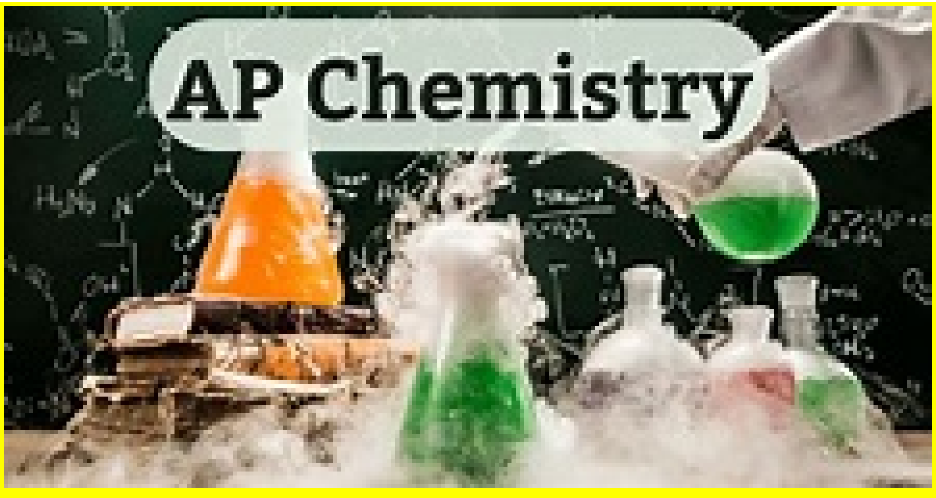
AP CHEMISTRY CURRICULUM

	
Grade Level(s): 11-12	**Curriculum Author(s):** Melissa Hodges

Course Description: Students will practice reasoning skills by using chemical models to analyze, explain, and predict phenomena, and by supporting claims with scientific evidence from data, models, and theories. Students will develop inquiry and reasoning skills by designing and conducting inquiry based laboratory investigations to answer scientific questions through observations, data collection, data analysis and interpretation, troubleshooting and procedural refinement,and error analysis. This course follows the CollegeBoard® AP Chemistry Curriculum.

Year At A Glance			
Unit Title	**Overarching Essential Question**	**Overarching Enduring Understanding**	**Vision of A Learner "I Can" Statements**
Atomic Structure and Properties (3 weeks)	How do we describe atoms and how do their properties relate to their position on the periodic table?	Although atoms represent the foundational level of chemistry, observations of chemical properties are made on collections of atoms.	TCC2(9-12)
Compound Structure and Properties (2.5 weeks)	How do atoms arrange themselves when forming compounds and how does that arrangement affect the properties of compounds?	Both the chemical and physical properties of materials can be explained by the structure and arrangement of atoms, ions, or molecules and the forces between them.	TCC3(9-12); CCE2(9-12)
Properties of Substances and Mixtures (4 weeks)	How are the properties of substances related to the arrangement of the atoms in those compounds?	The properties of solids, liquids, and gasses reflect the relative orderliness of the arrangement of particles in those states,their relative freedom of motion, and the nature and strength of the interactions between them.	TCC2(9-12); CCE3(9-12); DE1(9-12)
Chemical Reactions (3 weeks)	How can we predict both the amount and structure of products of a chemical reaction?	Chemical changes involve the making and breaking of chemical bonds while conserving the amount of atoms involved.	CCE3(9-12); DE4(9-12)
Kinetics (3.5 weeks)	How can we affect the rate of a reaction?	Reactions occur as a series of collisions and the frequency and effectiveness of those collisions are affected by temperature, surface area and concentration of reactants.	TCC2(9-12)
Thermochemistry (3 weeks)	How is energy transferred during both chemical and physical processes and	Energy is conserved during all chemical and physical processes; it only changes form.	AA1(9-12); AA2(9-12); P4(9-12)

	why do substances absorb/release heat at different rates?		
Equilibrium (3.5 weeks)	How can we describe and affect the ratio of products to reactants during chemical and physical processes?	Chemical equilibrium is a dynamic state in which opposing processes occur at the same rate, so concentration of products and reactants remain constant.	TCC1(9-12); TCC2(9-12); CCE3(9-12)
Acids and Bases (3 weeks)	How can we describe the strength and concentration of acids and bases?	The strength of acids and bases are explained using equilibrium expressions.	TI1(9-12); P1(9-12); P4(9-12):
Thermodynamics and Electrochemistry (3 weeks)	How can we predict if a reaction occurs in the forward or reverse direction?	The thermodynamics of a chemical reaction is connected to both the structural aspects of the reaction and the macroscopic outcomes of the reaction.	P2(9-12); P3(9-12); AA3(9-12)

2 Weeks are allotted for review for the AP Exam in May (Online Review Book)

Unit 1 - Atomic Structure and Properties

Desired Results - Students will describe the basic structure and properties of atoms relative to their position on the periodic table.

Established Goals:
Common Core State Standards:
RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words
RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes
HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays
HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

NGSS Standards:
HS-PS1-1 - Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms
HS-PS1-2 - Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
HS-PS1-3 - Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles
HS-PS2-4 - Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials

AP Chemistry Curricula Unit 1

Vision of A Learner Attributes: Students will be able to independently use their learning to... ("I can" statements to be demonstrated)
- TCC2(9-12): I can evaluate evidence from multiple perspectives, and recognize their limitations and implications, in order to justify new conclusions.

Understandings: Students will understand that...	**Essential Questions:**
• Macroscopic systems involve such large numbers of particles that they require the units of moles to translate between this and	• How can large quantities of objects be counted by weighing? • If atoms are too small to be observed directly, how do we know

the particulate scale. ● The organization of the periodic table reflects the periodicity of element properties as a function of atomic number. ● The electronic structure of an atom can be described by an electron configuration that provides a method for describing the distribution of electrons in an atom or ion.	how they're structured? ● Why does the periodic table have the shape that it does?
Students will know... ● Avogadro's number (N = 6.022 × 1023 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. ● There is a quantitative connection between the mass of a substance and the number of particles that the substance contains. ● 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. ● The average atomic mass of an element can be estimated from the weighted average of the isotopic masses ● 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.using the mass of each isotope and its relative abundance. ● 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. ● The chemical formula that lists the lowest whole number ratio of atoms of the elements in a compound is the empirical formula. ● Pure substances contain atoms, molecules, or formula units of a single type. Mixtures contain atoms, molecules, or formula units of two or more types, whose relative proportions can vary. ● Elemental analysis can be used to determine the relative numbers of atoms in a substance and to determine its purity. ● The atom is composed of negatively charged electrons and a positively charged nucleus that is made of protons and neutrons. ● Coulomb's law is used to calculate the force between two	**Students will be able to...** ● Calculate quantities of a substance or its relative number of particles using dimensional analysis and the mole concept. ● Explain the quantitative relationship between the mass spectrum of an element and the masses of the element's isotopes. ● Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance. ● Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture. ● Represent/write the ground-state electron configuration of an atom or its ions. ● Explain the relationship between the photoelectron spectrum of an atom or ion and: ○ The ground-state electron configuration of the species. ○ The interactions between the electrons and the nucleus. ● Explain the relationship between trends in atomic properties of elements and electronic structure and periodicity. ● Explain the relationship between trends in the reactivity of elements and periodicity.

charged particles.

- In atoms and ions, the electrons can be thought of as being in "shells (energy levels)" and "subshells (sublevels)," as described by the ground-state electron configuration.
- 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.
- 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 relative height of each peak is (ideally) proportional to the number of electrons in that subshell.
- The organization of the periodic table is based on patterns of recurring properties of the elements, which are explained by patterns of ground-state electron configurations and the presence of completely or partially filled shells (and subshells) of electrons in atoms.
- Trends in atomic properties within the periodic table (periodicity) can be predicted by the position of the element on the periodic table and qualitatively understood using Coulomb's law, the shell model, and the concepts of shielding and effective nuclear charge.
- The periodicity is useful to predict/estimate values of properties in the absence of data.
- The likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of elements.
- Elements in the same column of the periodic table tend to form analogous compounds.
- Typical charges of atoms in ionic compounds are governed by the number of valence electrons and predicted by their location on the periodic table.

Key Vocabulary: Avogadro's number, mole, mass spectrum, isotope, relative abundance, atomic number, ion, formula unit, molecule, empirical

formula, Law of Definite Proportions, pure substance, mixture, proton, neutron, electron, electron configuration, Coulomb's law, core electron, valence electron, PES diagram, photoelectron spectroscopy, ionization energy, electronegativity, atomic radius, electron affinity, effective nuclear charge, shielding effect, periodicity

Assessment Evidence	
Performance Tasks: ● Empirical Formula Lab ○ Students will experimentally determine the formula of a hydrate. This will also serve as a review for correct laboratory techniques.	**Other Evidence:** ● Moles/Molar Mass Notes/Worksheet ● Mass Spectra of Elements Notes/Worksheet ● Elemental Composition of Pure Substances Notes/Worksheet ● Combustion Analysis Worksheet ● Composition of Mixtures Notes/Worksheet ● Atomic Spectra and Electron Configuration Notes/Worksheet ● Photoelectron Spectroscopy Notes/Worksheet ● Periodic Trends Notes/Worksheet ● Periodic Trends POGIL ● Valence Electrons and Ionic Compounds Notes/Worksheet ● Unit Test

Learning Plan
RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words ● Translate visual representations of elements, compounds and mixtures into words and translate words into visual representations of elements, compounds and mixtures RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes ● Explain how to measure and calculate the empirical formula of a compound HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays ● Convert between moles and mass of elements and compounds ● Use percent composition to determine the empirical formula of a compound ● Interpret a PES diagram ● Interpret a Mass Spectrum diagram HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities ● Accurately measure mass to determine the empirical formula of a compound HS-PS1-1 - Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms

- Predict the properties of elements based on their position on the periodic table
- Write the electron configuration for elements

HS-PS1-2 - Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

- Use the periodic table to

HS-PS1-3 - Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles

- Explain why heating a hydrate allows us to determine its chemical formula and composition

HS-PS2-4 - Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

- Use Coulomb's law to explain the properties of Ionic Compounds
- Use Coulomb's law to explain periodic trends

HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials

- Explain the properties of ionic compounds

VOL Common Assessment
THINK CRITICALLY AND CREATIVELY
TCC2(9-12): I can evaluate evidence from multiple perspectives, and recognize their limitations and implications, in order to justify new conclusions.

- Empirical Formula Lab

Teacher Resources: Brown/Lemay Textbook, I Do, We Do, You Do Notes, Formula Sheet, AP Classroom Daily Videos, Daily Video Guides, AP Classroom Progress Check, AP Chemistry CED, Guided Inquiry Activities, Unit Review Videos, Unit 1 1-Pager, Topic Specific Videos

Unit 2 - Compound Structure and Properties	
Desired Results - Students will predict the properties and structure of compounds.	
Established Goals: **Common Core State Standards:** RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities **NGSS Standards:** HS-PS1-1 - Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms HS-PS1-3 - Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles HS-PS2-4 - Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials **AP Chemistry Curricula Unit 2**	
Vision of A Learner Attributes: Students will be able to independently use their learning to... ("I can" statements to be demonstrated) ● TCC3(9-12): I can integrate relevant information to produce multiple valid solutions. ● CCE2(9-12): I can give and receive actionable and relevant feedback with openness to be able to determine meaningful revisions for success.	
Understandings: Students will understand that… ● Both the chemical and physical properties of materials can be explained by the structure and arrangement of atoms, ions, or molecules and the forces between them. ● Chemical bonds are distinct from typical intermolecular interactions. ● Electronegativity can be used to make predictions about the type of bonding present between two atoms	**Essential Questions:** ● How are the atoms in molecular compounds arranged? ● Why are some bonds easier to break than others? ● In what ways does a diagram drawn on paper accurately reflect the structure of a molecule? In what ways does it not accurately reflect the structure?

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Students will know...

- 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.
- Valence electrons shared between atoms of similar electronegativity constitute a nonpolar covalent bond.
- Valence electrons shared between atoms of unequal electronegativity constitute a polar covalent bond
    - The atom with a higher electronegativity will develop a partial negative charge relative to the other atom in the bond.
    - In single bonds,greater differences in electronegativity lead to greater bond dipoles.
    - All polar bonds have some ionic character, and the differences between ionic and covalent compounds is not distinct but rather a continuum.
- Generally, bonds between a metal and nonmetal are ionic, and bonds between two nonmetals are covalent.
- In a metallic solid, the valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom.
- Interstitial alloys form between atoms of significantly different radii, where the smaller atoms fill the interstitial spaces between the larger atoms.
- Substitutional alloys form between atoms of comparable radius, where one atom substitutes for the other in the lattice.
- A graph of potential energy versus the distance between atoms (internuclear distance) 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).
- 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.

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Students will be able to…

- Explain the relationship between the type of bonding and the properties of the elements participating in the bond.
- Represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength.
- Represent an ionic solid with a particulate model that is consistent with Coulomb's law and the properties of the constituent ions.
- Represent a metallic solid and/or alloy using a model to show essential characteristics of the structure and interactions present in the substance.
- Represent a molecule with a Lewis diagram.
- Represent a molecule with a Lewis diagram that accounts for resonance between equivalent structures or that uses formal charge to select between nonequivalent structures.
- Explain structural properties of molecules.
- Explain electron properties of molecules.

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• Coulomb's law can be used to understand the strength of interactions between cations and anions • 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. • Lewis diagrams can be constructed according to an established set of principles. • In cases where more than one equivalent Lewis structure can be constructed, resonance must be included as a refinement to the Lewis structure. In many such cases,this refinement is needed to provide qualitatively accurate predictions of molecular structure and properties. • The octet rule and formal charge can be used as criteria for determining which of several possible valid Lewis diagrams provides the best model for predicting molecular structure and properties. • VSEPR theory uses the Coulombic repulsion between electrons as a basis for predicting the arrangement of electron pairs around a central atom. • Both Lewis diagrams and VSEPR theory must be used for predicting electronic and structural properties of many covalently bonded molecules and polyatomic ions. • The terms "hybridization" and "hybrid atomic orbital" are used to describe the arrangement of electrons around a central atom. When the central atom is sp hybridized, its ideal bond angles are 180°; for sp2 hybridized atoms the bond angles are 120°; and for sp3 hybridized atoms the bond angles are 109.5°. • Bond formation is associated with overlap between atomic orbitals. In multiple bonds, such overlap leads to the formation of both sigma and pi bonds. The overlap is stronger in sigma than pi bonds,which is reflected in sigma bonds having greater bond energy than pi bonds. The presence of a pi bond also prevents the rotation of the bond and leads to geometric isomers.	

Key Vocabulary: ionic, covalent, metallic, Lewis dot structure, intermolecular force, potential energy, alloy, resonance, formal charge, VSEPR, hybridization, hybrid atomic orbital, internuclear distance, interstitial alloy, substitutional alloy, octet rule, Molecular geometry (linear, trigonal planar, tetrahedral, trigonal pyramidal, bent, trigonal bipyramidal, seesaw, T-shaped, octahedral, square pyramidal, square planar), bond angle, dipole moment, bond energy, polar, nonpolar, electronegativity, geometric isomer, sigma bonding, pi bonding, single bond, double bond, triple bond

Assessment Evidence

Performance Tasks:

- Properties of Ionic, Metallic and Molecular Substances lab
  - Students will use laboratory data to determine the type of bonding present in several given substances.
- Put it all together Lewis Dot Structure Practice
  - Students will correctly draw lewis dot structure, indicate their shape and bond angles, indicate which molecules demonstrate resonance, determine the hybridization of the central atom and calculate the formal change of each structure.

Other Evidence:

- Types of Chemical Bonds Notes/Worksheet
- Intermolecular Force and Potential Energy Notes/Worksheet
- Structure of Ionic Solids Notes/Worksheet
- Structure of Metals and Alloys Notes/Worksheet
- Lewis Diagrams Notes/Worksheet
- Resonance and Formal Charge Notes/Worksheet
- VSEPR and Hybridization Notes/Worksheet
- Unit Test

Learning Plan

RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words

- Draw particulate level diagrams of compounds

RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes

- Explain how to determine the type of bonding present using lab data

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

- Accurately measure mass and temperature of compounds

HS-PS1-1 - Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms

- Use the periodic table to predict the type of bonding present in a compound
- Use the periodic table to predict the number of valence electrons available for bonding

HS-PS1-3 - Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles

- Use laboratory data to determine the type of bonding present in a compound

HS-PS2-4 - Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

- Use Coulomb's law to explain the properties of ionic compounds
- Use Coulomb's law to explain the properties and type of alloy present in a metallic compound

HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed

materials ● Use the type of bonding present to explain physical and chemical properties of compounds VOL Common Assessments: THINK CRITICALLY AND CREATIVELY TCC3(9-12): I can integrate relevant information to produce multiple valid solutions. ● Properties of Ionic, Metallic and Molecular Substances Lab COLLABORATE AND COMMUNICATE EFFECTIVELY CCE2(9-12): I can give and receive actionable and relevant feedback with openness to be able to determine meaningful revisions for success. ● Putting it All Together Lewis Structure Practice
Teacher Resources Brown/Lemay Textbook, I Do, We Do, You Do Notes, Formula Sheet, AP Classroom Daily Videos, Daily Video Guides, AP Classroom Progress Check, AP Chemistry CED, Guided Inquiry Activities, Unit Review Videos, Unit 2 1 pager, Topic Specific Videos

Unit 3 - Properties of Substances and Mixtures

Desired Results - Students will understand the relationship between the arrangement of atoms in a compound and the properties of the resulting compound or mixtures.

Established Goals:

Common Core State Standards:

RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words

RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes

HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

NGSS Standards:

HS-PS1-1 - Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms

HS-PS1-2 - Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-PS1-3 - Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles

HS-PS4-1 - Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

HS-PS4-3 - Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other

HS-PS-4-4 - Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter

HS-PS2-4 - Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials

AP Chemistry Curricula Unit 3

Vision of A Learner Attributes: Students will be able to independently use their learning to... ("I can" statements to be demonstrated)

- TCC2(9-12): I can evaluate evidence from multiple perspectives, and recognize their limitations and implications, in order to justify new conclusions.
- CCE3(9-12): I can show initiative in prompting group discourse and fostering collaboration among others, providing actionable feedback, and working with others to solve problems and/or design products.
- DE1(9-12): I can acknowledge, process, and respond appropriately to others' comments and perspectives.

Understandings: Students will understand that…

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

Essential Questions:

- How do interactions between particles influence the properties of pure substances and mixtures?
- How does the spacing and motion of particles relate to a substance's state of matter and the properties of gasses?
- How can you determine the structure and concentration of a chemical species in a mixture?

Students will know...

- 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.
  - Dispersion forces increase with increasing contact area between molecules and with increasing polarizability of the molecules.
  - 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.
  - The term "London dispersion forces" should not be used synonymously with the term "van der Waals forces".
- The dipole moment of a polar molecule leads to additional interactions with other chemical species.
  - Dipole-induced dipole interactions are present between a

Students will be able to…

- Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when:
  - i. The molecules are of the same chemical species.
  - ii. The molecules are of two different chemical species
- Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.
- Represent the differences between solid, liquid, and gas phases using a particulate level model.
- Explain the relationship between the macroscopic properties of a sample of gas or mixture of gasses using the ideal gas law.
- Explain the relationship between the motion of particles and the macroscopic properties of gasses with:
  - The kinetic molecular theory (KMT).
  - A particulate model.

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.
    - Dipole-dipole interactions are present between polar molecules. The interaction strength depends on the magnitude of the dipoles and their relative orientations. 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.
- 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.
- 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) indifferent molecule, or a different part of the same molecule.
- In large biomolecules, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule.
- Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present. Because intermolecular interactions are overcome completely 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.
- Particulate-level representations,showing multiple interacting chemical species, are a useful means to communicate or understand how intermolecular interactions help to establish macroscopic properties.
- Due to strong interactions between ions, ionic solids tend to

    - A graphical representation.
- Explain the relationship among non-ideal behavior of gasses, interparticle forces, and/or volumes.
- Calculate the number of solute particles, volume, or molarity of solutions.
- Use particulate models for mixtures:
    - Represent interactions between components.
    - Represent concentrations of components
- Explain the results of a separation experiment based on intermolecular interactions.
- Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles.
- Differences in absorption or emission of photons in different spectral regions are related to the different types of molecular motion or electronic transition:
    - Microwave radiation is associated with transitions in molecular rotational levels.
    - Infrared radiation is associated with transitions in molecular vibrational levels.
    - Ultraviolet/visible radiation is associated with transitions in electronic energy levels.
- Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.
- Explain the amount of light absorbed by a solution of molecules or ions in relationship to the concentration, path length, and molar absorptivity.

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 (i.e., in a molten state) or dissolved in water or another solvent. ● In covalent network solids, the atoms are covalently bonded together into a three dimensional network or layers of two-dimensional networks. These are only formed from nonmetals and metalloids: elemental or binary compounds. 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. ● 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. ● 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. ● 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. ● Solids can be crystalline, where the particles are arranged in regular three-dimensional structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. 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 interaction and the ability of the particles to pack together. ● 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. ● 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. ● 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 definite shape. ● The macroscopic properties of ideal gasses are related through the ideal gas law: $PV = nRT$. ● In a sample containing a mixture of ideal gasses, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the partial pressure of a gas within the mixture is proportional to its mole fraction (X), and the total pressure of the sample is the sum of the partial pressures. ● Graphical representations of the relationships between P, V, T, and n are useful to describe gas behavior. ● The kinetic molecular theory (KMT) relates the macroscopic properties of gasses 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. ● 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: $KE = \frac{1}{2} mv^2$ ● The Kelvin temperature of a sample of matter is proportional to the average kinetic energy of the particles in the sample. ● The Maxwell-Boltzmann Distribution provides a graphical representation of the energies/ velocities of particles at a given	

temperature.
• The ideal gas law does not explain the actual behavior of real gasses. 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.
• Solutions, also sometimes called homogeneous mixtures, can be solids, liquids, or gasses. 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.
• Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory.
    ○ $M = n_{solute} / L_{solution}$
• Particulate representations of solutions communicate the structure and properties of solutions, by illustration of the relative concentrations of the components in the solution and/or drawings that show interactions among the components.
• The components of a liquid solution cannot be separated by filtration. They Can,however, be separated using processes that take advantage of differences in intermolecular interactions of the components.
    ○ 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. The resulting chromatogram can be used to infer the relative polarities of components in a mixture.
    ○ 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.
• Substances with similar intermolecular interactions tend to be miscible or soluble in one another.	

- Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region.
- 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.
- The wavelength of the electromagnetic wave is related to its frequency and the speed of light by the equation: $c = \lambda v$.
- The energy of a photon is related to the frequency of the electromagnetic wave through Planck's equation: $E = \hbar v$.
- The Beer-Lambert law relates the absorption of light by a solution to three variables according to the equation: $A = \varepsilon bc$. The molar absorptivity, ε, describes how intensely a chemical species absorbs light of a specific wavelength. The Pathlength,b, and concentration, c, are proportional to the number light-absorbing particles in the light path.
- 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. The Spectrophotometer Is typically set to the wavelength of maximum absorbance (optimum wavelength) for the species being analyzed to ensure the maximum sensitivity of measurement.

Key Vocabulary: intermolecular forces, London dispersion forces, polarizability, dipole-dipole forces, dipole-induced dipole forces, Hydrogen bonding, polar, nonpolar, vapor, vapor pressure, boiling point, melting point, network solid, polymer, amorphous solid, real gas, ideal gas, kinetic molecular theory of gasses, kinetic energy, partial pressure, vapor pressure, Kelvin temperature, Maxwell-Boltzmann Distribution, solution, homogeneous mixture, solute, solvent, chromatography, mobile phase, stationary phase, chromatograph, distillation, miscible, soluble, electron transition, electromagnetic spectrum, photon, frequency, wavelength, Plank's constant, microwave radiation, ultraviolet radiation, infrared radiation, Beer-Lambert's Law, absorbance, spectrophotometer, colorimeter

Assessment Evidence

Performance Tasks:

- What Volume do you Want Lab
  - Students will be asked to experimentally produce a fixed amount of gaseous product given the correct reactants.
- Chromatography Lab

Other Evidence:

- Intermolecular and Interparticle Forces Notes/Worksheet
- Properties of Solids Notes/Worksheet
- Solids, Liquids, and Gases Notes/Worksheet
- Ideal Gas Law Notes/Worksheet

○ Students will separate the contents of a liquid mixture using paper chromatography and compare that to known chromatographs to determine the contents of the mixture. ● AP Investigation 2: % Cu in Brass Lab ○ Students will use Beer's Law to determine the percent of copper in brass.	● Kinetic Molecular Theory Notes/Worksheet ● Deviations From Ideal Gas Law Notes/Worksheet ● Solutions and Mixtures Notes/Worksheet ● Representations of Solutions Notes/Worksheet ● Separation of Solutions and Mixtures Notes/Worksheet ● Solubility Worksheet ● Spectroscopy and the Electromagnetic Spectrum Notes/Worksheet ● Properties of Photons Notes/Worksheet ● Beer-Lambert Law Notes/Worksheet ● Unit Test

Learning Plan

RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words
- Visually represent solids, liquids and gasses as it relates to the spacing between particles
- Visually represent temperature of particles relative to the speed of particles

RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes
- Explain how to determine a known quantity of gas
- Explain how to determine the composition of a liquid mixture

HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays
- Calculate the moles, pressure, volume or temperature of a gas
- Calculate the wavelength or frequency of light
- Calculate the energy of light
- Calculate the molarity of a solution
- Calculate the concentration of a solution given absorbance data

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities
- Accurately measure mass of solids
- Accurately measure the volume of a gas
- Accurately measure the distance of movement of a solvent front vs dye movement

HS-PS1-1 - Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms
- Predict the properties of compounds based on how the atoms are bonded

HS-PS1-2 - Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

- Use the periodic table to explain the difference between ionic and covalent compounds

HS-PS1-3 - Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles

- Use chromatography to separate components of a mixture

HS-PS4-1 - Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

- Calculate wavelength, frequency and energy of photons
- Predict the wavelength of light that ensures maximum absorbance data

HS-PS4-3 - Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other

- Describe the wave nature of light
- Describe the particle nature of light
- Use wavelength to determine the type of electromagnetic radiation

HS-PS-4-4 - Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter

- Explain how and why atoms produce light

HS-PS2-4 - Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

- Use Coulomb's law to explain the strength of interactions between molecules
- Use Coulomb's law to explain solubility
- Use Coulomb's law to explain the properties of ionic compounds

HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials

- Describe the particle interacts that results in a substance's state of matter

VOL Common Assessments:
THINK CRITICALLY AND CREATIVELY
TCC2(9-12): I can evaluate evidence from multiple perspectives, and recognize their limitations and implications, in order to justify new conclusions.

- % Cu in Brass Lab

COLLABORATE AND COMMUNICATE EFFECTIVELY
CCE3(9-12): I can show initiative in prompting group discourse and fostering collaboration among others, providing actionable feedback, and working with others to solve problems and/or design products.

- What Volume do You Want Lab
- Chromatography Lab

DEMONSTRATE EMPATHY
DE1(9-12): I can acknowledge, process, and respond appropriately to others' comments and perspectives.

- Chromatography Lab

Teacher Resources: Brown/Lemay Textbook, I Do, We Do, You Do Notes, Formula Sheet, AP Classroom Daily Videos, Daily Video Guides, AP Classroom Progress Check, AP Chemistry CED, Guided Inquiry Activities, Unit Review Videos, Unit 3 1 pager, AP Chemistry Lab Manual, Topic Specific Videos

Unit 4 - Chemical Reactions	
Desired Results - Students will predict the amount of structure of products during a chemical reaction.	
Established Goals: **Common Core State Standards:** RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities **NGSS Standards:** HS-PS1-1 - Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. HS-PS1-2 - Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. HS-PS1-7 - Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction **AP Chemistry Curricula Unit 4**	
Vision of A Learner Attributes: Students will be able to independently use their learning to... ("I can" statements to be demonstrated) ● CCE3(9-12): I can show initiative in prompting group discourse and fostering collaboration among others, providing actionable feedback, and working with others to solve problems and/or design products. ● DE4(9-12): I can work respectfully with all members of my community and support the needs of others.	
Understandings: Students will understand that…	**Essential Questions:**

• Chemical changes involve the making and breaking of chemical bonds. • Many properties of a chemical system can be understood using the concepts of varying strengths of chemical bonds and weaker intermolecular interactions. • When chemical changes occur, the new substances formed have properties that are distinguishable from the initial substance or substances. • Chemical reactions are the primary means by which transformations in matter occur. • Chemical equations are a representation of the rearrangement of atoms that occur during a chemical reaction	• In what ways can a chemical change be described and documented? • How can you predict that a chemical reaction will generate enough product? • How can you predict the amount of product produced during a chemical reaction?
Students will know… • 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. • 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. • All physical and chemical processes can be represented symbolically by balanced equations. • 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 and charge are conserved in chemical reactions. • 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. • Balanced chemical equations in their various forms can be translated into symbolic particulate representations.	**Students will be able to...** • Identify evidence of chemical and physical changes in matter. • Represent changes in matter with a balanced chemical or net ionic equation: ○ For physical changes. ○ For given information about the identity of the reactants and/or product. ○ For ions in a given chemical reaction. • Represent a given chemical reaction or physical process with a consistent particulate model. • Explain the relationship between macroscopic characteristics and bond interactions for: ○ Chemical processes. ○ Physical processes • Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process. • Identify the equivalence point in a titration based on the amounts of the titrant and analyte, assuming the titration reaction goes to completion. • Identify a reaction as acid base,oxidation-reduction,or precipitation. • Identify species as Brønsted Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species.

● 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. ● Sometimes physical processes involve the breaking of chemical bonds. ● 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. ● 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. ● Stoichiometric calculations can be combined with the ideal gas law and calculations involving molarity to quantitatively study gasses and solutions. ● Titrations may be used to determine the amount of an analyte in solution. The titrant has a known concentration of a species that reacts specificallyandquantitativelywiththeanalyte. 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. ● Acid-base reactions involve transfer of one or more protons (H^+ ions) between chemical species. ● Oxidation-reduction (redox) 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. ● In a redox reaction, electrons are transferred from the species that is oxidized to the species that is reduced.	● Represent a balanced redox reaction equation using half-reactions.

• 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. • 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. • By definition,a Brønsted-Lowry acid is a proton donor and a Brønsted-Lowry base is a proton acceptor. • 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. • When an acid or base ionizes in water,the conjugate acid-base pairs can be identified and their relative strengths compared. • Balanced chemical equations for redox reactions can be constructed from half-reactions.	
Key Vocabulary: reaction, net ionic equation, physical change, chemical change, stoichiometry, titration, end point, equivalence point, synthesis, decomposition, double replacement, single replacement, combustion acid, base, redox, reduction, oxidation, oxidation number, precipitate, aqueous, coefficient, Bronsted-Lowry acid/base, conjugate acid/base pair, half reaction	
Assessment Evidence	

Performance Tasks:
• Decomposition of Baking Soda
  ○ Students will use laboratory data to determine the correct balanced chemical equation for the decomposition of baking soda.
• Titration Lab
  ○ Students will use titration data to standardize an unknown concentration of sodium hydroxide.
	Other Evidence:
	• Introduction to Reactions Notes/Worksheet
	• Net Ionic Equations Notes/Worksheet
	• Representations of Reactions Notes/Worksheet
	• Physical and Chemical Changes Notes/Worksheet
	• Stoichiometry Notes/Worksheet
	• Introduction to Titrations Notes/Worksheet
	• Types of Chemical Reactions Notes/Worksheet
	• Introduction to Acid-Base Reactions Notes/Worksheet
	• Redox Reactions Notes/Worksheet
	• Unit Test

Learning Plan	
RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words	

- Create visual representations of chemical reactions and physical changes
- Create visual representations of proton transfer between acids and bases

RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes

- Explain how to predict the products and amount of product during a chemical reaction
- Explain how to differentiate between chemical and physical changes

HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

- Calculate the predicted amount of products
- Calculate Percent Yield
- Calculate necessary amount of reactants

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

- Accurately measure volume and mass of components of a chemical reaction
- Accurately perform a titration

HS-PS1-1 - Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

- Use the periodic table to predict products of chemical reactions

HS-PS1-2 - Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

- Use the periodic table to predict products of chemical reactions

HS-PS1-7 - Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction

- Calculate the predicted amount of products
- Calculate Percent Yield
- Calculate necessary amount of reactants

VOL Common Assessments:

COLLABORATE AND COMMUNICATE EFFECTIVELY

CCE3(9-12): I can show initiative in prompting group discourse and fostering collaboration among others, providing actionable feedback, and working with others to solve problems and/or design products.

- Titration Lab

DEMONSTRATE EMPATHY

DE4(9-12): I can work respectfully with all members of my community and support the needs of others.

- Decomposition of Baking Soda Lab

Teacher Resources: Brown/Lemay Textbook, I Do, We Do, You Do Notes, Formula Sheet, AP Classroom Daily Videos, Daily Video Guides, AP Classroom Progress Check, AP Chemistry CED, Guided Inquiry Activities, Unit Review Videos, Unit 4 1 Pager, Topic Specific Videos

Unit 5 - Kinetics	
Desired Results - Goals, Transfer, Meaning, Acquisition	
Established Goals: [Common Core State Standards:] RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities NGSS Standards: HS-PS1-5 - Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. HS-PS1-8 - Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay AP Chemistry Curricula Unit 5	
Vision of A Learner Attributes: Students will be able to independently use their learning to... ("I can" statements to be demonstrated) ● TCC2(9-12): I can evaluate evidence from multiple perspectives, and recognize their limitations and implications, in order to justify new conclusions.	
Understandings: Students will understand that... ● The rate at which chemical reactions occur is affected by e the concentration of reactants, temperature, catalysts, and other environmental factors. ● Chemical changes are represented by chemical reactions, and the rates of chemical reactions are determined by the details of the molecular collisions. ● Rates of change in chemical reactions are observable and measurable. ● When measuring rates of change,we are measuring the concentration of reactant or product species as a function of	**Essential Questions:** ● Why are some reactions faster than other reactions? ● How can the speed of a reaction be controlled by understanding the collisions that occur on the particle level?

time. ● Chemical processes may be observed in a variety of ways and often involve changes in energy as well.	
Students will know… ● 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. ● The rates of change of reactant and product concentrations are determined by the stoichiometry in the balanced chemical equation. ● The rate of a reaction is influenced by reactant concentrations, temperature, surface area, catalysts, and other environmental factors. ● Experimental methods can be used to monitor the amounts of reactants and/or products of a reaction over time and to determine the rate of the reaction. ● The rate law expresses the rate of a reaction as proportional to the concentration of each reactant raised to a power. ● The power of each reactant in the rate law is the order of the reaction with respect to that reactant. The sum of the powers of the reactant concentrations in the rate law is the overall order of the reaction. ● 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. ● Comparing initial rates of a reaction is a method to determine the order with respect to each reactant. ● The order of a reaction can be inferred from a graph of concentration of reactant versus time. ● 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. ● 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. ● The slopes of the concentration versus time data for zeroth, first, and second order reactions can be used to determine the rate	**Students will be able to…** ● Explain the relationship between the rate of a chemical reaction and experimental parameters. ● Represent experimental data with a consistent rate law expression. ● Identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time. ● Represent an elementary reaction as a rate law expression using stoichiometry. ● Explain the relationship between the rate of an elementary reaction and the frequency, energy, and orientation of particle collisions. ● Represent the activation energy and overall energy change in an elementary reaction using a reaction energy profile. ● Identify the components of a reaction mechanism. ● Identify the rate law for a reaction from a mechanism in which the first step is rate limiting. ● Identify the rate law for a reaction from a mechanism in which the first step is not rate limiting. ● Represent the activation energy and overall energy change in a multistep reaction with a reaction energy profile. ● Explain the relationship between the effect of a catalyst on a reaction and changes in the reaction mechanism.

constant for the reaction. ○ Zeroth order: $[A]_t - [A]_0 = -kt$ ○ First order: $\ln[A]_t - \ln[A]_0 = -kt$ ○ Second order: $1/[A]_t - 1/[A]_0 = kt$ ● 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: $t_{1/2} = 0.693/k$. ● Radioactive decay processes provide an important illustration of first order kinetics. ● The rate law of an elementary reaction can be inferred from the stoichiometry of the particles participating in a collision. ● Elementary reactions involving the simultaneous collision of three or more particles are rare. ● For an elementary reaction to successfully produce products, reactants must successfully collide to initiate bond-breaking and bond making events. ● In most reactions, only a small fraction of the collisions leads to a reaction. Successful collisions have both sufficient energy to overcome the activation energy requirements and orientations that allow the bonds to rearrange in the required manner. ● 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. ● Elementary reactions typically involve the breaking of some bonds and the forming of new ones. ● The reaction coordinate is the axis along which the complex set of motions involved in rearranging reactants to form products can be plotted. ● 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. ● The rate of an elementary reaction is temperature dependent because the proportion of particle collisions that are energetic enough to reach the transition state varies with temperature.	

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. • 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. • The elementary steps when combined should align with the overall balanced equation of a chemical reaction. • A reaction intermediate is produced by some elementary steps and consumed by others, such that it is present only while a reaction is occurring. • Experimental detection of a reaction intermediate is a common way to build evidence in support of one reaction mechanism over an alternative mechanism. • 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). • If the first elementary reaction is not rate limiting, approximations (such as pre-equilibrium) must be made to determine a rate law expression. • Knowledge of the energetics of each elementary reaction in a mechanism allows for the construction of an energy profile for a multistep reaction. • 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. • 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. • 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.	

• Some catalysts involve covalent bonding between the catalyst and the reactant(s). This introduces a new reaction intermediate and new elementary reactions involving that intermediate. • 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).	

Key Vocabulary: reaction rate, rate law, elementary step, collision model, energy profile, reaction mechanism, steady state approximation, catalysis, rate constant, integrated rate law, reactant order, overall order, half life, Maxwell-Boltzmann distribution curve, activation energy, transition state, forward reaction, reverse reaction, Arrhenius equation, intermediate, rate limiting or rate determining step, enzyme, kinetics

Assessment Evidence

Performance Tasks:	**Other Evidence:**
• Kinetics of Dye Fading lab ○ Students will collect concentration data over a fixed period of time. They will then graphically analyze that data to determine if the reaction is 0th, 1st or 2nd order kinetics.	• Reaction Rates Notes/Worksheet • Introduction to Rate Laws Notes/Worksheet • Concentration Changes Over Time Notes/Worksheet • Elementary Reactions Notes/Worksheet • Collision Model Notes/Worksheet • Reaction Energy Profile Notes/Worksheet • Introduction to Reaction Mechanisms Notes/Worksheet • Reaction Mechanism and Rate Law Notes/Worksheet • Steady-State Approximation Notes/Worksheet • Multistep Reaction Energy Profile Notes/Worksheet • Catalysis Notes/Worksheet • Unit Test

Learning Plan

RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words

- Use particle representations to describe successful and unsuccessful collisions

RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes

- Explain how to use numeric data to determine the rate law of a substance
- Explain how to use graphical data to determine the rate law of a substance

HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

● Calculate the rate law of a substance ● Calculate the initial concentration of a substance ● Calculate the remaining concentration of a substance ● Calculate the half life of a substance ● Calculate the rate constant of a substance HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities ● Accurately measure mass, absorbance and concentration to determine the kinetics of dye fading HS-PS1-5 - Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. ● Explain how concentration, surface area and temperature affect the amount and efficacy of collisions HS-PS1-8 - Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay ● Use data to determine the half life of a substance ● Use half life to determine the amount of remaining radioactive substance VOL Common Assessments: THINK CRITICALLY AND CREATIVELY TCC2(9-12): I can evaluate evidence from multiple perspectives, and recognize their limitations and implications, in order to justify new conclusions. ● Kinetics of Dye Fading Lab
Teacher Resources: Brown/Lemay Textbook, I Do, We Do, You Do Notes, Formula Sheet, AP Classroom Daily Videos, Daily Video Guides, AP Classroom Progress Check, AP Chemistry CED, Guided Inquiry Activities, Unit Review Videos, Unit 5 1 pager, Topic Specific Videos

Unit 6 - Thermochemistry

Desired Results - Students will explain and quantify enthalpy and entropy exchange during chemical and physical processes.

Established Goals:
Common Core State Standards:
RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words
RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes
HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays
HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

NGSS Standards:
HS-PS1-4 - Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.
HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
HS-PS3-1 - Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-3 - Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
HS-PS3-4 - Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

AP Chemistry Curricula Unit 6

Vision of A Learner Attributes: Students will be able to independently use their learning to... ("I can" statements to be demonstrated)

- AA1(9-12): I can evaluate different approaches and justify the best pathway to success.
- AA2(9-12): I can assess my past successes and mistakes to change my approach.
- P4(9-12): I can take-on challenges and continuously engage in my own long-term strategies to overcome them to demonstrate through personal experience that failures are more instructive than discouraging.

Understandings: Students will understand that…	**Essential Questions:**
• The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in	• How does a thermal energy transfer affect temperature, states of matter, and chemical bonds?

matter. ● The availability or disposition of energy plays a role in virtually all observed chemical processes. ● Thermochemistry provides tools for understanding this key role, particularly the conservation of energy, including energy transfer in the forms of heat and work. ● The breaking of a chemical bond inherently requires an energy input, and because bond formation is the reverse process, it will release energy.	● How can energy changes be tracked and measured when energy can't be seen? ● Why do combustion reactions that form carbon dioxide release energy?
Students will know… ● Temperature changes in a system indicate energy changes. ● 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. ● When a chemical reaction occurs, the energy of the system either decreases (exothermic reaction), increases (endothermic reaction), or remains the same. ● 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. ● A physical or chemical process can be described with an energy diagram that shows the endothermic or exothermic nature of that process. ● The particles in a warmer body have a greater average kinetic energy than those in a cooler body. ● 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." ● 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. ● The amount of heat transferred between two bodies may be quantified by the heat transfer equation: $q = mc\Delta T$. ● Calorimetry experiments are used to measure the transfer of heat.	**Students will be able to…** ● Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation. ● Represent a chemical or physical transformation with an energy diagram. ● Explain the relationship between the transfer of thermal energy and molecular collisions. ● 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. ● 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. ● Calculate the heat 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. ● Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction. ● Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation. ● Represent a chemical or physical process as a sequence of steps. ● Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual

• The first law of thermodynamics states that energy is conserved in chemical and physical processes. • 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. • Heating a system increases the energy of the system, while cooling a system decreases the energy of the system. • The specific heat capacity of a substance and the molar heat capacity are both used in energy calculations. • Chemical systems change their energy through three main processes: heating/cooling, phase transitions, and chemical reactions. • In calorimetry experiments involving dissolution, temperature changes of the mixture within the calorimeter can be used to determine the direction of energy flow. If the temperature of the mixture increases, thermal energy is released by the dissolution process (exothermic). If the temperature of the mixture decreases, thermal energy is absorbed by the dissolution process (endothermic). • 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 temperature of a pure substance remains constant during a phase change. • The energy absorbed during a phase change is equal to the energy released during a complementary phase change in the opposite direction. • 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. • 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 as the reactants convert to products in an exothermic reaction. Thermal energy is transferred from the surroundings as the	steps.

reactants convert to products in an endothermic reaction. ● The chemical potential energy of the products of a reaction is different from that of the reactants because of the breaking and forming of bonds. The energy difference results in a change in the kinetic energy of the particles, which manifests as a temperature change. ● During a chemical reaction, bonds are broken and/or formed, and these events change the potential energy of the system. ● 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. ● Tables of standard enthalpies of formation can be used to calculate the standard enthalpies of reactions: ○ $\Delta H°_{reaction} = \Sigma\Delta H_f°_{products} - \Sigma\Delta H_f°_{reactants}$ ● Many processes can be broken down into a series of steps. Each step in the series has its own energy change. ● Because total energy is conserved (first law of thermodynamics), and each individual reaction in a sequence transfers thermal energy to or from the surroundings, the net thermal energy transferred in the sequence will be equal to the sum of the thermal energy transfers in each of the steps. ● The following are essential principles of Hess's law: ○ When a reaction is reversed, the enthalpy change stays constant in magnitude but becomes reversed in mathematical sign. ○ When a reaction is multiplied by a factor c, the enthalpy change is multiplied by the same factor c. ○ 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 change of the overall reaction.	
Key Vocabulary: thermodynamics, enthalpy, work, endothermic, exothermic, Hess's Law, thermal equilibrium, heat capacity, calorimetry, bond	

enthalpy, enthalpy of formation, energy diagram, kinetic energy, first law of thermodynamics, molar heat capacity, kinetic energy, potential energy

Assessment Evidence	
Performance Tasks: ● Introduction to Calorimetry Lab ○ Students will use calorimetry data to determine effective contents of hot/cold packs. ● It's time for a change Lab ○ Students will be asked to dissolve 2 solids in water so that the resulting temperature change is 0. The dissolution of 1 solid is exothermic, while the other is endothermic. They must calculate the amount of each solid to use so that the resulting temperature change when mixed is negligible.	**Other Evidence:** ● Endothermic and Exothermic Processes Notes/Worksheet ● Energy Diagrams Notes/Worksheet ● Heat Transfer and Thermal Equilibrium Notes/Worksheet ● Heat Capacity and Calorimetry Notes/Worksheet ● Energy of Phase Changes Notes/Worksheet ● Introduction to Enthalpy of Reactions Notes/Worksheet ● Bond Enthalpies Notes/Worksheet ● Enthalpy of Formation Notes/Worksheet ● Hess's Law Notes/Worksheet ● Mixed Heat Review Worksheet ● Unit Test

Learning Plan

RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words

- Calculate the enthalpy change during chemical and physical processes
- Use potential energy diagrams to explain heat exchange

RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes

- Explain how to calculate and measure enthalpy changes during chemical reactions, heat transfer between 2 substances and the dissolution of solids

HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

- Use potential energy diagrams to describe enthalpy changes
- Calculate enthalpy changes for chemical and physical processes

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

- Accurately measure temperature, volume and mass to calculate heat exchange

HS-PS1-4 - Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

- Calculate enthalpy changes during a chemical reaction through stoichiometry
- Use potential energy diagrams to determine if a reaction is endothermic or exothermic
- Use potential energy diagrams to compare the stored energy of reactants vs. stored energy of products
- Use bond enthalpies to calculate the enthalpy change of a reaction

HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

- Use specific heat and calorimetry as an explanation for why substances do not change temperature at the same rate

HS-PS3-1 - Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

- Use calorimetry to calculate heat exchange

HS-PS3-3 - Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

- Use calorimetry to calculate the heat exchange of dissolving solids and determine if that heat exchange is exothermic or endothermic

HS-PS3-4 - Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

- Discuss the flaws in assuming energy is conserved during all heat exchanges as it relates to accurate experimental data.
- Use experimental data to calculate heat exchange, assuming energy is conserved in a calorimeter

VOL Common Assessments:
ADAPT AND ADJUST:
AA1(9-12): I can evaluate different approaches and justify the best pathway to success.

- Calorimetry Lab

AA2(9-12): I can assess my past successes and mistakes to change my approach.

- It's Time for a Change Lab

PERSEVERE:
P4(9-12): I can take-on challenges and continuously engage in my own long-term strategies to overcome them to demonstrate through personal experience that failures are more instructive than discouraging.

- Unit Test

Teacher Resources: Brown/Lemay Textbook, I Do, We Do, You Do Notes, Formula Sheet, AP Classroom Daily Videos, Daily Video Guides, AP Classroom Progress Check, AP Chemistry CED, Guided Inquiry Activities, Unit Review Videos, Unit 6 1 pager, Topic Specific Videos

Unit 7 - Equilibrium	
Desired Results - Students will calculate and predict the amounts of products and reactants present once a reaction reaches equilibrium	
Established Goals: **Common Core State Standards:** RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities **NGSS Standards:** HS-PS1-5 - Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. HS-PS1-6 - Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. **AP Chemistry Curricula Unit 7**	
Vision of A Learner Attributes: Students will be able to independently use their learning to... ("I can" statements to be demonstrated) ● TCC1(9-12): I can ask purposeful, insightful questions to find a variety of innovative solutions. ● TCC2(9-12): I can evaluate evidence from multiple perspectives, and recognize their limitations and implications, in order to justify new conclusions. ● CCE3(9-12): I can show initiative in prompting group discourse and fostering collaboration among others, providing actionable feedback, and working with others to solve problems and/or design products.	
Understandings: Students will understand that… ● Chemical equilibrium is a dynamic state in which opposing processes occur at the same rate. ● Any bond or intermolecular attraction that can be formed can be broken. These two processes are in a dynamic competition, sensitive to initial conditions and external perturbations. ● A change in conditions, such as addition of a chemical species,	**Essential Questions:** ● How are the rates of forward and reverse reactions related to the direction that a reversible reaction proceeds? ● How can the composition of a mixture at equilibrium be predicted? ● How can an equilibrium system be manipulated to maximize product yield?

change in temperature, or change in volume, can cause the rate of the forward and reverse reactions to fall out of balance. • Le Châtelier's principle provides a means to reason qualitatively about the direction of the shift in an equilibrium system resulting from various possible stresses • The expression for the equilibrium constant, K, is a mathematical expression that describes the equilibrium state associated with a chemical change. • Q, describes a chemical reaction at any point, enabling a comparison to the equilibrium state. • The dissolution of a solid in a solvent can also be understood by applying the principles of chemical equilibrium because it is a reversible reaction.	• What factors influence the degree to which a salt will dissolve?
Students will know... • Many observable processes are reversible. • 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. • The equilibrium state is dynamic. The forward and reverse processes continue to occur at equal rates, resulting in no net observable change. • 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. • 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. • The reaction quotient Q_c describes the relative concentrations of reaction species at any time. For gas phase reactions, the reaction quotient may instead be written in terms of partial pressures as Q_p . The reaction quotient tends toward the equilibrium constant such that at equilibrium $K_c = Q_c$ and $K_p = Q_p$.	**Students will be able to…** • Explain the relationship between the occurrence of a reversible chemical or physical process, and the establishment of equilibrium, to experimental observations. • Explain the relationship between the direction in which a reversible reaction proceeds and the relative rates of the forward and reverse reactions. • Represent the reaction quotient Q_c or Q_p, for a reversible reaction, and the corresponding equilibrium expressions $K_c = Q_c$ or $K_p = Q_p$. • Calculate K_c or K_p based on experimental observations of concentrations or pressures at equilibrium. • Explain the relationship between very large or very small values of K and the relative concentrations of chemical species at equilibrium. • Represent a multistep process with an overall equilibrium expression, using the constituent K expressions for each individual reaction. • Identify the concentrations or partial pressures of chemical species at equilibrium based on the initial conditions and the equilibrium constant. • Represent a system undergoing a reversible reaction with a particulate model. • Identify the response of a system at equilibrium to an external

• Equilibrium constants and reaction quotients are calculated for a generic reaction (aA + bB ⟷ cC + dD) using: ○ K_c or $Q_c = \frac{[C]^c[D]^b}{[A]^a[B]^b}$ ○ K_p or $Q_p = \frac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b}$ • The reaction quotient and equilibrium constant does not include substances whose concentrations (or partial pressures) are independent of the amount, such as for solids and pure liquids. • Equilibrium constants can be determined from experimental measurements of the concentrations or partial pressures of the reactants and products at equilibrium. • Some equilibrium reactions have very large K values and proceed essentially to completion. Others have very small K values and barely proceed at all. • When a reaction is reversed, K is inverted. • When the stoichiometric coefficients of a reaction are multiplied by a factor c, K is raised to the power c. • 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. • Since the expressions for K and Q have identical mathematical forms, all valid algebraic manipulations of K also apply to Q. • The concentrations or partial pressures of species at equilibrium can be predicted given the balanced reaction, initial concentrations, and the appropriate K. • When Q < K, the reaction will proceed with a net consumption of reactants and generation of products. When Q > K, the reaction will proceed with a net consumption of products and generation of reactants. When Q = K, the system is at dynamic equilibrium; both forward and reverse reactions proceed at the same rate, and the proportion of reactants and products remains constant.	stress, using Le Châtelier's principle. • Explain the relationships between Q, K, and the direction in which a reversible reaction will proceed to reach equilibrium. • Calculate the solubility of a salt based on the value of K_{sp} for the salt. • Identify the solubility of a salt, and/or the value of K_{sp} for the salt, based on the concentration of a common ion already present in solution.

• 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. • 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. • 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. • 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. • 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. • The dissolution of a salt is a reversible process whose extent can be described by K_{sp}, the solubility-product constant. • The solubility of a substance can be calculated from the K_{sp} for the dissolution process. This relationship can also be used to predict the relative solubility of different substances. • The solubility rules can be quantitatively related to K_{sp}, in which K_{sp} values >1 correspond to soluble salts. • The molar solubility of one or more species in a saturated solution can be used to calculate the K_{sp} of a substance. • 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 K_{sp} for the dissolution process.	

Key Vocabulary: dynamic equilibrium, Le Châtelier's principle, equilibrium expression, reaction quotient, solubility product, molar solubility, reversible reaction, common ion effect, ICE table

Assessment Evidence

Performance Tasks:	Other Evidence:

• Determining an Equilibrium Constant Lab
  ○ Students will experimentally determine the equilibrium constant for a reaction and compare it to the known value.
• Calculating Q Dry Lab
• Understanding Le Chatelier's Principle Lab
  ○ Students will apply several stresses to reactions and will explain their observations using Le Chatelier's Principle.
	• Introduction to Equilibrium Notes/Worksheet
	• Equilibrium Snowball Fight
	• Direction of Reversible Reactions Notes/Worksheet
	• Reaction Quotient and Equilibrium Constant Notes/Worksheet
	• Calculating the Equilibrium Constant Notes/Worksheet
	• Magnitude of the Equilibrium Constant Notes/Worksheet
	• Properties of the Equilibrium Constant Notes/Worksheet
	• Calculating Equilibrium Concentrations Notes/Worksheet
	• Representations of Equilibrium Notes/Worksheet
	• Le Chatelier Activity
	• Introduction to Le Châtelier's Principle Notes/Worksheet
	• Reaction Quotient and Le Châtelier's Principle Notes/Worksheet
	• Introduction to Solubility Equilibria Notes/Worksheet
	• Common Ion Effect Notes/Worksheet
	• Unit Test

Learning Plan

RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words
- Use particle diagrams to describe equilibrium mixtures
- Calculate reaction quotients using particle diagrams
- Calculate equilibrium constants using particle diagrams

RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes
- Predict how a reaction will respond to an added stress

HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays
- Use concentration vs. time graphs to explain how rates of reactions changed with added or removed products and reactants
- Calculate equilibrium constants

- Calculate reaction quotients
- Calculate concentrations at equilibrium
- Calculate K_{sp} values
- Calculate molar solubility

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

- Accurately measure mass and volume to calculate concentration

HS-PS1-5 - Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

- Predict how added or removed reactants affect the rate of the forward and reverse reactions
- Predict how added or removed products affect the rate of the forward and reverse reactions

HS-PS1-6 - Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

- Use Le Chatelier's principle to explain how any stress affects an equilibrium system

VOL Common Assessments:
THINK CRITICALLY AND CREATIVELY
TCC1(9-12): I can ask purposeful, insightful questions to find a variety of innovative solutions.

- Reaction Quotient Dry Lab

TCC2(9-12): I can evaluate evidence from multiple perspectives, and recognize their limitations and implications, in order to justify new conclusions.

- Understanding Le Chatelier's Principle Lab

COLLABORATE AND COMMUNICATE EFFECTIVELY
CCE3(9-12): I can show initiative in prompting group discourse and fostering collaboration among others, providing actionable feedback, and working with others to solve problems and/or design products.

- Determining an Equilibrium Constant Lab

Teacher Resources: Brown/Lemay Textbook, I Do, We Do, You Do Notes, Formula Sheet, AP Classroom Daily Videos, Daily Video Guides, AP Classroom Progress Check, AP Chemistry CED, Guided Inquiry Activities, Unit Review Videos, Unit 7 1 pager, Topic Specific Videos

Unit 8 - Acids and Bases	
Desired Results - Students will describe and calculate the strength and concentration of acids and bases using equilibrium expressions.	
Established Goals: **Common Core State Standards:** RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities **NGSS Standards:** HS-PS1-6 - Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. **AP Chemistry Curricula Unit 8**	
Vision of A Learner Attributes: Students will be able to independently use their learning to... ("I can" statements to be demonstrated) ● TI1(9-12): I can implement a realistic plan and adapt when necessary to achieve my goals. ● P1(9-12): I can self-reflect and seek feedback to build upon my strengths, apply those strengths to overcome obstacles, and share my strategies with others. ● P4(9-12): I can take-on challenges and continuously engage in my own long-term strategies to overcome them to demonstrate through personal experience that failures are more instructive than discouraging.	
Understandings: Students will understand that… ● The proton-exchange reactions of acid-base chemistry are reversible reactions that reach equilibrium quickly, and much of acid-base chemistry can be understood by applying the principles of chemical equilibrium. ● Most acid-base reactions have either large or small values of K, which means qualitative conclusions regarding equilibrium state can often be drawn without extensive computations.	**Essential Questions:** ● How is pH related to the concentration and strength of an acid, a base, or a mixture of them? ● How does acid or base strength relate to the concentrations of reactants and products when a system reaches equilibrium? ● Why are some acids stronger than others?

Students will know…	Students will be able to…

• The concentrations of hydronium ion and hydroxide ion are often reported as pH and pOH, respectively.
  ○ $pH = -\log[H_3O^+]$
  ○ $pOH = -\log[OH^-]$
• Water autoionizes with an equilibrium constant Kw.
  ○ $Kw = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$ at 25°C
• In pure water, pH = pOH is called a neutral solution.
  ○ At 25°C, $pK_w = 14.0$
  ○ pH = pOH = 7.0.
  ○ $pK_w = 14 = pH + pOH$ at 25°C
• The value of K_w is temperature dependent, so the pH of pure, neutral water will deviate from 7.0 at temperatures other than 25°C.
• Molecules of a strong acid (HCl, HBr, HI, $HClO_4$, H_2SO_4, and HNO_3) will completely ionize in aqueous solution to produce hydronium ions and the conjugate base of the acid. As such, the concentration of H_3O^+ 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.
• When dissolved in solution, strong bases (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 a group I hydroxide and double the initial concentration of a group II hydroxide, and thus the pOH (and pH) of the strong base solution is easily calculated.
• Weak acids react with water to produce hydronium ions. However, only a small percentage of molecules of a weak acid will ionize in this way. Thus, the concentration of H_3O^+ is much less than the initial concentration of the molecular acid, and the vast majority of the acid molecules remain un-ionized.
• A solution of a weak acid involves equilibrium between an un-ionized acid and its conjugate base. The equilibrium constant for this reaction is K_a, often reported as pK_a . The pH of a weak acid solution can be determined from the initial acid concentration and the pK_a.
  ○ $K_a = \frac{[H_3O^+][A^-]}{[HA]}$
	• Calculate the values of pH and pOH, based on Kw and the concentration of all species present in a neutral solution of water.
	• Calculate pH and pOH based on concentrations of all species in a solution of a strong acid or a strong base.
	• Explain the relationship among pH, pOH, and concentrations of all species in a solution of a monoprotic weak acid or weak base.
	• Explain the relationship among the concentrations of major species in a mixture of weak and strong acids and bases.
	• 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.
	• Explain the relationship between the strength of an acid or base and the structure of the molecule or ion.
	• Explain the relationship between the predominant form of a weak acid or base in solution at a given pH and the pK_a of the conjugate acid or the pK_b of the conjugate base.
	• 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.
	• Identify the pH of a buffer solution based on the identity and concentrations of the conjugate acid-base pair used to create the buffer.
	• Explain the relationship between buffer capacity of a solution and the relative concentrations of the conjugate acid and conjugate base components of the solution.
	• Identify the qualitative effect of changes in pH on the solubility of a salt.

    - $pK_a = -\log K_a$
- 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.
- A solution of a weak base involves equilibrium between an un-ionized base and its conjugate acid. The equilibrium constant for this reaction is K_b , often reported as pK_b. The pH of a weak base solution can be determined from the initial base concentration and the pK_b.
    - $K_a = \frac{[HB^+][OH^-]}{[B]}$
    - $pK_b = -\log K_b$
- The percent ionization of a weak acid (or base) can be calculated from its pK_a (pK_b) and the initial concentration of the acid (base). The percent ionization can also be calculated from the initial concentration of the acid (base) and the equilibrium concentration of any of the species in the equilibrium expression.
- For any conjugate acid-base pair, the acid ionization constant and base ionization constant are related by:
    - $K_w = K_a \times K_b$
    - $pK_w = pK_a + pK_b$
- When a strong acid and a strong base are mixed, they react quantitatively 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.
- When a weak acid and a strong base are mixed, they react quantitatively in a reaction represented by the equation: $HA_{(aq)} + OH^-_{(aq)} \rightarrow A^-_{(aq)} + H_2O_{(l)}$. If the weak acid is in excess, then a buffer solution is formed, and the pH can be determined from the Henderson-Hasselbalch equation. 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: $A^-_{(aq)} + H_2O_{(l)} \rightarrow$

$HA_{(aq)} + OH^-_{(aq)}$. ● When a weak base and a strong acid are mixed, they will react quantitatively in a reaction represented by the equation: $B_{(aq)} + H_3O^+_{(aq)} \rightarrow HB^+_{(aq)} + H_2O_{(l)}$. If the weak base is in excess, then a buffer solution is formed, and the pH can be determined from the Henderson-Hasselbalch 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: $HB^+_{(aq)} + H_2O_{(l)} \rightarrow B_{(aq)} + H_3O^+_{(aq)}$. ● 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: $HA_{(aq)} + B_{(aq)} \rightarrow A^-_{(aq)} + HB^+_{(aq)}$. ● 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. ● At the equivalence point for titrations of monoprotic acids or bases, 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. ● 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 = pK_a when the conjugate acid and base have equal concentrations, the pK_a can be determined from the pH at the half equivalence point in a titration. ● At the equivalence point, pH is determined by the major species in solution. Strong acid and strong base titrations result in neutral pH at the equivalence point. However, in titrations of weak acids (weak bases), the conjugate base of the weak acid (conjugate acid of the weak base) is present at the equivalence point and can undergo proton-transfer reactions with the	

surrounding water, producing basic (acidic) solutions.
• 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 pK_a associated with each proton in a weak polyprotic acid.
• 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.
  ○ Strong acids have very weak conjugate bases that are stabilized by electronegativity, inductive effects, resonance, or some combination thereof.
  ○ Carboxylic acids are one common class of weak acid.
  ○ Strong bases (such as group I and II hydroxides) have very weak conjugate acids.
  ○ Common weak bases include nitrogenous bases such as ammonia as well as carboxylate ions.
  ○ Electronegative elements tend to stabilize the conjugate base relative to the conjugate acid, and so increase acid strength.
• The protonation state of an acid or base can be predicted by comparing the pH of a solution to the pK_a of the acid in that solution. When solution pH $<$ acid pK_a, the acid form has a higher concentration than the base form. When solution pH $>$ acid pK_a, the base form has a higher concentration than the acid form.
• 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.
• To ensure accurate results in a titration experiment,acid-base indicators should be selected that have a pK_a close to the pH at the equivalence point.
• 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.
• The pH of the buffer is related to the pKa of the acid and the	

concentration ratio of the conjugate acid-base pair. This relation is a consequence of the equilibrium expression associated with the dissociation of a weak acid, and is described by the Henderson-Hasselbalch equation. Adding small amounts of acid or base to a buffered solution does not significantly change the ratio of $[A^{-}]/[HA]$ and thus does not significantly change the solution pH. The change in pH on addition of acid or base to a buffered solution is therefore much less than it would have been in the absence of the buffer.
    - $pH = pK_a + [A^-]/[HA]$
- 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.
- 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 than base.
- The solubility of a salt is pH sensitive when one of the constituent ions is a weak acid, a weak base, or the hydroxide ion. These effects can be understood qualitatively using Le Châtelier's principle.

Key Vocabulary: acid, base, strong acid/base, weak acid/base, equivalence point, half equivalence point, buffer, buffer capacity, pK_a, pK_b, pH, pOH, monoprotic, diprotic, polyprotic, conjugate acid, conjugate base, percent ionization, excess reagent, ICE table, indicator

Assessment Evidence

Performance Tasks:
- Ksp Lab
    - Students will experimentally determine the Ksp of a solid and will compare it to the known value.
- Lab 52 The Great Buffer Challenge
    - Students will design and create an effective buffer. They will then test their buffer against added acid and base.

Other Evidence:
- Introduction to Acids and Bases Notes/Worksheet
- pH and pOH of Strong Acids and Strong Bases Notes/Worksheet
- Weak Acid and Base Equilibria Notes/Worksheet
- Acid Base Reactions and Buffers Notes/Worksheet
- Acid Base Titrations
- Molecular Structure of Acids and Bases Notes/Worksheet
- pH and pK_a Notes/Worksheet
- Properties of Buffers Notes/Worksheet

	• Henderson-Hasselbalch Equation Notes/Worksheet • Buffer Capacity Notes/Worksheet • pH and Solubility Notes/Worksheet • Unit Test

Learning Plan

RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words

- Interpret the strength of an acid or base based on pictorial representations of ionization
- Calculate the pH of various solutions
- Interpret a titration curve
  - To calculate pH
  - To determine the strength of an acid or base

RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes

- Explain how to perform a titration

HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

- Calculate pH of various solutions

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

- Accurately measure mass and volumes as they relate to titrations

HS-PS1-6 - Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

- Calculate and explain how the concentrations of acids and bases change with added acid or base
- Calculate and decrease how to solubility of solids is affected by the pH of a solution

VOL Common Assessments:
TAKE INITIATIVE
TI1(9-12): I can implement a realistic plan and adapt when necessary to achieve my goals.

- Ksp Lab

PERSEVERE
P1(9-12): I can self-reflect and seek feedback to build upon my strengths, apply those strengths to overcome obstacles, and share my strategies with others.

- The Great Buffer Challenge

P4(9-12): I can take-on challenges and continuously engage in my own long-term strategies to overcome them to demonstrate through personal experience that failures are more instructive than discouraging.

- Unit Test

Teacher Resources: Brown/Lemay Textbook, I Do, We Do, You Do Notes, Formula Sheet, AP Classroom Daily Videos, Daily Video Guides, AP Classroom Progress Check, AP Chemistry CED, Guided Inquiry Activities, Unit Review Videos, Unit 8 1 Pager, Topic Specific Videos

Unit 9 - Thermodynamics and Electrochemistry

Desired Results - Students will calculate and predict the favorability of reactions.

Established Goals:

Common Core State Standards:

RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words

RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes

HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

NGSS Standards:

HS-PS1-4 - Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

HS-PS1-6 - Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

HS-PS3-1 - Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-3 - Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-PS3-5 - Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

AP Chemistry Curricula Unit 9

Vision of A Learner Attributes: Students will be able to independently use their learning to... (“I can” statements to be demonstrated)

- P2(9-12): I can strengthen my weaknesses by identifying, initiating, and practicing appropriate strategies to become confident in my ability to overcome my challenges.

- P3(9-12): I can accept constructive feedback and use setbacks to adjust my learning journey in order to reach my goals.
- AA3(9-12): I can adjust my expectations and behaviors to succeed in a changing and unpredictable environment.

Understandings: Students will understand that…

- All changes in matter involve some form of energy change.
- One key determinant of chemical transformations is the change in potential energy that results from changes in electrostatic forces.
- Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions.
- Applying the laws of thermodynamics will allow students to describe the essential role of energy and explain and predict the direction of changes in matter.

Essential Questions:

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

Students will know…

- Entropy increases when matter becomes more dispersed.
- 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.
- The entropy change for a process can be calculated from the absolute entropies of the species involved before and after the process occurs.
    - $\Delta S^\circ_{reaction} = \Sigma S^\circ_{products} - \Sigma S^\circ_{reactants}$
- 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 gasses at a pressure of 1.0 atm) is given the symbol ΔG°.
- The standard Gibbs free energy change for a chemical or physical process is a measure of thermodynamic favorability.
- 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.
    - $\Delta G^\circ_{reaction} = \Sigma \Delta G^\circ_{f(products)} - \Sigma \Delta G^\circ_{f(reactants)}$
- In some cases, it is necessary to consider both enthalpy and entropy to determine if a process will be thermodynamically favored.

Students will be able to…

- Identify the sign and relative magnitude of the entropy change associated with chemical or physical processes.
- Calculate the standard entropy change for a chemical or physical process based on the absolute entropies (standard molar entropies) of the species involved in the process.
- Explain whether a physical or chemical process is thermodynamically favored based on an evaluation of ΔG°.
- Explain, in terms of kinetics, why a thermodynamically favored reaction might not occur at a measurable rate.
- Explain whether a process is thermodynamically favored using the relationships between K, ΔG°, and T.
- Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process.
- Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes.
- Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.
- Explain whether an electrochemical cell is thermodynamically favored, based on its standard cell potential and the constituent half reactions with the cell.

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Knowing the values of ΔH° and ΔS° for a process at a given temperature allows ΔG° to be calculated directly.
$\Delta G° = \Delta H° - T\Delta S°$
In general, the temperature conditions for a process to be thermodynamically favored (ΔG° < 0) can be predicted from the signs of ΔH° and ΔS°.
In cases where ΔH° < 0 and ΔS° >, no 0 calculation of ΔG° is necessary to determine that the process is thermodynamically favored (ΔG° < 0). In cases where ΔH° > 0 and ΔS°< 0, no calculation of ΔG° is necessary to determine that the process is thermodynamically unfavored (ΔG° > 0).
Many processes that are thermodynamically favored do not occur to any measurable extent, or they occur at extremely slow rates.
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.
ΔGº < 0) means that the products are favored at equilibrium (K > 1) under standard conditions.
The equilibrium constant is related to free energy by the equations:
$K = e^{-\Delta G°/RT}$
$\Delta G° = -RT \ln K$
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.
Processes with ΔG° < 0 favor products (i.e., K > 1) and those with ΔG° > 0 favor reactants (i.e., K < 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

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Explain the relationship between deviations from standard cell conditions and changes in the cell potential.
Calculate the amount of charge flow based on changes in the amounts of reactants and products in an electrochemical cell.

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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. ● An external source of energy can be used to make a thermodynamically unfavorable process occur. ● A desired product can be formed by coupling a thermodynamically unfavorable reaction that produces that product to a favorable reaction. 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 $\Delta G° < 0$. ● 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. ● 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. ● For all electrochemical cells, oxidation occurs at the anode and reduction occurs at the cathode. ● 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). ● The standard cell potential of electrochemical cells can be calculated by identifying the oxidation and reduction half-reactions and their respective standard reduction potentials.	

• ΔG° (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 E° involves a thermodynamically favored reaction, and a cell with a negative E° involves a thermodynamically unfavored reaction.
  ○ $\Delta G^\circ = -nFE^\circ$
• 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.
• Equilibrium arguments such as Le Châtelier's principle do not apply to electrochemical systems, because the systems are not in equilibrium.
• The standard cell potential E° 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 E°. In concentration cells, the direction of spontaneous electron flow can be determined by considering the direction needed to reach equilibrium.
• 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:
  ○ $E = E^\circ - (RT/nF) \ln Q$
• Faraday's laws can be used to determine the stoichiometry of the redox reaction occurring in an electrochemical cell with respect to the following:
  ○ Number of electrons transferred
  ○ Mass of material deposited on or removed from an electrode (as in electroplating)	

○ Current ○ Time elapsed ○ Charge of ionic species ○ I = q/t	
Key Vocabulary: entropy, enthalpy, Gibbs free energy, kinetic control, thermodynamics, coupled reactions, galvanic cell, electrolytic cell, electrolysis, Faraday's constant, Faraday's Law, electroplate, spontaneous, nonspontaneous, thermodynamically favored, not thermodynamically favored, activation energy, salt bridge, cathode, anode, electrode, half cell, voltage, current, oxidation, reduction, standard reduction potential, Nernst equation	
Assessment Evidence	
Performance Tasks: ● Lab 40: Investigating Electrolytic Cells ○ Students will construct and investigate various electrochemical cells. ● Electroplating Lab ○ Students will predict the amount of plated solid during an electroplating reaction and will compare that to measured values in the lab.	**Other Evidence:** ● Introduction to Entropy Notes/Worksheet ● Absolute Entropy and Entropy Change Notes/Worksheet ● Gibbs Free Energy and Thermodynamic Favorability Notes/Worksheet ● Thermodynamic and Kinetic Control Notes/Worksheet ● Free Energy and Equilibrium Notes/Worksheet ● Free Energy of Dissolution Notes/Worksheet ● Coupled Reactions Notes/Worksheet ● Galvanic (Voltaic) and Electrolytic Cells Notes/Worksheet ● Cell Potential and Free Energy Notes/Worksheet ● Cell Potential Under Nonstandard Conditions Notes/Worksheet ● Electrolysis and Faraday's Law Notes/Worksheet ● Unit Test
Learning Plan	
RST.9-10.7 - Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words ● Describe the functioning of a galvanic or electrolytic cell ● Create a visual representation of a galvanic or electrolytic cell ● Use pictorial representations to describe changes in entropy ● Calculate Gibbs free energy ● Calculate voltage ● Calculate current RST.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical	

processes

- Describe how to create a thermodynamically favored galvanic cell

HSN-Q.A.1 - Use units as a way to understand and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

- Calculate Gibbs free energy
- Calculate voltage
- Calculate current
- Calculate the mass of electroplated solid

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities

- Accurately measure mass generated during an electrochemical cell
- Accurately measure and create a known concentration of solution

HS-PS1-4 - Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

- Use entropies of formation to calculate the entropy change of a given process
- Use Gibbs free energy change of formation to calculate the Gibbs free energy change of a give process

HS-PS1-6 - Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

- Use Le Chatelier's principle to explain how voltage of a galvanic cell changes under non-standard conditions

HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

- Explain the expected direction of electron flow in a galvanic or electrolytic cell

HS-PS3-1 - Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

- Use the enthalpy and entropy of a system to calculate the change in Gibbs free energy
- Use the enthalpy and entropy of a system to predict the favorability of a chemical or physical change

HS-PS3-3 - Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

- Design an electrolytic cell

HS-PS3-5 - Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

- Use the known voltage of half reactions to determine the overall voltage of a galvanic or electrochemical cell

VOL Common Assessments:
PERSEVERE:
P2(9-12): I can strengthen my weaknesses by identifying, initiating, and practicing appropriate strategies to become confident in my ability to overcome my challenges.

- Unit Test

P3(9-12): I can accept constructive feedback and use setbacks to adjust my learning journey in order to reach my goals.

- Investigating Electrolytic Cells Lab

ADAPT AND ADJUST AA3(9-12): I can adjust my expectations and behaviors to succeed in a changing and unpredictable environment. ● Electroplating Lab
Teacher Resources: Brown/Lemay Textbook, I Do, We Do, You Do Notes, Formula Sheet, AP Classroom Daily Videos, Daily Video Guides, AP Classroom Progress Check, AP Chemistry CED, Guided Inquiry Activities, Unit Review Videos, Unit 9 1 pager, Topic Specific Videos