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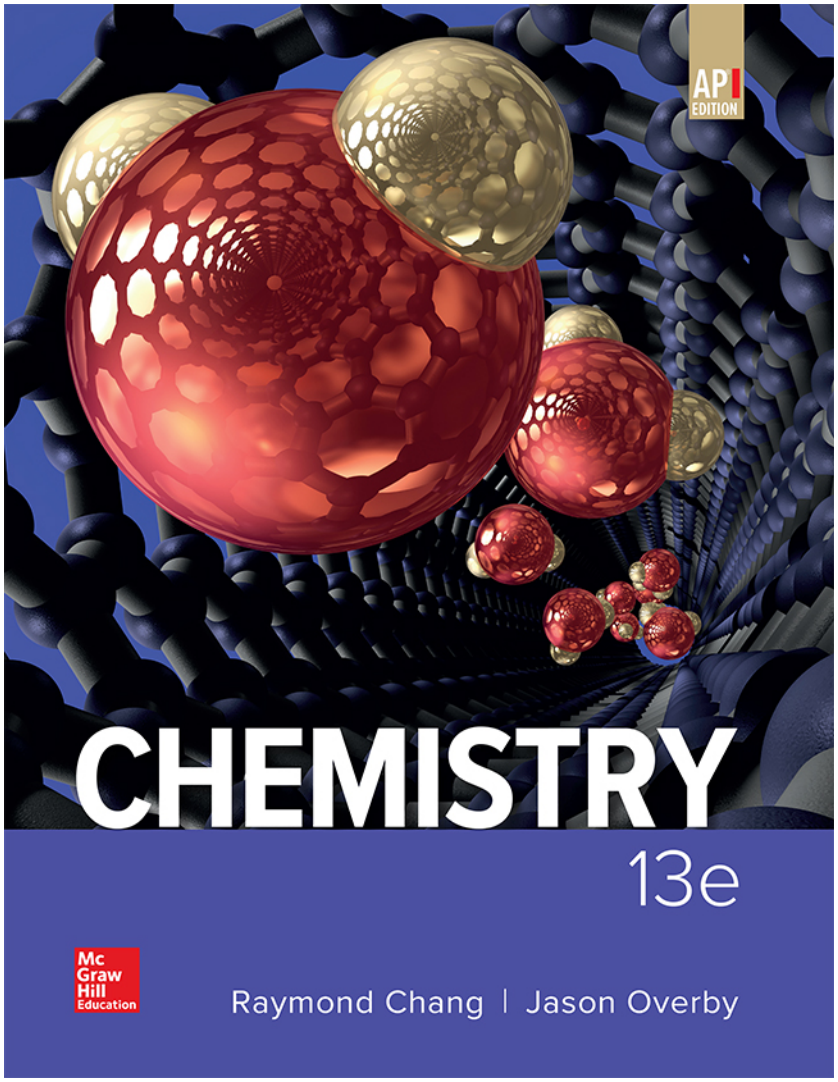
CORRELATION GUIDE

Chemistry



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13th Edition, © 2019
ISBN 978-0-07-681214-1

Based on College Board Course Framework:
AP Chemistry, Effective Fall 2019

Unit 1: Atomic Structure and Properties 7-9%

Topic Name	Enduring Understanding and Big Idea	Learning Objective	Essential Knowledge	Chapter	Page Numbers	Science Practices and Skills	Page Numbers	Reasoning Process	Page Numbers
1.1: Moles and Molar Mass	**SPQ-1:** The mole allows different units to be compared.	**SPQ-1.A:** Calculate quantities of a substance or its relative number of particles using dimensional analysis and the mole concept.	**SPQ-1.A.1:** One cannot count particles directly while performing laboratory work. Thus, there must be a connection between the masses of substances reacting and the actual number of particles undergoing chemical changes.	Chapter 3, Chapter 4, Chapter 5, Chapter 16	79-80, 82, 98-102; 151-159; 195-197; 724-733	**5.B:** Identify an appropriate theory, definition, or mathematical relationship to solve a problem.	81-82	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	111, Questions 3.13-3.30
			SPQ-1.A.2: Avogadro's number (N_A = 6.022 × 10^{23} mol^{-1}) provides the connection between the number of moles in a pure sample of a substance and the number of constituent particles (or formula units) of that substance.	Chapter 3, Chapter 5	81-82, 98-101; 195-197				
			SPQ-1.A.3: Expressing the mass of an individual atom or molecule in atomic mass units (amu) is useful because the average mass in amu of one particle (atom or molecule) or formula unit of a substance will always be numerically equal to the molar mass of that substance in grams. Thus, there is a quantitative connection between the mass of a substance and the number of particles that the substance contains. EQN: $n = m/M$	Chapter 3	83-86				
1.2 Mass Spectroscopy of Elements		**SPQ-1.B:** Explain the quantitative relationship between the mass spectrum of an element and the masses of the element's isotopes.	**SPQ-1.B.1:** The mass spectrum of a sample containing a single element can be used to determine the identity of the isotopes of that element and the relative abundance of each isotope in nature.	Chapter 3	87-88	**5.D:** Identify information presented graphically to solve a problem.	88	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	111, Questions 3.33-3.34
			SPQ-1.B.2: The average atomic mass of an element can be estimated from the weighted average of the isotopic masses using the mass of each isotope and its relative abundance. X Interpreting mass spectra of samples containing multiple elements or peaks arising from species other than singly charged monatomic ions will not be assessed on the AP Exam.	Chapter 3	88, AP120				

1.3 Elemental Composition of Pure Substances	**SPQ-2:** Chemical formulas identify substances by their unique combination of atoms.	**SPQ-2.A:** Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance.	**SPQ-2.A.1:** Some pure substances are composed of individual molecules, while others consist of atoms or ions held together in fixed proportions as described by a formula unit.	Chapter 2, Chapter 11	52-57; 482-487	**2.A:** Identify a testable scientific question based on an observation, data, or a model.	92	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	111-112, Questions 3.43-3.44
			SPQ-2.A.2: According to the law of definite proportions, the ratio of the masses of the constituent elements in any pure sample of that compound is always the same.	Chapter 2	42				
			SPQ-2.A.3: The chemical formula that lists the lowest whole number ratio of atoms of the elements in a compound is the empirical formula.	Chapter 2, Chapter 3	55-56; 91-92				
1.4 Composition of Mixtures		**SPQ-2.B:** Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture.	**SPQ-2.B.1:** While pure substances contain molecules or formula units of a single type, mixtures contain molecules or formula units of two or more types, whose relative proportions can vary.	Chapter 1, Chapter 4, Chapter 5, Chapter 21, Chapter 23	4-6; 147-153; 197-203; 928; 1004	**5.A:** Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).	88-89	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	111, Questions 3.31, 3.38
			SPQ-2.B.2: Elemental analysis can be used to determine the relative numbers of atoms in a substance and to determine its purity.	Chapter 3, Chapter 4	88-89; 151-152				
1.5 Atomic Structure and Electron Configuration	**SAP-1:** Atoms and molecules can be identified by their electron distribution and energy.	**SAP-1.A:** Represent the electron configuration of an element or ions of an element using the Aufbau principle.	**SAP-1.A.1:** The atom is composed of negatively charged electrons and a positively charged nucleus that is made of protons and neutrons.	Chapter 2, Chapter 7	43-47; 282-287	**1.A:** Describe the components of and quantitative information from models and representations that illustrate particulate-level properties only.	339-342	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	360, Questions 8.53-8.57
			SAP-1.A.2: Coulomb's law is used to calculate the force between two charged particles. EQN: F_coulombic∝(q_1 q_2)/r^2	Chapter 8, Chapter 9, Chapter 19	333-338, 339-345; 371-375; 859-860				
			SAP-1.A.3: In atoms and ions, the electrons can be thought of as being in "shells (energy levels)" and "subshells (sublevels)," as described by the electron configuration. Inner electrons are called core electrons, and outer electrons are called valence electrons. The electron configuration is explained by quantum mechanics, as delineated in the Aufbau principle and exemplified in the periodic table of the elements. ✗ The assignment of quantum numbers to electrons in subshells of an atom will not be assessed on the AP Exam. Rationale: Assignment of quantum numbers to electrons in specific subshells does not increase students' understanding of the structure of the atom.	Chapter 7, Chapter 8, Chapter 9, Chapter 10	287-313, 301-308; 331-333; 367-368; 443-447				

			SAP-1.A.4: The relative energy required to remove an electron from different subshells of an atom or ion or from the same subshell in different atoms or ions (ionization energy) can be estimated through a qualitative application of Coulomb's law. This energy is related to the distance from the nucleus and the effective (shield) charge of the nucleus.	Chapter 8	339-343				
1.6 Photoelectron Spectroscopy		**SAP-1.B:** Explain the relationship between the photoelectron spectrum of an atom or ion and- a. The electron configuration of the species. b. The interactions between the electrons and the nucleus.	**SAP-1.B.1:** The energies of the electrons in a given shell can be measured experimentally with photoelectron spectroscopy (PES). The position of each peak in the PES spectrum is related to the energy required to remove an electron from the corresponding subshell, and the height of each peak is (ideally) proportional to the number of electrons in that subshell.	Chapter 7	279-281 *see additional online activity	**4.B:** Explain whether a model is consistent with chemical theories.	279-281, 340 *see additional online activity	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	315, Question 7.29; 359, Question 8.49
1.7 Periodic Trends	**SAP-2: T**he periodic table shows patterns in electronic structure and trends in atomic properties.	**SAP-2.A:** Explain the relationship between trends in atomic properties of elements and electronic structure and periodicity.	**SAP-2.A.1:** The organization of the periodic table is based on the recurring properties of the elements and explained by the pattern of electron configurations and the presence of completely or partially filled shells (and subshells) of electrons in atoms. ✗ Writing the electron configuration of elements that are exceptions to the Aufbau principle will not be assessed on the AP Exam. Rationale: The mere rote recall of the exceptions does not match the goals of the curriculum revision.	Chapter 2, Chapter 8	50-52; 327-333	**4.A:** Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.	333-346	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	359-360, Questions 8.37, 8.43, 8.53, 8.62
			SAP-2.A.2: Trends in atomic properties within the periodic table (periodicity) can be qualitatively understood through the position of the element in the periodic table, Coulomb's law, the shell model, and the concept of shielding/effective nuclear charge. These properties include- a. Ionization energy b. Atomic and ionic radii c. Electron affinity d. Electronegativity	Chapter 8	333-346				
			SAP-2.A.3: The periodicity (in SAP-2.A.2) is useful to predict /estimate values of properties in the absence of data.	Chapter 8	333-346				

1.8 Valence Electrons and Ionic Compounds		**SAP-2.B:** Explain the relationship between trends in the reactivity of elements and periodicity.	**SAP-2.B.1:** The likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of elements.	Chapter 2, Chapter 8	52-57; 331, 346-354	**4.C:** Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.	50-57; 332-333	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	71, Question 2.10; 74, Questions 2.87, 2.93
			SAP-2.B.2: Elements in the same column of the periodic table tend to form analogous compounds.	Chapter 2, Chapter 21, Chapter 22	50-52; 938, 942; 981				
			SAP-2.B.3: Typical charges of atoms in ionic compounds are governed by their location on the periodic table and the number of valence electrons.	Chapter 2, Chapter 8, Chapter 9, Chapter 21, Chapter 22	52-53; 332-333; 368-370; 937-938, 942, 944; 981				

Unit 2: Molecular and Ionic Compound Structure and Properties 7-9%

Topic Name	Enduring Understanding and Big Idea	Learning Objective	Essential Knowledge	Chapter	Page Numbers	Science Practices and Skills	Page Numbers	Reasoning Process	Page Numbers
2.1 Types of Chemical Bonds	**SAP-3:** Atoms or ions bond due to interactions between them, forming molecules.	**SAP-3.A:** Explain the relationship between the type of bonding and the properties of the elements participating in the bond.	**SAP-3.A.1:** 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.	Chapter 9	378-379	**6.A:** Make a scientific claim.	379-380; 487-488	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	401, Question 9.7; 402, Question 9.32
			SAP-3.A.2: Valence electrons shared between atoms of similar electronegativity constitute a nonpolar covalent bond. For example, bonds between carbon and hydrogen are effectively nonpolar even though carbon is slightly more electronegative than hydrogen.	Chapter 2, Chapter 9, Chapter 10	54-55; 375-377, 379-380; 421-426				
			SAP-3.A.3: Valence electrons shared between atoms of unequal electronegativity constitute a polar covalent bond. a. The atom with a higher electronegativity will develop a partial negative charge relative to the other atom in the bond. b. In single bonds, greater differences in electronegativity lead to greater bond dipoles. c. All polar bonds have some ionic character, and the difference between ionic and covalent bonding is not distinct but rather a continuum.	Chapter 2, Chapter 9, Chapter 10	54-55; 379-380; 421-426				

			SAP-3.A.4: The difference in electronegativity is not the only factor in determining if a bond should be designated as ionic or covalent. Generally, bonds between a metal and nonmetal are ionic, and bonds between two nonmetals are covalent. Examination of the properties of a compound is the best way to characterize the type of bonding.	Chapter 8, Chapter 9	339-346; 379-380				
			SAP-3.A.5: In a metallic solid, the valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom.	Chapter 11, Chapter 21	487-488; 935-936				
2.2 Intramolecular Force and Potential Energy		**SAP-3.B:** Represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength.	**SAP-3.B.1:** A graph of potential energy versus the distance between atoms is a useful representation for describing the interactions between atoms. Such graphs illustrate both the equilibrium bond length (the separation between atoms at which the potential energy is lowest) and the bond energy (the energy required to separate the atoms).	Chapter 9, Chapter 10	377; 426-428	**3.A:** Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.	370-377	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	402, Questions 9.19, 9.21, 9.23
			SAP-3.B.2: In a covalent bond, the bond length is influenced by both the size of the atom's core and the bond order (i.e., single, double, triple). Bonds with a higher order are shorter and have larger bond energies.	Chapter 9	375-377, 395-400				
			SAP-3.B.3: Coulomb's law can be used to understand the strength of interactions between cations and anions. a. Because the interaction strength is proportional to the charge on each ion, larger charges lead to stronger interactions. b. Because the interaction strength increases as the distance between the centers of the ions (nuclei) decreases, smaller ions lead to stronger interactions.	Chapter 6, Chapter 8, Chapter 9	260; 336-337; 370-375				

2.3 Structure of Ionic Solids		**SAP-3.C:** Represent an ionic solid with a particulate model that is consistent with Coulomb's law and the properties of the constituent ions.	**SAP-3.C.1:** 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. ✗Knowledge of specific types of crystal structures will not be assessed on the AP Exam. Rationale: Study of specific crystal structures is not essential to an understanding of the big ideas.	Chapter 11	482-486	**4.C:** Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.	482-486	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	506, Questions 11.33, 11.34
2.4 Structure of Metals and Alloys		**SAP-3.D:** Represent a metallic solid and/or alloy using a model to show essential characteristics of the structure and interactions present in the substance.	**SAP-3.D.1:** Metallic bonding can be represented as an array of positive metal ions surrounded by delocalized valence electrons (i.e., a "sea of electrons").	Chapter 11, Chapter 21	487; 935-936	**4.C:** Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.	487; 935-937	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	506, Question 11.50; 949, Question 21.28, 950, Question 21.55
			SAP-3.D.2: Interstitial alloys form between atoms of different radii, where the smaller atoms fill the interstitial spaces between the larger atoms (e.g., with steel in which carbon occupies the interstices in iron).	Chapter 21	930-933				
			SAP-3.D.3: Substitutional alloys form between atoms of comparable radius, where one atom substitutes for the other in the lattice. (In certain brass alloys, other elements, usually zinc, substitute for copper.)	Chapter 21	928				

Unit 3: Intermolecular Forces and Properties 18-22%

Topic Name	Enduring Understanding and Big Idea	Learning Objective	Essential Knowledge	Chapter	Page Numbers	Science Practices and Skills	Page Numbers	Reasoning Process	Page Numbers
3.1 Intermolecular Forces	**SAP-5:** Intermolecular forces can explain the physical properties of a material.	**SAP-5.A:** Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when- a. The molecules are of the same chemical species. b. The molecules are of two different chemical species.	**SAP-5.A.1:** London dispersion forces are a result of the Coulombic interactions between temporary, fluctuating dipoles. London dispersion forces are often the strongest net intermolecular force between large molecules. a. Dispersion forces increase with increasing contact area between molecules and with increasing polarizability of the molecules. b. The polarizability of a molecule increases with an increasing number of electrons in the molecule; and the size of the electron cloud. It is enhanced by the presence of pi bonding. c. The term “London dispersion forces” should not be used synonymously with the term “van der Waals forces.”	Chapter 11, Chapter 25	464-466; 1065	**4.D:** Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.	464-465, 467-469	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	505, Questions, 11.5, 11.7-11.20; 506, Questions 11.31-11.32

			SAP-5.A.2: The dipole moment of a polar molecule leads to additional interactions with other chemical species. a. Dipole-induced dipole interactions are present between a polar and nonpolar molecule. These forces are always attractive. The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule. b. Dipole-dipole interactions are present between polar molecules. The interaction strength depends on the magnitudes of the dipoles and their relative orientation. Interactions between polar molecules are typically greater than those between nonpolar molecules of comparable size because these interactions act in addition to London dispersion forces. c. Ion-dipole forces of attraction are present between ions and polar molecules. These tend to be stronger than dipole-dipole forces.	Chapter 10, Chapter 11, Chapter 12, Chapter 24	421; 464-465; 516; 1032				
			SAP-5.A.3: The relative strength and orientation dependence of dipole-dipole and ion-dipole forces can be understood qualitatively by considering the sign of the partial charges responsible for the molecular dipole moment, and how these partial charges interact with an ion or with an adjacent dipole.	Chapter 11	464-465				
			SAP-5.A.4: Hydrogen bonding is a strong type of intermolecular interaction that exists when hydrogen atoms covalently bonded to the highly electronegative atoms (N, O, and F) are 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.	Chapter 11	467-469, 470-473, 494-495				
			SAP-5.A.5: In large biomolecules, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule.	Chapter 25	1065, 1073				

3.2 Properties of Solids		**SAP-5.B:** Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.	**SAP-5.B.1:** Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present. Because intermolecular interactions are broken when a substance vaporizes, the vapor pressure and boiling point are directly related to the strength of those interactions. Melting points also tend to correlate with interaction strength, but because the interactions are only rearranged, in melting, the relations can be more subtle.	Chapter 11	490-497	**4.C:** Explain the connection between particulate-level and macroscopic properties of a substance using models and representations	464-497	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	506-507, Questions 11.51-11.56, 11.63-11.64, 11.79, 11.83; 509, Questions 11.112, 11.115
			SAP-5.B.2: Particulate-level representations, showing multiple interacting chemical species, are a useful means to communicate or understand how intermolecular interactions help to establish macroscopic properties.	Chapter 4, Chapter 11, Chapter 12, Chapter 15, Chapter 25	124-125; 464-465, 468-469, 473; 516; 670; 1065, 1070				
			SAP-5.B.3 Due to strong interactions between ions, ionic solids tend to have low vapor pressures, high melting points, and high boiling points. They tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer. They conduct electricity only when the ions are mobile, as when the ionic solid is melted or dissolved in water or another solvent.	Chapter 4, Chapter 5, Chapter 9, Chapter 11, Chapter 12	122-124; 175; 370-375, 377; 482-486; 538-540				
			SAP-5.B.4: In covalent network solids, the atoms are covalently bonded together into a three-dimensional network (e.g., diamond) or layers of two-dimensional networks (e.g., graphite). These are only formed from nonmetals: elemental (e.g., diamond, graphite) or binary compounds of two nonmetals (e.g., silicon dioxide and silicon carbide). Due to the strong covalent interactions, covalent solids have high melting points. Three-dimensional network solids are also rigid and hard, because the covalent bond angles are fixed. However, graphite is soft because adjacent layers can slide past each other relatively easily.	Chapter 11	486-487				

			SAP-5.B.5: Molecular solids are composed of distinct, individual units of covalently-bonded molecules attracted to each other through relatively weak intermolecular forces. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. They do not conduct electricity because their valence electrons are tightly held within the covalent bonds and the lone pairs of each constituent molecule. Molecular solids are sometimes composed of very large molecules or polymers.	Chapter 5, Chapter 9, Chapter 11, Chapter 25	175-176; 375-377; 486-487; 1055-1060				
			SAP-5.B.6: Metallic solids are good conductors of electricity and heat, due to the presence of free valence electrons. They also tend to be malleable and ductile, due to the ease with which the metal cores can rearrange their structure. In an interstitial alloy, interstitial atoms tend to make the lattice more rigid, decreasing malleability and ductility. Alloys typically retain a sea of mobile electrons and so remain conducting.	Chapter 11, Chapter 21	487; 928, 930-933, 935-936				
			SAP-5.B.7: In large biomolecules or polymers, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule. The functionality and properties of such molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions.	Chapter 24, Chapter 25	1042-1043; 1064-1065, 1070-1071				
3.3 Solids, Liquids, and Gases	**SAP-6:** Matter exists in three states: solid, liquid, and gas, and their differences are influenced by variances in spacing and motion of the molecules.	**SAP-6.A:** Represent the differences between solid, liquid, and gas phases using a particulate-level model.	**SAP-6.A.1:** Solids can be crystalline, where the particles are arranged in a regular three-dimensional 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 overall translation with respect to each other. The structure of the solid is influenced by interparticle interactions and the ability of the particles to pack together.	Chapter 1, Chapter 11	8-9; 474-479, 482-489	**3.C:** Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).	8-9; 474-478, 482-486	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	505, Questions 11.21, 11.23; 506, Question 11.29; 507, Question 11.57

			SAP-6.A.2: The constituent particles in liquids are in close contact with each other, and they are continually moving and colliding. The arrangement and movement of particles are influenced by the nature and strength of the forces (e.g., polarity, hydrogen bonding, and temperature) between the particles.	Chapter 1, Chapter 11	8-9; 469-474				
			SAP-6.A.3: The solid and liquid phases for a particular substance typically have similar molar volume because, in both phases, the constituent particles are in close contact at all times.	Chapter 1, Chapter 11	8-9; 496-497				
			SAP-6.A.4: In the gas phase, the particles are in constant motion. Their frequencies of collision and the average spacing between them are dependent on temperature, pressure, and volume. Because of this constant motion, and minimal effects of forces between particles, a gas has neither a definite volume nor a definite shape. ✗ Understanding/interpreting phase diagrams will not be assessed on the AP Exam. Rationale: Phase diagrams of pure substances are considered prior knowledge.	Chapter 1, Chapter 5	8-9; 177, 204-205				
3.4 Ideal Gas Law	**SAP-7:** Gas properties are explained macroscopically—using the relationships among pressure, volume, temperature, moles, gas constant—and molecularly by the motion of the gas.	**SAP-7.A:** Explain the relationship between the macroscopic properties of a sample of gas or mixture of gases using the ideal gas law.	**SAP-7.A.1:** The macroscopic properties of ideal gases are related through the ideal gas law- EQN: PV = nRT.	Chapter 5, Chapter 14	186-197, 211-214; 621, 640-641	**5.C:** Explain the relationship between variables within an equation when one variable changes.	186-188, 197-201	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	217-218, Questions 5.31-5.52
			SAP-7.A.2: In a sample containing a mixture of ideal gases, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the total pressure of the sample is the sum of the partial pressures. EQN: PA = Ptotal × XA, where XA = moles A/total moles; EQN: Ptotal = PA + PB + PC +…	Chapter 5, Chapter 14	197-203; 641				
			SAP-7.A.3: Graphical representations of the relationships between P, V, T, and n are useful to describe gas behavior.	Chapter 5, Chapter 17	183, 184, 201, 206, 212; 788				
3.5 Kinetic Molecular Theory		**SAP-7.B:** Explain the relationship between the motion of particles and the macroscopic properties of gases with- a. The kinetic molecular theory (KMT).	**SAP-7.B.1:** The kinetic molecular theory (KMT) relates the macroscopic properties of gases to motions of the particles in the gas. The Maxwell-Boltzmann distribution describes the distribution of the kinetic energies of particles at a given temperature.	Chapter 5, Chapter 13	203-214; 582-583	**4.A:** Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models,	203-213	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	220, Questions 5.77-5.88

		b. A particulate model. c. A graphical representation.	**SAP-7.B.2:** All the particles in a sample of matter are in continuous, random motion. The average kinetic energy of a particle is related to its average velocity by the equation- EQN: KE = ½ mv2.	Chapter 5	203-204	and representations.			
			SAP-7.B.3: The Kelvin temperature of a sample of matter is proportional to the average kinetic energy of the particles in the sample.	Chapter 5, Chapter 13	183-185; 582-583				
			SAP-7.B.4: The Maxwell-Boltzmann distribution provides a graphical representation of the energies/velocities of particles at a given temperature.	Chapter 5	205-207				
3.5 Kinetic Molecular Theory		**SAP-7.C:** Explain the relationship among non-ideal behaviors of gases, interparticle forces, and/or volumes.	**SAP-7.C.1:** The ideal gas law does not explain the actual behavior of real gases. Deviations from the ideal gas law may result from interparticle attractions among gas molecules, particularly at conditions that are close to those resulting in condensation. Deviations may also arise from particle volumes, particularly at extremely high pressures.	Chapter 5, Chapter 11	211-214; 494	**6.E:** Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.	211-214	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	220, Questions 5.89-5.94
3.7 Solutions and Mixtures	**SPQ-3:** Interactions between intermolecular forces influence the solubility and separation of mixtures.	**SPQ-3.A:** Calculate the number of solute particles, volume, or molarity of solutions.	**SPQ-3.A.1:** Solutions, also sometimes called homogeneous mixtures, can be solids, liquids, or gases. In a solution, the macroscopic properties do not vary throughout the sample. In a heterogeneous mixture, the macroscopic properties depend on location in the mixture.	Chapter 1, Chapter 4, Chapter 5, Chapter 12, Chapter 16	4, 6; 122; 197-198, 202-203; 514-517, 541-542; 736-741	**5.F:** Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).	147, 150	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	163, Questions 4.61-4.62
			SPQ-3.A.2: Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory. EQN: $M = n_{solute}/L_{solution}$	Chapter 4, Chapter 12	147-151, 154-158; 517-522				
3.8 Representations of Solutions		**SPQ-3.B:** Using particulate models for mixtures- a. Represent interactions between components. b. Represent concentrations of components.	**SPQ-3.B.1:** Particulate representations of solutions communicate the structure and properties of solutions, by illustration of the relative concentrations of the components in the solution and drawings that show interactions among the components. ✗Colligative properties will not be assessed on the AP Exam. ✗Calculations of molality, percent by mass, and percent by volume will not be assessed on the AP Exam.	Chapter 4, Chapter 5, Chapter 12, Chapter 15	124-125, 136-137, 150; 198; 516, 524, 533, 535, 539, 542-543; 670, 688	**3.C:** Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).	124-125, 136-137, 150, 198; 516, 524, 533, 535, 539, 542-543; 670, 688	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	161, Questions 4.7, 4.8, 4.17, 4.18

3.9 Separation of Solutions and Mixtures Chromatography		**SPQ-3.C:** Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles.	**SPQ-3.C.1:** The components of a liquid solution cannot be separated by filtration. They can, however, be separated using processes that take advantage of differences in the intermolecular interactions of the components. a. Chromatography (paper, thin-layer, and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components of the solution (the mobile phase) and with the surface components of the stationary phase. b. Distillation separates 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.	Chapter 8, Chapter 10, Chapter 12, Chapter 24	355; 424* See additional online activity; 529-530; 1042	**2.C:** Identify experimental procedures that are aligned to the question (which may include a sketch of a lab setup).	530	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	551, Question 12.130
3.10 Solubility			**SPQ-3.C.2:** Substances with similar intermolecular interactions tend to be miscible or soluble in one another.	Chapter 4, Chapter 12, Chapter 16	125; 516, 515-517, 523-526; 738, 745, 749-754	**4.D:** Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.	515-516, 523-524	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	544-545, Questions 12.9, 12.12
3.11 Spectroscopy and the Electromagnetic Spectrum	**SAP-8:** Spectroscopy can determine the structure and concentration in a mixture of a chemical species.	**SAP-8.A:** Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region.	**SAP-8.A.1:** Differences in absorption or emission of photons in different spectral regions are related to the different types of molecular motion or electronic transition- a. Microwave radiation is associated with transitions in molecular rotational levels. b. Infrared radiation is associated with transitions in molecular vibrational levels. c. Ultraviolet/visible radiation is associated with transitions in electronic energy levels.in electronic energy levels.	Chapter 7, Chapter 20	277-286; 909-910	**4.A:** Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.	277-286	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	314, Question 7.3; 315, Question 7.14; 318, Question 7.101; 319, Question 7.118

3.12 Photoelectric Effect		**SAP-8.B:** Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.	**SAP-8.B.1:** When a photon is absorbed (or emitted) by an atom or molecule, the energy of the species is increased (or decreased) by an amount equal to the energy of the photon.	Chapter 7, Chapter 23	275, 279-286; 1005-1006	**5.F:** Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).	276-279	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	314-315, Questions 7.7-7.12, 7.15-7.22
			SAP-8.B.2: The wavelength of the electromagnetic wave is related to its frequency and the speed of light by the equation- EQN: $c = \lambda\nu$. The energy of a photon is related to the frequency of the electromagnetic wave through Planck's equation ($E = h\nu$).	Chapter 7, Chapter 23	276, 278-279; 1005-1007				
3.13 Beer-Lambert Law		**SAP-8.C:** Explain the amount of light absorbed by a solution of molecules or ions in relationship to the concentration, path length, and molar absorptivity.	**SAP-8.C.1:** The Beer-Lambert law relates the absorption of light by a solution to three variables according to the equation- EQN: $A = \varepsilon bc$. The molar absorptivity ε describes how intensely a sample of molecules or ions absorbs light of a specific wavelength. The path length b and concentration c are proportional to the number of absorbing species.	Chapter 4, Chapter 13, Chapter 23	146; 559; 1005-1007	**2.E:** Identify or describe potential sources of experimental error.	1005-1007	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	1017, Questions 23.36-23.37, 23.46
			SAP-8.C.2: In most experiments the path length and wavelength of light are held constant. In such cases, the absorbance is proportional only to the concentration of absorbing molecules or ions.	Chapter 12, Chapter 23	517-518; 1006				

Unit 4: Chemical Reactions 7-9%

Topic Name	Enduring Understanding and Big Idea	Learning Objective	Essential Knowledge	Chapter	Page Numbers	Science Practices and Skills	Page Numbers	Reasoning Process	Page Numbers
4.1 Introduction for Reactions	**TRA-1:** A substance that changes its properties, or that changes into a different substance, can be represented by chemical equations.	**TRA-1.A:** Identify evidence of chemical and physical changes in matter.	**TRA-1.A.1:** A physical change occurs when a substance undergoes a change in properties but not a change in composition. Changes in the phase of a substance (solid, liquid, gas) or formation/separation of mixtures of substances are common physical changes.	Chapter 1, Chapter 11	4, 9; 463, 489-498	**2.B:** Formulate a hypothesis or predict the results of an experiment.	125, 130, 136, 141-145, 151-153; 489-498	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	162, Questions 4.22-4.23, 4.34; 507, Questions 11.62, 11.66
			TRA-1.A.2: A chemical change occurs when substances are transformed into new substances, typically with different compositions. Production of heat or light, formation of a gas, formation of a precipitate, and/or color change provide possible evidence that a chemical change has occurred.	Chapter 1, Chapter 3, Chapter 4, Chapter 6	9-10; 93; 125, 130, 135, 136, 141-145, 151-153; 232-234				
4.2 Net Ionic Equations		**TRA-1.B:** Represent changes in matter with a balanced chemical or net ionic equation- a. For physical changes. b. For given information about the identity of the reactants and/or product. c. For ions in a given chemical reaction.	**TRA-1.B.1:** All physical and chemical processes can be represented symbolically by balanced equations.	Chapter 3, Chapter 4, Chapter 18, Chapter 19	93-98; 127-128; 807-809; 858	**5.E:** Determine a balanced chemical equation for a given chemical phenomena.	93-98, 127-128, 807-809	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	112, Questions 3.57-3.58; 165, Question 4.103
			TRA-1.B.2: Chemical equations represent chemical changes. These changes are the result of a rearrangement of atoms into new combinations; thus, any representation of a chemical change must contain equal numbers of atoms of every element before and after the change occurred. Equations thus demonstrate that mass is conserved in chemical reactions.	Chapter 2, Chapter 3, Chapter 4, Chapter 9, Chapter 18	52; 93-98; 127-128; 368-369, 375; 807-809				
			TRA-1.B.3: Balanced molecular, complete ionic, and net ionic equations are differing symbolic forms used to represent a chemical reaction. The form used to represent the reaction depends on the context in which it is to be used.	Chapter 3, Chapter 4, Chapter 18	93-98; 127-128; 807-809				

4.3 Representations of Reactions		**TRA-1.C:** Represent a given chemical reaction or physical process with a consistent particulate model.	**TRA-1.C.1:** Balanced chemical equations in their various forms can be translated into symbolic particulate representations.	Chapter 1, Chapter 2, Chapter 3, Chapter 4, Chapter 5, Chapter 6, Chapter 9, Chapter 12, Chapter 13, Chapter 14, Chapter 15, Chapter 17, Chapter 18, Chapter 19, Chapter 20, Chapter 24, Chapter 25	3, 9, 10; 42; 94, 98, 103; 125, 131, 132, 136, 137, 150; 198; 243, 245, 259; 390, 394, 398, 399; 516, 524, 535, 539, 542; 558, 561, 565, 567, 570, 573, 575, 578, 584, 587, 588, 591, 592, 595; 618, 623, 624, 633, 634, 641, 645; 663, 670, 695; 772, 775, 780, 782; 811, 828; 872, 873; 910; 1032; 1066	**3.B:** Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).	3, 9, 10, 42, 94, 98, 103, 125, 131, 132, 136, 137, 150, 198, 243, 245, 259, 390, 394, 398, 399, 516, 524, 535, 539, 542, 558, 561, 565, 567, 570, 573, 575, 578, 584, 587, 588, 591, 592, 595, 618, 623, 624, 633, 634, 641, 645, 663, 670, 695, 772, 775, 780, 782, 811, 828, 872, 873, 910, 1032, 1066	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	317, Questions 7.71-7.74
4.4 Physical and Chemical Changes		**TRA-1.D:** Explain the relationship between macroscopic characteristics and bond interactions for- a. Chemical processes. b. Physical processes.	**TRA-1.D.1:** Processes that involve the breaking and/or formation of chemical bonds are typically classified as chemical processes. Processes that involve only changes in intermolecular interactions, such as phase changes, are typically classified as physical processes.	Chapter 1, Chapter 3, Chapter 4, Chapter 6, Chapter 9, Chapter 11	7-10; 93-94; 122-124; 253; 368-370, 375-377; 463, 489-498	**6.B:** Support a claim with evidence from experimental data.	489-498, 515-517	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	507, Question 11.59; 544, Question 12.3
			TRA-1.D.2: Sometimes physical processes involve the breaking of chemical bonds. For example, plausible arguments could be made for the dissolution of a salt in water, as either a physical or chemical process, involves breaking of ionic bonds, and the formation of ion-dipole interactions between ions and solvent.	Chapter 4, Chapter 6, Chapter 9, Chapter 12	122-124; 258-260; 370; 515-517				

4.5 Stoichiometry	**SPQ-4:** When a substance changes into a new substance, or when its properties change, no mass is lost or gained.	**SPQ-4.A:** Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process.	**SPQ-4.A.1:** Because atoms must be conserved during a chemical process, it is possible to calculate product amounts by using known reactant amounts, or to calculate reactant amounts given known product amounts.	Chapter 3, Chapter 4, Chapter 12	98-109; 147-158; 519	**5.C:** Explain the relationship between variables within an equation when one variable changes.	195-197	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	549, Question 5.97
			SPQ-4.A.2: 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 involving the mole concept.	Chapter 3, Chapter 4, Chapter 18	93-109; 127-129; 840-841				
			SPQ-4.A.3: Stoichiometric calculations can be combined with the ideal gas law and calculations involving molarity to quantitatively study gases and solutions.	Chapter 4, Chapter 5, Chapter 12	147-158; 195-197; 519-521				
4.6 Introduction to Titration		**SPQ-4.B:** Identify the equivalence point in a titration based on the amounts of the titrant and analyte, assuming the titration reaction goes to completion.	**SPQ-4.B.1:** Titrations may be used to determine the concentration of an analyte in solution. The titrant has a known concentration of a species that reacts specifically and quantitatively with the analyte. The equivalence point 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 endpoint of the titration.	Chapter 4, Chapter 16	153-157; 724-735	**3.A:** Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.	725, 729, 732	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	759, Question 16.26
4.7 Types of Chemical Reactions	**TRA-2:** A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it.	**TRA-2.A:** Identify a reaction as acid-base, oxidation-reduction, or precipitation.	**TRA-2.A.1:** Acid-base reactions involve transfer of one or more protons between chemical species.	Chapter 4, Chapter 15, Chapter 16	130-135; 661-664; 724-732	**1.B:** Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.	130-140, 661-664, 724-742	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	161, Questions 4.17-4.18; 166, Questions 4.108-4.109; 709, Question 15.158; 759, Question 16.22-16.23
			TRA-2.A.2: Oxidation-reduction reactions involve transfer of one or more electrons between chemical species, as indicated by changes in oxidation numbers of the involved species. Combustion is an important subclass of oxidation-reduction reactions, in which a species reacts with oxygen gas. In the case of hydrocarbons, carbon dioxide and water are products of complete combustion.	Chapter 4, Chapter 18, Chapter 24	136-146,141; 807-810; 1033				
			TRA-2.A.3: In a redox reaction, electrons are transferred from the species that is oxidized to the species that is reduced. ✗ The meaning of the terms “reducing agent” and “oxidizing agent” will not be assessed on the AP Exam. Rationale: Understanding this terminology is not necessary for reasoning about redox chemistry.	Chapter 4, Chapter 18	136-137; 807-818				

			TRA-2.A.4: Oxidation numbers may be assigned to each of the atoms in the reactants and products; this is often an effective way to identify the oxidized and reduced species in a redox reaction.	Chapter 4, Chapter 18	138-141, 807-818				
			TRA-2.A.5: Precipitation reactions frequently involve mixing ions in aqueous solution to produce an insoluble or sparingly soluble ionic compound. All sodium, potassium, ammonium, and nitrate salts are soluble in water. X Rote memorization of "solubility rules" other than those implied in TRA-2.A.5 will not be assessed on the AP Exam.	Chapter 4, Chapter 12, Chapter 16	125-126, 151-153; 515-516; 736-742, 746-747, 754-757				
4.8 Introduction to Acid-Base Reactions		**TRA-2.B:** Identify species as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species.	**TRA-2.B.1:** By definition, a Brønsted-Lowry acid is a proton donor and a Brønsted-Lowry base is a proton acceptor.	Chapter 4, Chapter 15	130-132; 661-662, 699	**1.B:** Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.	130-132, 661-664	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	162, Questions 4.33-4.34; 704, Questions 15.31-15.32; 706, Question 15.99
			TRA-2.B.2: Only in aqueous solutions, water plays an important role in many acid-base reactions, as its molecular structure allows it to accept protons from and donate protons to dissolved species.	Chapter 4, Chapter 15	130-132; 663-664				
			TRA-2.B.3: When an acid or base ionizes in water, the conjugate acid-base pairs can be identified and their relative strengths compared. ✗ Lewis acid-base concepts will not be assessed on the AP Exam. Rationale: Lewis acid-base concepts are important ideas for organic chemistry. However, as the emphasis in AP Chemistry is on reactions in aqueous solution, these concepts will not be examined.	Chapter 4, Chapter 15	130-132; 661-663, 670-684				
4.9 Oxidation-Reduction (Redox) Reactions		**TRA-2.C:** Represent a balanced redox reaction equation using half-reactions.	**TRA-2.C.1:** Balanced chemical equations for redox reactions can be constructed from half-reactions.	Chapter 4, Chapter 18	136-140; 807-810, 837-838	**5.E:** Determine a balanced chemical equation for a given chemical phenomena.	136-140, 807-810	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	162-163, Questions 4.43-4.44; 843, Questions 18.1-18.2

Unit 5: Kinetics 7-9%

Topic Name	Enduring Understanding and Big Idea	Learning Objective	Essential Knowledge	Chapter	Page Numbers	Science Practices and Skills	Page Numbers	Reasoning Process	Page Numbers
5.1 Reaction Rates	**TRA-3:** Some reactions happen quickly, while others happen more slowly and depend on reactant concentrations and temperature.	**TRA-3.A:** Explain the relationship between the rate of a chemical reaction and experimental parameters.	**TRA-3.A.1:** The kinetics of a chemical reaction is defined as the rate at which an amount of reactants is converted to products per unit of time.	Chapter 13	557-560	**6.E:** Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.	557-562	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	603, Questions 13.1-13.4
			TRA-3.A.2: The rates of change of reactant and product concentrations are determined by the stoichiometry in the balanced chemical equation.	Chapter 13	562-564				
			TRA-3.A.3: The rate of a reaction is influenced by reactant concentrations, temperature, surface area, catalysts, and other environmental factors.	Chapter 13	559-587, 593-601				
5.2 Introduction to Rate Law		**TRA-3.B:** Represent experimental data with a consistent rate law expression.	**TRA-3.B.1:** Experimental methods can be used to monitor the amounts of reactants and/or products of a reaction and to determine the rate of the reaction.	Chapter 13	558-562, 565-568	**5.C:** Explain the relationship between variables within an equation when one variable changes.	565-568	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	604, Questions 13.8-13.20
			TRA-3.B.2: The rate law expresses the rate of a reaction as proportional to the concentration of each reactant raised to a power.	Chapter 13	565-568				
			TRA-3.B.3: 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.	Chapter 13	565-568				
			TRA-3.B.4: The proportionality constant in the rate law is called the rate constant. The value of this constant is temperature dependent and the units reflect the overall reaction order.	Chapter 13	561, 568, 569-579				
			TRA-3.B.5: Comparing initial rates of a reaction is a method to determine the order with respect to each reactant.	Chapter 13	559-564				
5.3 Concentration Changes Over Time		**TRA-3.C:** Identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time.	**TRA-3.C.1:** The order of a reaction can be inferred from a graph of concentration of reactant versus time.	Chapter 13	557-568, 579	**5.B:** Identify an appropriate theory, definition, or mathematical relationship to solve a problem.	569-581	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	604, Questions 13.19-13.20
			TRA-3.C.2: If a reaction is first order with respect to a reactant being monitored, a plot of the natural log (ln) of the reactant concentration as a function of time will be linear.	Chapter 13	569-575, 579				

			TRA-3.C.3: If a reaction is second order with respect to a reactant being monitored, a plot of the reciprocal of the concentration of that reactant versus time will be linear.	Chapter 13	576-578, 579				
			TRA-3.C.4: The slopes of the concentration versus time data for zeroth, first, and second order reactions can be used to determine the rate constant for the reaction. Zeroth order- EQN: [A]t − [A]0 = −kt First order- EQN: ln[A]t − ln[A]0 = −kt Second order- EQN: 1/[A]t − 1/[A]0 = kt	Chapter 13	569-579				
			TRA-3.C.5: Half-life is a critical parameter for first order reactions because the half-life is constant and related to the rate constant for the reaction by the equation- EQN: t1/2 = 0.693/k.	Chapter 13, Chapter 19	574-575, 580-581; 866-868				
			TRA-3.C.6: Radioactive decay processes provide an important illustration of first order kinetics.	Chapter 19	866-868				
5.4 Elementary Reactions	**TRA-4:** There is a relationship between the speed of a reaction and the collision frequency of particle collisions.	**TRA-4.A:** Represent an elementary reaction as a rate law expression using stoichiometry.	**TRA-4.A.1:** The rate law of an elementary reaction can be inferred from the stoichiometry of the molecules participating in a collision.	Chapter 13	588-593	**5.E:** Determine a balanced chemical equation for a given chemical phenomenon.	588-593	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	607, Question 13.58
			TRA-4.A.2: Elementary reactions involving the simultaneous collision of three or more particles are rare.	Chapter 13	588				
5.5 Collision Model		**TRA-4.B:** Explain the relationship between the rate of an elementary reaction and the frequency, energy, and orientation of molecular collisions.	**TRA-4.B.1:** For an elementary reaction to successfully produce products, reactants must successfully collide to initiate bond-breaking and bond-making events.	Chapter 13	582-583, 588-592	**6.E:** Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.	582-593	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	606, Question 13.47
			TRA-4.B.2: In most reactions, only a small fraction of the collisions leads to a reaction. Successful collisions have both sufficient energy to overcome energy barriers and orientations that allow the bonds to rearrange in the required manner.	Chapter 13	582-593				
			TRA-4.B.3: The Maxwell-Boltzmann distribution curve 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.	Chapter 5, Chapter 13	206; 582-583, 593-595, 597-601				

5.6 Reaction Energy Profile		**TRA-4.C:** Represent the activation energy and overall energy change in an elementary reaction using a reaction energy profile.	**TRA-4.C.1:** Elementary reactions typically involve the breaking of some bonds and the forming of new ones.	Chapter 13	588	**3.B:** Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).	582-593	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	606, Questions 13.42-13.46; 606-607, Questions 13.50-13.56
			TRA-4.C.2: The reaction coordinate is the axis along which the complex set of motions involved in rearranging reactants to form products can be plotted.	Chapter 13	557-561, 560, 575, 583, 590				
			TRA-4.C.3: The energy profile gives the energy along the reaction coordinate, which typically proceeds from reactants, through a transition state, to products. The energy difference between the reactants and the transition state is the activation energy for the forward reaction.	Chapter 13	582-584				
			TRA-4.C.4: The Arrhenius equation relates the temperature dependence of the rate of an elementary reaction to the activation energy needed by molecular collisions to reach the transition state. ✗Calculations involving the Arrhenius equation will not be assessed on the AP Exam.	Chapter 13	582-587				
5.7 Introduction to Reaction Mechanisms	**TRA-5:** Many chemical reactions occur through a series of elementary reactions. These elementary reactions when combined form a chemical equation.	**TRA-5.A:** Identify the components of a reaction mechanism.	**TRA-5.A.1:** A reaction mechanism consists of a series of elementary reactions, or steps, that occur in sequence. The components may include reactants, intermediates, products, and catalysts.	Chapter 13	588-601	**1.B:** Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.	588-593	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	607, Question 13.56; 608, Question 13.76, 601, Question 13.101
			TRA-5.A.2: The elementary steps when combined should align with the overall balanced equation of a chemical reaction.	Chapter 13	588				
			TRA-5.A.3: A reaction intermediate is produced by some elementary steps and consumed by others, such that it is present only while a reaction is occurring.	Chapter 13	588-589				
			TRA-5.A.4: Experimental detection of a reaction intermediate is a common way to build evidence in support of one reaction mechanism over an alternative mechanism. ✗Collection of data pertaining to detection of a reaction intermediate will not be assessed on the AP Exam. Rationale: Designing an experiment to identify reaction intermediates often requires knowledge that is beyond the scope of a general chemistry course.	Chapter 13	592-593				

5.8 Reaction Mechanism and Rate Law		**TRA-5.B:** Identify the rate law for a reaction from a mechanism in which the first step is rate limiting.	**TRA-5.B.1:** For reaction mechanisms in which each elementary step is irreversible, or in which the first step is rate limiting, the rate law of the reaction is set by the molecularity of the slowest elementary step (i.e., the rate-limiting step). ✗Collection of data pertaining to detection of a reaction intermediate will not be assessed on the AP Exam. Rationale: Designing an experiment to identify reaction intermediates often requires knowledge that is beyond the scope of a general chemistry course.	Chapter 13	588-591	**5.B:** Identify an appropriate theory, definition, or mathematical relationship to solve a problem.	588-591	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	611, Question 13.110; 613, Question 13.127; AP614, Question 4
5.9 Steady-State Approximation		**TRA-5.C:** Identify the rate law for a reaction from a mechanism in which the first step is not rate limiting.	**TRA-5.C.1:** If the first elementary reaction is not rate limiting, approximations (such as steady state) must be made to determine a rate law expression.	Chapter 13	588-591	**5.B:** Identify an appropriate theory, definition, or mathematical relationship to solve a problem.	588-591	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	607, Question 13.58
5.10 Multistep Reaction Energy Profile		**TRA-5.D:** Represent the activation energy and overall energy change in a multistep reaction with a reaction energy profile.	**TRA-5.D.1:** Knowledge of the energetics of each elementary reaction in a mechanism allows for the construction of an energy profile for a multistep reaction.	Chapter 13	583, 590-591, 594	**3.B:** Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).	590, 594	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	612, Question 13.118; AP614, Question 6
5.11 Catalysis	**ENE-1:** The speed at which a reaction occurs can be influenced by a catalyst.	**ENE-1.A:** Explain the relationship between the effect of a catalyst on a reaction and changes in the reaction mechanism.	**ENE-1.A.1:** In order for a catalyst to increase the rate of a reaction, the addition of the catalyst must increase the number of effective collisions and/or provide a reaction path with a lower activation energy relative to the original reaction coordinate.	Chapter 13, Chapter 14	593-601; 643	**6.E:** Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.	593-601	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	652, Questions 14.58-14.60; 656, Question 14.111
			ENE-1.A.2: In a reaction mechanism containing a catalyst, the net concentration of the catalyst is constant. However, the catalyst will frequently be consumed in the rate-determining step of the reaction, only to be regenerated in a subsequent step in the mechanism.	Chapter 13	593-594				
			ENE-1.A.3: Some catalysts accelerate a reaction by binding to the reactant(s). The reactants are either oriented more favorably or react with lower activation energy. There is often a new reaction intermediate in which the catalyst is bound to the reactant(s). Many enzymes function in this manner.	Chapter 13	593-594, 598-601				

			ENE-1.A.4: Some catalysts involve covalent bonding between the catalyst and the reactant(s). An example is acid-base catalysis, in which a reactant or intermediate either gains or loses a proton. This introduces a new reaction intermediate and new elementary reactions involving that intermediate.	Chapter 13	593-594, 596-598				
			ENE-1.A.5: In surface catalysis, a reactant or intermediate binds to, or forms a covalent bond with, the surface. This introduces elementary reactions involving these new bound reaction intermediate(s).	Chapter 13	593-596				

Unit 6: Thermodynamics 7-9%

Topic Name	Enduring Understanding and Big Idea	Learning Objective	Essential Knowledge	Chapter	Page Numbers	Science Practices and Skills	Page Numbers	Reasoning Process	Page Numbers
6.1 Endothermic and Exothermic Processes	**ENE-2:** Changes in a substance's properties or change into a different substance requires an exchange of energy.	**ENE-2.A:** Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation.	**ENE-2.A.1:** Temperature changes in a system indicate energy changes.	Chapter 1, Chapter 6	11; 232-234, 236-239, 258-260	**6.D:** Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.	232-234, 236-239, 258-260	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	262, Questions 6.6, 6.9-6.10; 265, Questions 6.65-6.70
			ENE-2.A.2: Energy changes in a system can be described as endothermic and exothermic processes such as the heating or cooling of a substance, phase changes, or chemical transformations.	Chapter 1, Chapter 6	11; 232-234				
			ENE-2.A.3: When a chemical reaction occurs, the energy of the system either decreases (exothermic reaction), increases (endothermic reaction), or remains the same. For exothermic reactions, the energy lost by the reacting species (system) is gained by the surroundings, as heat transfer from or work done by the system. Likewise, for endothermic reactions, the system gains energy from the surroundings by heat transfer to or work done on the system.	Chapter 1, Chapter 6	11; 232-239, 246-249				
			ENE-2.A.4: 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.	Chapter 6	258-260				

6.2 Energy Diagrams		**ENE-2.B:** Represent a chemical or physical transformation with an energy diagram.	**ENE-2.B.1:** A physical or chemical process can be described with an energy diagram that shows the endothermic or exothermic nature of that process.	Chapter 6	233, 242, 259	**3.A:** Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.	233, 255	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	268, Question 6.113
6.3 Heat Transfer and Thermal Equilibrium		**ENE-2.C:** Explain the relationship between the transfer of thermal energy and molecular collisions.	**ENE-2.C.1:** The particles in a warmer body have a greater average kinetic energy than those in a cooler body.	Chapter 5, Chapter 6	203-206; 231-232	**6.E:** Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.	203-206, 231-236	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	220, Question 5.77, 5.79; 262, Question 6.2; AP271, Question 6
			ENE-2.C.2: Collisions between particles in thermal contact can result in the transfer of energy. This process is called "heat transfer," "heat exchange," or "transfer of energy as heat."	Chapter 5, Chapter 6	203-206; 232-234, 238-243				
			ENE-2.C.3: Eventually, thermal equilibrium is reached as the particles continue to collide. At thermal equilibrium, the average kinetic energy of both bodies is the same, and hence, their temperatures are the same.	Chapter 6	231-232, 235-236				
6.4 Heat Capacity and Calorimetry		**ENE-2.D:** Calculate the heat q absorbed or released by a system undergoing heating/cooling based on the amount of the substance, the heat capacity, and the change in temperature.	**ENE-2.D.1:** The heating of a cool body by a warmer body is an important form of energy transfer between two systems. The amount of heat transferred between two bodies may be quantified by the heat transfer equation- EQN: $q = mc\Delta T$. Calorimetry experiments are used to measure the transfer of heat.	Chapter 6	246-249	**2.D:** Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.	233, 246-252	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	263-264, Questions 6.29-6.38
			ENE-2.D.2: The first law of thermodynamics states that energy is conserved in chemical and physical processes.	Chapter 6	235				
			ENE-2.D.3: 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.	Chapter 6	246				
			ENE-2.D.4: Heating a system increases the energy of the system, while cooling a system decreases the energy of the system.	Chapter 6	235-242				
			ENE-2.D.5: The specific heat capacity of a substance and the molar heat capacity are both used in energy calculations.	Chapter 6	246-249				

			ENE-2.D.6: Chemical systems change their energy through three main processes: heating/cooling, phase transitions, and chemical reactions.	Chapter 6, Chapter 11	231-234, 240-244; 489-498				
6.5 Energy of Phase Changes		**ENE-2.E:** Explain changes in the heat q absorbed or released by a system undergoing a phase transition based on the amount of the substance in moles and the molar enthalpy of the phase transition.	**ENE-2.E.1:** Energy must be transferred to a system to cause a substance to melt (or boil). The energy of the system therefore increases as the system undergoes a solid-to-liquid (or liquid-to-gas) phase transition. Likewise, a system releases energy when it freezes (or condenses). The energy of the system decreases as the system undergoes a liquid-to-solid (or gas-to-liquid) phase transition. The temperature of a pure substance remains constant during a phase change.	Chapter 11	489-498	**1.B:** Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.	490-491, 496-497	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	505, Question 11.19; 508, Questions 11.89, 11.92; 512, Question 11.150
			ENE-2.E.2: The energy absorbed during a phase change is equal to the energy released during a complementary phase change in the opposite direction. For example, the molar heat of condensation of a substance is equal to the negative of its molar heat of vaporization.	Chapter 11	489-498				
6.6 Introduction to Enthalpy of Reaction		**ENE-2.F:** Calculate the heat q absorbed or released by a system undergoing a chemical reaction in relationship to the amount of the reacting substance in moles and the molar enthalpy of reaction.	**ENE-2.F.1:** The enthalpy change of a reaction gives the amount of heat energy released (for negative values) or absorbed (for positive values) by a chemical reaction at constant pressure. X The technical distinctions between enthalpy and internal energy will not be assessed on the AP Exam. Rationale: These distinctions are beyond the scope of the AP Chemistry course. Most reactions studied at the AP level are carried out at constant pressure. Under these conditions the enthalpy change of the process is equal to the heat (and by extension, the energy) of reaction. For example, in the AP Chemistry course the terms “bond energy” and “bond enthalpy” are often used interchangeably.	Chapter 6	242	**4.C:** Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.	242	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	262, Questions 6.1-6.2; 263, Questions 6.21, 6.23
6.7 Bond Enthalpies	**ENE-3:** The energy exchanged in a chemical transformation is required to break and form bonds.	**ENE-3.A:** Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction.	**ENE-3.A.1:** During a chemical reaction, bonds are broken and/or formed, and these events change the potential energy of the system.	Chapter 6, Chapter 9	231-232; 395-399	**5.F:** Calculate, estimate, or predict an unknown quantity from known	231-232, 395-399	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	264, Question 6.50, 6.51; 266,

			ENE-3.A.2: The average energy required to break all of the bonds in the reactant molecules can be estimated by adding up the average bond energies of all the bonds in the reactant molecules. Likewise, the average energy released in forming the bonds in the product molecules can be estimated. If the energy released is greater than the energy required, the reaction is exothermic. If the energy required is greater than the energy released, the reaction is endothermic.	Chapter 8, Chapter 9	354-355; 395-399	quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).			Question 6.84
6.8 Enthalpy of Formation		**ENE-3.B:** Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation.	**ENE-3.B.1:** Tables of standard enthalpies of formation can be used to calculate the standard enthalpies of reactions. EQN: ΔHoreaction = ΣΔHfoproducts − Σ ΔHforeactants	Chapter 6	252-254	**5.F:** Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).	252-254	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	268, Question 6.118; 269, Question 6.125
6.9 Hess's Law		**ENE-3.C:** Represent a chemical or physical process as a sequence of steps.	**ENE-3.C.1:** Although the concept of "state function" is not required for the course, two principles of Hess's law should be understood. First, when a reaction is reversed, the enthalpy change stays constant in magnitude but becomes reversed in mathematical sign. Second, when two (or more) reactions are added to obtain an overall reaction, the individual enthalpy changes of each reaction are added to obtain the net enthalpy of the overall reaction.	Chapter 6	252-255	**5.A:** Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).	252-255	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	263, Question 6.24; 265, Questions 6.61-6.64
		ENE-3.D: Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual steps.	**ENE-3.D.1:** When the products of a reaction are at a different temperature than their surroundings, they exchange energy with the surroundings to reach thermal equilibrium. Thermal energy is transferred to the surroundings from the products of an exothermic reaction. Thermal energy is transferred from the surroundings to the products of an endothermic reaction.	Chapter 6, Chapter 14	231-234; 641-642	**5.A:** Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).	231-234, 642	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	263, Question 6.14, 652, Question 14.55

Unit 7: Equilibrium 7-9%

Topic Name	Enduring Understanding and Big Idea	Learning Objective	Essential Knowledge	Chapter	Page Numbers	Science Practices and Skills	Page Numbers	Reasoning Process	Page Numbers
7.1 Introduction to Equilibrium	**TRA-6:** Some reactions can occur in both forward and reverse directions, sometimes proceeding in each direction simultaneously.	**TRA-6.A:** Explain the relationship between the occurrence of a reversible chemical or physical process, and the establishment of equilibrium, to experimental observations.	**TRA-6.A.1:** Many observable processes are reversible. Examples include evaporation and condensation of water, absorption and desorption of a gas, or dissolution and precipitation of a salt. Some important reversible chemical processes include the transfer of protons in acid-base reactions and the transfer of electrons in redox reactions.	Chapter 4, Chapter 5, Chapter 11, Chapter 12, Chapter 15, Chapter 16, Chapter 18	125-129, 133-134, 136-138; 208-210; 490-494; 524-526; 661-662; 736-741, 743-744; 807-808	**6.D:** Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification	490-494, 617-620, 627-633, 640, 736-741	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	649, Questions 14.4, 14.7, 14.13; 651, Question 14.38
			TRA-6.A.2: When equilibrium is reached, no observable changes occur in the system. Reactants and products are simultaneously present, and the concentrations or partial pressures of all species remain constant.	Chapter 14	617-620, 632-633				
			TRA-6.A.3: The equilibrium state is dynamic. The forward and reverse processes continue to occur at equal rates, resulting in no net observable change.	Chapter 11, Chapter 14	491; 617-620				
			TRA-6.A.4: Graphs of concentration, partial pressure, or rate of reaction versus time for simple chemical reactions can be used to understand the establishment of chemical equilibrium.	Chapter 13, Chapter 14	558, 560, 562, 570, 572, 574, 575, 576, 579, 600; 618, 640, 646-647				
7.2 Direction of Reversible Reactions		**TRA-6.B:** Explain the relationship between the direction in which a reversible reaction proceeds and the relative rates of the forward and reverse reactions.	**TRA-6.B.1:** If the rate of the forward reaction is greater than the reverse reaction, then there is a net conversion of reactants to products. If the rate of the reverse reaction is greater than that of the forward reaction, then there is a net conversion of products to reactants. An equilibrium state is reached when these rates are equal.	Chapter 14	618-620, 632-634	**4.D:** Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.	618-620	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	649, Questions 14.13, 14.14; 651, Question 14.34

7.3 Reaction Quotient and Equilibrium Constant	**TRA-7:** A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and equilibrium constant *K*.	**TRA-7.A:** Represent the reaction quotient Qc or Qp, for a reversible reaction, and the corresponding equilibrium expressions Kc = Qc or Kp = Qp.	**TRA-7.A.1:** The reaction quotient Qc describes the relative concentrations of reaction species at any time. For gas phase reactions, the reaction quotient may instead be written in terms of pressures as Qp. The reaction quotient tends toward the equilibrium constant such that at equilibrium Kc = Qc and Kp = Qp. As examples, for the reaction aA + bB ⇌ cC + dD the equilibrium expression for (Kc, Qc) is EQN: $K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$ and that for (K_p, Q_p) is EQN: $K_p = \frac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b}$ X Conversion between Kc and Kp will not be assessed on the AP Exam. Rationale: Conversion between Kc and Kp is an algorithm that does not deepen understanding of equilibrium. However, students should be aware of the conceptual differences and pay attention to whether Kc or Kp is used in an exam question. X Equilibrium calculations on systems where a dissolved species is in equilibrium with that species in the gas phase will not be assessed on the AP Exam. Rationale: The need to account for the relative volumes of the liquid and gas phase is complex in these mixed equilibria.	Chapter 14	632-638	**3.A:** Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.	620-638	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	651, Question 14.37, 14.39-14.48
			TRA-7.A.2: The reaction quotient does not include substances whose concentrations (or partial pressures) are independent of the amount, such as for solids and pure liquids.	Chapter 14	620-638				
7.4 Calculating the Equilibrium Constant		**TRA-7.B** Calculate Kc or Kp based on experimental observations of concentrations or pressures at equilibrium.	**TRA-7.B.1** Equilibrium constants can be determined from experimental measurements of the concentrations or partial pressures of the reactants and products at equilibrium.	Chapter 14, Chapter 15, Chapter 16	617-620, 622-630; 679; 739	**5.C:** Explain the relationship between variables within an equation when one variable changes.	617-620	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	650, Questions 14.19-14.20

7.5 Magnitude of the Equilibrium Constant		**TRA-7.C:** Explain the relationship between very large or very small values of K and the relative concentrations of chemical species at equilibrium.	**TRA-7.C.1:** Some equilibrium reactions have very large K values and proceed essentially to completion. Others have very small K values and barely proceed at all.	Chapter 14	619, 631-633	**6.D:** Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.	623-633	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	649, Question 14.13; 651, Question 14.34; 653, Question 14.70
7.6 Properties of the Equilibrium Constant		**TRA-7.D:** Represent a multistep process with an overall equilibrium expression, using the constituent K expressions for each individual reaction.	**TRA-7.D.1:** When a reaction is reversed, K is inverted.	Chapter 14	629	**5.A:** Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).	629-635	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	649, Question 14.15; 651, Question 14.32
			TRA-7.D.2: When the stoichiometric coefficients of a reaction are multiplied by a factor c, K is raised to the power c.	Chapter 14	629-630				
			TRA-7.D.3: When reactions are added together, the K of the resulting overall reaction is the product of the K's for the reactions that were summed.	Chapter 14	627-628				
			TRA-7.D.4: Since the expressions for K and Q have identical mathematical forms, all valid algebraic manipulations of K also apply to Q.	Chapter 14	632-635				
7.7 Calculating Equilibrium Concentrations		**TRA-7.E:** Identify the concentrations or partial pressures of chemical species at equilibrium based on the initial conditions and the equilibrium constant.	**TRA-7.E.1:** The concentrations or partial pressures of species at equilibrium can be predicted given the balanced reaction, initial concentrations, and the appropriate K.	Chapter 14, Chapter 15, Chapter 16	618-620, 624, 634-638; 664-669, 674-688, 692-696; 715-733, 736-740	**3.A:** Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.	491; 618, 680	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	656, Question 14.111
7.8 Representations of Equilibrium		**TRA-7.F:** Represent a system undergoing a reversible reaction with a particulate model.	**TRA-7.F.1:** Particulate representations can be used to describe the relative numbers of reactant and product particles present prior to and at equilibrium, and the value of the equilibrium constant.	Chapter 14, Chapter 15, Chapter 16	626, 638, 641, 649, 653, 655, 656; 670, 688, 697; 743	**3.C:** Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).	626, 638, 641, 649, 653, 655, 656, 670, 688, 697, 743	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	649, Questions 14.13 - 14.14; 653, Question 14.66; 655. Question 14.99
7.9 Introduction to Le Châtelier's Principle	**TRA-8:** Systems at equilibrium respond to external stresses to offset the effect of the stress.	**TRA-8.A:** Identify the response of a system at equilibrium to an external stress, using Le Châtelier's principle.	**TRA-8.A.1:** Le Châtelier's principle can be used to predict the response of a system to stresses such as addition or removal of a chemical species, change in temperature, change in volume/pressure of a gas-phase system, or dilution of a reaction system.	Chapter 14	638-644	**6.F:** Explain the connection between experimental results and chemical concepts, processes, or theories.	638-644	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	652, Questions 14.49-14.62
			TRA-8.A.2: Le Châtelier's principle can be used to predict the effect that a stress will have on experimentally measurable properties such as pH, temperature, and color of a solution.	Chapter 14, Chapter 16	638-644; 715-724, 745-749				

7.10 Reaction Quotient and Le Châtelier's Principle		**TRA-8.B:** Explain the relationships between Q, K, and the direction in which a reversible reaction will proceed to reach equilibrium.	**TRA-8.B.1:** A disturbance to a system at equilibrium causes Q to differ from K, thereby taking the system out of equilibrium. The system responds by bringing Q back into agreement with K, thereby establishing a new equilibrium state.	Chapter 14	632-638	**5.F:** Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).	632-644	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	651, Questions 14.39-14.47
			TRA-8.B.2: Some stresses, such as changes in concentration, cause a change in Q only. A change in temperature causes a change in K. In either case, the concentrations or partial pressures of species redistribute to bring Q and K back into equality.	Chapter 14	632-644				
7.11 Introduction to Solubility Equilibria	**SPQ-5:** The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.	**SPQ-5.A:** Calculate the solubility of a salt based on the value of K_{sp} for the salt.	**SPQ-5.A.1:** The dissolution of a salt is a reversible process whose extent can be described by Ksp, the solubility-product constant.	Chapter 16	736-737	**5.B:** Identify an appropriate theory, definition, or mathematical relationship to solve a problem.	736-738	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	761, Questions 16.51-16.54
			SPQ-5.A.2: The solubility of a substance can be calculated from the Ksp for the dissolution process. This relationship can also be used to predict the relative solubility of different substances.	Chapter 16	738-741, 745-754				
			SPQ-5.A.3: The solubility rules (see TRA-2.A.5) can be quantitatively related to Ksp, in which Ksp values >1 correspond to soluble salts.	Chapter 16	737-741				
7.12 Common-Ion Effect		**SPQ-5.B:** Identify the solubility of a salt, and/or the value of Ksp for the salt, based on the concentration of a common ion already present in solution.	**SPQ-5.B.1:** The solubility of a salt is reduced when it is dissolved into a solution that already contains one of the ions present in the salt. The impact of this "common-ion effect" on solubility can be understood qualitatively using Le Châtelier's principle or calculated from the Ksp for the dissolution process.	Chapter 16	745-749	**2.F:** Explain how modifications to an experimental procedure will alter results.	745-747	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	758, Question 16.2; 761, Question 16.66
7.13 pH and Solubility		**SPQ-5.C:** Identify the qualitative effect of changes in pH on the solubility of a salt.	**SPQ-5.C.1:** The solubility of a salt is pH sensitive when one of the constituent ions is a weak acid or base. These effects can be understood qualitatively using Le Châtelier's principle. ✗Computations of solubility as a function of pH will not be assessed on the AP Exam.	Chapter 16	746-748	**2.D:** Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.	746-747	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	761, Questions 16.71-16.76

7.14 Free Energy of Dissolution		**SPQ-5.D:** Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process.	**SPQ-5.D.1:** The free energy change (ΔG°) for dissolution of a substance reflects a number of factors: the breaking of the intermolecular interactions that hold the solid together, the reorganization of the solvent around the dissolved species, and the interaction of the dissolved species with the solvent. It is possible to estimate the sign and relative magnitude of the enthalpic and entropic contributions to each of these factors. However, making predictions for the total change in free energy of dissolution can be challenging due to the cancellations among the free energies associated with the three factors cited.	Chapter 6, Chapter 12, Chapter 17	258-261; 515-516; 774-775, 791-794	**4.D:** Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.	515-517, 774-775	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	798, Question 17.3

Unit 8: Acids and Bases 11-15%

Topic Name	Enduring Understanding and Big Idea	Learning Objective	Essential Knowledge	Chapter	Page Numbers	Science Practices and Skills	Page Numbers	Reasoning Process	Page Numbers
8.1 Introduction to Acid and Bases	**SAP-9:** The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium concentrations being related to the strength of the acids and bases involved.	**SAP-9.A:** Calculate the values of pH and pOH, based on Kw and the concentration of all species present in a neutral solution of water.	**SAP-9.A.1:** The concentrations of hydronium ion and hydroxide ion are often reported as pH and pOH, respectively. EQN: pH = −log[H3O+] EQN: pOH = −log[OH−] The terms “hydrogen ion” and “hydronium ion” and the symbols H+(aq) and H3O+(aq) are often used interchangeably for the aqueous ion of hydrogen. Hydronium ion and H3O+(aq) are preferred, but H+(aq) is also accepted on the AP Exam.	Chapter 4, Chapter 15, Chapter 16	130-131; 664-667; 746-749	**5.B:** Identify an appropriate theory, definition, or mathematical relationship to solve a problem.	663-666	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	703-704, Questions 15.5-15.26
			SAP-9.A.2: Water autoionizes with an equilibrium constant Kw. EQN: Kw = [H3O+][OH−] = 1.0 × 1014 at 25°C	Chapter 15	663-664				
			SAP-9.A.3: In pure water, pH = pOH is called a neutral solution. At 25°C, pKw = 14.0 and thus pH = pOH = 7.0. EQN: pKw = 14 = pH + pOH at 25°C	Chapter 15	666-667				
			SAP-9.A.4: The value of Kw is temperature dependent, so the pH of pure, neutral water will deviate from 7.0 at temperatures other than 25°C.	Chapter 15	665				

8.2 pH and pOH of Strong Acids and Bases		**SAP-9.B:** Calculate pH and pOH based on concentrations of all species in a solution of a strong acid or a strong base.	**SAP-9.B.1:** Molecules of a strong acid (e.g., HCl, HBr, HI, HClO4, H2SO4, and HNO3) will completely ionize in aqueous solution to produce hydronium ions. 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.	Chapter 4, Chapter 15	130-132; 670-673	**5.B:** Identify an appropriate theory, definition, or mathematical relationship to solve a problem.	670-673	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	704, Questions 15.31-15.38
			SAP-9.B.2: When dissolved in solution, strong bases (e.g., group I and II hydroxides) completely dissociate to produce hydroxide ions. As such, the concentration of OH− in a strong base solution is equal to the initial concentration of the strong base, and thus the pOH (and pH) of the strong base solution is easily calculated.	Chapter 4, Chapter 15	130-132; 670-673				
8.3 Weak Acid and Base Equilibria		**SAP-9.C:** Explain the relationship among pH, pOH, and concentrations of all species in a solution of a monoprotic weak acid or weak base.	**SAP-9.C.1:** Weak acids react with water to produce hydronium ions. However, molecules of a weak acid will 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. Thus, the concentration of H3O+ is much less than the initial concentration of the molecular acid, and the vast majority of the acid molecules remain un-ionized.	Chapter 15	674, 688-701	**5.C:** Explain the relationship between variables within an equation when one variable changes.	674-688	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	704-705, Questions 15.39-15.58
			SAP-9.C.2: A solution of a weak acid 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. EQN: $K_a = \frac{[H_3O^+][A^-]}{[HA]}$ EQN: $pK_a = -\log K_a$	Chapter 15, Chapter 16	674-680, 684-688; 715-716				
			SAP-9.C.3: Weak bases react with water to produce hydroxide ions in solution. However, ordinarily just a small percentage of the molecules of a weak base in solution will ionize in this way. Thus, the concentration of OH– in the solution does not equal the initial concentration of the base, and the vast majority of the base molecules remain un-ionized.	Chapter 15	681, 692, 697-701				

			SAP-9.C.4: A solution of a weak base involves between an un-ionized base and its conjugate equilibrium constant for this reaction is Kb, oft as pKb. The pH of a weak base solution can b from the initial base concentration and the pK EQN: $K_b = \frac{[OH^-][HB^+]}{[B]}$ EQN: $pK_b = -\log K_b$	Chapter 15	681-684				
			SAP-9.C.5: The percent ionization of a weak acid (or base) can be calculated from its pKa (pKb) and the initial concentration of the acid (base).	Chapter 15	680				
8.4 Acid-Base Reactions and Buffers		**SAP-9.D:** Explain the relationship among the concentrations of major species in a mixture of weak and strong acids and bases.	**SAP-9.D.1:** When a strong acid and a strong base are mixed, they react quantitatively (K = 1014 at 25°C) in a reaction represented by the equation- $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$. The pH of the resulting solution may be determined from the concentration of excess reagent.	Chapter 4, Chapter 16	133-134; 724-725, 728	**5.F:** Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).	724-733	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	758-760, Questions 16.2-16.40
			SAP-9.D.2: When a weak acid and a strong base are mixed, they react quantitatively in a reaction represented by the equation- $HA(aq) + OH^-(aq) \rightleftharpoons A^-(aq) + H_2O(l)$. If the weak acid is in excess, then a buffer solution is formed, and the pH can be determined from the Henderson-Hasselbalch (H-H) equation (see SAP-10.C.1). If the strong base is in excess, then the pH can be determined from the moles of excess hydroxide ion and the total volume of solution. If they are equimolar, then the (slightly basic) pH can be determined from the equilibrium represented by the equation- $A^-(aq) + H_2O(l) \rightleftharpoons HA(aq) + OH^-(aq)$.	Chapter 16	728-731				

			SAP-9.D.3: When a weak base and a strong acid are mixed, they will react quantitatively in a reaction represented by the equation- $B(aq) + H_3O^+(aq) \rightleftharpoons HB^+(aq) + H_2O(l)$. If the weak base is in excess, then a buffer solution is formed, and the pH can be determined from the H-H equation. If the strong acid is in excess, then the pH can be determined from the moles of excess hydronium ion and the total volume of solution. If they are equimolar, then the (slightly acidic) pH can be determined from the equilibrium represented by the equation- $HB^+(aq) + H_2O(l) \rightleftharpoons B(aq) + H_3O^+(aq)$.	Chapter 16	731-733				
			SAP-9.D.4: When a weak acid and a weak base are mixed, they will react to an equilibrium state whose reaction may be represented by the equation- $HA(aq) + B(aq) \rightleftharpoons A^-(aq) + HB^+(aq)$.	Chapter 16	724 *This is not an explanation. Could not find a full explanation in the text.				
8.5 Acid-Base Titrations		**SAP-9.E:** Explain results from the titration of a mono- or polyprotic acid or base solution, in relation to the properties of the solution and its components.	**SAP-9.E.1:** An acid-base reaction can be carried out under controlled conditions in a titration. A titration curve, plotting pH against the volume of titrant added, is useful for summarizing results from a titration.	Chapter 4, Chapter 16	153-156; 724-733	**5.D:** Identify information presented graphically to solve a problem.	724-733, 760	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	759-760, Questions 16.27-16.40
			SAP-9.E.2: At the equivalence point, the number of moles of titrant added is equal to the number of moles of analyte originally present. This relationship can be used to obtain the concentration of the analyte. This is the case for titrations of strong acids/bases and weak acids/bases.	Chapter 4, Chapter 16	153-156; 724-733				
			SAP-9.E.3: For titrations of weak acids/bases, it is useful to consider the point halfway to the equivalence point, that is, the half-equivalence point. At this point, there are equal concentrations of each species in the conjugate acid-base pair, for example, for a weak acid $[HA] = [A^-]$. Because pH = pKa when the conjugate acid and base have equal concentrations, the pKa can be determined from the pH at the half-equivalence point in a titration.	Chapter 16	729-730, 760 *Not explicitly stated or shown in text, but problems are related to content.				

			SAP-9.E.4: For polyprotic acids, titration curves can be used to determine the number of acidic protons. In doing so, the major species present at any point along the curve can be identified, along with the pKa associated with each proton in a weak polyprotic acid. ✗ Computation of the concentration of each species present in the titration curve for polyprotic acids will not be assessed on the AP Exam. Rationale: Such computations for titration of monoprotic acids are within the scope of the course, as is qualitative reasoning regarding what species are present in large versus small concentrations at any point in titration of a polyprotic acid. However, additional computations of the concentration of each species present in the titration curve for polyprotic acids may encourage algorithmic calculations rather than deepen understanding.	Chapter 15, Chapter 16	684-687; AP766 *Titration curves for polyprotic acids are not shown in text. Practice problems include abbreviated diagrams.				
8.6 Molecular Structure of Acids and Bases		**SAP-9.F:** Explain the relationship between the strength of an acid or base and the structure of the molecule or ion.	**SAP-9.F.1:** The protons on a molecule that will participate in acid-base reactions, and the relative strength of these protons, can be inferred from the molecular structure. a. Strong acids (such as HCl, HBr, HI, HClO4, H2SO4, and HNO3) have very weak conjugate bases that are stabilized by electronegativity, inductive effects, resonance, or some combination thereof. b. Carboxylic acids are one common class of weak acid. c. Strong bases (such as group I and II hydroxides) have very weak conjugate acids. d. Common weak bases include nitrogenous bases such as ammonia as well as carboxylate ions. e. Electronegative elements tend to stabilize the conjugate base relative to the conjugate acid, and so increase acid strength.	Chapter 15, Chapter 24	670-699; 1039-1040	**6.C:** Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.	670-699	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	705-706, Questions 15.67-15.96; 762, Question 16.96
8.7 pH and pKa	**SAP-10:** A buffered solution resists changes to its pH when small amounts of acid or base are added.	**SAP-10.A:** Explain the relationship between the predominant form of a weak acid or base in solution at a given pH and the pKa of the conjugate acid or the pKb of the conjugate base.	**SAP-10.A.1:** The protonation state of an acid or base (i.e., the relative concentrations of HA and A–) can be predicted by comparing the pH of a solution to the pKa of the acid in that solution. When solution pH < acid pKa, the acid form has a higher concentration than the base form. When solution pH > acid pKa, the base form has a higher concentration than the acid form.	Chapter 15	674-684	**2.D:** Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.	674-680; 734	**Reasoning Process #2:** Explain Comparisons: Similarities, Differences, Contrasts, Juxtapositions	704, Questions 15.39-15.40; 705, Question 15.51; 760, Question 16.41; 766, Questions

			SAP-10.A.2: Acid-base indicators are substances that exhibit different properties (such as color) in their protonated versus deprotonated state, making that property respond to the pH of a solution.	Chapter 16	733-735				16.145, 16.147
8.8 Properties of Buffers		**SAP-10.B:** Explain the relationship between the ability of a buffer to stabilize pH and the reactions that occur when an acid or a base is added to a buffered solution.	**SAP-10.B.1:** 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. These reactions are responsible for the ability of a buffer to stabilize pH.	Chapter 16	719-720	**6.D:** Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.	719-720	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	759, Questions 16.7-16.8
8.9 Henderson-Hasselbalch Equation		**SAP-10.C:** Identify the pH of a buffer solution based on the identity and concentrations of the conjugate acid-base pair used to create the buffer.	**SAP-10.C.1:** The pH of the buffer is related to t acid and the concentration ratio of the conjuga pair. This relation is a consequence of the equ expression associated with the dissociation of and is described by the Henderson-Hasselbal Adding small amounts of acid or base to a buf does not significantly change the ratio of [A–]/[does not significantly change the solution pH. in pH on addition of acid or base to a buffered therefore much less than it would have been i absence of the buffer. EQN: $pH = pK_a + \log \frac{[A^-]}{[HA]}$ ✗ Computation of the change in pH resulting from th an acid or a base to a buffer will not be assessed on ✗ Derivation of the Henderson-Hasselbalch equatior assessed on the AP Exam.	Chapter 16	719-724	**5.F:** Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).	717-719	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	759, Questions 16.13-16.24
8.10 Buffer Capacity		**SAP-10.D:** Explain the relationship between the buffer capacity of a solution and the relative concentrations of the conjugate acid and conjugate base components of the solution.	**SAP-10.D.1:** Increasing the concentration of the buffer components (while keeping the ratio of these concentrations constant) keeps the pH of the buffer the same but increases the capacity of the buffer to neutralize added acid or base.	Chapter 16	719-724	**6.G:** Explain how potential sources of experimental error may affect the experimental results.	717-719	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	759, Questions 16.13-16.24
			SAP-10.D.2: When a buffer has more conjugate acid than base, it has a greater buffer capacity for addition of added base than acid. When a buffer has more conjugate base than acid, it has a greater buffer capacity for addition of added acid	Chapter 16	719-724, 729-733				

			than base.						

Unit 9: Applications of Thermodynamics 7-9%

Topic Name	Enduring Understanding and Big Idea	Learning Objective	Essential Knowledge	Chapter	Page Numbers	Science Practices and Skills	Page Numbers	Reasoning Process	Page Numbers
9.1 Introduction to Entropy	**ENE-4:** Some chemical or physical processes cannot occur without intervention.	**ENE-4.A:** Identify the sign and relative magnitude of the entropy change associated with chemical or physical processes.	**ENE-4.A.1:** Entropy increases when matter becomes more dispersed. For example, the phase change from solid to liquid or from liquid to gas results in a dispersal of matter as the individual particles become freer to move and generally occupy a larger volume. Similarly, 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. For reactions involving gas-phase reactants or products, the entropy generally increases when the total number of moles of gas-phase products is greater than the total number of moles of gas-phase reactants.	Chapter 17	773-776	**6.C:** Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.	773-776	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	798, Questions 17.4-17.6
			ENE-4.A.2: Entropy increases when energy is dispersed. According to kinetic molecular theory (KMT), the distribution of kinetic energy among the particles of a gas broadens as the temperature increases. As a result, the entropy of the system increases with an increase in temperature.	Chapter 5, Chapter 17	203-207; 773-776				

9.2 Absolute Entropy and Entropy Change		**ENE-4.B:** Calculate the entropy change for a chemical or physical process based on the absolute entropies of the species involved in the process.	**ENE-4.B.1:** The entropy change for a process can be calculated from the absolute entropies of the species involved before and after the process occurs. EQN: $\Delta S^{o}_{reaction} = \Sigma S^{o}_{products} - \Sigma s^{o}_{reactants}$	Chapter 17	777-781	**5.F:** Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).	777-781	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	798, Questions 17.11-17.12
9.3 Gibbs Free Energy and Thermodynamic Favorability		**ENE-4.C:** Explain whether a physical or chemical process is thermodynamically favored based on an evaluation of ΔG^{o}.	**ENE-4.C.1:** The Gibbs free energy change for a chemical process in which all the reactants and products are present in a standard state (as pure substances, as solutions of 1.0 M concentration, or as gases at a pressure of 1.0 atm (or 1.0 bar)) is given the symbol $\Delta G°$.	Chapter 17	782-783	**6.E:** Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.	782-790	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	798, Question 17.17; 799, Questions 17.19-17.20; 800, Question 17.44
			ENE-4.C.2: The standard Gibbs free energy change for a chemical or physical process is a measure of thermodynamic favorability. Historically, the term “spontaneous” has been used to describe processes for which $\Delta G^{o} < 0$. The phrase “thermodynamically favored” is preferred instead so that common misunderstandings (equating “spontaneous” with “suddenly” or “without cause”) can be avoided. When $\Delta G^{o} < 0$ for the process, it is said to be thermodynamically favored.	Chapter 17	782-786				
			ENE-4.C.3: The standard Gibbs free energy change for a physical or chemical process may also be determined from the standard Gibbs free energy of formation of the reactants and products. EQN: $\Delta G^{o}_{reaction} = \Sigma \Delta G^{o}_{f\,products} - \Sigma \Delta G^{o}_{f\,reactants}$	Chapter 17	782-786				
			ENE-4.C.4: In some cases, it is necessary to consider both enthalpy and entropy to determine if a process will be thermodynamically favored. The freezing of water and the dissolution of sodium nitrate are examples of such phenomena.	Chapter 17	786-787				

<table>
<tr><td rowspan="2"></td><td rowspan="4"></td><td rowspan="2"></td><td>ENE-4.C.5: Knowing the values of ΔH^o and ΔS^o for a process at a given temperature allows ΔG^o to be calculated directly.
EQN: $\Delta G^\circ = \Delta H^\circ - T\,\Delta S^\circ$</td><td>Chapter 17</td><td>788-790</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>ENE-4.C.6: In general, the temperature conditions for a process to be thermodynamically favored ($\Delta G^o < 0$) can be predicted from the signs of ΔH^o and ΔS^o as shown in the table below-
<table>
<tr><th>ΔH°</th><th>ΔS°</th><th>Symbols</th><th>$\Delta G^\circ < 0$, favored at:</th></tr>
<tr><td>< 0</td><td>> 0</td><td>$< >$</td><td>all T</td></tr>
<tr><td>> 0</td><td>< 0</td><td>$> <$</td><td>no T</td></tr>
<tr><td>> 0</td><td>> 0</td><td>$> >$</td><td>high T</td></tr>
<tr><td>< 0</td><td>< 0</td><td>$< <$</td><td>low T</td></tr>
</table>
In cases where $\Delta H^o < 0$ and $\Delta S^o > 0$, no calculation of ΔG^o is necessary to determine that the process is thermodynamically favored ($\Delta G^o < 0$). In cases where $\Delta H^o > 0$ and $\Delta S^o < 0$, no calculation of ΔG^o is necessary to determine that the process is thermodynamically unfavored ($\Delta G^o > 0$).</td><td>Chapter 17</td><td>786-787</td></tr>
<tr><td rowspan="2">9.4 Thermodynamic and Kinetic Control</td><td rowspan="2">ENE-4.D: Explain, in terms of kinetics, why a thermodynamically favored reaction might not occur at a measurable rate.</td><td>ENE-4.D.1: Many processes that are thermodynamically favored do not occur to any measurable extent, or they occur at extremely slow rates.</td><td>Chapter 17</td><td>771-773, 782-783, 787-788</td><td rowspan="2">6.E: Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.</td><td rowspan="2">583, 771-773</td><td rowspan="2">Reasoning Process #3: Explain Cause and Effect: Cause, Effect, Consequence, Factors</td><td rowspan="2">798, Questions 17.1-17.3, 17.16</td></tr>
<tr><td>ENE-4.D.2: Processes that are thermodynamically favored, but do not proceed at a measurable rate, are 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 rate does not mean that the chemical system is at equilibrium. If a process is known to be thermodynamically favored, and yet does not occur at a measurable rate, it is reasonable to conclude that the process is under kinetic control.</td><td>Chapter 13, Chapter 17</td><td>582-587; 771-773</td></tr>
</table>

9.5 Free Energy and Equilibrium	**ENE-5:** The relationship between ΔG° and K can be used to determine favorability of a chemical or physical transformation.	**ENE-5.A:** Explain whether a process is thermodynamically favored using the relationships between K, ΔGo, and T.	**ENE-5.A.1:** The phrase "thermodynamically favored" (ΔGo < 0) means that the products are favored at equilibrium (K > 1).	Chapter 17	791-794	**6.D:** Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification	791-794	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	799, Questions 17.23-17.32
			ENE-5.A.2: The equilibrium constant is related to free energy by the equations EQN: K = e −ΔG°/RT and EQN: ΔG° = −RT ln K.	Chapter 17	791-794				
			ENE-5.A.3: Connections between K and ΔG° can be made qualitatively through estimation. When ΔG° is near zero, the equilibrium constant will be close to 1. When ΔG° is much larger or much smaller than RT, the value of K deviates strongly from 1.	Chapter 17	791-792				
			ENE-5.A.4: Processes with ΔG° < 0 favor products (i.e., K > 1) and those with ΔG° > 0 favor reactants (i.e., K < 1).	Chapter 17	791-792				
9.6 Coupled Reactions		**ENE-5.B:** Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes.	**ENE-5.B.1:** An external source of energy can be used to make a thermodynamically unfavorable process occur. Examples include- a. Electrical energy to drive an electrolytic cell or charge a battery. b. Light to drive the overall conversion of carbon dioxide to glucose in photosynthesis.	Chapter 17	791-792, 795-796	**4.D** Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.	791-796	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	799, Questions 17.33-17.34
			ENE-5.B.2: A desired product can be formed by coupling a thermodynamically unfavorable reaction that produces that product to a favorable reaction (e.g., the conversion of ATP to ADP in biological systems). In the coupled system, the individual reactions share one or more common intermediates. The sum of the individual reactions produces an overall reaction that achieves the desired outcome and has ΔG° < 0.	Chapter 17	795-796				

9.7 Galvanic (Voltaic) and Electrolytic Cells	**ENE-6:** Electrical energy can be generated by chemical reactions.	**ENE-6.A:** Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.	**ENE-6.A.1:** Each component of an electrochemical cell (electrodes, solutions in the half-cells, salt bridge, voltage/current measuring device) plays a specific role in the overall functioning of the cell. The operational characteristics of the cell (galvanic vs. electrolytic, direction of electron flow, reactions occurring in each half-cell, change in electrode mass, evolution of a gas at an electrode, ion flow through the salt bridge) can be described at both the macroscopic and particulate levels.	Chapter 18	810-818	**2.F:** Explain how modifications to an experimental procedure will alter results.	810-819, 826-830, 836-837	**Reasoning Process #1:** Define/Classify: Characteristics, Traits	843, Questions 18.3, 18.6; 844, Question 18.16
			ENE-6.A.2: Galvanic, sometimes called voltaic, cells involve a thermodynamically favored reaction, whereas electrolytic cells involve a thermodynamically unfavored reaction. Visual representations of galvanic and electrolytic cells are tools of analysis to identify where half-reactions occur and in what direction current flows.	Chapter 18	813, 818-819, 826-828, 830, 836-837				
			ENE-6.A.3: For all electrochemical cells, oxidation occurs at the anode and reduction occurs at the cathode. X Labeling an electrode as positive or negative will not be assessed on the AP Exam. Rationale: Sign conventions vary depending on the type of electrochemical cell, even though oxidation always occurs at the anode.	Chapter 18	810-814, 826-830, 836-837				
9.8 Cell Potential and Free Energy		**ENE-6.B:** Explain whether an electrochemical cell is thermodynamically favored, based on its standard cell potential and the constituent half-reactions within the cell.	**ENE-6.B.1:** Electrochemistry encompasses the study of redox reactions that occur within electrochemical cells. The reactions are either thermodynamically favored (resulting in a positive voltage) or thermodynamically unfavored (resulting in a negative voltage and requiring an externally applied potential for the reaction to proceed).	Chapter 18	807, 818-820	**5.F:** Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision and/or units where appropriate (e.g., performing dimensional analysis	812-820	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	844, Questions 18.11-18.15, 18.22
			ENE-6.B.2: The standard cell potential of electrochemical cells can be calculated by identifying the oxidation and reduction half-reactions and their respective standard reduction potentials.	Chapter 18	812-816				

			ENE-6.B.3: ΔGo (standard Gibbs free energy change) is proportional to the negative of the cell potential for the redox reaction from which it is constructed. Thus, a cell with a positive Eo involves a thermodynamically favored reaction, and a cell with a negative Eo involves a thermodynamically unfavored reaction. EQN: ΔGo = − nFEo	Chapter 18	818-819	and attending to significant figures).			
9.9 Cell Potential Under Nonstandard Conditions		**ENE-6.C:** Explain the relationship between deviations from standard cell conditions and changes in the cell potential.	**ENE-6.C.1:** In a real system under nonstandard conditions, the cell potential will vary depending on the concentrations of the active species. The cell potential is a driving force toward equilibrium; the farther the reaction is from equilibrium, the greater the magnitude of the cell potential.	Chapter 18	812-826	**6.D:** Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.	812-826	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	845-846, Questions 18.29-18.36
			ENE-6.C.2: Equilibrium arguments such as Le Châtelier's principle do not apply to electrochemical systems, because the systems are not in equilibrium.	Chapter 18	818-824				
			ENE-6.C.3: 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 Eo. Deviations from standard conditions that take the cell closer to equilibrium than Q = 1 will decrease the magnitude of the cell potential relative to Eo. In concentration cells, the direction of spontaneous electron flow can be determined by considering the direction needed to reach equilibrium.	Chapter 18	818-824				
			ENE-6.C.4: Algorithmic calculations using the Nernst equation are insufficient to demonstrate an understanding of electrochemical cells under nonstandard conditions. However, students should qualitatively understand the effects of concentration on cell potential and use conceptual reasoning, including the qualitative use of the Nernst equation- EQN: E = Eo – (RT/nF) ln Q to solve problems.	Chapter 18	821-826				

9.10 Electrolysis and Faraday's Law		**ENE-6.D:** Calculate the amount of charge flow based on changes in the amounts of reactants and products in an electrochemical cell.	**ENE-6.D.1:** Faraday's laws can be used to determine the stoichiometry of the redox reaction occurring in an electrochemical cell with respect to the following- a. Number of electrons transferred b. Mass of material deposited on or removed from an electrode c. Current d. Time elapsed e. Charge of ionic species EQN: I = q/t	Chapter 18	818-819, 839-840	**5.B** Identify an appropriate theory, definition, or mathematical relationship to solve a problem.	839-840	**Reasoning Process #3:** Explain Cause and Effect: Cause, Effect, Consequence, Factors	845-846, Questions 18.47-18.64