West Windsor-Plainsboro Regional School District
Course Title: AP Chemistry
Grades: 11-12

The Mission of the West Windsor-Plainsboro Science Department

Our mission is to cultivate science learners who have the foundational knowledge to make ethical, scientifically literate decisions and the ability to apply scientific practices in order to contribute to the needs of society and a changing world.

- **Vision**

  We envision a K-12 science experience that supports and challenges every student in their science learning journey. We will:
  - *Capitalize on diversity by reaching and exciting students at all levels and interests by differentiating learning within classrooms and by offering a robust program of studies.*
  - *Emphasize authentic science and engineering practices and leverage the interdisciplinary nature of science with arts, technology, math, reading, and writing.*
  - *Integrate scientific knowledge and 21st century competencies to prepare students to make informed decisions and take action to address real world problems.*

Unit 1: Pre-AP Foundations Review	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
This unit reviews fundamental concepts of dimensional analysis, significant figures, atomic structure, formula writing, the periodic table, the mole, and stoichiometry. The textbook reference is Zumdahl chapters 1 – 3. Students review this first-year chemistry material as they complete the summer assignment. This first unit sets the foundation for the course by examining the atomic theory of matter, the fundamental premise of chemistry. Although atoms represent the foundational level of chemistry, observations of chemical properties are made on collections of atoms. Macroscopic systems involve such large numbers that they require moles as a unit of comparison. The periodic table provides information about each element's predictable periodicity as a function of the 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. In subsequent units, students will apply their understanding of atomic structure to models and representations of chemical phenomena and explain changes and interactions of chemical substances.	
Recommended Pacing	
6 hours	
Standards/Performance Expectations	
Standard	
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. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] *[Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]***
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. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] *[Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]***
HS-PS1-7	**Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem solving techniques.] *[Assessment Boundary: Assessment does not include complex chemical reactions.]***

Instructional Focus
Unit Enduring Understandings ● The mole allows different units to be compared ● Chemical formulas identify substances by their unique combination of atoms ● A substance that changes its properties, or that changes into a different substance, can be represented by chemical equations ● When a substance changes into a new substance, or when its properties change, no mass is lost or gained

Unit Essential Questions

- How does the mole unit quantify matter?
- What are the representative particles that make up all matter?
- What experimental evidence supports the existence of isotopes?
- What is the difference between an empirical and a molecular formula?
- How does the law of definite proportions support atomic theory?
- Can you distinguish between a chemical and a physical change?
- Can you translate a particulate representation into a balanced chemical equation?
- How is a balanced chemical equation used to calculate quantities involved in a chemical reaction?

Content Statements (DCI)

PS1.A: Structure and Properties of Matter

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1)
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1)
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Identify an appropriate theory, definition, or mathematical relationship to solve a problem.
- Identify information presented graphically to solve a problem.
- Identify a testable scientific question based on an observation, data, or a model.
- Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).
- Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties
- Explain whether a model is consistent with chemical theories.
- Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.
- Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.

Learning Objectives. SWBAT

- 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
- Identify evidence of chemical and physical changes in matter
- Represent a given chemical reaction or physical process with a consistent particulate model
- Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process

<u>Sample Performance Tasks - Specific for Unit 1: SWBAT:</u>

- **Precipitation lab**

- Using their knowledge to describe and predict chemical reactions and observe patterns within the solubility rules, students will plan and carry out an investigation to determine the identity of unknown aqueous solutions.

Resources

Core Text: Chemistry, from Cengage Learning, by Zumdahl, Zumdahl, and DeCoste, Copyright 2018
Lab Manual: AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices Student Manual, by College Board, Copyright 2013

Suggested Resources: AP Chemistry Course and Exam Description:
https://apstudents.collegeboard.org/ap/pdf/ap-chemistry-course-and-exam-description.pdf

Unit 2: Types of Reactions	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
This unit explores chemical transformations of matter, building on the principles of stoichiometry and the law of mass (atom) conservation from the previous Unit. Particular focus is made on the difference between strong and weak electrolyte solutions, both on a particle level and in properly writing net ionic equations. Acid/base reactions are introduced in this unit, focusing on net ionic equation writing and the stoichiometry of a titration analysis. Chemical changes involve the making and breaking of chemical bonds. 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. The textbook reference is Zumdahl chapter 4, and supplemental notes on predicting reaction types given in the summer assignment.	
Recommended Pacing	
9 hours	
NGSS Standards/Performance Expectations	
Standard	
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. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] *[Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]***
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. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] *[Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]***
HS-PS1-7	**Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem solving techniques.] *[Assessment Boundary: Assessment does not include complex chemical reactions.]***

Connecting with English Language Arts/Literacy and Mathematics

English Language Arts/Literacy

- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest.
- Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs.
- Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.
- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Use a mathematical model to explain how the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols.
- Use units as a way to understand an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret units consistently in formulas representing the effects of changing the temperature or concentration of the

reacting particles on the rate at which a reaction occurs. Choose and interpret the scale and the origin in graphs and

- data displays representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use a mathematical model to explain how to increase amounts of products at equilibrium in a chemical system. Identify important quantities in the cycling of matter and flow of energy among organisms in an ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

21st Century Life and Careers/Technology Standards:

8.1 Educational Technology: All students will use digital tools to access, manage, evaluate, and synthesize information in order to solve problems individually and collaborate and to create and communicate knowledge.
8.2 Technology Education, Engineering, Design, and Computational Thinking - Programming:
All students will develop an understanding of the nature and impact of technology, engineering, technological design, computational thinking and the designed world as they relate to the individual, global society, and the environment.
9.2.12.C.4 Analyze how economic conditions and societal changes influence employment trends and future education.

9.2.12.C.3 Identify transferable career skills and design alternate career plans.

Social Studies

Standard 6.1 U.S. History: America in the World. All students will acquire the knowledge and skills to think analytically about how past and present interactions of people, cultures, and the environment shape the American heritage. Such knowledge and skills enable students to make informed decisions that reflect fundamental rights and core democratic values as productive citizens in local, national, and global communities.
Standard 6.2 World History: Global Studies: All students will acquire the knowledge and skills to think analytically and systematically about how past interactions of people, cultures, and the environment affect issues across time and cultures. Such knowledge and skills enable students to make informed decisions as socially and ethically responsible world citizens in the 21st century.

Instructional Focus

Unit Enduring Understandings

- A substance that changes its properties, or that changes into a different substance, can be represented by chemical equations
- When a substance changes into a new substance, or when its properties change, no mass is lost or gained
- A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it
- Interactions between intermolecular forces influence the solubility and separation of mixtures

Unit Essential Questions

- What is the difference between a strong and a weak electrolyte?
- Why is molarity a more convenient concentration unit than percent concentration?
- What must be done to convert a total ionic equation into a net ionic equation?
- How is stoichiometry used to calculate quantities involved in a chemical reaction?
- How is the equivalence point of a titration “seen” in the lab?
- How can electron transfer be “tracked” in a chemical reaction?
- What is a precipitate?

- When hydrogen ions are transferred, which species acts as the Brønsted-Lowry acid and which acts as the Brønsted-Lowry base?

Content Statements (DCI)

PS1.B: Chemical Reactions

- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HSPS1-4),(HS-PS1-5)
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties
- Explain the relationship between variables within an equation when one variable changes
- Represent chemical substances or phenomena with appropriate diagrams or models (e.g., particle diagrams of strong v. weak electrolytes)
- Determine a balanced chemical equation for a given chemical phenomena
- Represent chemical phenomena using appropriate graphing techniques, including correct scale and units
- Formulate a hypothesis or predict the results of an experiment
- Support a claim with evidence from experimental data

Learning Objectives. SWBAT

- Calculate the number of solute particles, volume, or molarity of solutions
- Represent interactions between components, and concentrations of components, using particulate models for mixtures
- Identify a reaction as acid-base, oxidation-reduction, or precipitation
- Represent changes in matter with a balanced chemical or net ionic equation
- Represent a given chemical reaction or physical process with a consistent particulate model
- Use stoichiometry to 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 that sodium, potassium, ammonium and nitrate salts are always soluble in water ***(only solubility rules that are assessed on the AP Exam)***
- Identify species as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species
- Represent a balanced redox reaction equation using half-reactions.

<u>Sample Performance Tasks - Specific for Unit 2:</u>

- **Using the Principle That Each Substance Has Unique Properties to Purify a Mixture: An Experiment Applying Green Chemistry to Purification** (Investigation 7 from College Board lab manual)
    - Students will plan and carry out an investigation to determine the relative amounts of two substances in a mixture as they track the flow of matter and conservation of atoms during a chemical reaction.
- **Standardization of base: Titration experiment.**

- Students will research and explain a titration reaction system, and analyze and interpret data from an acid/base chemical reaction titration experiment to standardize a solution of NaOH.

Resources

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Suggested Resources: AP Chemistry Course and Exam Description:
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Unit 3: Thermochemistry	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter. The availability or disposition of energy plays a role in virtually all observed chemical processes. Thermodynamics provides tools for understanding this key role, particularly the conservation of energy, including energy transfer in the forms of heat and work. Chemical bonding is central to chemistry. A key concept to know is that the breaking of a chemical bond inherently requires an energy input, and because bond formation is the reverse process, it will release energy. In subsequent units, the application of thermodynamics will determine the favorability of a reaction occurring. The unit provides context for students to complete an engineering design task (The Handwarmer Challenge). Students will examine how chemical transformations in solution formation that require bonds to break and form are influenced by energy and strengths of IMAs and chemical bonds. The textbook reference for this unit is chapter 6 in Zumdahl; however further references to the energetics of phase changes is found in chapter 10, section 8.	
Recommended Pacing	
8 hours	
Standards/Performance Expectations	
Standard	
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. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] *[Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]***
HS-PS3-2	**Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative position of particles (objects). [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]**
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). [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] *[Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]***

HS-ETS1-3	**Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.**

Connecting with English Language Arts/Literacy and Mathematics

English Language Arts/Literacy

- Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS3-4)
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-PS3-4)
- Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS3-4)
- Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS3-4)
- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest.
- Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs.
- Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.
- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Reason abstractly and quantitatively. (HS-PS3-4)
- Model with mathematics. (HS-PS3-4)
- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.

- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Use a mathematical model to explain how the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
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- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use a mathematical model to explain how to increase amounts of products at equilibrium in a chemical system. Identify important quantities in the cycling of matter and flow of energy among organisms in an ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

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9.2.12.C.4 Analyze how economic conditions and societal changes influence employment trends and future education.

9.2.12.C.3 Identify transferable career skills and design alternate career plans.

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Standard 6.2 World History: Global Studies: All students will acquire the knowledge and skills to think analytically and systematically about how past interactions of people, cultures, and the environment affect issues across

time and cultures. Such knowledge and skills enable students to make informed decisions as socially and ethically responsible world citizens in the 21st century.

Instructional Focus

Unit Enduring Understandings

- Changes in a substance's properties or change into a different substance requires an exchange of energy
- The energy exchanged in a chemical transformation is required to break and form bonds

Unit Essential Questions

- How are energy changes in a system measured?
- How do we know if a process is exothermic or endothermic?
- What are the differences in energy transfer as heat or work?
- What role do IMAs play in justifying a dissolution process as being exothermic or endothermic?
- Can you create an energy diagram for an exothermic or endothermic process?
- Can you describe the process of "heat transfer?"
- When do two systems in contact transfer energy, and when does the transfer stop?
- How is energy transfer as heat calculated?
- What is calorimetry?
- To what physical process does specific heat capacity refer?
- Does temperature always change during an energy transfer? When does it not, and why?
- What is enthalpy?
- How is bond breaking and bond making related to changes in the potential energy of a chemical system?
- What is a standard enthalpy of formation, and how is it used?
- How is Hess's law used to determine reaction enthalpies?

Content Statements (DCI)

PS3.A: Definitions of Energy

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. There is a single quantity called energy due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HSPS3-1),(HS-PS3-2)
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HSPS3-2) (HS-PS3-3)
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1)
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1),(HS-PS3-4)
- Uncontrolled systems always evolve toward more stable states— that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4)

PS3.D: Energy in Chemical Processes

- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4)

ETS1.A: Defining and Delimiting Engineering Problems

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS3-3)

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification
- Represent chemical phenomena using appropriate graphing techniques, including correct scale and units
- Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels
- Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate
- Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties
- Explain the connection between particulate-level and macroscopic properties of a substance using models and representations
- Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)
- Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables)

Learning Objectives. SWBAT

- 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 q absorbed or released by a system undergoing a chemical reaction in relationship to the amount of the reacting substance in moles and the molar enthalpy of reaction
- 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 (Hess's law)
- Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual steps

Sample Performance Task - Specific for Unit 3:

- **The Hand Warmer Design Challenge: Where Does the Heat Come From?** (Investigation 12 from College Board lab manual)
    - Students will track the flow of thermal energy with a dissolution system as they design a solution for the handwarmer engineering challenge. The ideal hand warmer increases in temperature by 20°C (but no more) as quickly as possible, has a volume of about 50 mL, costs as little as possible to make, and uses chemicals that are as safe and environmentally friendly as possible. Students will carry out an experiment to determine which substances, in what amounts, to use in order to make a hand warmer that meets these criteria.

Resources

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Lab Manual: AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices Student Manual, by College Board, Copyright 2013

Suggested Resources: AP Chemistry Course and Exam Description: https://apstudents.collegeboard.org/ap/pdf/ap-chemistry-course-and-exam-description.pdf

Unit 4: Atomic Structure and Periodicity	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
This unit focuses on the periodic table as an organizational and predictive tool. The periodic table provides information about each element's predictable periodicity as a function of the 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. Properties of the elements can be accurately predicted based on their placement on the table, and trends can be explained using Coulomb's law and knowledge of atomic structure. This unit provides an anchor for the study of radiation and spectroscopy. Electron structure can be experimentally verified using PES data, and visible spectroscopy experiments provide an opportunity to apply the Beer-Lambert law to relate absorbance to a solution's molar concentration. Students should develop an appreciation for how different types of radiation affect samples in unique ways. The textbook reference is Zumdahl chapter 7, as well as Appendix 3 and Appendix 7 for spectroscopy information.	
Recommended Pacing	
9 hours	
Standards/Performance Expectations	
Standard	
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. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.]** ***[Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]***
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. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.]** ***[Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]***
HS-PS4-1	**Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. [Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the earth.]** ***[Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]***
HS-PS4-4	**Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. [Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.]** ***[Assessment Boundary: Assessment is limited to qualitative descriptions.]***

Connecting with English Language Arts/Literacy and Mathematics

English Language Arts/Literacy

- Ask and refine questions to support uniform energy distribution among the components in a system when two components of different temperature are combined, using specific textual evidence.
- Conduct short as well as more sustained research projects to determine energy distribution in a system when two components of different temperature are combined.
- Collect relevant data across a broad spectrum of sources about the distribution of energy in a system and assess the strengths and limitations of each source.

Mathematics

- Use symbols to represent energy distribution in a system when two components of different temperatures are combined, and manipulate the representing symbols. Make sense of quantities and relationships in the energy distribution in a system when two components of different temperatures are combined.
- Use a mathematical model to describe energy distribution in a system when two components of different temperatures are combined. Identify important quantities in energy distribution in a system when two components of different temperatures are combined and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

21st Century Life and Careers/Technology Standards:

8.1 Educational Technology: All students will use digital tools to access, manage, evaluate, and synthesize information in order to solve problems individually and collaborate and to create and communicate knowledge.
8.2 Technology Education, Engineering, Design, and Computational Thinking - Programming:
All students will develop an understanding of the nature and impact of technology, engineering, technological design, computational thinking and the designed world as they relate to the individual, global society, and the environment.
9.2.12.C.4 Analyze how economic conditions and societal changes influence employment trends and future education.

9.2.12.C.3 Identify transferable career skills and design alternate career plans.

Social Studies

Standard 6.1 U.S. History: America in the World. All students will acquire the knowledge and skills to think analytically about how past and present interactions of people, cultures, and the environment shape the American heritage. Such knowledge and skills enable students to make informed decisions that reflect fundamental rights and core democratic values as productive citizens in local, national, and global communities.
Standard 6.2 World History: Global Studies: All students will acquire the knowledge and skills to think analytically and systematically about how past interactions of people, cultures, and the environment affect issues across time and cultures. Such knowledge and skills enable students to make informed decisions as socially and ethically responsible world citizens in the 21st century.

Instructional Focus

Unit Enduring Understandings

- Atoms and molecules can be identified by their electron distribution and energy
- The periodic table shows patterns in electronic structure and trends in atomic properties
- Spectroscopy can determine the structure and concentration in a mixture of a chemical species

Unit Essential Questions

- Can you describe the proton and electron balance in both neutral atoms and charged ions?
- How does Coulomb's law describe forces between charged particles?
- Can you describe the organization of electrons within an atom, referring to shells, subshells and orbitals?
- Can you use Coulomb's law to justify ionization energies for various atoms?
- What information does a photoelectron spectrum (PES) provide?
- How is the organization of elements on the periodic table related to electron configuration?
- Can you use atomic structure and Coulomb's law to explain trends in these properties: Ionization energy, Atomic and ionic radii, Electron affinity, and Electronegativity?
- Can you use periodicity to predict/estimate values of properties in the absence of data?
- Why do elements in the same column of the periodic table tend to form analogous compounds?
- Can you use the periodic table to predict ion charges?
- How does the type of radiation determine the level of interaction (vibration, rotation, or change in energy level) of electrons within a sample of matter?
- How are photon energies, wavelengths, frequencies, and speeds related?
- How does the Beer-Lambert law relate absorbance of radiation to molar concentration?

Content Statements (DCI)

PS1.A: Structure and Properties of Matter

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1)
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1)

PS1.B: Chemical Reactions

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7)

PS2.B: Types of Interactions

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (secondary to HS-PS1- 1),(secondary to HS-PS1-3)

PS4.A: Wave Properties

- The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. (HS-PS4-1)

PS4.B: Electromagnetic Radiation

- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. (HS-PS4-3)
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. (HS-PS4-4)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Describe the components of and quantitative information from models and representations that illustrate particulate-level properties
- Explain whether a model is consistent with chemical theories

- Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations
- Explain the connection between particulate-level and macroscopic properties of a substance using models and representations
- Identify or describe potential sources of experimental error
- Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)
- Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations

Learning Objectives. SWBAT

- Represent the electron configuration of an element or ions of an element using the Aufbau principle
- Explain the relationship between the photoelectron spectrum of an atom or ion and: a. The electron configuration of the species; and b. 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 a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region
- 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

Sample Performance Tasks - Specific for Unit 4:

- **What Is the Relationship Between the Concentration of a Solution and the Amount of Transmitted Light Through the Solution?** (Investigation 1 from College Board lab manual)
    - Students will analyze and interpret spectroscopic data to relate the absorbance of radiation to the molar concentration of a solution. The Beer-Lambert law will be modeled graphically.

- **Hydrogen Spectrum Lab**
    - Students will use mathematical representations to explain spectral-tube phenomenon, relating the energy flow within the gas discharge tube to the wavelength and energy of light observed.

Resources

Core Text: Chemistry, from Cengage Learning, by Zumdahl, Zumdahl, and DeCoste, Copyright 2018
Lab Manual: AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices Student Manual, by College Board, Copyright 2013

Suggested Resources: AP Chemistry Course and Exam Description:
https://apstudents.collegeboard.org/ap/pdf/ap-chemistry-course-and-exam-description.pdf

Unit 5: Bonding	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
In this unit, students apply their knowledge of atomic structure at the particulate level and connect it to the macroscopic properties of a substance. 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. These forces, called chemical bonds, are distinct from typical intermolecular interactions. Electronegativity can be used to make predictions about the type of bonding present between two atoms. Students will practice modeling with molecular model kits and relating their models to Lewis structures, and refine their graphical analysis skills as they interpret Born-Haber cycles. Constructing arguments for valid resonance structures allows students the opportunity to argue from evidence. The textbook reference is Zumdahl chapter 8, and chapter 9, section 1 only.	
Recommended Pacing	
12 hours	
Standards/Performance Expectations	
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. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] *[Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]***
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. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] *[Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]***
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. [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] *[Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.]***
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. [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] *[Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.]***

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. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] *[Assessment Boundary: Assessment is limited to systems with two objects.]***

Connecting with English Language Arts/Literacy and Mathematics

English Language Arts/Literacy

- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest.
- Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs.
- Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.
- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Use a mathematical model to explain how the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the effects of changing the temperature or

concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols.

- Use units as a way to understand an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret units consistently in formulas representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret the scale and the origin in graphs and data displays representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use a mathematical model to explain how to increase amounts of products at equilibrium in a chemical system. Identify important quantities in the cycling of matter and flow of energy among organisms in an ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

21st Century Life and Careers/Technology Standards:

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8.2 Technology Education, Engineering, Design, and Computational Thinking - Programming:
All students will develop an understanding of the nature and impact of technology, engineering, technological design, computational thinking and the designed world as they relate to the individual, global society, and the environment.
9.2.12.C.4 Analyze how economic conditions and societal changes influence employment trends and future education.

9.2.12.C.3 Identify transferable career skills and design alternate career plans.

Social Studies

Standard 6.1 U.S. History: America in the World. All students will acquire the knowledge and skills to think analytically about how past and present interactions of people, cultures, and the environment shape the American heritage. Such knowledge and skills enable students to make informed decisions that reflect fundamental rights and core democratic values as productive citizens in local, national, and global communities.
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Instructional Focus

Unit Enduring Understandings

- Atoms or ions bond due to interactions between them, forming molecules
- The energy exchanged in a chemical transformation is required to break and form bonds
- Molecular compounds are arranged based on Lewis diagrams and Valence Shell Electron Pair Repulsion (VSEPR) theory

Unit Essential Questions

- How is electronegativity used to justify bond type?
- How are polar and nonpolar covalent bonds different?
- What is bond character? Is there truly a “pure” covalent bond?
- How do a compound’s properties give insight into the type of bonding present within the compound?
- Can you describe changes in potential energy that occur during bond formation?

- What is bond order, and how does it impact the length and energy of the bond?
- How can Coulomb's law be used to describe bond energy?
- How do attractive and repulsive forces organize ions within an ionic crystal lattice?
- Why is bond energy tabulated as an "average" energy?
- How can the overall enthalpy change of a reaction be determined from average bond energies?
- What principles support a valid Lewis structure?
- How do the principles of formal charge support or refute a valid Lewis structure?
- How is resonance used in cases where more than one equivalent Lewis structure can be constructed?
- How does Coulomb's law support VSEPR theory?
- What is a hybrid orbital, and can you describe the difference between sp^3, sp^2, and sp hybrid orbitals?
- How do sigma and pi bonds form?

Content Statements (DCI)

PS1.A: Structure and Properties of Matter

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1)
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1)
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3),(secondary to HS-PS2-6)
- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. (HS-PS1-4)

PS1.B: Chemical Reactions

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7)

PS2.B: Types of Interactions

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (secondary to HS-PS1- 1),(secondary to HS-PS1-3)
- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)
- Make a scientific claim
- Represent chemical phenomena using appropriate graphing techniques, including correct scale and units
- Explain the connection between particulate-level and macroscopic properties of a substance using models and representations
- Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration)
- Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules
- Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules

Learning Objectives. SWBAT

- 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
- Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction
- 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, and explain electron properties of molecules, based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities

Sample Performance Tasks - Specific for Unit 5:

- **Molecular model kits**
    - Students will carry out an investigation of molecular structure, observing patterns in bond angles and polarity.

Resources

Core Text: Chemistry, from Cengage Learning, by Zumdahl, Zumdahl, and DeCoste, Copyright 2018
Lab Manual: AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices Student Manual, by College Board, Copyright 2013

Suggested Resources: AP Chemistry Course and Exam Description:
https://apstudents.collegeboard.org/ap/pdf/ap-chemistry-course-and-exam-description.pdf

Unit 6: Introduction to Equilibrium	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
This unit leverages the Big Idea of *Transformations* as students explore the fundamental principles of chemical equilibrium. Students will reason both macroscopically and microscopically as they develop an understanding of the changes a chemical system undergoes on its way to equilibrium, as well as responses to a disruption of the equilibrium condition. Qualitative particle-level understanding of the equilibrium condition is followed by quantitative calculations and interpretation of the equilibrium constant Kc or Kp. The textbook reference is Zumdahl chapter 13 as well as chapter 16, sections 1 and 2 only (not 16.3).	
Recommended Pacing	
15 hours	
Standards/Performance Expectations	
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. [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] *[Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]***

Connecting with English Language Arts/Literacy and Mathematics

English Language Arts/Literacy

- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest.
- Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs.
- Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.
- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.

- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Use a mathematical model to explain how the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols.
- Use units as a way to understand an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret units consistently in formulas representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret the scale and the origin in graphs and data displays representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use a mathematical model to explain how to increase amounts of products at equilibrium in a chemical system. Identify important quantities in the cycling of matter and flow of energy among organisms in an ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

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9.2.12.C.4 Analyze how economic conditions and societal changes influence employment trends and future education.

9.2.12.C.3 Identify transferable career skills and design alternate career plans.

Social Studies
Standard 6.1 U.S. History: America in the World. All students will acquire the knowledge and skills to think analytically about how past and present interactions of people, cultures, and the environment shape the American heritage. Such knowledge and skills enable students to make informed decisions that reflect fundamental rights and core democratic values as productive citizens in local, national, and global communities. Standard 6.2 World History: Global Studies: All students will acquire the knowledge and skills to think analytically and systematically about how past interactions of people, cultures, and the environment affect issues across time and cultures. Such knowledge and skills enable students to make informed decisions as socially and ethically responsible world citizens in the 21st century.

Instructional Focus
Unit Enduring Understandings ● Some reactions can occur in both forward and reverse directions, sometimes proceeding in each direction simultaneously ● A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and equilibrium constant K ● Systems at equilibrium respond to external stresses to offset the effect of the stress ● The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions
Unit Essential Questions ● How can a chemical reaction occur in more than one direction? ● Is a chemical reaction ever "complete?" ● Can you explain this statement? "A system can have many equilibrium positions, but only one equilibrium constant."
Content Statements (DCI) **PS1.B: Chemical Reactions** • Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HSPS1-4),(HS-PS1-5) • In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6) • The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7)
Ability Objectives **Science Practices and Skills Objectives. SWBAT** ● Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification ● Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties ● Represent chemical phenomena using appropriate graphing techniques, including correct scale and units ● Explain the relationship between variables within an equation when one variable changes ● Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables) ● Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic) ● Explain the connection between experimental results and chemical concepts, processes, or theories

- Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)
- Identify an appropriate theory, definition, or mathematical relationship to solve a problem
- Explain how modifications to an experimental procedure will alter results
- Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate

Learning Objectives. SWBAT

- 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 Qc or Qp, for a reversible reaction, and the corresponding equilibrium expressions Kc = Qc or Kp = Qp
- Calculate Kc or Kp 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 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 Ksp for the salt
- Identify the solubility of a salt, and/or the value of Ksp for the salt, based on the concentration of a common ion already present in solution
- Identify the qualitative effect of changes in pH on the solubility of a salt.
- Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process

Sample Performance Tasks - Specific for Unit 6:

- **pH of salts activity**
  - Students will observe the effect of dissolving various salts on the pH of the resulting solution, and construct arguments for the role the dynamic equilibrium plays in producing the observed pH.

- **Determination of an equilibrium constant, K_c**
  - Students will define and justify an equilibrium system, and then carry out an investigation to determine its equilibrium constant.

Resources

Core Text: Chemistry, from Cengage Learning, by Zumdahl, Zumdahl, and DeCoste, Copyright 2018
Lab Manual: AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices Student Manual, by College Board, Copyright 2013

Suggested Resources: AP Chemistry Course and Exam Description:
https://apstudents.collegeboard.org/ap/pdf/ap-chemistry-course-and-exam-description.pdf

Unit 7: Acid and Base Equilibrium	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
This unit builds on the content about chemical equilibrium studied in Unit 6. Chemical equilibrium plays an important role in acid-base chemistry and solubility. 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. The textbook reference is Zumdahl chapter 14.	
Recommended Pacing	
10 hours	
Standards/Performance Expectations	
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. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] *[Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]***
HS-PS-1-2	**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. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] *[Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]***
HS-PS-1-7	**Use mathematical representations of phenomena to support claims that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] *[Assessment Boundary: Assessment does not include complex chemical reactions.]***

Connecting with English Language Arts/Literacy and Mathematics
English Language Arts/Literacy • Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest.

- Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs.
- Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.
- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Use a mathematical model to explain how the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols.
- Use units as a way to understand an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret units consistently in formulas representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret the scale and the origin in graphs and data displays representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use a mathematical model to explain how to increase amounts of products at equilibrium in a chemical system. Identify important quantities in the cycling of matter and flow of energy among organisms in an

ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

21st Century Life and Careers/Technology Standards:

8.1 Educational Technology: All students will use digital tools to access, manage, evaluate, and synthesize information in order to solve problems individually and collaborate and to create and communicate knowledge.
8.2 Technology Education, Engineering, Design, and Computational Thinking - Programming:
All students will develop an understanding of the nature and impact of technology, engineering, technological design, computational thinking and the designed world as they relate to the individual, global society, and the environment.
9.2.12.C.4 Analyze how economic conditions and societal changes influence employment trends and future education.

9.2.12.C.3 Identify transferable career skills and design alternate career plans.

Social Studies

Standard 6.1 U.S. History: America in the World. All students will acquire the knowledge and skills to think analytically about how past and present interactions of people, cultures, and the environment shape the American heritage. Such knowledge and skills enable students to make informed decisions that reflect fundamental rights and core democratic values as productive citizens in local, national, and global communities.
Standard 6.2 World History: Global Studies: All students will acquire the knowledge and skills to think analytically and systematically about how past interactions of people, cultures, and the environment affect issues across time and cultures. Such knowledge and skills enable students to make informed decisions as socially and ethically responsible world citizens in the 21st century.

Instructional Focus

Unit Enduring Understandings

- The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium concentrations being related to the strength of the acids and bases involved
- Acid-base reactions, also known as neutralization, are a subset of double replacement reactions

Unit Essential Questions

- What are characteristics of molecules that have acidic or basic properties?
- What does pH measure?
- What is pOH?
- What is the difference between H^+ and H_3O^+ ?
- What does it mean to say water "autoionizes"? Can you write an equilibrium constant expression (K_w) for this process?
- Why is pure water neutral?
- Why is pH based on a scale of 0-14 (isn't 14 an unusual number?)?
- How are pH and K_w influenced by temperature?
- What is the difference between a strong and weak acid?
- How do you calculate the pH of a strong acid?
- What is K_a? How do you use it to calculate the pH of a weak acid?
- What is the difference between a strong and weak base?
- What is K_b? How do you use it to calculate the pH of a weak base?
- What is the relationship between an acid and its conjugate base? A base and its conjugate acid?
- What is percent ionization and how can it be calculated?
- How is acid strength related to bond length and number of oxygen atoms in a molecule?
- What are the products of a reaction between a strong acid and strong base?

Content Statements (DCI)

PS1.A: Structure and Properties of Matter

- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3),*(secondary to HS-PS2-6)*

PS1.B: Chemical Reactions

- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Identify an appropriate theory, definition, or mathematical relationship to solve a problem
- Explain the relationship between variables within an equation when one variable changes
- Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)
- Identify information presented graphically to solve a problem
- Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules
- Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate

Learning Objectives. SWBAT

- 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 the relationship between the strength of an acid or base and the structure of the molecule or ion.

Sample Performance Tasks - Specific for Unit 7:

- **Strong and Weak Acid and Base Titration**
  - Students will carry out an investigation of the four types of titrations. They will graph pH versus volume to detect any patterns in these acid-base chemical reactions.

- **pH of Salt Solutions**
  - Students will dissolve different salts (ionic compounds) in water and note the pH of the resulting solution. Based on the structure and formula of the salt, they can engage in argument from evidence regarding why the resulting solution is acidic, basic, or neutral.

Resources

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Unit 8: Applications of Acid/Base Equilibria; Buffers and Titrations	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
This unit builds on the content about chemical equilibrium studied in the previous acid/base unit (Unit 7), with specific emphasis on buffers and titrations. Buffer systems, solutions that resist pH change, are in the world all around us, from the oceans to our blood. Titration is a precise, accurate lab technique for determining the concentration of an unknown solution. The textbook reference is Zumdahl chapter 15.	
Recommended Pacing	
13 hours	
Standards/Performance Expectations	
Standards	
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. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] *[Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]***
HS-PS1-7	**Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] *[Assessment Boundary: Assessment does not include complex chemical reactions.]***
HS-ETS1-1	**Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.**

Connecting with English Language Arts/Literacy and Mathematics
English Language Arts/Literacy • Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest. • Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs. • Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.

- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Use a mathematical model to explain how the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols.
- Use units as a way to understand an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret units consistently in formulas representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret the scale and the origin in graphs and data displays representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use a mathematical model to explain how to increase amounts of products at equilibrium in a chemical system. Identify important quantities in the cycling of matter and flow of energy among organisms in an ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

21st Century Life and Careers/Technology Standards:

8.1 Educational Technology: All students will use digital tools to access, manage, evaluate, and synthesize information in order to solve problems individually and collaborate and to create and communicate knowledge.
8.2 Technology Education, Engineering, Design, and Computational Thinking - Programming:

All students will develop an understanding of the nature and impact of technology, engineering, technological design, computational thinking and the designed world as they relate to the individual, global society, and the environment.
9.2.12.C.4 Analyze how economic conditions and societal changes influence employment trends and future education.

9.2.12.C.3 Identify transferable career skills and design alternate career plans.

Social Studies

Standard 6.1 U.S. History: America in the World. All students will acquire the knowledge and skills to think analytically about how past and present interactions of people, cultures, and the environment shape the American heritage. Such knowledge and skills enable students to make informed decisions that reflect fundamental rights and core democratic values as productive citizens in local, national, and global communities.
Standard 6.2 World History: Global Studies: All students will acquire the knowledge and skills to think analytically and systematically about how past interactions of people, cultures, and the environment affect issues across time and cultures. Such knowledge and skills enable students to make informed decisions as socially and ethically responsible world citizens in the 21st century.

Instructional Focus

Unit Enduring Understandings

- The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium concentrations being related to the strength of the acids and bases involved
- Acid-base reactions, also known as neutralization, are a subset of double replacement reactions
- A buffered solution resists changes to its pH when small amounts of acid or base are added

Unit Essential Questions

- What are the products of a reaction between a strong acid and strong base? How do you determine the pH of the resulting solution?
- What are the products of a reaction between a strong acid and weak base? How do you determine the pH of the resulting solution?
- What are the products of a reaction between a weak acid and strong base? How do you determine the pH of the resulting solution?
- What are the products of a reaction between a weak acid and weak base? How do you determine the pH of the resulting solution?
- What is a titration curve? What is it used for? What are the most important parts of the curve?
- What are the characteristics of a titration curve when the reactants are a strong acid and strong base? Strong acid and weak base? Weak acid and strong base? Weak acid and weak base?
- What is the equivalence point of a titration, and why is it useful?
- What is the half-equivalence point of a titration, and why is it useful, especially for weak acids or bases?
- How is the equivalence point different from the end point?
- How is the titration curve for a polyprotic acid similar/different than one for a monoprotic acid?
- What components are necessary to create a buffer?
- How/why does a buffer resist changes in pH if a strong acid or strong base is added to the solution?
- What is buffer capacity?
- How can you create a buffer with a large capacity?

Content Statements (DCI)

PS1.B: Chemical Reactions

- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6)
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7)

ETS1.A: Defining and Delimiting an Engineering Problem

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS3-3)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Identify information presented graphically to solve a problem
- Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification
- Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)
- Explain how potential sources of experimental error may affect the experimental results

Learning Objectives. SWBAT

- 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 among the concentrations of major species in a mixture of weak and strong acids and bases
- 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 the buffer capacity of a solution and the relative concentrations of the conjugate acid and conjugate base components of the solution

Sample Performance Tasks - Specific for Unit 8:

- **How Much Acid Is in Fruit Juice and Soft Drinks?** (Investigation 4 from College Board lab manual)
  - Students will plan and carry out an investigation to determine the pH of soda and/or juice. They will look for patterns in their titration curves, which are chemical reactions of an acid and base.

- **Buffer Lab**
  - Students will plan and carry out an investigation to create a buffer at a specific pH. They will test this buffer to note its stability and change (or lack thereof) in pH when acid and/or base is added.

Resources

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Suggested Resources: AP Chemistry Course and Exam Description:
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Unit 9: Thermodynamics	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
This unit is an extension and more in-depth analysis of Unit 3, in that it integrates the idea of equilibrium and equilibrium concepts addressed in Unit 6. The thermodynamics of a chemical reaction is connected to both the structural aspects of the reaction and the macroscopic outcomes of the reaction. 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. The textbook reference is Zumdahl chapter 17.	
Recommended Pacing	
7 hours	
Standards/Performance Expectations	
Standards	
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. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] *[Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]***

Connecting with English Language Arts/Literacy and Mathematics
English Language Arts/Literacy ● Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS3-4) ● Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-PS3-4) ● Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS3-4) ● Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS3-4) ● Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest. ● Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs.

- Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.
- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Reason abstractly and quantitatively. (HS-PS3-4)
- Model with mathematics. (HS-PS3-4)
- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
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ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

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9.2.12.C.3 Identify transferable career skills and design alternate career plans.

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Standard 6.2 World History: Global Studies: All students will acquire the knowledge and skills to think analytically and systematically about how past interactions of people, cultures, and the environment affect issues across time and cultures. Such knowledge and skills enable students to make informed decisions as socially and ethically responsible world citizens in the 21st century.

Instructional Focus

Unit Enduring Understandings

- Some chemical or physical processes cannot occur without intervention
- The relationship between ΔG° and K can be used to determine favorability of a chemical or physical transformation

Unit Essential Questions

- How does the entropy of a system change during a phase change?
- How does the entropy of a gaseous system change when the volume changes?
- How does the entropy of a gaseous system change when the number of moles changes?
- How does the entropy of a system change when the temperature changes?
- How can the entropy change of a reaction be calculated?
- What is Gibbs free energy, ΔG°?
- What does it mean to say a process is “spontaneous”?
- How can the change in Gibbs free energy of a reaction be calculated?
- What is the significance of the sign of ΔG°?
- How do enthalpy and entropy influence ΔG° at various temperatures?
- Will a thermodynamically favorable reaction happen immediately?
- What is the relationship between the sign of ΔG° and K, the equilibrium constant, for a reaction?
- How can you make a thermodynamically unfavorable reaction occur?

Content Statements (DCI)

PS1.B: Chemical Reactions

- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6)

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7)

PS3.B: Conservation of Energy and Energy Transfer

- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules
- Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)
- Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels
- Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification
- Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties
- Explain how modifications to an experimental procedure will alter results

Learning Objectives. SWBAT

- Identify the sign and relative magnitude of the entropy change associated with chemical or physical processes
- Calculate the entropy change for a chemical or physical process based on the absolute entropies of the species involved in the process
- Explain whether a physical or chemical process is thermodynamically favored based on an evaluation of ΔG^{o}
- 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^{o} , and T
- Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes

Sample Performance Tasks - Specific for Unit 9:

- **Borax Lab**
  - Students will create three saturated solutions of borax at different temperatures. Then they will use mathematics and computational thinking to calculate the equilibrium constant at each temperature, create a linear plot of lnK v 1/T, and determine ΔH and ΔS from the slope and y-intercept.

Resources

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Unit 10: Electrochemistry	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
All changes in matter involve some form of energy change. Investigating electrochemistry will allow students to describe the essential role of electron transfer in chemical reactions. In some instances, electricity is generated by a chemical reaction, and in other cases, electricity is required for a reaction to occur. When energy that is generated by a reaction is harnessed, it can be turned into something useful such as a battery. The textbook reference is Zumdahl chapter 18.	
Recommended Pacing	
8 hours	
Standards/Performance Expectations	
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. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [*Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.*]**
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. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [*Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.*]**

Connecting with English Language Arts/Literacy and Mathematics

English Language Arts/Literacy

- Ask and refine questions to support uniform energy distribution among the components in a system when two components of different temperatures are combined, using specific textual evidence.
- Conduct short as well as more sustained research projects to determine energy distribution in a system when two components of different temperature are combined.
- Collect relevant data across a broad spectrum of sources about the distribution of energy in a system and assess the strengths and limitations of each source.

Mathematics

- Use symbols to represent energy distribution in a system when two components of different temperatures are combined, and manipulate the representing symbols. Make sense of quantities and relationships in the energy distribution in a system when two components of different temperatures are combined.
- Use a mathematical model to describe energy distribution in a system when two components of different temperatures are combined. Identify important quantities in energy distribution in a system when two

components of different temperatures are combined and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

21st Century Life and Careers/Technology Standards:

8.1 Educational Technology: All students will use digital tools to access, manage, evaluate, and synthesize information in order to solve problems individually and collaborate and to create and communicate knowledge.
8.2 Technology Education, Engineering, Design, and Computational Thinking - Programming:
All students will develop an understanding of the nature and impact of technology, engineering, technological design, computational thinking and the designed world as they relate to the individual, global society, and the environment.
9.2.12.C.4 Analyze how economic conditions and societal changes influence employment trends and future education.

9.2.12.C.3 Identify transferable career skills and design alternate career plans.

Social Studies

Standard 6.1 U.S. History: America in the World. All students will acquire the knowledge and skills to think analytically about how past and present interactions of people, cultures, and the environment shape the American heritage. Such knowledge and skills enable students to make informed decisions that reflect fundamental rights and core democratic values as productive citizens in local, national, and global communities.
Standard 6.2 World History: Global Studies: All students will acquire the knowledge and skills to think analytically and systematically about how past interactions of people, cultures, and the environment affect issues across time and cultures. Such knowledge and skills enable students to make informed decisions as socially and ethically responsible world citizens in the 21st century.

Instructional Focus

Unit Enduring Understandings

- Electrical energy can be generated by chemical reactions
- Some chemical or physical processes cannot occur without intervention
- The relationships between E° and ΔG°, and E° and K can be used to determine favorability of a chemical or physical transformation.

Unit Essential Questions

- What is a “redox” reaction?
- What are the components of a voltaic (also known as galvanic) cell?
- What is the function of each component in a voltaic cell?
- How does a voltaic cell differ from an electrolytic cell? How are the two cells the same?
- What is the purpose of separating an electrochemical process into half-reactions?
- How can standard cell potential be calculated?
- What is the significance of the sign (positive or negative) for standard cell potential?
- How is standard cell potential related to Gibbs Free Energy?
- How is standard cell potential related to the equilibrium constant?
- How can you make a thermodynamically unfavorable electrochemical reaction occur?
- How does the cell potential change under nonstandard conditions?
- How does the cell potential change as the system approaches equilibrium?
- How can stoichiometry of a redox reaction be used to determine mass of material deposited on or removed from an electrode, time elapsed, etc.?

Content Statements (DCI)

PS1.A: Structure and Properties of Matter

- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3), *(secondary to HS-PS2-6)*

PS1.B: Chemical Reactions

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7)

PS2.B: Types of Interactions

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. *(secondary to HS-PS1-1),(secondary to HS-PS1-3)*

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification
- Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties
- Explain how modifications to an experimental procedure will alter results
- Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)
- Calculate the amount of charge flow based on changes in the amounts of reactants and products in an electrochemical cell
- Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification
- Identify an appropriate theory, definition, or mathematical relationship to solve a problem

Learning Objectives. SWBAT

- 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 within the cell
- Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes
- Explain the relationship between deviations from standard cell conditions and changes in the cell potential
- Explain whether a process is thermodynamically favored using the relationships between E°, K, and ΔG°

<u>Sample Performance Tasks - Specific for Unit 10:</u>

- **Electrochemical Cells**
  - Students will obtain, evaluate, and communicate information regarding cell potential (voltage) generated when various metals are paired with a zinc standard electrode. They will then analyze the cause and effect relationship of voltage and concentration when the concentration of one of the solutions is changed.

- **How Can We Determine the Actual Percentage of H_2O_2 in a Drugstore Bottle of Hydrogen Peroxide?** (Investigation 8 in College Board lab manual)
  - Students will plan and carry out an investigation to perform a redox titration with hydrogen peroxide. They will then engage in argument from evidence regarding the stability of hydrogen peroxide on a store shelf or in a medicine cabinet.

Resources

Core Text: Chemistry, from Cengage Learning, by Zumdahl, Zumdahl, and DeCoste, Copyright 2018
Lab Manual: AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices Student Manual, by College Board, Copyright 2013

Suggested Resources: AP Chemistry Course and Exam Description:
https://apstudents.collegeboard.org/ap/pdf/ap-chemistry-course-and-exam-description.pdf

Unit 11: Kinetics	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
Students will develop an understanding of the rates at which chemical changes occur and the factors that influence the rates. 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, students are measuring the concentration of reactant or product species as a function of time. These chemical processes may be observed in a variety of ways and often involve changes in energy as well. The textbook reference is Zumdahl chapter 12.	
Recommended Pacing	
10 hours	
Standards/Performance Expectations	
Standards	
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. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] *[Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]***
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. [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.]**
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. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] *[Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]***

Connecting with English Language Arts/Literacy and Mathematics

English Language Arts/Literacy

- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest.
- Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs.

- Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.
- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Use a mathematical model to explain how the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols.
- Use units as a way to understand an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret units consistently in formulas representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret the scale and the origin in graphs and data displays representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use a mathematical model to explain how to increase amounts of products at equilibrium in a chemical system. Identify important quantities in the cycling of matter and flow of energy among organisms in an ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

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Social Studies

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Instructional Focus

Unit Enduring Understandings

- Some reactions happen quickly, while others happen more slowly and depend on reactant concentrations and temperature
- There is a relationship between the speed of a reaction and the collision frequency of particle collisions
- Many chemical reactions occur through a series of elementary reactions. These elementary reactions when combined form a chemical equation
- The speed at which a reaction occurs can be influenced by a catalyst

Unit Essential Questions

- What is reaction rate and how is it determined/calculated?
- What factors influence the rate of reaction?
- What is a rate law and how is it determined?
- What is the order of reaction and how is it determined?
- What is a rate constant and how is it determined?
- How is half-life different for first, second, and zeroth order reactions?
- What is an elementary reaction and how is it different than an overall reaction?
- What are the requirements for particles to collide successfully and create a product?
- What is activation energy and what factors influence it?
- What is a reaction mechanism?
- What is a rate-determining step?
- What is a catalyst and how does it work?

Content Statements (DCI)

PS1.A: Structure and Properties of Matter

- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. (HS-PS1-4)

PS1.B: Chemical Reactions

- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with

consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-4),(HS-PS1-5)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels
- Explain the relationship between variables within an equation when one variable changes
- Identify an appropriate theory, definition, or mathematical relationship to solve a problem
- Determine a balanced chemical equation for a given chemical phenomena
- Represent chemical substances or phenomena with appropriate diagrams or models (e.g. reaction coordinate)
- Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties

Learning Objectives. SWBAT

- 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 molecular 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

Sample Performance Tasks - Specific for Unit 11:

- **What Is the Rate Law of the Fading of Crystal Violet Using Beer's Law?** (Investigation 11 from the College Board Lab Manual)
    - Students will analyze and interpret data to determine the order of reaction between crystal violet and sodium hydroxide. They will make this determination by creating three graphs and noticing any patterns in the linearity (or lack thereof) in the data.

- **Alka Seltzer Lab**
    - Students will plan and carry out an investigation to determine which factors most influence the rate at which Alka-Seltzer dissolves in water.

Resources

Core Text: Chemistry, from Cengage Learning, by Zumdahl, Zumdahl, and DeCoste, Copyright 2018
Lab Manual: AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices Student Manual, by College Board, Copyright 2013

Suggested Resources: AP Chemistry Course and Exam Description:
https://apstudents.collegeboard.org/ap/pdf/ap-chemistry-course-and-exam-description.pdf

Unit 12: States of Matter	
Content Area: Science	
Course & Grade Level: AP Chemistry, 11-12	
Summary and Rationale	
Transformations of matter can be observed in ways that are generally categorized as either a chemical or a 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 gases 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 gases, as well as the structure of the constituent particles of those materials on the molecular and atomic scale. The textbook reference is Zumdahl chapters 5, 10, and 11.	
Recommended Pacing	
10 hours	
Standards/Performance Expectations	
Standards	
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. [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [*Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.*]**
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. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [*Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.*]**
HS-PS3-2	**Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects). [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]**

Connecting with English Language Arts/Literacy and Mathematics
English Language Arts/Literacy ● Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS3-4) ● Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-PS3-4)

- Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS3-4)
- Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS3-4)
- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest.
- Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs.
- Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.
- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Reason abstractly and quantitatively. (HS-PS3-4)
- Model with mathematics. (HS-PS3-4)
- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Use a mathematical model to explain how the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols.

Make sense of quantities and relationships about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols.

- Use units as a way to understand an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret units consistently in formulas representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret the scale and the origin in graphs and data displays representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use a mathematical model to explain how to increase amounts of products at equilibrium in a chemical system. Identify important quantities in the cycling of matter and flow of energy among organisms in an ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

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9.2.12.C.4 Analyze how economic conditions and societal changes influence employment trends and future education.

9.2.12.C.3 Identify transferable career skills and design alternate career plans.

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Instructional Focus

Unit Enduring Understandings

- Intermolecular forces can explain the physical properties of a material
- Matter exists in three states: solid, liquid, and gas, and their differences are influenced by variances in spacing and motion of the molecules
- Gas properties are explained macroscopically—using the relationships among pressure, volume, temperature, moles, gas constant—and molecularly by the motion of the gas
- Interactions between intermolecular forces influence the solubility and separation of mixtures
- Spectroscopy can determine the structure and concentration in a mixture of a chemical species

Unit Essential Questions

- What are the main types of intermolecular forces (IMFs)?

- What is responsible or what causes each of the main types of IMFs?
- How do the main IMFs compare to each other in terms of relative strength?
- How does the size of a molecule influence the strength of its IMF?
- Can a particular-level representation communicate how intermolecular interactions contribute to macroscopic properties such as melting point, conductivity, haradness, etc.? (Examples of substances include ionic compounds, covalent network solids, metallic solids, or molecular solids - crystalline or amorphous)
- How does IMF strength influence melting point; boiling point; enthalpy of vaporization; surface tension; and vapor pressure?
- How are solids and liquids similar? How are they different?
- Why are gases so different from solids or liquids?
- What is the ideal gas law?
- How are pressure, temperature, volume, and number of moles of a gas related (directly or inversely proportional)?
- How are total pressure, partial pressure, and mole fraction of a gas related?
- How does kinetic molecular theory (KMT) relate the macroscopic properties of gases to motions of the particles in the gas?
- What is a Maxwell-Boltzmann distribution and what does it represent?
- How is average kinetic energy related to temperature? To average velocity?
- How do real gases differ from ideal gases?
- Which two assumptions of the ideal gas law result in deviations for real gases?
- Which types of homogeneous mixtures can be solutions (e.g. gas in gas; solid in liquid; liquid in liquid; etc.)?
- How is the composition of a solution calculated?
- How can particulate representations of solutions communicate the structure and properties of solutions?
- What are the three steps in creating a solution? Are these steps endothermic or exothermic?
- How can components of a liquid mixture be separated? What properties do these separation methods take advantage of?
- What causes substances to be soluble or insoluble in each other?
- How are the absorbance of a solution and its concentration related?
- How can the concentration of an unknown solution be determined with spectroscopy?
- How are wavelength and frequency of electromagnetic radiation related?
- How are wavelength and energy of electromagnetic radiation related?

Content Statements (DCI)

PS1.A: Structure and Properties of Matter

- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3),(secondary to HS-PS2-6)

- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (HS-ESS2-4)

PS3.A Definitions of Energy

- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3)

- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases

the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)

PS3.B Conservation of Energy and Energy Transfer

- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1)

Ability Objectives

Science Practices and Skills Objectives. SWBAT

- Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties
- Explain the connection between particulate-level and macroscopic properties of a substance using models and representations
- Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic)
- Explain the relationship between variables within an equation when one variable changes
- Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations
- Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels
- Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures)
- Identify experimental procedures that are aligned to the question (which may include a sketch of a lab setup)
- Identify or describe potential sources of experimental error

Learning Objectives. SWBAT

- Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when
    - The molecules are of the same chemical species
    - 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 gases using the ideal gas law
- Explain the relationship between the motion of particles and the macroscopic properties of gases with
    - The kinetic molecular theory (KMT)
    - A particulate model
    - A graphical representation
- Explain the relationship among non-ideal behaviors of gases, interparticle forces, and/or volumes
- Calculate the number of solute particles, volume, or molarity of solutions
- Using particulate models for mixtures
    - Represent interactions between components
    - Represent concentrations of components
- Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles
- Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region

- 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

Sample Performance Tasks - Specific for Unit 12:

- **Molar Mass of Butane**
  - Students will collect butane gas from a lighter submersed in water. They will use mathematics and computational thinking to calculate the molar mass of butane from their data. Then they will determine the cause of any errors and the effect these errors would have on their calculated value.

- **Intermolecular Forces Lab**
  - Students will obtain, evaluate, and communicate information about the state of matter, viscosity, deflection, and change in temperature when evaporating for a variety of covalent compounds. Then they will analyze the structure of the covalent compounds to draw conclusions regarding the strength of the intermolecular forces between neighboring molecules.

- **How Can Color Be Used to Determine the Mass Percent of Copper in Brass?** (Investigation 2 from the College Board Lab Manual)
  - Students will develop a model of concentration versus absorbance for several different copper solutions of known concentrations. Then they will test an unknown solution and apply principles of scale, proportion, and quantity to determine the concentration of the unknown solution.

- **Sticky Question: How Do You Separate Molecules That Are Attracted to One Another?** (Investigation 5 from the College Board Lab Manual)
  - Students will engage in argument from evidence regarding which solvent is best at separating a mixture of dyes. They will base their argument on the structure of the solvents, dyes, and chromatography paper.

Resources

Core Text: Chemistry, from Cengage Learning, by Zumdahl, Zumdahl, and DeCoste, Copyright 2018
Lab Manual: AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices Student Manual, by College Board, Copyright 2013
Suggested Resources: AP Chemistry Course and Exam Description:
https://apstudents.collegeboard.org/ap/pdf/ap-chemistry-course-and-exam-description.pdf