Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present. 1. Boiling point 2. Surface tension 3. Capillary action 4. Vapor pressure	490-493
b. Substances with similar intermolecular interactions tend to be miscible or soluble in one another.	534-535
c. The presence of intermolecular forces among gaseous particles, including noble gases, leads to deviations from ideal behavior, and it can lead to condensation at sufficiently low temperatures and/or sufficiently high pressures.	241-244
d. Graphs of the pressure-volume relationship for real gases can demonstrate the deviation from ideal behavior; these deviations can be interpreted in terms of the presence and strengths of intermolecular forces.	241
e. The structure and function of many biological	539-344; 730-731

systems depend on the strength and nature of the various Coulombic forces. 1. Substrate interactions with the active sites in enzyme catalysis 2. Hydrophilic and hydrophobic regions in proteins that determine three-dimensional structure in water solutions	

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.
Enduring Understanding 2.B. 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.

Learning Objective	Reference
(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, connects to 5.E.1]**	534-535; 580, Comprehensive Problems 13.124
(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]**	539-544; 526, Concept Review Questions 12.14

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.
Enduring Understanding 2.C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
Enduring Understanding 2.C.1. In covalent bonding, electrons are shared between the nuclei of two atoms to form a molecule or polyatomic ion. Electronegativity differences between the two atoms account for the distribution of the shared electrons and the polarity of the bond.

Essential Knowledge Component	Reference
a. Electronegativity is the ability of an atom in a molecule to attract shared electrons to it.	390
b. Electronegativity values for the representative elements increase going from left to right across a period and decrease going down a group. These trends can be understood qualitatively through the electronic structure of the atoms, the shell model, and Coulomb's law.	391
c. Two or more valence electrons shared between atoms of identical electronegativity constitute a nonpolar covalent bond.	392
d. However, bonds between carbon and hydrogen are often considered to be nonpolar even though carbon is slightly more electronegative than hydrogen. The formation of a nonpolar covalent bond can be represented graphically as a plot of potential energy vs. distance for the interaction of two identical atoms. Hydrogen atoms are often used	379

as an example. 1. The relative strengths of attractive and repulsive forces as a function of distance determine the shape of the graph. 2. The bond length is the distance between the bonded atoms' nuclei, and is the distance of minimum potential energy where the attractive and repulsive forces are balanced. 3. The bond energy is the energy required for the dissociation of the bond. This is the net energy of stabilization of the bond compared to the two separated atoms. Typically, bond energy is given on a per mole basis.	
e. Two or more valence electrons shared between atoms of unequal electronegativity constitute a polar covalent bond. 1. The difference in electronegativity for the two atoms involved in a polar covalent bond is not equal to zero. 2. The atom with a higher electronegativity will develop a partial negative charge relative to the other atom in the bond. For diatomic molecules, the partial negative charge on the more electronegative atom is equal in magnitude to the partial positive charge on the less electronegative atom. 3. Greater differences in electronegativity lead to greater partial charges, and consequently greater bond dipoles. 4. The sum of partial charges in any molecule or ion must be equal to the overall charge on the species.	392-393
f. All bonds have some ionic character, and the difference between ionic and covalent bonding is not distinct but rather a continuum. The difference in electronegativity is not the only factor in determining if a bond is designated ionic or covalent. Generally, bonds between a metal and nonmetal are ionic, and between two nonmetals the bonds are covalent. Examination of the properties of a compound is the best way to determine the type of bonding.	390-393
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.	
Enduring Understanding 2.C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.	
Learning Objective	**Reference**
(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]**	392-393

(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]**	392-393; 402 Skill Building Exercise 9.66
(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]**	390-393; 402 Skill Building Exercise 9.65
(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]**	390-393; 402 Skill Building Exercise 9.67

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.

Enduring Understanding 2.C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.

Essential Knowledge 2.C.2. Ionic bonding results from the net attraction between oppositely charged ions, closely packed together in a crystal lattice.

Essential Knowledge Component	Reference
a. The cations and anions in an ionic crystal are arranged in a systematic, periodic 3-D array that maximizes the attractive forces among cations and anions while minimizing the repulsive forces.	504-505
b. Coulomb's law describes the force of attraction between the cations and anions in an ionic crystal. 1. Because the force is proportional to the charge on each ion, larger charges lead to stronger interactions. 2. Because the force is inversely proportional to the square of the distance between the centers of the ions (nuclei), smaller ions lead to stronger interactions.	64-65

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.

Enduring Understanding 2.C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.

Learning Objective	Reference
(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, connects to 2.D.1., 2.D.2.]**	504-505; 400 Concept Review Questions 9.17

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.	
Enduring Understanding 2.C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.	
Enduring Understanding 2.C.3. Metallic bonding describes an array of positively charged metal cores surrounded by a sea of mobile valence electrons.	
Essential Knowledge Component	Reference
a. The valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom.	396-397
b. Metallic bonding can be represented as an array of positive metal ions with valence electrons drawn among them, as if the electrons were moving (i.e., a sea of electrons).	370-371
c. The electron sea model can be used to explain several properties of metals, including electrical conductivity, malleability, ductility, and low volatility.	396-397
d. The number of valence electrons involved in metallic bonding, via the shell model, can be used to understand patterns in these properties, and can be related to the shell model to reinforce the connections between metallic bonding and other forms of bonding.	394-395

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.	
Enduring Understanding 2.C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.	
Learning Objective	Reference
(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, connects to 2.D.2.]**	396-397; 402, Concept Review Questions 9.70

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.	
Enduring Understanding 2.C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.	
Enduring Understanding 2.C.4. The localized electron bonding model describes and predicts molecular geometry using Lewis diagrams and the VSEPR model.	
Essential Knowledge Component	Reference
a. Lewis diagrams can be constructed according to a well-established set of principles.	371
b. The VSEPR model uses the Coulombic repulsion between electrons as a basis for predicting the arrangement of electron pairs around a central atom.	417-427
c. In cases where more than one equivalent Lewis structure can be constructed, resonance	409-411

must be included as a refinement to the Lewis structure approach in order to provide qualitatively accurate predictions of molecular structure and properties (in some cases).	
d. Formal charge can be used as a criterion for determining which of several possible valid Lewis diagrams provides the best model for predicting molecular structure and properties.	411-412
e. The combination of Lewis diagrams with the VSEPR model provides a powerful model for predicting structural properties of many covalently bonded molecules and polyatomic ions, including the following: 1. Molecular geometry 2. Bond angles 3. Relative bond energies based on bond order 4. Relative bond lengths (multiple bonds, effects of atomic radius) 5. Presence of a dipole moment	417-427
f. As with any model, there are limitations to the use of the Lewis structure model, particularly in cases with an odd number of valence electrons. Recognizing that Lewis diagrams have limitations is of significance.	413-414
g. Organic chemists commonly use the terms "hybridization" and "hybrid orbital" to describe the arrangement of electrons around a central atom. When there is a bond angle of 180°, the central atom is said to be sp hybridized; for 120°, the central atom is sp2 hybridized; and for 109°, the central atom is sp3 hybridized. Students should be aware of this terminology, and be able to use it. When an atom has more than four pairs of electrons surrounding the central atom, students are only responsible for the shape of the resulting molecule.	443-455
h. Bond formation is associated with overlap between atomic orbitals. In multiple bonds, such overlap leads to the formation of both sigma and pi bonds. The overlap is stronger in sigma than pi bonds, which is reflected in sigma bonds having larger bond energy than pi bonds. The presence of a pi bond also prevents the rotation of the bond, and leads to structural isomers. In systems, such as benzene, where atomic p-orbitals overlap strongly with more than one other p-orbital, extended pi bonding exists, which is delocalized across more than two nuclei. Such descriptions provide an alternative description to resonance in Lewis structures. A useful example of delocalized pi bonding is molecular solids that conduct electricity. The	451-455

discovery of such materials at the end of the 1970s overturned a long-standing assumption in chemistry that molecular solids will always be insulators.	
i. Molecular orbital theory describes covalent bonding in a manner that can capture a wider array of systems and phenomena than the Lewis or VSEPR models. Molecular orbital diagrams, showing the correlation between atomic and molecular orbitals, are a useful qualitative tool related to molecular orbital theory.	455-462

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.

Enduring Understanding 2.C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.

Learning Objective	Reference
(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]**	444-451; 441, Comprehensive Problems 10.92

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.

Enduring Understanding 2.D. The type of bonding in the solid state can be deduced from the properties of the solid state.

Enduring Understanding 2.D.1. Ionic solids have high melting points, are brittle, and conduct electricity only when molten or in solution.

Essential Knowledge Component	Reference
a. Many properties of ionic solids are related to their structure. 1. Ionic solids generally have low vapor pressure due to the strong Coulombic interactions of positive and negative ions arranged in a regular three-dimensional array. 2. Ionic solids tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer. 3. Ionic solids do not conduct electricity. However, when ionic solids are melted, they do conduct electricity because the ions are free to move. 4. When ionic solids are dissolved in water, the separated ions are free to move; therefore, these solutions will conduct electricity. Dissolving a nonconducting solid in water, and observing the solution's ability to conduct electricity, is one way to identify an ionic solid. 5. Ionic compounds tend not to dissolve in nonpolar solvents because the attractions among the ions are much stronger than the attractions among the separated ions and the nonpolar solvent molecules.	146-147; 503-506

b. The attractive force between any two ions is governed by Coulomb's law: The force is directly proportional to the charge of each ion and inversely proportional to the square of the distance between the centers of the ions. 1. For ions of a given charge, the smaller the ions, and thus the smaller the distance between ion centers, the stronger the Coulombic force of attraction, and the higher the melting point. 2. Ions with higher charges lead to higher Coulombic forces, and therefore higher melting points.	64-66

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.

Enduring Understanding 2.D. The type of bonding in the solid state can be deduced from the properties of the solid state.

Learning Objective	Reference
(LO) 2.1 Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. **[SP 6.4, 7.1]**	146-148; 502-507; 400, Concept Review Questions 9.17
(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]**	64-66; 808, Follow Up Problems 18.6A
(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, 6.4]**	146-147; 503-506; Test Bank Chapter 9, Question 9-4
(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]**	64-66; Test Bank Chapter 9, Question 9-9
(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]**	146-147; 503-506; 401, Problems in Context 9.32

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.

Enduring Understanding 2.D. The type of bonding in the solid state can be deduced from the properties of the solid state.

Enduring Understanding 2.D.2. Metallic solids are good conductors of heat and electricity, have a wide range of melting points, and are shiny, malleable, ductile, and readily alloyed.

Essential Knowledge Component	Reference
a. A metallic solid can be represented as positive kernels (or cores) consisting of the nucleus and inner electrons of each atom surrounded by a sea of mobile valence electrons.	395-397

1. Metals are good conductors because the electrons are delocalized and relatively free to move. 2. Metals are malleable and ductile because deforming the solid does not change the environment immediately surrounding each metal core.	
b. Metallic solids are often pure substances, but may also be mixtures called alloys. 1. Some properties of alloys can be understood in terms of the size of the component atoms: -Interstitial alloys form between atoms of different radius, where the smaller atoms fill the interstitial spaces between the larger atoms. (Steel is an example in which carbon occupies the interstices in iron.) The interstitial atoms make the lattice more rigid, decreasing malleability and ductility. -Substitutional alloys form between atoms of comparable radius, where one atom substitutes for the other in the lattice. (Brass is an example in which some copper atoms are substituted with a different element, usually zinc.) The density typically lies between those of the component metals, as with interstitial alloys, substitutional alloys are less malleable and ductile than pure metals. 2. Alloys typically retain a sea of mobile electrons and so remain conducting. 3. Often the surface of a metal or alloy is changed through a chemical reaction. An example is formation of a chemically inert oxide layer in stainless steel, through reaction with oxygen in the air.	395-397; 1012-1014
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.	
Enduring Understanding 2.D. The type of bonding in the solid state can be deduced from the properties of the solid state.	
Learning Objective	**Reference**
(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]**	WebQuest 6
(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]**	395-397
(LO) 2.27. The student can create a representation of a metallic solid that shows essential characteristics of the structure and	WebQuest 6

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]**	WebQuest 6
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.	
Enduring Understanding 2.D. The type of bonding in the solid state can be deduced from the properties of the solid state.	
Enduring Understanding 2.D.3. Covalent network solids have properties that reflect their underlying 2-D or 3-D networks of covalent bonds. Covalent network solids generally have extremely high melting points and are hard.	
Essential Knowledge Component	**Reference**
a. Covalent network solids consist of atoms that are covalently bonded together into a two-dimensional or three-dimensional network. 1. Covalent network solids are only formed from nonmetals: elemental (diamond, graphite) or two nonmetals (silicon dioxide and silicon carbide). 2. The properties of covalent network solids are a reflection of their structure. 3. Covalent network solids have high melting points because all of the atoms are covalently bonded. 4. Three-dimensional covalent networks tend to be rigid and hard because the covalent bond angles are fixed. 5. Generally, covalent network solids form in the carbon group because of their ability to form four covalent bonds.	379-383
b. Graphite is an allotrope of carbon that forms sheets of two-dimensional networks. 1. Graphite has a high melting point because the covalent bonds between the carbon atoms making up each layer are relatively strong. 2. Graphite is soft because adjacent layers can slide past each other relatively easily; the major forces of attraction between the layers are London dispersion forces.	506
c. Silicon is a covalent network solid and a semiconductor. 1. Silicon forms a three-dimensional network similar in geometry to a diamond. 2. Silicon's conductivity increases as temperature increases. 3. Periodicity can be used to understand why doping with an element with one extra valence electron converts silicon into an n-type semiconducting (negative charge carrying)	509-514

material, while doping with an element with one less valence electron converts silicon into a p-type semiconducting (positive charge carrying) material. Junctions between n-doped and p-doped materials can be used to control electron flow, and thereby are the basis of modern electronics.	
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.	
Enduring Understanding 2.D. The type of bonding in the solid state can be deduced from the properties of the solid state.	
Learning Objective	**Reference**
(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]**	383; Test Bank Chapter 12, Question 12-11
(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]**	383; 403, Comprehensive Problems 9.82
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.	
Enduring Understanding 2.D. The type of bonding in the solid state can be deduced from the properties of the solid state.	
Enduring Understanding 2.D.4. Molecular solids with low molecular weight usually have low melting points and are not expected to conduct electricity as solids, in solution, or when molten.	
Essential Knowledge Component	**Reference**
a. Molecular solids consist of nonmetals, diatomic elements, or compounds formed from two or more nonmetals.	383
b. Molecular solids are composed of distinct, individual units of covalently bonded molecules attracted to each other through relatively weak intermolecular forces. 1. Molecular solids are not expected to conduct electricity because their electrons are tightly held within the covalent bonds of each constituent molecule. 2. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. 3. Molecular solids are sometimes composed of very large molecules, or polymers, with important commercial and biological applications.	383

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.	
Enduring Understanding 2.D. The type of bonding in the solid state can be deduced from the properties of the solid state.	
Learning Objective	**Reference**
(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]**	383; Test Bank Chapter 14, Question 14-7
(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]**	Test Bank Question 14-7, Chapter 14, 2.D.4.b

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.A. Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.	
Enduring Understanding 3.A.1. A chemical change may be represented by a molecular, ionic, or net ionic equation.	
Essential Knowledge Component	**Reference**
a. Chemical equations represent chemical changes, and therefore must contain equal numbers of atoms of every element on each side to be "balanced."	111-114
b. Depending on the context in which it is used, there are different forms of the balanced chemical equations that are used by chemists. It is important not only to write a balanced molecular, ionic, or net ionic reaction equation, but also to have an understanding of the circumstances under which any of them might be the most useful form.	155-157
c. The balanced chemical equation for a reaction is capable of representing chemistry at any level, and thus it is important that it can be translated into a symbolic depiction at the particulate level, where much of the reasoning of chemistry occurs.	158
d. Because chemistry is ultimately an experimental science, it is important that students be able to describe chemical reactions observed in a variety of laboratory contexts.	111-116

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons	
Enduring Understanding 3.A. Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.	
Learning Objective	**Reference**
(LO) 3.1. Students can translate among macroscopic observations of change, chemical equations, and particle views. **[See SP 1.5, 7.1]**	111-116
(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, 7.1]**	111-116; 197, Concept Review Questions 4.40

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.A. Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.	
Enduring Understanding 3.A.2. Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note, so that it does not seem to be simply an exercise done only by chemists.	
Essential Knowledge Component	**Reference**
a. Coefficients of balanced chemical equations contain information regarding the proportionality of the amounts of substances involved in the reaction. These values can be used in chemical calculations that apply the mole concept; the most important place for this type of quantitative exercise is the laboratory. 1. Calculate amount of product expected to be produced in a laboratory experiment. 2. Identify limiting and excess reactant; calculate percent and theoretical yield for a given laboratory experiment.	116-118
b. The use of stoichiometry with gases also has the potential for laboratory experimentation, particularly with respect to the experimental determination of molar mass of a gas.	224-225; 228-230
c. Solution chemistry provides an additional avenue for laboratory calculations of stoichiometry, including titrations.	172-174

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.A. Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.	
Learning Objective	**Reference**
(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]**	116-118; 199 Problems in Context 4.73
(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]**	224-225; 228-230; 199, Problems in Context 4.75

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.B. 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.	
Enduring Understanding 3.B.1. Synthesis reactions are those in which atoms and/or molecules combine to form a new compound. Decomposition is the reverse of synthesis, a process whereby molecules are decomposed, often by the use of heat.	
Essential Knowledge Component	**Reference**
a. Synthesis or decomposition reactions can be used for acquisition of basic lab techniques and observations that help students deal with the abstractions of atoms and stoichiometric calculations.	181-187

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.B. 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.	
Learning Objective	**Reference**
(LO) 3.1 Students can translate among macroscopic observations of change, chemical equations, and particle views. **[See SP 1.5, 7.1]**	181-187; 139 Skill Building Exercises 3.80
(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]**	181-187, Test Bank Chapter 2, 2-1
(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]**	181-187; 139 Skill Building Exercises 3.83

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.B. 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.	
Enduring Understanding 3.B.2. In a neutralization reaction, protons are transferred from an acid to a base.	
Essential Knowledge Component	**Reference**
a. The amphoteric nature of water plays an important role in the chemistry of aqueous solutions, since water can both accept protons from and donate protons to dissolved species.	803-804
b. Acid-base reactions: 1. Only reactions in aqueous solutions are considered. 2.The Brønsted-Lowry concept of acids and bases is the focus of the course. 3. When an acid or base ionizes in water, the conjugate acid-base pairs can be identified and	803-805

their relative strengths compared.	
Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.B. 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.	
Learning Objective	**Reference**
(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]**	803-805; 836, Skill Building Exercises 18.47
Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.B. 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.	
Enduring Understanding 3.B.3. In oxidation-reduction (redox) reactions, there is a net transfer of electrons. The species that loses electrons is oxidized, and the species that gains electrons is reduced.	
Essential Knowledge Component	**Reference**
a. In a redox reaction, electrons are transferred from the species that is oxidized to the species that is reduced.	174-176
b. Oxidation numbers may be assigned to each of the atoms in the reactant and products; this is often an effective way to identify the oxidized and reduced species in a redox reaction.	176-178
c. Balanced chemical equations for redox reactions can be constructed from tabulated half-reactions.	940-943
d. Recognizing that a reaction is a redox reaction is an important skill; an apt application of this type of reaction is a laboratory exercise where students perform redox titrations.	179-180
e. There are a number of important redox reactions in energy production processes (combustion of hydrocarbons and metabolism of sugars, fats, and proteins).	186-187
Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.B. 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.	
Learning Objective	**Reference**
(LO) 3.8. The student is able to identify redox reactions and justify the identification in terms of electron transfer. **[See SP 6.1]**	174-176; 202, Comprehensive Problems 4.138
(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]**	179-180; 200, Problems in Context 4.96

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.C. Chemical and physical transformations may be observed in several ways and typically involve a change in energy.	
Enduring Understanding 3.C.1. Production of heat or light, formation of a gas, and formation of a precipitate and/or a color change are possible evidences that a chemical change has occurred.	
Essential Knowledge Component	**Reference**
a. Laboratory observations are made at the macroscopic level, so students must be able to characterize changes in matter using visual clues and then make representations or written descriptions.	5-6
b. Distinguishing the difference between chemical and physical changes at the macroscopic level is a challenge; therefore, the ability to investigate chemical properties is important.	5
c. In order to develop the ability to distinguish experimentally between chemical and physical changes, students must make observations and collect data from a variety of reactions and physical changes within the laboratory setting.	5-7
d. Classification of reactions provides important organizational clarity for chemistry; therefore, students need to identify precipitation, acid-base, and redox reactions.	155-188

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.C. Chemical and physical transformations may be observed in several ways and typically involve a change in energy	
Learning Objective	**Reference**
(LO) 3.1 Students can translate among macroscopic observations of change, chemical equations, and particle views. **[See SP 1.5, 7.1]**	5-7
(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, connects to 5.D.2]**	5-7, Follow Up Problems 1.2

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.C. Chemical and physical transformations may be observed in several ways and typically involve a change in energy.	
Enduring Understanding 3.C.2. Net changes in energy for a chemical reaction can be endothermic or exothermic.	
Essential Knowledge Component	**Reference**
a. Macroscopic observations of energy changes when chemicals react are made possible by measuring temperature changes.	258-259

b. These observations should be placed within the context of the language of exothermic and endothermic change.	266-267
c. The ability to translate observations made at the macroscopic level in the laboratory to a conceptual framework is aided by a graphical depiction of the process called an energy diagram, which provides a visual representation of the exothermic or endothermic nature of a reaction.	719-720
d. It is important to be able to use an understanding of energy changes in chemical reactions to identify the role of endothermic and exothermic reactions in real-world processes.	544-549
Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.C. Chemical and physical transformations may be observed in several ways and typically involve a change in energy.	
Learning Objective	**Reference**
(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]**	266-267; 288, Skill-Building Exercise 6.27
Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.C. Chemical and physical transformations may be observed in several ways and typically involve a change in energy.	
Enduring Understanding 3.C.3. Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.	
Essential Knowledge Component	**Reference**
a. Electrochemistry encompasses the study of redox reactions that occur within electrochemical cells. The reactions either generate electrical current in galvanic cells, or are driven by an externally applied electrical potential in electrolytic cells. Visual representations of galvanic and electrolytic cells are tools of analysis to identify where half-reactions occur and the direction of current flow.	944-946
b. Oxidation occurs at the anode, and reduction occurs at the cathode for all electrochemical cells.	944-946
c. The overall electrical potential of galvanic cells can be calculated by identifying the oxidation half-reaction and reduction half-reaction, and using a table of Standard Reduction Potentials.	950-956
d. Many real systems do not operate at standard conditions and the electrical potential	961-964

determination must account for the effect of concentrations. The qualitative effects of concentration on the cell potential can be understood by considering the cell potential as a driving force toward equilibrium, in that the farther the reaction is from equilibrium, the greater the magnitude of the cell potential. The standard cell potential, Eo, corresponds to the standard conditions of Q = 1. As the system approaches equilibrium, the magnitude (i.e., absolute value) of the cell potential decreases, reaching zero at equilibrium (when Q = K). Deviations from standard conditions that take the cell further from equilibrium than Q = 1 will increase the magnitude of the cell potential relative to E°. Deviations from standard conditions that take the cell closer to equilibrium than Q = 1 will decrease the magnitude of the cell potential relative to E°. In concentration cells, the direction of spontaneous electron flow can be determined by considering the direction needed to reach equilibrium.	
e. ΔG° (standard Gibbs free energy) is proportional to the negative of the cell potential for the redox reaction from which it is constructed.	944-946
f. Faraday's laws can be used to determine the stoichiometry of the redox reactions occurring in an electrochemical cell with respect to the following: i. Number of electrons transferred ii. Mass of material deposited or removed from an electrode iii. Current iv. Time elapsed v. Charge of ionic species	980-981
Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.	
Enduring Understanding 3.C. Chemical and physical transformations may be observed in several ways and typically involve a change in energy.	
Learning Objective	Reference
(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]**	944-946; 988, Skill Building Exercises 21.27
(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]**	944-946; 989 Skill Building Exercises 21.28

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.A. Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.	
Enduring Understanding 4.A.1. The rate of a reaction is influenced by the concentration or pressure of reactants, the phase of the reactants and products, and environmental factors such as temperature and solvent.	
Essential Knowledge Component	**Reference**
a. The rate of a reaction is measured by the amount of reactants converted to products per unit of time.	691
b. A variety of means exist to experimentally measure the loss of reactants or increase of products as a function of time. One important method involves the spectroscopic determination of concentration through Beer's law.	699
c. The rate of a reaction is influenced by reactant concentrations (except in zero-order processes), temperature, surface area, and other environmental factors.	692-693

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.A. Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.	
Learning Objective	**Reference**
(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]**	699; 734, Concept Review Questions 16.4, 16.5

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.A. Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.	
Enduring Understanding 4.A.2. The rate law shows how the rate depends on reactant concentrations.	
Essential Knowledge Component	**Reference**
a. The rate law expresses the rate of a reaction as proportional to the concentration of each reactant raised to a power. The power of each reactant in the rate law is the order of the reaction with respect to that reactant. The sum of the powers of the reactant concentrations in the rate law is the overall order of the reaction. When the rate is independent of the concentration of a reactant, the reaction is zeroth order in that reactant, since raising the reactant concentration to the power zero is equivalent to the reactant concentration being absent from the rate law.	698-701

b. In cases in which the concentration of any other reactants remain essentially constant during the course of the reaction, the order of a reaction with respect to a reactant concentration can be inferred from plots of the concentration of reactant versus time. An appropriate laboratory experience would be for students to use spectrophotometry to determine how concentration varies with time.	698-701
c. The method of initial rates is useful for developing conceptual understanding of what a rate law represents, but simple algorithmic application should not be considered mastery of the concept. Investigation of data for initial rates enables prediction of how concentration will vary as the reaction progresses.	694-697

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.A. Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.	
Learning Objective	**Reference**
(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, 6.4, connects to 4.A.3]**	698-701; 738 Skill Building Exercises 16.34

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.A. Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.	
Enduring Understanding 4.A.3. The magnitude and temperature dependence of the rate of reaction is contained quantitatively in the rate constant.	
Essential Knowledge Component	**Reference**
a. The proportionality constant in the rate law is called the rate constant.	698
b. The rate constant is an important measurable quantity that characterizes a chemical reaction.	698
c. Rate constants vary over many orders of magnitude because reaction rates vary widely.	692-693
d. The temperature dependence of reaction rates is contained in the temperature dependence of the rate constant.	715
e. For first-order reactions, half-life is often used as a representation for the rate constant because they are inversely proportional, and the half-life is independent of concentration. For example, radioactive decay processes provide real-world context.	711-714

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.A. Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.	
Learning Objective	**Reference**
(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]**	711-714; 713 Follow-Up Problems 16.7

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.B. Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.	
Enduring Understanding 4.B.1. Elementary reactions can be unimolecular or involve collisions between two or more molecules.	
Essential Knowledge Component	**Reference**
a. The order of an elementary reaction can be inferred from the number of molecules participating in a collision: unimolecular reactions are first order, reactions involving bimolecular collisions are second order, etc.	721-722
b. Elementary reactions involving the simultaneous collision of three particles are rare.	722

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.B. Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.	
Learning Objective	**Reference**
(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, connects to 4.A.3, 4.B.2]**	721-722; 743 Comprehensive Problems 16.112

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding: 4.B. Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.	
Enduring Understanding 4.B.2. Not all collisions are successful. To get over the activation energy barrier, the colliding species need sufficient energy. Also, the orientations of the reactant molecules during the collision must allow for the rearrangement of reactant bonds to form product bonds.	
Essential Knowledge Component	**Reference**
a. Unimolecular reactions occur because collisions with solvent or background molecules activate the molecule in a way that can be understood in terms of a Maxwell-Boltzmann thermal distribution of particle energies.	715-721

b. Collision models provide a qualitative explanation for order of elementary reactions and the temperature dependence of the rate constant.	715-716
c. In most reactions, only a small fraction of the collisions leads to a reaction. Successful collisions have both sufficient energy to overcome activation energy barriers and orientations that allow the bonds to rearrange in the required manner.	715
d. The Maxwell-Boltzmann distribution describes the distribution of particle energies; this distribution can be used to gain a qualitative estimate of the fraction of collisions with sufficient energy to lead to a reaction, and also how that fraction depends on temperature.	715-716
Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.B. Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.	
Learning Objective	**Reference**
(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]**	715; 739, Concept Review Questions 16.50
Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.B. Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.	
Enduring Understanding 4.B.3. A successful collision can be viewed as following a reaction path with an associated energy profile.	
Essential Knowledge Component	**Reference**
a. Elementary reactions typically involve the breaking of some bonds and the forming of new ones. It is usually possible to view the complex set of motions involved in this rearrangement as occurring along a single reaction coordinate.	720
b. The energy profile gives the energy along this path, which typically proceeds from reactants, through a transition state, to products.	720
c. The Arrhenius equation can be used to summarize experiments on the temperature dependence of the rate of an elementary reaction and to interpret this dependence in terms of the activation energy needed to reach the transition state.	716-717

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.B. Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.	
Learning Objective	**Reference**
(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]**	719; 741 Comprehensive Problem 16.84
(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, connects to 4.C.1, 4.C.2, 4.C.3]**	719; 740 Problems in Context 16.77
Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.C. Many reactions proceed via a series of elementary reactions.	
Enduring Understanding 4.C.1. The mechanism of a multistep reaction consists of a series of elementary reactions that add up to the overall reaction.	
Essential Knowledge Component	**Reference**
a. The rate law of an elementary step is related to the number of reactants, as accounted for by collision theory.	716
b. The elementary steps add to give the overall reaction. The balanced chemical equation for the overall reaction specifies only the stoichiometry of the reaction, not the rate.	721-722
c. A number of mechanisms may be postulated for most reactions, and experimentally determining the dominant pathway of such reactions is a central activity of chemistry.	721
Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.C. Many reactions proceed via a series of elementary reactions	
Enduring Understanding 4.C.2. In many reactions, the rate is set by the slowest elementary reaction, or rate-limiting step	
Essential Knowledge Component	**Reference**
a. For reactions in which each elementary step is irreversible, the rate of the reaction is set by the slowest elementary step (i.e., the rate-limiting step).	723-726

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.C. Many reactions proceed via a series of elementary reactions.	
Enduring Understanding 4.C.3. Reaction intermediates, which are formed during the reaction but not present in the overall reaction, play an important role in multistep reactions.	
Essential Knowledge Component	**Reference**
a. A reaction intermediate is produced by some elementary steps and consumed by others, such that it is present only while a reaction is occurring.	723-726
b. Experimental detection of a reaction intermediate is a common way to build evidence in support of one reaction mechanism over an alternative mechanism.	723-726
Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.D. Reaction rates may be increased by the presence of a catalyst.	
Enduring Understanding 4.D.1. Catalysts function by lowering the activation energy of an elementary step in a reaction mechanism, and by providing a new and faster reaction mechanism.	
Essential Knowledge Component	**Reference**
a. A catalyst can stabilize a transition state, lowering the activation energy and thus increasing the rate of a reaction.	727-730
b. A catalyst can increase a reaction rate by participating in the formation of a new reaction intermediate, thereby providing a new reaction pathway or mechanism.	727-730
Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding: 4.D. Reaction rates may be increased by the presence of a catalyst.	
Learning Objective	**Reference**
(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]**	727-730; 740 Concept Review Question 16.78
Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.D. Reaction rates may be increased by the presence of a catalyst.	
Enduring Understanding 4.D.2. Important classes in catalysis include acid-base catalysis, surface catalysis, and enzyme catalysis.	
Essential Knowledge Component	**Reference**
a. In acid-base catalysis, a reactant either gains or loses a proton; this changes the rate of the reaction.	727-730
b. In surface catalysis, either a new reaction intermediate is formed, or the probability of successful collisions is modified.	727-730
c. Some enzymes accelerate reactions by binding to the reactants in a way that lowers the activation energy. Other enzymes react with	727-730

reactant species to form a new reaction intermediate.	
Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.	
Enduring Understanding 4.D. Reaction rates may be increased by the presence of a catalyst.	
Learning Objective	**Reference**
(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]**	727-730; 742, Comprehensive Problem 16.99

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter	
Enduring Understanding 5.A. 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.	
Enduring Understanding 5.A.1. Temperature is a measure of the average kinetic energy of atoms and molecules.	
Essential Knowledge Component	**Reference**
a. All of the molecules in a sample are in motion.	231
b. The Kelvin temperature of a sample of matter is proportional to the average kinetic energy of the particles in the sample. When the average kinetic energy of the particles in the sample doubles, the Kelvin temperature is doubled. As the temperature approaches 0 K (zero Kelvin), the average kinetic energy of a system approaches a minimum near zero.	235
c. The Maxwell-Boltzmann distribution shows that the distribution of kinetic energies becomes greater (more disperse) as temperature increases.	232

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter	
Enduring Understanding 5.A. 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.	
Learning Objective	**Reference**
(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]**	258-261; 289 Skill Building Exercises 6.46
(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]**	232; 251 Skill Building Exercise 5.78

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter	
Enduring Understanding 5.A. 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.	
Enduring Understanding 5.A.2. The process of kinetic energy transfer at the particulate scale is referred to in this course as heat transfer, and the spontaneous direction of the transfer is always from a hot to a cold body.	
Essential Knowledge Component	**Reference**
a. On average, molecules in the warmer body have more kinetic energy than the molecules in the cooler body.	234-236
b. Collisions of molecules that are in thermal contact transfer energy.	231
c. Scientists describe this process as "energy is transferred as heat."	258-260
d. Eventually, thermal equilibrium is reached as the molecular collisions continue. The average kinetic energy of both substances is the same at thermal equilibrium.	235
e. Heat is not a substance, i.e., it makes no sense to say that an object contains a certain amount of heat. Rather, "heat exchange" or "transfer of energy as heat" refers to the process in which energy is transferred from a hot to a cold body in thermal contact.	257-260
f. The transfer of a given amount of thermal energy will not produce the same temperature change in equal masses of matter with differing specific heat capacities.	268

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.A 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.	
Learning Objective	**Reference**
(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]**	232-234; 251 Concept Review Question 5.70

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter	
Enduring Understanding 5.B. Energy is neither created nor destroyed, but only transformed from one form to another.	
Enduring Understanding 5.B.1. Energy is transferred between systems either through heat transfer or through one system doing work on the other system.	
Essential Knowledge Component	**Reference**
a. Heating a cold body with a hot body is a form of energy transfer between two systems. The	257

transfer of thermal energy is an important concept in thermodynamics.	
b. An additional form of energy transfer is through work. Work is described by other scientific frameworks, such as Newtonian Mechanics or electromagnetism.	247-260
c. In this course, calculations involving work are limited to that associated with changes in volume of a gas. An example of the transfer of energy between systems through work is the expansion of gas in a steam engine or car piston. Reasoning about this energy transfer can be based on molecular collisions with the piston: The gas is doing work on the piston, and energy is transferred from the gas to the piston.	263-264
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter	
Enduring Understanding 5.B. Energy is neither created nor destroyed, but only transformed from one form to another.	
Learning Objective	**Reference**
(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]**	263-264; 289 Skill Building Exercise 6.31
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.B. Energy is neither created nor destroyed, but only transformed from one form to another.	
Enduring Understanding 5.B.2. When two systems are in contact with each other and are otherwise isolated, the energy that comes out of one system is equal to the energy that goes into the other system. The combined energy of the two systems remains fixed. Energy transfer can occur through either heat exchange or work.	
Essential Knowledge Component	**Reference**
a. When energy is transferred from system 1 to system 2, the energy transferred from system 1 is equal in magnitude to the energy transferred to system 2.	261
b. If a system transfers energy to another system, its energy must decrease. Likewise, if energy is transferred into a system, its energy must increase.	261
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter	
Enduring Understanding 5.B. Energy is neither created nor destroyed, but only transformed from one form to another.	
Learning Objective	**Reference**
(LO) 5.4. The student is able to use conservation of energy to relate the magnitudes	261; 289 Skill Building Exercises 6.30

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, connects to 5.B.1, 5.B.2]**	
(LO) 5.5. 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 SP 2.2, connects to 5.B.1, 5.B.2]**	261; 289 Skill Building Exercises 6.45
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter	
Enduring Understanding 5.B. Energy is neither created nor destroyed, but only transformed from one form to another.	
Enduring Understanding 5.B.3. Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions.	
Essential Knowledge Component	**Reference**
a. Heating a system increases the energy of the system, while cooling a system decreases the energy. A liter of water at 50°C has more energy than a liter of water at 25°C.	257
b. The amount of energy needed to heat one gram of a substance by 1°C is the specific heat capacity of that substance.	268
c. Energy must be transferred to a system to cause it to melt (or boil). The energy of the system therefore increases as the system undergoes a solid-liquid (or liquid-gas) phase transition. Likewise, a system gives off energy when it freezes (or condenses). The energy of the system decreases as the system undergoes a liquid-solid (or gas-liquid) phase transition.	475-478
d. The amount of energy needed to vaporize one mole of a pure substance is the molar enthalpy of vaporization, and the energy released in condensation has an equal magnitude. The molar enthalpy of fusion is the energy absorbed when one mole of a pure solid melts or changes from the solid to liquid state and the energy released when the liquid solidifies has an equal magnitude	471-474
e. When a chemical reaction occurs, the energy of the system decreases (exothermic reaction), increases (endothermic reaction), or remains the same. For exothermic reactions, the energy lost by the reacting molecules (system) is gained by the surroundings. The energy is transferred to the surroundings by either heat or work. Likewise, for endothermic reactions, the system gains energy from the surroundings by heat transfer or work done on the system.	266-267

f. The enthalpy change of reaction gives the amount of energy released (for negative values) or absorbed (for positive values) by a chemical reaction at constant pressure.	266-267
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter	
Enduring Understanding5.B Energy is neither created nor destroyed, but only transformed from one form to another.	
Learning Objective	**Reference**
(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]**	266-267; 291 Skill Building Exercises 6.74
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.B. Energy is neither created nor destroyed, but only transformed from one form to another.	
Enduring Understanding 5.B.4. Calorimetry is an experimental technique that is used to determine the heat exchanged/transferred in a chemical system.	
Essential Knowledge Component	**Reference**
a. The experimental setup for calorimetry is the following: A chemical system is put in thermal contact with a heat bath. The heat bath is a substance, such as water, whose heat capacity has been well established by previous experiments. A process is initiated in the chemical system (heating/cooling, phase transition, or chemical reaction), and the change in temperature of the heat bath is determined.	268-273
b. Because the heat capacity of the heat bath is known, the observed change in temperature can be used to determine the amount of energy exchanged between the system and the heat bath.	268-273
c. The energy exchanged between the system and the heat bath is equal in magnitude to the change in energy of the system. If the heat bath increased in temperature, its energy increased, and the energy of the system decreased by this amount. If the heat bath decreased in temperature, and therefore energy, the energy of the system increased by this amount.	268-273
d. Because calorimetry measures the change in energy of a system, it can be used to determine the heat associated with each of the processes listed in 5.B.3. In this manner, calorimetry may be used to determine heat capacities,	268-273

enthalpies of vaporization, enthalpies of fusion, and enthalpies of reactions. Only constant pressure calorimetry is required in the course	
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.B. Energy is neither created nor destroyed, but only transformed from one form to another.	
Learning Objective	**Reference**
(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, 6.4]**	268-273; 289 Skill Building Exercises 6.47
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.C. Breaking bonds requires energy, and making bonds releases energy.	
Enduring Understanding 5.C.1. Potential energy is associated with a particular geometric arrangement of atoms or ions and the electrostatic interactions between them.	
Essential Knowledge Component	**Reference**
a. The attraction between the electrons of one atom and the protons of another explains the tendency for the atoms to approach one another. The repulsion between the nuclei (or core electrons) explains why the atoms repel one another at close distance. The distance at which the energy of interaction is minimized is called the bond length, and the atoms vibrate about this minimum energy position.	379
b. A graph of energy versus the distance between atoms can be plotted and interpreted. Using this graph, it is possible to identify bond length and bond energy.	379
c. Conceptually, bond making and bond breaking are opposing processes that have the same magnitude of energy associated with them. Thus, convention becomes important, so we define the bond energy as the energy required to break a bond.	380-383
d. Because chemical bonding arises from electrostatic interaction between electrons and nuclei, larger charges tend to lead to larger strengths of interaction. Thus, triple bonds are stronger than double or single bonds because they share more pairs of electrons.	380-383
e. Stronger bonds tend to be shorter bonds.	380-383

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.C. Breaking bonds requires energy, and making bonds releases energy.	
Learning Objective	**Reference**
(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]**	380-381; 401 Concept Review Questions 9.48

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.C. Breaking bonds requires energy, and making bonds releases energy.	
Enduring Understanding 5.C.2. The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.	
Essential Knowledge Component	**Reference**
a. During a chemical reaction, bonds are broken and/or formed, and these events change the potential energy of the reaction system.	386-390
b. The average energy required to break all of the bonds in the reactant molecules can be estimated by adding up the average bond energies or bond enthalpies for all the bonds in the reactant molecules. Likewise, the average energy released in forming the bonds in the products can be estimated. If the energy released is greater than the energy required, then the reaction is exothermic. If the energy required is greater than the energy released, then the reaction is endothermic.	386-390
c. For an exothermic reaction, the products are at a lower potential energy compared with the reactants. For an endothermic reaction, the products are at a higher potential energy than the reactants.	386-390
d. In an isolated system, energy is conserved. Thus, if the potential energy of the products is lower than that of the reactants, then the kinetic energy of the products must be higher. For an exothermic reaction, the products are at a higher kinetic energy. This means that they are at a higher temperature. Likewise, for an endothermic reaction, the products are at a lower kinetic energy and, thus, at a lower temperature.	386-390

e. Because the products of a reaction are at a higher or lower temperature than their surroundings, the products of the reaction move toward thermal equilibrium with the surroundings. Thermal energy is transferred to the surroundings from the hot products in an exothermic reaction. Thermal energy is transferred from the surroundings to the cold products in an endothermic reaction.	258-259
f. Although the concept of "state functions" is not required for the course, students should understand these Hess's law ideas: When a reaction is reversed, the sign of the enthalpy of the reaction is changed; when two (or more) reactions are summed to obtain an overall reaction, the enthalpies of reaction are summed to obtain the net enthalpy of reaction.	275-276
g. Tables of standard enthalpies of formation can be used to calculate the standard enthalpy of reactions. Uses should go beyond algorithmic calculations and include, for instance, the use of such tables to compare related reactions, such as extraction of elemental metals from metal oxides.	278-280

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.C. Breaking bonds requires energy, and making bonds releases energy.	
Learning Objective	**Reference**
(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]**	386-390; 401 Skill Building Exercises 9.46

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.D. Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.	
Enduring Understanding 5.D.1. Potential energy is associated with the interaction of molecules; as molecules draw near each other, they experience an attractive force.	
Essential Knowledge Component	**Reference**
a. Chemists categorize intermolecular forces in terms of the nature of the charge distributions in the molecules involved. Thus, dipole-dipole, dipole-induced dipole, and induced dipole-induced dipole (dispersion) can be defined.	484-490
b. All substances will manifest dispersion forces, and these forces tend to be larger when the molecules involved have more electrons or have a larger surface area.	488-489
c. Hydrogen bonding is a relatively strong type of intermolecular interaction that occurs when	486-487

hydrogen atoms that are covalently bonded to the highly electronegative atoms (N, O, and F) are also attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a different molecule, or a different part of the same molecule. When hydrogen bonding is present, even small molecules may have strong intermolecular attractions.	

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.

Enduring Understanding 5.D. Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.

Learning Objective	Reference
(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]**	386-390; 484-490; 527, Concept Review Question 12.33
(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]**	484-490; 527 Skill Building Exercise 12.39

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.

Enduring Understanding 5.D. Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.

Enduring Understanding 5.D.2. At the particulate scale, chemical processes can be distinguished from physical processes because chemical bonds can be distinguished from intermolecular interactions.

Essential Knowledge Component	Reference
a. The distinction between chemical and physical processes relates to the nature of the change in molecular interactions. Processes that involve the breaking and/or formation of chemical bonds are classified as chemical processes. Processes that involve only changes in weak intermolecular interactions, such as phase changes, are classified as physical processes.	5-7
b. A gray area exists between these two extremes. For instance, the dissolution of a salt in water involves breaking of ionic bonds and the formation of interactions between ions and solvent. The magnitude of these interactions	WebQuest 10

can be comparable to covalent bond strengths, and so plausible arguments can be made for classifying dissolution of a salt as either a physical or chemical process.	
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.D. Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.	
Learning Objective	**Reference**
(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]**	5-7; 37, Concept Review Question 1.1
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.D. Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.	
Essential Knowledge 5.D.3. Noncovalent and intermolecular interactions play important roles in many biological and polymer systems.	
Essential Knowledge Component	**Reference**
a. In large biomolecules, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule.	539-544
b. The functionality and properties of molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions. For example, the function of enzymes is dictated by their structure, and properties of synthetic polymers are modified by manipulating their chemical composition and structure.	431-432
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.D. Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.	
Learning Objective	**Reference**
(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]**	539-544; 576, Concept Review Question 13.17
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Essential Knowledge 5.E.1. Entropy is a measure of the dispersal of matter and energy.	
Essential Knowledge Component	**Reference**
a. Entropy may be understood in qualitative	547; 898

terms rather than formal statistical terms. Although this is not the most rigorous approach to entropy, the use of qualitative reasoning emphasizes that the goal is for students to be able to make predictions about the direction of entropy change, $\Delta S°$, for many typical chemical and physical processes.	
b. Entropy increases when matter is dispersed. The phase change from solid to liquid, or from liquid to gas, results in a dispersal of matter in the sense that the individual particles become more free to move, and generally occupy a larger volume. Another way in which entropy increases in this context is when the number of individual particles increases when a chemical reaction precedes whose stoichiometry results in a larger number of product species than reacting species. Also, for a gas, the entropy increases when there is an increase in volume (at constant temperature), and the gas molecules are able to move within a larger space.	547-549
c. Entropy increases when energy is dispersed. From KMT, we know that the distribution of kinetic energy among the particles of a gas broadens as the temperature increases. This is an increase in the dispersal of energy, as the total kinetic energy of the system becomes spread more broadly among all of the gas molecules. Thus, as temperature increases, the entropy increases.	898
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Learning Objective	**Reference**
(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]**	547; 898; 933 Concept Review Question 20.30
(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]**	547-549; 932 Skill Building Exercises 20.14

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Essential Knowledge 5.E.2. Some physical or chemical processes involve both a decrease in the internal energy of the components ($\Delta H^\circ < 0$) under consideration and an increase in the entropy of those components ($\Delta S^\circ > 0$). These processes are necessarily "thermodynamically favored" ($\Delta G^\circ < 0$).	
Essential Knowledge Component	**Reference**
a. For the purposes of thermodynamic analysis in this course, the enthalpy and the internal energy will not be distinguished.	258
b. The phrase "thermodynamically favored" means that products are favored at equilibrium (K > 1\])	922-924; 927-928
c. Historically, the term "spontaneous" has been used to describe processes for which $\Delta G^\circ < 0$. The phrase "thermodynamically favored" is used here to avoid misunderstanding and confusion that can occur because of the common connotation of the term "spontaneous," which students may believe means "immediately" or "without cause."	896
d. For many processes, students will be able to determine, either quantitatively or qualitatively, the signs of both ΔH° and ΔS° for a physical or chemical process. In those cases where $\Delta H^\circ < 0$ and $\Delta S^\circ > 0$, there is no need to calculate ΔG° in order to determine that the process is thermodynamically favored.	917
e. As noted below in 5.E.5, the fact that a process is thermodynamically favored does not mean that it will proceed at a measurable rate.	909
f. Any process in which both $\Delta H^\circ > 0$ and $\Delta S^\circ < 0$ are not thermodynamically favored, ($\Delta G^\circ > 0$) and the process must favor reactants at equilibrium ($K < 1$). Because the signs of $\Delta S^\circ$and ΔH° reverse when a chemical or physical process is reversed, this must be the case.	917
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Learning Objective	**Reference**
(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 ΔH° andΔS°, and calculation or estimation of ΔG° when needed. **[See SP 2.2, 2.3, 6.4, connects to 5.E.3]**	917; 934 Skill Building Exercises 20.55

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Essential Knowledge 5.E.3. If a chemical or physical process is not driven by both entropy and enthalpy changes, then the Gibbs free energy change can be used to determine whether the process is thermodynamically favored.	
Essential Knowledge Component	Reference
a. Some exothermic reactions involve decreases in entropy.	916-919
b. When $\Delta G° > 0$, the process is not thermodynamically favorable. When $\Delta G° < 0$, the process is thermodynamically favorable.	912-914
c. In some reactions, it is necessary to consider both enthalpy and entropy to determine if a reaction will be thermodynamically favorable. The freezing of water and the dissolution of sodium nitrate in water provide good examples of such situations.	916-917

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Learning Objective	Reference
(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, connects to 5.E.2]**	912-914; 934 Skill Building Exercises 20.55

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Essential Knowledge 5.E.4. External sources of energy can be used to drive change in cases where the Gibbs free energy change is positive.	
Essential Knowledge Component	Reference
a. Electricity may be used to cause a process to occur that is not thermodynamically favored. Useful examples are charging of a battery and the process of electrolysis.	944; 974-979
b. Light may also be a source of energy for driving a process that in isolation is not thermodynamically favored. Useful examples are as follows: 1. The photoionization of an atom, because although the separation of a negatively charged electron from the remaining positively charged ion is highly endothermic, ionization is observed to occur in conjunction with the absorption of a photon. 2. The overall conversion of carbon dioxide to glucose through photosynthesis, for which	299-301

6\space 6 CO_2 (g)+6 H_2O(l)→$C_6H_{12}O_6$ (aq) +6 O_2 (g) has ΔG° = +2880 kJ/mol rxn], yet is observed to occur through a multistep process that is initiated by the absorption of several photons in the range of 400-700 nm.	
c. A thermodynamically unfavorable reaction may be made favorable by coupling it to a favorable reaction, such as the conversion of ATP to ADP in biological systems. In this context, coupling means the process involves a series of reactions with common intermediates, such that the reactions add up to produce an overall reaction with a negative ΔG°.	920
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Learning Objective	Reference
(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]**	920; 922 Problem B20.2
(LO) 5.16. The student can use Le Chatelier'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, connects to 6.B.1]**	920; 936, Comprehensive Problem 20.99
(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, connects to 6.A.2]**	920; 936, Comprehensive Problem 20.99
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Essential Knowledge 5.E.5. A thermodynamically favored process may not occur due to kinetic constraints (kinetic vs. thermodynamic control).	
Essential Knowledge Component	Reference
a. Many processes that are thermodynamically favored do not occur to any measurable extent, or they occur at extremely slow rates.	909
b. Processes that are thermodynamically favored, but do not proceed at a measurable rate, are said to be under "kinetic control." High activation energy is a common reason for a process to be under kinetic control. The fact that a process does not proceed at a noticeable	909; 912-919

rate does not mean that the chemical system is at equilibrium. If a process is known to be thermodynamically favored (through qualitative and/or quantitative analysis of ΔH° and ΔS°), and yet it is not occurring at a measurable rate, then the conclusion is that the process is under kinetic control.	
Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.	
Enduring Understanding 5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	
Learning Objective	Reference
(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, connects to 6.D.1]**	920; 931, Concept Review Questions 20.1

Big Idea 6: 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.	
Enduring Understanding 6.A Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	
Essential Knowledge 6.A.1. In many classes of reactions, it is important to consider both the forward and reverse reaction.	
Essential Knowledge Component	**Reference**
a. Many readily observable processes are reversible. Examples include evaporating and condensing water, absorption of a gas, or dissolving and precipitating a salt. Relevant and interesting contexts include biological examples (binding of oxygen to hemoglobin and the attachment of molecules to receptor sites in the nose) and environmental examples (transfer of carbon between atmosphere and biosphere and transfer of dissolved substances between atmosphere and hydrosphere).	188-190; 472-478; 747-749
b. Dissolution of a solid, transfer of protons in acid-base reactions, and transfer of electrons in redox reactions are important examples of reversible reactions.	188-190

Big Idea 6: 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.	
Enduring Understanding 6.A. Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	
Learning Objective	**Reference**
(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]**	188-190; 472-478; 747-749; 201, Concept Review Questions 4.125

Big Idea 6: 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.	
Enduring Understanding 6.A Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	
Essential Knowledge 6.A.2. The current state of a system undergoing a reversible reaction can be characterized by the extent to which reactants have been converted to products. The relative quantities of reaction components are quantitatively described by the reaction quotient, Q.	
Essential Knowledge Component	**Reference**
a. Given an initial set of reactant and product concentrations, only those sets of concentrations that are consistent with the reaction stoichiometry can be attained. ICE (initial, change, equilibrium) tables are useful for	760-763

determining which sets of concentration values are possible.	
b. The reaction quotient, Q, provides a convenient measure of the current progress of a reaction. Q does not include substances whose concentrations are independent of the amount of substance, such as for a solid in contact with a liquid solution or with a gas, or for a pure solid or liquid in contact with a gas.	750-756
c. The value of Q (and so also K) changes when a reaction is reversed. When reactions are added together through the presence of a common intermediate, Q (and so also K) of the resulting reaction is a product of the values of Q (or K) for the original reactions.	753-756
Big Idea 6: 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.	
Enduring Understanding 6.A. Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	
Learning Objective	**Reference**
(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]**	753-756; 786, Problems in Context 17.24
Big Idea 6: 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.	
Enduring Understanding 6.A Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	
Essential Knowledge 6.A.3. When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point Q = K.	
Essential Knowledge Component	**Reference**
a. When equilibrium is reached, no observable changes occur in the system. 1. Reactant and product molecules are present. 2. Concentration of all species remains constant.	747-749
b. If the rate of the forward reaction is greater than the reverse reaction, there is a net conversion of reactants to products. If the rate of the reverse reaction is greater than the forward reaction, there is a net conversion of products to reactants. An equilibrium state is reached when these rates balance, at which point the progress of reaction, Q, becomes equal to the equilibrium constant, K.	748-749

c. Comparing Q to K allows the determination of whether the reaction is at equilibrium, or will proceed toward products or reactants to reach equilibrium.	757-758
d. Equilibrium constants can be determined from experimental measurements of the concentrations of the reactants and products at equilibrium.	750-756
e. Given a single reaction, initial concentrations, and K, the concentrations at equilibrium may be predicted.	763-764
f. Graphs of concentration over time for simple chemical reactions can be used to understand the establishment of chemical equilibrium.	751
Big Idea 6: 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.	
Enduring Understanding 6.A. Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	
Learning Objective	Reference
(LO) 6.3. The student can connect kinetics to equilibrium by using reasoning about equilibrium, such as Le Chatelier's principle, to infer the relative rates of the forward and reverse reactions. **[See SP 7.2]**	747-749; 785, Concept Review Questions 17.2
(LO) 6.4. The student can, given a set of initial conditions (concentrations or partial pressures) and the equilibrium constant, K, use 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]**	757-758; 786, Concept Review Questions 17.35
(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, 6.4]**	760-762; 788 Problems in Context 17.56
(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]**	750-756; 787 Skill Building Exercises 17.53

Big Idea 6: 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.	
Enduring Understanding 6.A Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	
Essential Knowledge 6.A.4. The magnitude of the equilibrium constant, K, can be used to determine whether the equilibrium lies toward the reactant side or product side.	
Essential Knowledge Component	**Reference**
a. For many aqueous reactions, K is either very large or very small, and this may be used to reason qualitatively about equilibrium systems.	749
b. Particulate representations can be used to describe the relationship between the numbers of reactant and product particles present at equilibrium, and the value of the equilibrium constant.	749

Big Idea 6: 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.	
Enduring Understanding 6.A. Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	
Learning Objective	**Reference**
(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]**	749; 789, Problems in Context 17.76

Big Idea 6: 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.	
Enduring Understanding 6.B. Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.	
Essential Knowledge 6.B.1. Systems at equilibrium respond to disturbances by partially countering the effect of the disturbance (Le Chatelier's principle).	
Essential Knowledge Component	**Reference**
a. Le Chatelier's principle can be used to predict the response of a system to the following stresses: addition or removal of a chemical species, change in temperature, change in volume/pressure of a gas phase system, and dilution of a reaction system with water or other solvent.	770-780
b. Le Chatelier's principle can be used to reason about the effects a stress will have on experimentally measurable properties, such as pH, temperature, and color of a solution.	770-780

Big Idea 6: 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.	
Enduring Understanding 6.B. Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.	
Learning Objective	**Reference**
(LO) 6.8. The student is able to use Le Chatelier'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**]	770-780; 788 Concept Review Questions 17.62
(LO) 6.9. The student is able to use Le Chatelier's principle to design a set of conditions that will optimize a desired outcome, such as product yield. [**See SP 4.2**]	770-780; 788 Skill Building Exercises 17.69

Big Idea 6: 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.	
Enduring Understanding 6.B. Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.	
Essential Knowledge 6.B.2. A disturbance to a system at equilibrium causes Q to differ from K, thereby taking the system out of the original equilibrium state. The system responds by bringing Q back into agreement with K, thereby establishing a new equilibrium state.	
Essential Knowledge Component	**Reference**
a. Le Chatelier's principle involves qualitative reasoning that is closely connected to the quantitative approach of 6.A.3.	770-780
b. Some stresses, such as changes in concentration, cause a change in Q. A change in temperature causes a change in K. In either case, the reaction shifts to bring Q and K back into equality.	770-780

Big Idea 6: 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.	
Enduring Understanding 6.B. Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.	
Learning Objective	**Reference**
(LO) 6.10. The student is able to connect Le Chatelier'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**]	770-780; 790 Comprehensive Problems 17.94

Big Idea 6: 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.	
Enduring Understanding 6.C. Chemical equilibrium plays an important role in acid-base chemistry and in solubility.	
Essential Knowledge 6.C.1. Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.	
Essential Knowledge Component	**Reference**
a. The concentrations of hydronium ion and	799-802

hydroxide ion are often reported as pH and pOH, respectively.	
b. Water autoionizes with an equilibrium constant, Kw. For pure water, pH = pOH, and this condition is called "neutrality," or a neutral solution. At 25°C, pKw = 14, and thus pH and pOH add to 14. In pure water at 25°C, pH = pOH = 7.	799-800
c. Common strong acids include HCl, HBr, HI, HClO4, H2SO4, and HNO3. The molecules of strong acids completely ionize in solution to produce hydronium ions. In other words, 100 percent of the molecules of the strong acid are ionized in a solution (assuming that the concentration is not extremely high). As such, the concentration of H3O+ in a strong acid solution is equal to the initial concentration of the strong acid, and thus the pH of the strong acid solution is easily calculated.	165; 801-802
d. Common strong bases include group I and II hydroxides. When dissolved in solution, strong bases completely dissociate to produce hydroxide ions. Note that some group II hydroxides are slightly soluble in water. However, 100 percent of the dissolved base is ionized.	165
e. Weak acid molecules react with water to transfer a proton to the water molecule. However, weak acid molecules only partially ionize in this way. In other words, only a small percentage of the molecules of a weak acid are ionized in a solution (assuming that the initial concentration is not extremely low). Thus, the concentration of H3O+ does not equal the initial concentration of the molecular acid, and the vast majority of the acid molecules remain un-ionized. A solution of a weak acid thus involves equilibrium between an un-ionized acid and its conjugate base. The equilibrium constant for this reaction is Ka, often reported as pKa. The pH of a weak acid solution can be determined from the initial acid concentration and the pKa. The common weak acids include carboxylic acids. The relative magnitudes of Ka's are influenced by structural factors such as bond strength, solvation, and electronegativity of the atom bonded to the labile proton.	165; 795-796; 808-811
f. The common weak bases include ammonia, amines and pyridines, other nitrogenous bases, and conjugate bases (defined below in g). Weak base molecules in aqueous solutions react with water molecules to produce hydroxide ions.	165; 818-823

However, only a small percentage of the molecules of a weak base in a solution ionize in this way (assuming that the initial concentration is not extremely low). Thus, the concentration of OH- in the solution does not equal the initial concentration of the molecular base, and the vast majority of the base molecules remain un-ionized. A solution of a weak base thus involves an equilibrium between an un-ionized base and its conjugate acid. The equilibrium constant for this reaction is Kb, often reported as pKb. The pH of a weak base solution can be determined from the initial base concentration and the pKb.	
g. When an acid molecule loses its proton, it becomes a base, since the resultant ion could react with water as a base. The acid and base are referred to as a conjugate acid-base pair. The ionization constants for the acid-base pair are related to Kw, and at 25°C, pKa + pKb= 14. This relation can be used to reason qualitatively about the relative strengths of conjugate acids and bases. For example, the conjugate base of a strong acid is a much weaker base than H2O, and therefore does not react as a base in aqueous solutions.	804; 811
h. The pH of an acid solution depends on both the strength of the acid and the concentration of the acid. If we compare solutions of a weak acid and of a strong acid at the same pH, we find that both solutions have the same concentration of H3O-(aq). However, the strong acid is completely dissociated into ions in solution, whereas the weak acid is only partially dissociated into ions in solution. Thus, there are vastly more un-ionized acid molecules in the weak acid solution than in the strong acid solution at the same pH. Thus, to achieve solutions of equal pH, the weak acid solution must be a much greater concentration than the strong acid solution. If we compare solutions of a weak acid and of a strong acid of the same initial concentration, the concentration of H3O+ in the strong acid solution is much larger (and the pH thus lower) since the strong acid is 100 percent ionized.	799-802
i. Reactions of acids and bases are called neutralization reactions, and these reactions generally have K > 1, and thus can be considered to go to completion. i. For a mixture of a strong acid with a strong base, the neutralization reaction is H3O+ + OH- →H2O. The K for this reaction is 10^14 at 25°C,	165-171; 799-802; 823-825

so the reaction goes to completion. This allows the pH of mixtures of strong acids and bases to be determined from the limiting reactant, either the acid or the base. ii. When a strong base is added to a solution of a weak acid, a neutralization reaction occurs: conjugate acid + OH-→conjugate base + H2O. iii. When a strong acid is added to a solution of a weak base, a neutralization reaction occurs: conjugate base + H3O+→conjugate acid + H2O.	
j. For a weak acid solution and a strong acid solution with the same pH, it takes much more base to neutralize the weak acid solution because the initial acid concentration is much larger. The weak acid solution contains a large amount of un-ionized acid molecules. Therefore, a weak acid solution resists changes in pH for a much greater amount of added base.	811-815
k. A titration technique exists for neutralization reactions. At the equivalence point, the moles of titrant and the moles of titrate are present in stoichiometric proportions. In the vicinity of the equivalence point, the pH rapidly changes. This can be used to determine the concentration of the titrant.	172-173; 853-857
l. As base is added to either a strong acid solution or a weak acid solution, the H3O+ (aq) concentration does not change much. The change in pH is less than ~1.5 for the region where 10 to 90 percent of the base needed to reach the equivalence point has been added.	172-173; 853-857
m. The pKa of an acid can be determined from the pH at the half equivalence point of the titration if the equivalence point is known (i.e., the concentration of both the titrant and analyte are known).	856
n. For polyprotic acids, the use of titration curves to evaluate the number of labile protons is important, as well as knowing which species are present in large concentrations at any region along the curve.	862-863
o. Halfway to the equivalence point, the contents of a solution, formed by titrating a weak acid, is different from that formed by titrating a strong acid. For a strong acid, the main species in a solution halfway to the equivalence point are H3O+(aq), the anion from the acid (e.g., Cl-, NO3-), and the cation from the base (e.g., Na+). The total positive charge is equal to the total negative charge. For a weak acid, the main species in a solution halfway to the equivalence point are H3O+(aq), the anion	853-860

from the acid (e.g., CH3COO-, F-), the cation from the base (e.g., Na+), and undissociated acid, HA. The total positive charge is equal to the total negative charge, and [HA] = [A-].	
Big Idea 6: 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.	
Enduring Understanding 6.C. Chemical equilibrium plays an important role in acid-base chemistry and in solubility.	
Learning Objective	Reference
(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]**	169; 801-802; 889, Concept Review Questions 19.40
(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, 6.4, connects to 1.E.2]**	165; 795-796; 808-811; 839, Comprehensive Problems 18.155
(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, 6.4, connects to 1.E.2]**	172-174; 853-860; 889, Concept Review Questions 19.43
(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]**	853-860; 835, Problems in Context 18.36
(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]**	165-171; 799-802; 823-825; 199 Skill Building Exercises 4.72
(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]**	165-171; 799-802; 823-825; 841 Comprehensive Problems 18.186

(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]**	165-171; 799-802; 823-825; 199, Skill Building Exercise 4.68
Big Idea 6: 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.	
Enduring Understanding 6.C. Chemical equilibrium plays an important role in acid-base chemistry and in solubility.	
Essential Knowledge 6.C.2. The pH is an important characteristic of aqueous solutions that can be controlled with buffers. Comparing pH to pKa allows one to determine the protonation state of a molecule with a labile proton.	
Essential Knowledge Component	**Reference**
a. A buffer solution contains a large concentration of both members in a conjugate acid-base pair. The conjugate acid reacts with added base and the conjugate base reacts with added acid. The pH of the buffer is related to the pKa and the concentration ratio of acid and base forms. The buffer capacity is related to absolute concentrations of the acid and base forms. These relationships can be used both quantitatively and qualitatively to reason about issues such as the ratio of acid to base forms in a given buffer, the impact of this on the buffer capacity for added acid or base, and the choice of an appropriate conjugate acid-base pair for a desired buffer pH (including polyprotic acids).	843-850
b. If [A-]/[HA] starts as 1, it is not until the ratio changes by a factor of 10 that a 1 pH unit change occurs; adding small amounts of either acid or base does not change the ratio much, so the pH changes are much smaller for buffers than unbuffered solutions.	848-849
c. Weak acids and their conjugate bases make good buffers. Strong acids and bases do not. It takes much more base to change the pH of a weak acid solution because there is a large reservoir of undissociated weak acid.	842-846
d. By comparing the pH of a solution to the pKa of any acid in the solution, the concentration ratio between the acid and base forms of that acid (the protonation state) can be determined. For example, if pH < pKa, the acid form has a higher concentration than the base form. If pH > pKa, the base form has a higher concentration than the acid form. Applications of this relationship include the use of acid-base indicators, the protonation state of protein side	842-846; 851

chains (including acids or proteins with multiple labile protons), and the pH required for acid-catalyzed reactions in organic chemistry.	
Big Idea 6: 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.	
Enduring Understanding 6.C. Chemical equilibrium plays an important role in acid-base chemistry and in solubility.	
Learning Objective	**Reference**
(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]**	842-846; 851; 887, Concept Review Questions 19.7
(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]**	842-846; 841, Comprehensive Problems 18.186
(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]**	842-846; 888, Concept Review Question 19.10
Big Idea 6: 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.	
Enduring Understanding 6.C. Chemical equilibrium plays an important role in acid-base chemistry and in solubility.	
Essential Knowledge 6.C.3. The solubility of a substance can be understood in terms of chemical equilibrium.	
Essential Knowledge Component	**Reference**
a. The dissolution of a substance in a solvent is a reversible reaction, and so has an associated equilibrium constant. For dissolution of a salt, the reaction quotient, Q, is referred to as the solubility product, and the equilibrium constant for this reaction is denoted as Ksp, the solubility-product constant.	864-866
b. The solubility of a substance can be calculated from the Ksp for the dissolution reaction. This relation can also be used to reason qualitatively about the relative solubility of different substances.	867-868

c. The free energy change ($\Delta G°$) for dissolution of a substance reflects both the breaking of the forces that hold the solid together and the interaction of the dissolved species with the solvent. In addition, entropic effects must be considered. Qualitative reasoning regarding solubility requires consideration of all of these contributions to the free energy.	547-549
d. All sodium, potassium, ammonium, and nitrate salts are soluble in water.	159
e. A salt is less soluble in a solution that has an ion in common with the salt. This has important consequences for solubility of salts in sea water and other natural bodies of water. This phenomenon can be understood qualitatively using Le Chatelier's principle.	866-871
f. The solubility of a salt will be pH sensitive when one of the ions is an acid or base. Applications include the iron hydroxides of acid-mine drainage and the effects of acid rain on solubility of carbonates. These effects can be understood qualitatively with Le Chatelier's principle.	869-870
Big Idea 6: 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.	
Enduring Understanding 6.C. Chemical equilibrium plays an important role in acid-base chemistry and in solubility.	
Learning Objective	**Reference**
(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]**	864-871; 890 Skill Building Exercise 19.75
(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]**	864-871; 890 Skill Building Exercise 19.74
(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, 6.4]**	864-871; 890 Skill Building Exercise 19.78
(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, connects to 5.E]**	864-871; 577, Concept Review Questions 13.29

Big Idea 6: 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.	
Enduring Understanding 6.D. The equilibrium constant is related to temperature and the difference in Gibbs free energy between reactants and products.	
Essential Knowledge 6.D.1. When the difference in Gibbs free energy between reactants and products ($\Delta G°$) is much larger than the thermal energy (RT), the equilibrium constant is either very small (for $\Delta G° > 0$) or very large (for $\Delta G° < 0$). When $\Delta G°$ is comparable to the thermal energy (RT), the equilibrium constant is near 1.	
Essential Knowledge Component	**Reference**
a. The free energy change for a chemical process in which all of the reactants and products are present in a standard state (as pure substances, as solutions of 1 molar concentration, or as gases at a pressure of 1 bar, or 1 atm) is given a particular symbol, $\Delta G°$.	913
b. The equilibrium constant is related to free energy by $K = e^{-\Delta G°/RT}$. This relation may be used to connect thermodynamic reasoning about a chemical process to equilibrium reasoning about this process. This reasoning can be done quantitatively through numerical examples or qualitatively through estimation. For example, the thermal energy (RT) at room temperature is 2.4 kJ/mol. This sets the energy scale for relating the enthalpy and entropy changes to the magnitude of K, since when the magnitude of $\Delta G°$ is large compared to the thermal energy, then K deviates strongly from 1.	922-924; 927-928
c. The relation $K = e^{-\Delta G°/RT}$ provides a refinement of the statement in 5.E that processes with $\Delta G° < 0$ favor products, while those with $\Delta G° > 0$favor reactants. If $\Delta G° < 0$, then $K > 1$, while if $\Delta G° > 0$, then $K < 1$. The phrase "favors products" in 5.E is therefore more precisely stated as $K > 1$, while "favors reactants" in 5.E is more precisely stated as $K < 1$.	922-928
d. Since K is directly related to free energy, when the magnitude of K is of primary interest, it is useful to consider whether a reaction is exergonic ($\Delta G° < 0$) or endergonic ($\Delta G° > 0$). (Exothermic versus endothermic is the useful distinction when the issue of interest is whether a reaction releases or consumes energy.) In many biological applications, the magnitude of K is of central importance, and so the exergonic/endergonic distinction is useful.	922-928

Big Idea 6: 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.	
Enduring Understanding 6.D. The equilibrium constant is related to temperature and the difference in Gibbs free energy between reactants and products.	
Learning Objective	**Reference**
(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]**	922-928; 934, Skill Building Exercises 20.67

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.	
Science Practice Component	**Reference**
1.1 The student can *create representations and models* of natural or man-made phenomena and systems in the domain.	Test Bank, Chapter 13, Free-Response Question
1.2 The student can *describe representations and models* of natural or man-made phenomena and systems in the domain.	Test Bank, Chapter 13, Question 13-10
1.3 The student can *refine representation and models* of natural or man-made phenomena and systems in the domain.	Test Bank, Chapter 20, Question 20-2
1.4 The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively.	Test Bank, Chapter 17, Question 17-6
1.5 The student can *reexpress key elements* of natural phenomena across multiple representations in the domain.	Test Bank, Chapter 8, Question 8-1
Science Practice 2: The student can use mathematics appropriately.	
Science Practice Component	**Reference**
2.1 The student can *justify the selection of a mathematical routine* to solve problems.	Test Bank, Chapter 2, Question 2-1
2.2 The student can *apply mathematical routines* to quantities that describe natural phenomena.	Test Bank, Chapter 21, Question 21-7
2.3 The student can *estimate numerically* quantities that describe natural phenomena.	Test Bank, Chapter 13, Question 13-1
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.	
Science Practice Component	**Reference**
3.1 The student can *pose scientific questions*.	Test Bank, Chapter 14, Questions 14-9
3.2 The student can *refine scientific questions.*	326, Concept Review Question 7.46
3.3 The student can *evaluate scientific questions.*	1033, Comprehension Problem 22.66

Science Practice 4: The student can plan and implement data collection strategies appropriate to a particular scientific question.	
Science Practice Component	**Reference**
4.1 The student can *justify the selection of the kind of data* needed to answer a particular scientific question.	Test Bank, Chapter 8, Free-Response Question
4.2 The student can *design a plan* for collecting data to answer a particular scientific question.	Test Bank, Chapter 2, Question 2-10
4.3 The student can *collect data* to answer a particular scientific question.	202, Comprehensive Problem 4.145
4.4 The student an *evaluate sources of data* to answer a particular scientific question.	581, Comprehensive Problem 13.142
Science Practice 5: The student can perform data analysis and evaluation of evidence.	
Science Practice Component	**Reference**
5.1 The student can *analyze data* to identify patterns or relationships.	Test Bank, Chapter 15, Question 15-7
5.2 The student can *refine observations and measurements* based on data analysis.	37, Concept Review Question 1.14
5.3 The student can *evaluate the evidence provided by data sets* in relation to a particular scientific question.	88, Concept Review Question 2.35
Science Practice 6: The student can work with scientific explanations and theories	
Science Practice Component	**Reference**
6.1 The student can *justify claims with evidence.*	Test Bank, Chapter 14, Question 14-4
6.2 The student can *construct explanations of phenomena based on evidence* produced through scientific practices.	Test Bank, Chapter 12, Question 12-2
6.3 The student can *articulate the reasons that scientific explanations and theories are refined or replaced.*	Test Bank, Chapter 7, Free-Response Question
6.4 The student can *make claims are predictions about natural phenomena* based on scientific theories and models.	Test Bank, Chapter 1, Question 1-6
6.5 The student can *evaluate alternative scientific explanations.*	743, Comprehensive Problem 16.110
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains	
Science Practice Component	**Reference**
7.1 The student can *connect phenomena and models* across spatial and temporal scales.	Test Bank, Chapter 16, Question 16-8
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.	Test Bank, Chapter 17, Question 17-1