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SCIENCE
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MATHEMATICS
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RAHWAY PUBLIC SCHOOLS

CURRICULUM & INSTRUCTION

Content Area: Science

**Course: Advanced Placement
Chemistry**

Grade Level: 11-12

This curriculum is part of the Educational Program of Studies of the Rahway Public Schools.

ACKNOWLEDGMENTS

Jeffery Kurczeski,

Program Supervisor of 7-12 Math & Science and 9-12 Business & Technology Education

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Julie Koft, Science Teacher

Dr. Tiffany A. Beer, Director of Curriculum and Instruction

Subject/Course Title:
Advanced Placement Chemistry
Grades 11-12

Date of Board Adoption:
August 26, 2025

RAHWAY PUBLIC SCHOOLS CURRICULUM

Advanced Placement Chemistry: Grades 11-12

PACING GUIDE

Unit	Title	Pacing
1	Atomic Structure and Properties	2 weeks
2	Compound Structure and Properties	3 weeks
3	Properties of Substances and Mixtures	4 weeks
4	Chemical Reactions	3 weeks
5	Kinetics	4 weeks
6	Thermochemistry	5 weeks
7	Equilibrium	5 weeks
8	Acids and Bases	4 weeks
9	Thermodynamics and Electrochemistry	3 weeks

ACCOMMODATIONS

<p>504 Accommodations:</p> <ul style="list-style-type: none"> ● Provide scaffolded vocabulary and vocabulary lists. ● Provide extra visual and verbal cues and prompts. ● Provide adapted/alternate/excerpted versions of the text and/or modified supplementary materials. ● Provide links to audio files and utilize video clips. ● Provide graphic organizers and/or checklists. ● Provide modified rubrics. ● Provide a copy of teaching notes, especially any key terms, in advance. ● Allow additional time to complete assignments and/or assessments. ● Provide shorter writing assignments. ● Provide sentence starters. ● Utilize small group instruction. ● Utilize Think-Pair-Share structure. ● Check for understanding frequently. ● Have student restate information. ● Support auditory presentations with visuals. ● Weekly home-school communication tools (notebook, daily log, phone calls or email messages). ● Provide study sheets and teacher outlines prior to assessments. ● Quiet corner or room to calm down and relax when anxious. ● Reduction of distractions. ● Permit answers to be dictated. ● Hands-on activities. ● Use of manipulatives. ● Assign preferential seating. ● No penalty for spelling errors or sloppy handwriting. ● Follow a routine/schedule. ● Provide student with rest breaks. ● Use verbal and visual cues regarding directions and staying on task. ● Assist in maintaining agenda book. 	<p>IEP Accommodations:</p> <ul style="list-style-type: none"> ● Provide scaffolded vocabulary and vocabulary lists. ● Differentiate reading levels of texts (e.g., Newsela). ● Provide adapted/alternate/excerpted versions of the text and/or modified supplementary materials. ● Provide extra visual and verbal cues and prompts. ● Provide links to audio files and utilize video clips. ● Provide graphic organizers and/or checklists. ● Provide modified rubrics. ● Provide a copy of teaching notes, especially any key terms, in advance. ● Provide students with additional information to supplement notes. ● Modify questioning techniques and provide a reduced number of questions or items on tests. ● Allow additional time to complete assignments and/or assessments. ● Provide shorter writing assignments. ● Provide sentence starters. ● Utilize small group instruction. ● Utilize Think-Pair-Share structure. ● Check for understanding frequently. ● Have student restate information. ● Support auditory presentations with visuals. ● Provide study sheets and teacher outlines prior to assessments. ● Use of manipulatives. ● Have students work with partners or in groups for reading, presentations, assignments, and analyses. ● Assign appropriate roles in collaborative work. ● Assign preferential seating. ● Follow a routine/schedule.
<p>Gifted and Talented Accommodations:</p> <ul style="list-style-type: none"> ● Differentiate reading levels of texts (e.g., Newsela). ● Offer students additional texts with higher lexile levels. ● Provide more challenging and/or more supplemental readings and/or activities to deepen understanding. ● Allow for independent reading, research, and projects. ● Accelerate or compact the curriculum. ● Offer higher-level thinking questions for deeper analysis. ● Offer more rigorous materials/tasks/prompts. ● Increase number and complexity of sources. ● Assign group research and presentations to teach the class. ● Assign/allow for leadership roles during collaborative work and in other learning activities. 	<p>ELL Accommodations:</p> <ul style="list-style-type: none"> ● Provide extended time. ● Assign preferential seating. ● Assign peer buddy who the student can work with. ● Check for understanding frequently. ● Provide language feedback often (such as grammar errors, tenses, subject-verb agreements, etc...). ● Have student repeat directions. ● Make vocabulary words available during classwork and exams. ● Use study guides/checklists to organize information. ● Repeat directions. ● Increase one-on-one conferencing. ● Allow student to listen to an audio version of the text. ● Give directions in small, distinct steps. ● Allow copying from paper/book. ● Give student a copy of the class notes.

- Provide written and oral instructions.
- Differentiate reading levels of texts (e.g., Newsela).
- Shorten assignments.
- Read directions aloud to student.
- Give oral clues or prompts.
- Record or type assignments.
- Adapt worksheets/packets.
- Create alternate assignments.
- Have student enter written assignments in criterion, where they can use the planning maps to help get them started and receive feedback after it is submitted.
- Allow student to resubmit assignments.
- Use small group instruction.
- Simplify language.
- Provide scaffolded vocabulary and vocabulary lists.
- Demonstrate concepts possibly through the use of visuals.
- Use manipulatives.
- Emphasize critical information by highlighting it for the student.
- Use graphic organizers.
- Pre-teach or pre-view vocabulary.
- Provide student with a list of prompts or sentence starters that they can use when completing a written assignment.
- Provide audio versions of the textbooks.
- Highlight textbooks/study guides.
- Use supplementary materials.
- Give assistance in note taking
- Use adapted/modified textbooks.
- Allow use of computer/word processor.
- Allow student to answer orally, give extended time (time-and-a-half).
- Allow tests to be given in a separate location (with the ESL teacher).
- Allow additional time to complete assignments and/or assessments.
- Read question to student to clarify.
- Provide a definition or synonym for words on a test that do not impact the validity of the exam.
- Modify the format of assessments.
- Shorten test length or require only selected test items.
- Create alternative assessments.
- On an exam other than a spelling test, don't take points off for spelling errors.

UNIT 1 OVERVIEW

Content Area: Science

Unit Title: Atomic Structure and Properties

Target Course/Grade Level: Advanced Placement Chemistry/Grades 11-12

Unit Summary: 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 of particles that they require the units of moles to translate between this and the particulate scale. The organization of the periodic table reflects the periodicity of element properties as a function of atomic number. The electronic structure of an atom can be described by an electron configuration that provides a method for describing the distribution of electrons in an atom or ion. In subsequent units, students will apply their understanding of atomic structure to models and representations of chemical phenomena to explain changes and interactions of chemical substances.

Approximate Length of Unit: 2 weeks

LEARNING TARGETS

NJ Student Learning Standards:

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

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

HS-PS1-8 Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

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.

Career Readiness, Life Literacies, and Key Skills:

9.3.ST.2 Use technology to acquire, manipulate, analyze and report data.

9.3.ST.3 Describe and follow safety, health and environmental standards related to science, technology, engineering and mathematics (STEM) workplaces.

9.3 ST.4 Understand the nature and scope of the Science, Technology, Engineering & Mathematics Career Cluster and the role of STEM in society and the economy.

9.3.ST-ET.1 Use STEM concepts and processes to solve problems involving design and/or production.

9.3.ST-ET.5 Apply the knowledge learned in STEM to solve problems.

9.3.ST-SM.3 Analyze the impact that science and mathematics has on society.

9.3.ST-SM.4 Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.

9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas.

9.4.12.CI.3 Investigate new challenges and opportunities for personal growth, advancement, and transition.

9.4.12.CT.1 Identify problem-solving strategies used in the development of an innovative product or practice.

- 9.4.12.CT.2** Explain the potential benefits of collaborating to enhance critical thinking and problem solving.
- 9.4.12.CT.4** Participate in online strategy and planning sessions for course-based, school-based, or other project and determine the strategies that contribute to effective outcomes.
- 9.4.12.IML.3** Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions.
- 9.4.12.IML.5** Evaluate, synthesize, and apply information on climate change from various sources appropriately.
- 9.4.12.IML.7** Develop an argument to support a claim regarding a current workplace or societal/ethical issue such as climate change.
- 9.4.12.TL.1** Assess digital tools based on features such as accessibility options, capacities, and utility for accomplishing a specified task.
- 9.4.12.TL.2** Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.
- 9.4.12.TL.4** Collaborate in online learning communities or social networks or virtual worlds to analyze and propose a resolution to a real-world problem.

Interdisciplinary Connections and Standards:

ELA

- RI.CR.11–12.1** Accurately cite a range of thorough textual evidence and make relevant connections to strongly support a comprehensive analysis of multiple aspects of what an informational text says explicitly and inferentially, as well as interpretations of the text.
- RI.MF.11–12.6** Synthesize complex information across multiple sources and formats to develop ideas, resolve conflicting information, or develop an interpretation that goes beyond explicit text information (e.g., express a personal point of view, new interpretation of the concept).
- W.AW.11–12.1** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
- W.SE.11–12.6** 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 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.
- SL.UM.11–12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Mathematics

- N.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- N.Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- A.SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- A.SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- A.CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- A.CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- F.IF.C.7** Graph functions are expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
- F.BF.A.1** Write a function that describes a relationship between two quantities.
- S.ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that...

- Observations of chemical properties are made on collections of atoms. The mole unit and its ratios are needed to translate between observations and the particulate scale.
- The periodic table organizes elements based on their properties and can be used to determine information about any known element.
- The electronic structure of an atom can be described by an electron configuration. This electron configuration, in turn, impacts the properties of an element and how it interacts with light and energy.

Unit Essential Questions:

- How can the same element be used in nuclear fuel rods and fake diamonds?
- How can large quantities of objects be counted by weighing?
- If atoms are too small to be observed directly, how do we know how they're structured?
- Why does the periodic table have the shape that it does?

Knowledge and Skills:

Students will know...

Subtopic 1.1 Moles and Molar Mass:

- One cannot count particles directly while performing laboratory work. Thus, there must be a connection between the masses of substances reacting and the actual number of particles undergoing chemical changes.
- Avogadro's number ($N = 6.022 \times 10^{23} \text{ mol}^{-1}$) provides the connection between the number of moles in a pure sample of a substance and the number of constituent particles (or formula units) of that substance.
- Expressing the mass of an individual atom or molecule in atomic mass units (amu) is useful because the average mass in amu of one particle (atom or molecule) or formula unit of a substance will always be numerically equal to the molar mass of that substance in grams. Thus, there is a quantitative connection between the mass of a substance and the number of particles that the substance contains.

Subtopic 1.2 Mass Spectra of Elements

- The mass spectrum of a sample containing a single element can be used to determine the identity of the isotopes of that element and the relative abundance of each isotope in nature
- The average atomic mass of an element can be estimated from the weighted average of the isotopic masses using the mass of each isotope and its relative abundance.

Subtopic 1.3 Elemental Composition of Pure Substances

- Some pure substances are composed of individual molecules, while others consist of atoms or ions held together in fixed proportions as described by a formula unit
- According to the law of definite proportions, the ratio of the masses of the constituent elements in any pure sample of that compound is always the same.
- The chemical formula that lists the lowest whole number ratio of atoms of the elements in a compound is the empirical formula.

Subtopic 1.4 Composition of Mixtures

- Pure substances contain atoms, molecules, or formula units of a single type. Mixtures contain atoms, molecules, or formula units of two or more types, whose relative proportions can vary.
- Elemental analysis can be used to determine the relative numbers of atoms in a substance and to determine its purity.

Subtopic 1.5 Atomic Structure and Electron Configuration

- The atom is composed of negatively charged electrons and a positively charged nucleus that is made of protons and neutrons.
- Coulomb's law is used to calculate the force between two charged particles.

- In atoms and ions, the electrons can be thought of as being in “shells (energy levels)” and “subshells (sublevels),” as described by the ground-state electron configuration. Inner electrons are called core electrons, and outer electrons are called valence electrons. The electron configuration is explained by quantum mechanics, as delineated in the Aufbau principle and exemplified in the periodic table of the elements.
- The relative energy required to remove an electron from different subshells of an atom or ion or from the same subshell in different atoms or ions (ionization energy) can be estimated through a qualitative application of Coulomb’s law. This energy is related to the distance from the nucleus and the effective (shield) charge of the nucleus.

Subtopic 1.6 Photoelectron Spectroscopy

- The energies of the electrons in a given shell can be measured experimentally with photoelectron spectroscopy (PES). The position of each peak in the PES spectrum is related to the energy required to remove an electron from the corresponding subshell, and the relative height of each peak is (ideally) proportional to the number of electrons in that subshell.

Subtopic 1.7 Periodic Trends

- The organization of the periodic table is based on patterns of recurring properties of the elements, which are explained by patterns of ground-state electron configurations and the presence of completely or partially filled shells (and subshells) of electrons in atoms.
- Trends in atomic properties within the periodic table (periodicity) can be predicted by the position of the element on the periodic table and qualitatively understood using Coulomb’s law, the shell model, and the concepts of shielding and effective nuclear charge. These properties include: Ionization energy, Atomic and ionic radii, Electron affinity, and Electronegativity.
- The periodicity is useful to predict/ estimate values of properties in the absence of data.

Subtopic 1.8 Valence Electrons and Ionic Compounds

- The likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of the elements.
- Elements in the same column of the periodic table tend to form analogous compounds.
- Typical charges of atoms in ionic compounds are governed by the number of valence electrons and predicted by their location on the periodic table.

Students will be able to...

Subtopic 1.1 Moles and Molar Mass

- Calculate quantities of a substance or its relative number of particles using dimensional analysis and the mole concept.

Subtopic 1.2 Mass Spectra of Elements

- Explain the quantitative relationship between the mass spectrum of an element and the masses of the element’s isotopes.

Subtopic 1.3 Elemental Composition of Pure Substances

- Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance.

Subtopic 1.4 Composition of Mixtures

- Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture.

Subtopic 1.5 Atomic Structure and Electron Configuration

- Represent the ground-state electron configuration of an atom of an element or its ions using the Aufbau principle.

Subtopic 1.6 Photoelectron Spectroscopy

- Explain the relationship between the photoelectron spectrum of an atom or ion and the ground-state electron configuration of the species
- Explain the relationship between the photoelectron spectrum of an atom or ion and the interactions between the electrons and the nucleus.

Subtopic 1.7 Periodic Trends

- Explain the relationship between trends in atomic properties of elements and electronic structure, and periodicity

Subtopic 1.8 Valence Electrons and Ionic Compounds

- Explain the relationship between trends in the reactivity of elements and periodicity.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly “understand”?

- End of Unit Common Assessment - See folder for assessment links.
- A mix of conceptual, representation-based, math-based, and data analysis questions will be used to gather formative data through:
 - Do now questions, exit tickets, and independent classwork/homework.
 - Group whiteboarding problems, card sort activities, and exploratory analysis activities.
 - AP Classroom Topic Questions
- Summative data will be collected through:
 - AP Classroom Progress Check
 - Analysis and CER conclusions of labs such as:
 - Formula of a Hydrate
 - Empirical Formula of Iron Oxide

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Inquiry investigations and labs including:
 - Formula of a Hydrate Lab
 - Empirical Formula of Iron Oxide Lab
 - Mole Sample Think Pair Share
 - Mass Spectrometry Simulation Activity
 - Percent Composition Lab Report Critique
 - PES data and representation predictions
 - Ionization energy POGIL
- Instruction on vocabulary, concepts, and problem solving techniques following the gradual release framework.
- Collaborative and independent practice of foundational skills.
- Collaborative and independent practice breaking down and answering College Board MCQ and FRQ style questions.

RESOURCES

Teacher Resources:

- AP Classroom
- AP Chemistry Lab Manual
- Textbook: Zumdahl, Steven S., Zumdahl, Susan A., DeCoste, Donald J. *Chemistry*, 10th Edition.

Equipment Needed:

- Projection and computer equipment
- Group whiteboards and dry erase materials
- Poster and individual periodic tables
- Calculators
- Laboratory equipment and chemicals for labs, activities, and demonstrations
- Student copies of the textbook

UNIT 2 OVERVIEW

Content Area: Science

Unit Title: Compound Structure and Properties

Target Course/Grade Level: Advanced Placement Chemistry/Grades 11-12

Unit Summary: In Unit 2, 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. In subsequent units, students will use the periodic table and the atomic properties to predict the type of bonding present between two atoms based on position.

Approximate Length of Unit: 2 weeks

LEARNING TARGETS

NJ Student Learning Standards:

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

Career Readiness, Life Literacies, and Key Skills:

- 9.3.ST.2** Use technology to acquire, manipulate, analyze and report data.
- 9.3.ST.3** Describe and follow safety, health and environmental standards related to science, technology, engineering and mathematics (STEM) workplaces.
- 9.3 ST.4** Understand the nature and scope of the Science, Technology, Engineering & Mathematics Career Cluster and the role of STEM in society and the economy.
- 9.3.ST-ET.1** Use STEM concepts and processes to solve problems involving design and/or production.
- 9.3.ST-ET.5** Apply the knowledge learned in STEM to solve problems.
- 9.3.ST-SM.3** Analyze the impact that science and mathematics has on society.
- 9.3.ST-SM.4** Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.
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- A.CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
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- F.BF.A.1** Write a function that describes a relationship between two quantities.
- S.ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that...

- Chemical and physical properties of materials can be explained by the structure and arrangement of atoms, ions, or molecules and the forces between them.
- Chemical bonds are distinct from intermolecular interactions, as their strength impacts the identity of the substance.
- Electronegativity and Coulomb's law can help us understand the strength of attraction holding together a bond and, therefore, the chemical properties of the substance.
- The particle-level structure of a substance is 3-dimensional, so representations and mental models that only use 2 dimensions will always have a degree of inaccuracy.

Unit Essential Questions:

- How are molecular compounds arranged?
- Why are some bonds easier to break than others?
- In what ways does a diagram drawn on paper accurately reflect the structure of a molecule?
- In what ways does a diagram drawn on paper not accurately reflect the structure of a molecule?

Knowledge and Skills:

Students will know...

Subtopic 2.1 Types of Chemical Bonds

- Electronegativity values for the representative elements increase going from left to right across a period and decrease going down a group. These trends can be understood qualitatively through the electronic structure of the atoms, the shell model, and Coulomb's law.
- Valence electrons shared between atoms of similar electronegativity constitute a nonpolar covalent bond. For example, bonds between carbon and hydrogen are effectively nonpolar even though carbon is slightly more electronegative than hydrogen.
- Valence electrons shared between atoms of unequal electronegativity constitute a polar covalent bond.
- The atom with a higher electronegativity will develop a partial negative charge relative to the other atom in the bond.
- In single bonds, greater differences in electronegativity lead to greater bond dipoles.
- All polar bonds have some ionic character, and the difference between ionic and covalent bonding is not distinct but rather a continuum.
- The difference in electronegativity is not the only factor in determining if a bond should be designated as ionic or covalent. Generally, bonds between a metal and nonmetal are ionic, and bonds between two nonmetals are covalent. Examination of the properties of a compound is the best way to characterize the type of bonding.
- In a metallic solid, the valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom.

Subtopic 2.2 Intramolecular Force and Potential Energy

- A graph of potential energy versus the distance between atoms (internuclear distance) is a useful representation for describing the interactions between atoms. Such graphs illustrate both the equilibrium bond length (the separation between atoms at which the potential energy is lowest) and the bond energy (the energy required to separate the atoms).
- In a covalent bond, the bond length is influenced by both the size of the atom's core and the bond order (i.e., single, double, triple). Bonds with a higher order are shorter and have larger bond energies.
- Coulomb's law can be used to understand the strength of interactions between cations and anions. Because the interaction strength is proportional to the charge on each ion, larger charges lead to stronger interactions. Because the interaction strength increases as the distance between the centers of the ions (nuclei) decreases, smaller ions lead to stronger interactions.

Subtopic 2.3 Structure of Ionic Solids

- The cations and anions in an ionic crystal are arranged in a systematic, periodic 3-D array that maximizes the attractive forces among cations and anions while minimizing the repulsive forces.

Subtopic 2.4 Structure of Metals and Alloys

- Metallic bonding can be represented as an array of positive metal ions surrounded by delocalized valence electrons (i.e., a “sea of electrons”)
- Interstitial alloys form between atoms of significantly different radii, where the smaller atoms fill the interstitial space between the larger atoms (e.g., with steel in which carbon occupies the interstices in iron).
- Substitutional alloys form between atoms of comparable radius, where one atom substitutes for the other in the lattice. (e.g., in certain brass alloys, other elements, usually zinc, substitute for copper.)

Subtopic 2.5 Lewis Diagrams

- Lewis diagrams can be constructed according to an established set of principles.

Subtopic 2.6 Resonance and Formal Charge

- In cases where more than one equivalent Lewis structure can be constructed, resonance must be included as a refinement to the Lewis structure. In many such cases, this refinement is needed to provide qualitatively accurate predictions of molecular structure and properties.
- The octet rule and formal charge can be used as criteria for determining which of several possible valid Lewis diagrams provides the best model for predicting molecular structure and properties.
- As with any model, there are limitations to the use of the Lewis structure model, particularly in cases with an odd number of valence electrons.

Subtopic 2.7 VSEPR and Hybridization

- VSEPR theory uses the Coulombic repulsion between electrons as a basis for predicting the arrangement of electron pairs around a central atom.
- Both Lewis diagrams and VSEPR theory must be used for predicting electronic and structural properties of many covalently bonded molecules and polyatomic ions, including the following:
 - Molecular geometry (linear, trigonal planar, tetrahedral, trigonal pyramidal, bent, trigonal bipyramidal, seesaw, T-shaped, octahedral, square pyramidal, square planar)
 - Bond angles
 - Relative bond energies based on bond order
 - Relative bond lengths (multiple bonds, effects of atomic radius)
 - Presence of a dipole moment
 - Hybridization of valence orbitals of atoms within a molecule or polyatomic ion
- The terms “hybridization” and “hybrid atomic orbital” are used to describe the arrangement of electrons around a central atom. When the central atom is sp hybridized, its ideal bond angles are 180° ; for sp^2 hybridized atoms, the bond angles are 120° ; and for sp^3 hybridized atoms, the bond angles are 109.5° .
- Bond formation is associated with overlap between atomic orbitals. In multiple bonds, such overlap leads to the formation of both sigma and pi bonds. The overlap is stronger in sigma than pi bonds, which is reflected in sigma bonds having greater bond energy than pi bonds. The presence of a pi bond also prevents the rotation of the bond and leads to geometric isomers.

Students will be able to...

Subtopic 2.1 Types of Chemical Bonds

- Explain the relationship between the type of bonding and the properties of the elements participating in the bond.

Subtopic 2.2 Intramolecular Force and Potential Energy

- Represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength.

Subtopic 2.3 Structure of Ionic Solids

- Represent an ionic solid with a particulate model that is consistent with Coulomb's law and the properties of the constituent ions.

Subtopic 2.4 Structure of Metals and Alloys

- Represent a metallic solid and/or alloy using a model to show essential characteristics of the structure and interactions present in the substance.

Subtopic 2.5 Lewis Diagrams

- Represent a molecule with a Lewis diagram.

Subtopic 2.6 Resonance and Formal Charge

- Represent a molecule with a Lewis diagram that accounts for resonance between equivalent structures or that uses formal charge to select between nonequivalent structures.

Subtopic 2.7 VSEPR and Hybridization

- Based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities, explain the structural properties of molecules.
- Based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities, explain the electron properties of molecules.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- A mix of conceptual, representation-based, math-based, and data analysis questions will be used to gather formative data through:
 - Do now questions, exit tickets, and independent classwork/homework.
 - Group whiteboarding problems, card sort activities, and exploratory analysis activities.
 - AP Classroom Topic Questions
- Summative data will be collected through:
 - AP Classroom Progress Check
 - Analysis and CER conclusions of labs such as:
 - Identifying the Unknown Compound
 - Penny Alchemy

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Inquiry investigations and labs including:
 - Identifying the Unknown Compound Lab
 - Penny Alchemy Lab
 - Think Pair Share investigating PE and internuclear distance graphs
 - Modeling Crystal Lattice Structure with Magnets activity
 - Whiteboard Modeling of Alloys
 - VSEPR Modeling with PhET and Balloons
- Instruction on vocabulary, concepts, and problem solving techniques following gradual release framework.
- Collaborative and independent practice of foundational skills.
- Collaborative and independent practice breaking down and answering College Board MCQ and FRQ style questions.

RESOURCES

Teacher Resources:

- AP Classroom
- AP Chemistry Lab Manual
- Textbook: Zumdahl, Steven S., Zumdahl, Susan A., DeCoste, Donald J. *Chemistry*, 10th Edition.

Equipment Needed:

- Projection and computer equipment
- Group whiteboards and dry erase materials
- Poster and individual periodic tables
- Calculators
- Laboratory equipment and chemicals for labs, activities, and demonstrations
- Student copies of textbook

UNIT 3 OVERVIEW

Content Area: Science

Unit Title: Properties of Substances and Mixtures

Target Course/Grade Level: Advanced Placement Chemistry/Grades 11-12

Unit Summary: Transformations of matter can be observed in ways that are generally categorized either as a chemical or physical change. The shapes of the particles involved and the space between them are key factors in determining the nature of physical changes. The properties of solids, liquids, and 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. In subsequent units, students will explore chemical transformations of matter.

Approximate Length of Unit: 4 weeks

LEARNING TARGETS

NJ Student Learning 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.
- HS-PS1-5** Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- HS-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
- HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
- HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- 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 motions of particles (objects) and energy associated with the relative position of particles (objects).
- HS-PS-4-** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
- HS-PS4-3** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

Career Readiness, Life Literacies, and Key Skills:

- 9.3.ST.2** Use technology to acquire, manipulate, analyze and report data.
- 9.3.ST.3** Describe and follow safety, health and environmental standards related to science, technology, engineering and mathematics (STEM) workplaces.

- 9.3 ST.4** Understand the nature and scope of the Science, Technology, Engineering & Mathematics Career Cluster and the role of STEM in society and the economy.
- 9.3.ST-ET.1** Use STEM concepts and processes to solve problems involving design and/or production.
- 9.3.ST-ET.5** Apply the knowledge learned in STEM to solve problems.
- 9.3.ST-SM.3** Analyze the impact that science and mathematics has on society.
- 9.3.ST-SM.4** Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.
- 9.4.12.CI.1** Demonstrate the ability to reflect, analyze, and use creative skills and ideas.
- 9.4.12.CI.3** Investigate new challenges and opportunities for personal growth, advancement, and transition.
- 9.4.12.CT.1** Identify problem-solving strategies used in the development of an innovative product or practice.
- 9.4.12.CT.2** Explain the potential benefits of collaborating to enhance critical thinking and problem solving.
- 9.4.12.CT.4** Participate in online strategy and planning sessions for course-based, school-based, or other project and determine the strategies that contribute to effective outcomes.
- 9.4.12.IML.3** Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions.
- 9.4.12.IML.5** Evaluate, synthesize, and apply information on climate change from various sources appropriately.
- 9.4.12.IML.7** Develop an argument to support a claim regarding a current workplace or societal/ethical issue such as climate change.
- 9.4.12.TL.1** Assess digital tools based on features such as accessibility options, capacities, and utility for accomplishing a specified task.
- 9.4.12.TL.2** Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.
- 9.4.12.TL.4** Collaborate in online learning communities or social networks or virtual worlds to analyze and propose a resolution to a real-world problem.

Interdisciplinary Connections and Standards:

ELA

- RI.CR.11–12.1** Accurately cite a range of thorough textual evidence and make relevant connections to strongly support a comprehensive analysis of multiple aspects of what an informational text says explicitly and inferentially, as well as interpretations of the text.
- RI.MF.11–12.6** Synthesize complex information across multiple sources and formats to develop ideas, resolve conflicting information, or develop an interpretation that goes beyond explicit text information (e.g., express a personal point of view, new interpretation of the concept).
- W.AW.11–12.1** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
- W.SE.11–12.6** 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 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.
- SL.UM.11–12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Mathematics

- N.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- N.Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- A.SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- A.SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.

A.CED.A.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.

A.CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

F.IF.C.7 Graph functions are expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.

F.BF.A.1 Write a function that describes a relationship between two quantities.

S.ID.A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that...

- The shapes of the particles involved and the space between them are key factors in determining the nature of physical changes.
- The particle-level structure of a substance is determined by the attractive forces at work within the substance through both intermolecular forces and chemical bonds. In turn, this structure impacts the macroscopic properties of the substance.
- The changes in substance experience depend on the interactions between particles; impacting these interactions will impact the rate of the change.
- Attractive forces can explain the result of many changes/reactions. Often the most likely result/product will bring particles with the strongest attraction closer together.

Unit Essential Questions:

- How do interactions between particles influence the properties of pure substances and mixtures?
- Why does the smell of perfume only last for a short time?
- Why can you swim in water, but you can't walk through a wall?
- How does the spacing and motion of particles relate to a substance's state of matter and the properties of gases?
- How can you determine the structure and concentration of a chemical species in a mixture?

Knowledge and Skills:

Students will know...

Subtopic 3.1 Intermolecular and Interparticle Forces

- London dispersion forces are a result of the Coulombic interactions between temporary, fluctuating dipoles. London dispersion forces are often the strongest net intermolecular force between large molecules.
- Dispersion forces increase with increasing contact area between molecules and with increasing polarizability of the molecules.
- The polarizability of a molecule increases with an increasing number of electrons in the molecule and the size of the electron cloud. It is enhanced by the presence of pi bonding.
- The term "London dispersion forces" should not be used synonymously with the term van der Waals forces
- The dipole moment of a polar molecule leads to additional interactions with other chemical species.
- Dipole-induced dipole interactions are between a polar and nonpolar molecule. These forces are always attractive. The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule.
- Dipole-dipole interactions are present between polar molecules. The interaction strength depends on the magnitudes of the dipoles and their relative orientation. Interactions between polar molecules are typically greater than those between nonpolar molecules of comparable size because these interactions act in addition to London dispersion forces.

- Ion-dipole forces of attraction are present between ions and polar molecules. These tend to be stronger than dipole-dipole forces.
- The relative strength and orientation dependence of dipole-dipole and ion-dipole forces can be understood qualitatively by considering the sign of the partial charges responsible for the molecular dipole moment, and how these partial charges interact with an ion or with an adjacent dipole.
- Hydrogen bonding is a strong type of intermolecular interaction that exists when hydrogen atoms covalently bonded to the highly electronegative atoms (N, O, and F) are attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a different molecule, or a different part of the same molecule.
- In large biomolecules, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule.

Subtopic 3.2 Properties of Solids

- Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present. Because intermolecular interactions are overcome completely when a substance vaporizes, the vapor pressure and boiling point are directly related to the strength of those interactions. Melting points also tend to correlate with interaction strength, but because the interactions are only rearranged, in melting, the relations can be more subtle.
- Particulate-level representations, showing multiple interacting chemical species, are a useful means to communicate or understand how intermolecular interactions help to establish macroscopic properties.
- Due to strong interactions between ions, ionic solids tend to have low vapor pressures, high melting points, and high boiling points. They tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer. They conduct electricity only when the ions are mobile, as when the ionic solid is melted (i.e., in a molten state) or dissolved in water or another solvent.
- In covalent network solids, the atoms are covalently bonded together into a three dimensional network (e.g., diamond) or layers of two-dimensional networks (e.g., graphite). These are only formed from nonmetals and metalloids: elemental (e.g., diamond, graphite) or binary compounds (e.g., silicon dioxide and silicon carbide). Due to the strong covalent interactions, covalent solids have high melting points. Three-dimensional network solids are also rigid and hard because the covalent bond angles are fixed. However, graphite is soft because adjacent layers can slide past each other relatively easily.
- Molecular solids are composed of distinct, individual units of covalently-bonded molecules attracted to each other through relatively weak intermolecular forces. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. They do not conduct electricity because their valence electrons are tightly held within the covalent bonds and the lone pairs of each constituent molecule. Molecular solids are sometimes composed of very large molecules or polymers.
- Metallic solids are good conductors of electricity and heat, due to the presence of free valence electrons. They also tend to be malleable and ductile, due to the ease with which the metal cores can rearrange their structure. In an interstitial alloy, interstitial atoms tend to make the lattice more rigid, decreasing malleability and ductility. Alloys typically retain a sea of mobile electrons and so remain conducting.
- In large biomolecules or polymers, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule. The functionality and properties of such molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions.

Subtopic 3.3 Solids, Liquids, and Gases

- Solids can be crystalline, where the particles are arranged in a regular three-dimensional structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. In both

cases, the motion of the individual particles is limited, and the particles do not undergo overall translation with respect to each other. The structure of the solid is influenced by interparticle interactions and the ability of the particles to pack together.

- The constituent particles in liquids are in close contact with each other, and they are continually moving and colliding. The arrangement and movement of particles are influenced by the nature and strength of the forces (e.g., polarity, hydrogen bonding, and temperature) between the particles.
- The solid and liquid phases for a particular substance typically have similar molar volume because, in both phases, the constituent particles are in close contact at all times.
- In the gas phase, the particles are in constant motion. Their frequencies of collision and the average spacing between them are dependent on temperature, pressure, and volume. Because of this constant motion, and minimal effects of forces between particles, a gas has neither a definite volume nor a definite shape.

Subtopic 3.4 Ideal Gas Law

- The macroscopic properties of ideal gases are related through the ideal gas law
- In a sample containing a mixture of ideal gases, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the partial pressure of a gas within the mixture is proportional to its mole fraction (X), and the total pressure of the sample is the sum of the partial pressures
- Graphical representations of the relationships between P , V , T , and n are useful to describe gas behavior.

Subtopic 3.5 Kinetic Molecular Theory

- The kinetic molecular theory (KMT) relates the macroscopic properties of gases to motions of the particles in the gas. The Maxwell-Boltzmann distribution describes the distribution of the kinetic energies of particles at a given temperature.
- All the particles in a sample of matter are in continuous, random motion. The average kinetic energy of a particle is related to its average velocity.
- The Kelvin temperature of a sample of matter is proportional to the average kinetic energy of the particles in the sample.
- The Maxwell-Boltzmann distribution provides a graphical representation of the energies/velocities of particles at a given temperature.

Subtopic 3.6 Deviation from Ideal Gas Law

- The ideal gas law does not explain the actual behavior of real gases. Deviations from the ideal gas law may result from interparticle attractions among gas molecules, particularly at conditions that are close to those resulting in condensation. Deviations may also arise from particle volumes, particularly at extremely high pressures.

Subtopic 3.7 Solutions and Mixtures

- Solutions, also sometimes called homogeneous mixtures, can be solids, liquids, or gases. In a solution, the macroscopic properties do not vary throughout the sample. In a heterogeneous mixture, the macroscopic properties depend on location in the mixture.
- Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory.

Subtopic 3.8 Representations of Solutions

- Particulate representations of solutions communicate the structure and properties of solutions, by illustration of the relative concentrations of the components in the solution and/or drawings that show interactions among the components.

Subtopic 3.9 Separation of Solutions and Mixtures

- The components of a liquid solution cannot be separated by filtration. They can, however, be separated using processes that take advantage of differences in intermolecular interactions of the components.

- Chromatography (paper, thin-layer, and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components of the solution (the mobile phase) and with the surface components of the stationary phase. The resulting chromatogram can be used to infer the relative polarities of components in a mixture.
- Distillation separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components and the effects these interactions have on the vapor pressures of the components in the mixture.

Subtopic 3.10 Solubility

- Substances with similar intermolecular interactions tend to be miscible or soluble in one another.

Subtopic 3.11 Spectroscopy and the Electromagnetic Spectrum

- Differences in absorption or emission of photons in different spectral regions are related to the different types of molecular motion or electronic transition.
- Microwave radiation is associated with transitions in molecular rotational levels.
- Infrared radiation is associated with transitions in molecular vibrational levels.
- Ultraviolet/visible radiation is associated with transitions in electronic energy levels.

Subtopic 3.12 Properties of Photons

- When a photon is absorbed (or emitted) by an atom or molecule, the energy of the species is increased (or decreased) by an amount equal to the energy of the photon
- The wavelength of the electromagnetic wave is related to its frequency and the speed of light.
- The energy of a photon is related to the frequency of the electromagnetic wave through Planck's equation.

Subtopic 3.13 Beer-Lambert Law

- The Beer-Lambert law relates the absorption of light by a solution to three variables. The molar absorptivity, ϵ , describes how intensely a chemical species absorbs light of a specific wavelength. The path length, b , and concentration, c , are proportional to the number of light-absorbing particles in the light path.
- In most experiments, the path length and wavelength of light are held constant. In such cases, the absorbance is proportional only to the concentration of absorbing molecules or ions. The spectrophotometer is typically set to the wavelength of maximum absorbance (optimum wavelength) for the species being analyzed to ensure the maximum sensitivity of measurement.

Students will be able to...

Subtopic 3.1 Intermolecular and Interparticle Forces

- 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, and when the molecules are of two different chemical species.

Subtopic 3.2 Properties of Solids

- Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles

Subtopic 3.3 Solids, Liquids, and Gases

- Represent the differences between solid, liquid, and gas phases using a particulate-level model.

Subtopic 3.4 Ideal Gas Law

- Explain the relationship between the macroscopic properties of a sample of gas or a mixture of gases using the ideal gas law.

Subtopic 3.5 Kinetic Molecular Theory

- Explain the relationship between the motion of particles and the macroscopic properties of gases with the kinetic molecular theory (KMT), a particulate model, and a graphical representation.

Subtopic 3.6 Deviation from Ideal Gas Law

- Explain the relationship among non-ideal behaviors of gases, interparticle forces, and/or volumes.

Subtopic 3.7 Solutions and Mixtures

- Calculate the number of solute particles, volume, or molarity of solutions

Subtopic 3.8 Representations of Solutions

- Using particulate models for mixtures represent interactions between components and represent concentrations of components.

Subtopic 3.9 Separation of Solutions and Mixtures

- Explain the results of a separation experiment based on intermolecular interactions.

Subtopic 3.10 Solubility

- Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles.

Subtopic 3.11 Spectroscopy and the Electromagnetic Spectrum

- Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region.

Subtopic 3.12 Properties of Photons

- Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.

Subtopic 3.13 Beer-Lambert Law

- Explain the amount of light absorbed by a solution of molecules or ions in relationship to the concentration, path length, and molar absorptivity.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly “understand”?

- End of Unit Common Assessment - See folder for assessment links.
- A mix of conceptual, representation-based, math-based, and data analysis questions will be used to gather formative data through:
 - Do now questions, exit tickets, and independent classwork/homework.
 - Group whiteboarding problems, card sort activities, and exploratory analysis activities.
 - AP Classroom Topic Questions
- Summative data will be collected through:
 - AP Classroom Progress Check
 - Analysis and CER conclusions of labs such as:
 - Separation of Mixtures
 - Analysis of Alka Seltzer
 - Analysis of Food Dyes with Beer's Law

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Inquiry investigations and labs including:
 - Separation of Mixtures Lab
 - Analysis of Alka Seltzer Lab
 - Analysis of Food Dyes with Beer's Law Lab
 - Modeling liquid-liquid dissolving activity
 - Particulate Model of Substances activity
 - Modeling Solubility activity
- Instruction on vocabulary, concepts, and problem solving techniques following gradual release framework.
- Collaborative and independent practice of foundational skills.

- Collaborative and independent practice breaking down and answering College Board MCQ and FRQ style questions.

RESOURCES

Teacher Resources:

- AP Classroom
- AP Chemistry Lab Manual
- Textbook: Zumdahl, Steven S., Zumdahl, Susan A., DeCoste, Donald J. *Chemistry*, 10th Edition.

Equipment Needed:

- Projection and computer equipment
- Group whiteboards and dry erase materials
- Poster and individual periodic tables
- Calculators
- Laboratory equipment and chemicals for labs, activities, and demonstrations
- Student copies of textbook

UNIT 4 OVERVIEW

Content Area: Science

Unit Title: Chemical Reactions

Target Course/Grade Level: Advanced Placement Chemistry/Grades 11-12

Unit Summary: This unit explores chemical transformations of matter by building on the physical transformations studied in Unit 3. Chemical changes involve the making and breaking of chemical bonds. Many properties of a chemical system can be understood using the concepts of varying strengths of chemical bonds and weaker intermolecular interactions. When chemical changes occur, the new substances formed have properties that are distinguishable from the initial substance or substances. Chemical reactions are the primary means by which transformations in matter occur. Chemical equations are a representation of the rearrangement of atoms that occur during a chemical reaction. In subsequent units, students will explore rates at which chemical changes occur

Approximate Length of Unit: 3 weeks

LEARNING TARGETS

NJ Student Learning Standards:

- HS-PS1-1** Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
- HS-PS1-2** Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- HS-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

Career Readiness, Life Literacies, and Key Skills:

- 9.3.ST.2** Use technology to acquire, manipulate, analyze and report data.
- 9.3.ST.3** Describe and follow safety, health and environmental standards related to science, technology, engineering and mathematics (STEM) workplaces.
- 9.3 ST.4** Understand the nature and scope of the Science, Technology, Engineering & Mathematics Career Cluster and the role of STEM in society and the economy.
- 9.3.ST-ET.1** Use STEM concepts and processes to solve problems involving design and/or production.
- 9.3.ST-ET.5** Apply the knowledge learned in STEM to solve problems.
- 9.3.ST-SM.3** Analyze the impact that science and mathematics has on society.
- 9.3.ST-SM.4** Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.
- 9.4.12.CI.1** Demonstrate the ability to reflect, analyze, and use creative skills and ideas.
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- 9.4.12.CT.1** Identify problem-solving strategies used in the development of an innovative product or practice.
- 9.4.12.CT.2** Explain the potential benefits of collaborating to enhance critical thinking and problem solving.

- 9.4.12.CT.4** Participate in online strategy and planning sessions for course-based, school-based, or other project and determine the strategies that contribute to effective outcomes.
- 9.4.12.IML.3** Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions.
- 9.4.12.IML.5** Evaluate, synthesize, and apply information on climate change from various sources appropriately.
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- 9.4.12.TL.4** Collaborate in online learning communities or social networks or virtual worlds to analyze and propose a resolution to a real-world problem.

Interdisciplinary Connections and Standards:

ELA

- RI.CR.11–12.1** Accurately cite a range of thorough textual evidence and make relevant connections to strongly support a comprehensive analysis of multiple aspects of what an informational text says explicitly and inferentially, as well as interpretations of the text.
- RI.MF.11–12.6** Synthesize complex information across multiple sources and formats to develop ideas, resolve conflicting information, or develop an interpretation that goes beyond explicit text information (e.g., express a personal point of view, new interpretation of the concept).
- W.AW.11–12.1** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
- W.SE.11–12.6** 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 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.
- SL.UM.11–12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Mathematics

- N.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- N.Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- A.SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- A.SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- A.CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- A.CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- F.IF.C.7** Graph functions are expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
- F.BF.A.1** Write a function that describes a relationship between two quantities.
- S.ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that...

- Chemical equations are a representation of the rearrangement of atoms that occur during a chemical reaction.
- Attractive forces can explain the result of many changes/reactions. Often the most likely result/product will bring particles with the strongest attraction closer together.
- Ratios can be used to determine the theoretical yield of a reaction if we assume the limiting reactant is completely reacted. This assumption is impacted by reaction rate, equilibrium, and various experimental errors.

Unit Essential Questions:

- What makes fireworks explode?
- In what ways can a chemical change be described and documented?
- How can you predict that a chemical reaction will generate enough product?

Knowledge and Skills:

Students will know...

Subtopic 4.1 Introduction for Reactions

- A physical change occurs when a substance undergoes a change in properties but not a change in composition. Changes in the phase of a substance (solid, liquid, gas) or formation/separation of mixtures of substances are common physical changes.
- A chemical change occurs when substances are transformed into new substances, typically with different compositions. Production of heat or light, formation of a gas, formation of a precipitate, and/or color change provide possible evidence that a chemical change has occurred.

Subtopic 4.2 Net Ionic Equations

- All physical and chemical processes can be represented symbolically by balanced equations
- Chemical equations represent chemical changes. These changes are the result of a rearrangement of atoms into new combinations; thus, any representation of a chemical change must contain equal numbers of atoms of every element before and after the change occurred. Equations thus demonstrate that mass and charge are conserved in chemical reactions.
- Balanced molecular, complete ionic, and net ionic equations are different symbolic forms used to represent a chemical reaction. The form used to represent the reaction depends on the context in which it is to be used.

Subtopic 4.3 Representations of Reactions

- Balanced chemical equations in their various forms can be translated into symbolic particulate representations.

Subtopic 4.4 Physical and Chemical Changes

- Processes that involve the breaking and/or formation of chemical bonds are typically classified as chemical processes. Processes that involve only changes in intermolecular interactions, such as phase changes, are typically classified as physical processes.
- Sometimes physical processes involve the breaking of chemical bonds. For example, plausible arguments could be made for the dissolution of a salt in water, as either a physical or chemical process, involves breaking of ionic bonds, and the formation of ion-dipole interactions between ions and solvent.

Subtopic 4.5 Stoichiometry

- Because atoms must be conserved during a chemical process, it is possible to calculate product amounts by using known reactant amounts, or to calculate reactant amounts given known product amounts.
- Coefficients of balanced chemical equations contain information regarding the proportionality of the amounts of substances involved in the reaction. These values can be used in chemical calculations involving the mole concept.

- Stoichiometric calculations can be combined with the ideal gas law and calculations involving molarity to quantitatively study gases and solutions.

Subtopic 4.6 Introduction to Titration

- Titrations may be used to determine the amount of an analyte in solution. The titrant has a known concentration of a species that reacts specifically and quantitatively with the analyte. The equivalence point of the titration occurs when the analyte is totally consumed by the reacting species in the titrant. The equivalence point is often indicated by a change in a property (such as color) that occurs when the equivalence point is reached. This observable event is called the endpoint of the titration.

Subtopic 4.7 Types of Chemical Reactions

- Acid-base reactions involve the transfer of one or more protons (H^+ ions) between chemical species.
- Oxidation-reduction (redox) reactions involve the transfer of one or more electrons between chemical species, as indicated by changes in oxidation numbers of the involved species. Combustion is an important subclass of oxidation-reduction reactions, in which a species reacts with oxygen gas. In the case of hydrocarbons, carbon dioxide and water are products of complete combustion.
- In a redox reaction, electrons are transferred from the species that is oxidized to the species that is reduced.
- Oxidation numbers may be assigned to each of the atoms in the reactants and products; this is often an effective way to identify the oxidized and reduced species in a redox reaction.
- Precipitation reactions frequently involve mixing ions in aqueous solution to produce an insoluble or sparingly soluble ionic compound. All sodium, potassium, ammonium, and nitrate salts are soluble in water.

Subtopic 4.8 Introduction to Acid-Base Reactions

- By definition, a Brønsted-Lowry acid is a proton donor and a Brønsted-Lowry base is a proton acceptor.
- Only in aqueous solutions, water plays an important role in many acid-base reactions, as its molecular structure allows it to accept protons from and donate protons to dissolved species.
- When an acid or base ionizes in water, the conjugate acid-base pairs can be identified and their relative strengths compared.

Subtopic 4.9 Oxidation-Reduction (Redox) Reactions

- Balanced chemical equations for redox reactions can be constructed from half-reactions.

Students will be able to...

Subtopic 4.1 Introduction for Reactions

- Identify evidence of chemical and physical changes in matter.

Subtopic 4.2 Net Ionic Equations

- Represent changes in matter with a balanced chemical or net ionic equation for or physical changes, given information about the identity of the reactants and/or product, and ions in a given chemical reaction.

Subtopic 4.3 Representations of Reactions

- Represent a given chemical reaction or physical process with a consistent particulate model.

Subtopic 4.4 Physical and Chemical Changes

- Explain the relationship between macroscopic characteristics and bond interactions for chemical processes and physical processes

Subtopic 4.5 Stoichiometry

- Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process.

Subtopic 4.6 Introduction to Titration

- Identify the equivalence point in a titration based on the amounts of the titrant and analyte, assuming the titration reaction goes to completion.

Subtopic 4.7 Types of Chemical Reactions

- Identify a reaction as acid-base, oxidation-reduction, or precipitation.

Subtopic 4.8 Introduction to Acid-Base Reactions

- Identify species as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, based on proton transfer involving those species.

Subtopic 4.9 Oxidation-Reduction (Redox) Reactions

- Represent a balanced redox reaction equation using half-reactions

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly “understand”?

- End of Unit Common Assessment - See folder for assessment links.
- A mix of conceptual, representation-based, math-based, and data analysis questions will be used to gather formative data through:
 - Do now questions, exit tickets, and independent classwork/homework.
 - Group whiteboarding problems, card sort activities, and exploratory analysis activities.
 - AP Classroom Topic Questions
- Summative data will be collected through:
 - AP Classroom Progress Check
 - Analysis and CER conclusions of labs such as:
 - Intro to Titration
 - Carbonate Analysis
 - Ionic Precipitation

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Inquiry investigations and labs including:
 - Intro to Titration Lab
 - Carbonate Analysis Lab
 - Ionic Precipitation Lab
 - Translating Between Macroscopic, Particulate, and Symbolic Levels Activity
 - Limiting Reactant Activity
 - Titration Curve Think Pair Share Activity
 - Identify the Type of Chemical Reaction Activity
- Instruction on vocabulary, concepts, and problem solving techniques following gradual release framework.
- Collaborative and independent practice of foundational skills.
- Collaborative and independent practice breaking down and answering College Board MCQ and FRQ style questions.

RESOURCES

Teacher Resources:

- AP Classroom
- AP Chemistry Lab Manual
- Textbook: Zumdahl, Steven S., Zumdahl, Susan A., DeCoste, Donald J. *Chemistry*, 10th Edition.

Equipment Needed:

- Projection and computer equipment
- Group whiteboards and dry erase materials
- Poster and individual periodic tables
- Calculators
- Laboratory equipment and chemicals for labs, activities, and demonstrations
- Student copies of textbook

UNIT 5 OVERVIEW

Content Area: Science

Unit Title: Kinetics

Target Course/Grade Level: Advanced Placement Chemistry/Grades 11-12

Unit Summary: Unit 4 focused on chemical changes; in Unit 5 students will develop an understanding of the rates at which chemical changes occur and the factors that influence the rates. Those factors include the concentration of reactants, temperature, catalysts, and other environmental factors. Chemical changes are represented by chemical reactions, and the rates of chemical reactions are determined by the details of the molecular collisions. Rates of change in chemical reactions are observable and measurable. When measuring rates of change, 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. In subsequent units, students will describe the role of energy in changes in matter.

Approximate Length of Unit: 3 weeks

LEARNING TARGETS

NJ Student Learning Standards:

HS-PS1-5 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-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 motions of particles (objects) and energy associated with the relative position of particles (objects).

Career Readiness, Life Literacies, and Key Skills:

9.3.ST.2 Use technology to acquire, manipulate, analyze and report data.

9.3.ST.3 Describe and follow safety, health and environmental standards related to science, technology, engineering and mathematics (STEM) workplaces.

9.3 ST.4 Understand the nature and scope of the Science, Technology, Engineering & Mathematics Career Cluster and the role of STEM in society and the economy.

9.3.ST-ET.1 Use STEM concepts and processes to solve problems involving design and/or production.

9.3.ST-ET.5 Apply the knowledge learned in STEM to solve problems.

9.3.ST-SM.3 Analyze the impact that science and mathematics has on society.

9.3.ST-SM.4 Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.

9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas.

9.4.12.CI.3 Investigate new challenges and opportunities for personal growth, advancement, and transition.

9.4.12.CT.1 Identify problem-solving strategies used in the development of an innovative product or practice.

9.4.12.CT.2 Explain the potential benefits of collaborating to enhance critical thinking and problem solving.

9.4.12.CT.4 Participate in online strategy and planning sessions for course-based, school-based, or other project and determine the strategies that contribute to effective outcomes.

- 9.4.12.IML.3** Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions.
- 9.4.12.IML.5** Evaluate, synthesize, and apply information on climate change from various sources appropriately.
- 9.4.12.IML.7** Develop an argument to support a claim regarding a current workplace or societal/ethical issue such as climate change.
- 9.4.12.TL.1** Assess digital tools based on features such as accessibility options, capacities, and utility for accomplishing a specified task.
- 9.4.12.TL.2** Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.
- 9.4.12.TL.4** Collaborate in online learning communities or social networks or virtual worlds to analyze and propose a resolution to a real-world problem.

Interdisciplinary Connections and Standards:

ELA

- RI.CR.11–12.1** Accurately cite a range of thorough textual evidence and make relevant connections to strongly support a comprehensive analysis of multiple aspects of what an informational text says explicitly and inferentially, as well as interpretations of the text.
- RI.MF.11–12.6** Synthesize complex information across multiple sources and formats to develop ideas, resolve conflicting information, or develop an interpretation that goes beyond explicit text information (e.g., express a personal point of view, new interpretation of the concept).
- W.AW.11–12.1** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
- W.SE.11–12.6** 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 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.
- SL.UM.11–12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Mathematics

- N.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- N.Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- A.SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- A.SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- A.CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- A.CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- F.IF.C.7** Graph functions are expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
- F.BF.A.1** Write a function that describes a relationship between two quantities.
- S.ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that...

- The changes substances experience depend on the interactions between particles; impacting these interactions will impact the rate of the change.

- The rate of a chemical reaction can be influenced by factors including the concentration of reactants, temperature, catalysts, and other environmental factors.
- To quantify a rate of change, we measure the concentration of reactant or product species as a function of time.

Unit Essential Questions:

- Why are some reactions faster than other reactions?
- Why are some medications taken every 8 hours and others once a day?
- Why is food stored in a refrigerator, but bread dough is kept in a warm place to rise?
- How can the speed of a reaction be controlled by understanding the collisions that occur on the particle level?

Knowledge and Skills:

Students will know...

Subtopic 5.1 Reaction Rates

- The kinetics of a chemical reaction is defined as the rate at which an amount of reactants is converted to products per unit of time.
- The rates of change of reactant and product concentrations are determined by the stoichiometry in the balanced chemical equation.
- The rate of a reaction is influenced by reactant concentrations, temperature, surface area, catalysts, and other environmental factors.

Subtopic 5.2 Introduction to Rate Law

- Experimental methods can be used to monitor the amounts of reactants and/or products of a reaction over time and to determine the rate of the reaction.
- The rate law expresses the rate of a reaction as proportional to the concentration of each reactant raised to a power.
- The power of each reactant in the rate law is the order of the reaction with respect to that reactant. The sum of the powers of the reactant concentrations in the rate law is the overall order of the reaction.
- The proportionality constant in the rate law is called the rate constant. The value of this constant is temperature dependent and the units reflect the overall reaction order.
- Comparing initial rates of a reaction is a method to determine the order with respect to each reactant.

Subtopic 5.3 Concentration Changes Over Time

- The order of a reaction can be inferred from a graph of concentration of reactant versus time.
- If a reaction is first order with respect to a reactant being monitored, a plot of the natural log (\ln) of the reactant concentration as a function of time will be linear
- If a reaction is second order with respect to a reactant being monitored, a plot of the reciprocal of the concentration of that reactant versus time will be linear.
- The slopes of the concentration versus time data for zeroth, first, and second order reactions can be used to determine the rate constant for the reaction.
- Half-life is a critical parameter for first-order reactions because the half-life is constant and related to the rate constant for the reaction
- Radioactive decay processes provide an important illustration of first-order kinetics.

Subtopic 5.4 Elementary Reactions

- The rate law of an elementary reaction can be inferred from the stoichiometry of the particles participating in a collision.
- Elementary reactions involving the simultaneous collision of three or more particles are rare.

Subtopic 5.5 Collision Model

- For an elementary reaction to successfully produce products, reactants must successfully collide to initiate bond-breaking and bond-making events.
- In most reactions, only a small fraction of the collisions leads to a reaction. Successful collisions have both sufficient energy to overcome the activation energy requirements and orientations that allow the bonds to rearrange in the required manner.
- The Maxwell-Boltzmann distribution curve describes the distribution of particle energies; this distribution can be used to gain a qualitative estimate of the fraction of collisions with sufficient energy to lead to a reaction, and also how that fraction depends on temperature.

Subtopic 5.6 Reaction Energy Profile

- Elementary reactions typically involve the breaking of some bonds and the forming of new ones.
- The reaction coordinate is the axis along which the complex set of motions involved in rearranging reactants to form products can be plotted.
- The energy profile gives the energy along the reaction coordinate, which typically proceeds from reactants, through a transition state, to products. The energy difference between the reactants and the transition state is the activation energy for the forward reaction.
- The rate of an elementary reaction is temperature-dependent because the proportion of particle collisions that are energetic enough to reach the transition state varies with temperature. The Arrhenius equation relates the temperature dependence of the rate of an elementary reaction to the activation energy needed by molecular collisions to reach the transition state.

Subtopic 5.7 Introduction to Reaction Mechanisms

- A reaction mechanism consists of a series of elementary reactions, or steps, that occur in sequence. The components may include reactants, intermediates, products, and catalysts.
- The elementary steps, when combined, should align with the overall balanced equation of a chemical reaction.
- A reaction intermediate is produced by some elementary steps and consumed by others, such that it is present only while a reaction is occurring.
- Experimental detection of a reaction intermediate is a common way to build evidence in support of one reaction mechanism over an alternative mechanism.

Subtopic 5.8 Reaction Mechanism and Rate Law

- For reaction mechanisms in which each elementary step is irreversible, or in which the first step is rate-limiting, the rate law of the reaction is set by the molecularity of the slowest elementary step (i.e., the rate-limiting step).

Subtopic 5.9 Pre-Equilibrium Approximation

- If the first elementary reaction is not rate-limiting, approximations (such as pre-equilibrium) must be made to determine a rate law expression.

Subtopic 5.10 Multistep Reaction Energy Profile

- Knowledge of the energetics of each elementary reaction in a mechanism allows for the construction of an energy profile for a multistep reaction.

Subtopic 5.11 Catalysis

- In order for a catalyst to increase the rate of a reaction, the addition of the catalyst must increase the number of effective collisions and/ or provide a reaction path with a lower activation energy relative to the original reaction coordinate
- In a reaction mechanism containing a catalyst, the net concentration of the catalyst is constant. However, the catalyst will frequently be consumed in the rate-determining step of the reaction, only to be regenerated in a subsequent step in the mechanism.
- Some catalysts accelerate a reaction by binding to the reactant(s). The reactants are either oriented more favorably or react with lower activation energy. There is often a new reaction intermediate in which the catalyst is bound to the reactant(s). Many enzymes function in this manner.

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

Students will be able to...

Subtopic 5.1 Reaction Rates

- Explain the relationship between the rate of a chemical reaction and experimental parameters.

Subtopic 5.2 Introduction to Rate Law

- Represent experimental data with a consistent rate law expression.

Subtopic 5.3 Concentration Changes Over Time

- Identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time

Subtopic 5.4 Elementary Reactions

- Represent an elementary reaction as a rate law expression using stoichiometry.

Subtopic 5.5 Collision Model

- Explain the relationship between the rate of an elementary reaction and the frequency, energy, and orientation of particle collisions.

Subtopic 5.6 Reaction Energy Profile

- Represent the activation energy and overall energy change in an elementary reaction using a reaction energy profile.

Subtopic 5.7 Introduction to Reaction Mechanisms

- Identify the components of a reaction mechanism.

Subtopic 5.8 Reaction Mechanism and Rate Law

- Identify the rate law for a reaction from a mechanism in which the first step is rate-limiting.

Subtopic 5.9 Pre-Equilibrium Approximation

- Identify the rate law for a reaction from a mechanism in which the first step is not rate-limiting.

Subtopic 5.10 Multistep Reaction Energy Profile

- Represent the activation energy and overall energy change in a multistep reaction with a reaction energy profile

Subtopic 5.11 Catalysis

- Explain the relationship between the effect of a catalyst on a reaction and changes in the reaction mechanism.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly “understand”?

- End of Unit Common Assessment - See folder for assessment links.
- A mix of conceptual, representation-based, math-based, and data analysis questions will be used to gather formative data through:
 - Do now questions, exit tickets, and independent classwork/homework.
 - Group whiteboarding problems, card sort activities, and exploratory analysis activities.
 - AP Classroom Topic Questions
- Summative data will be collected through:
 - AP Classroom Progress Check

- Analysis and CER conclusions of labs such as:
 - Intro to Reaction Rates
 - Iodine Clock Reaction

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Inquiry investigations and labs including:
 - Intro to Reaction Rates Lab
 - Iodine Clock Reaction Lab
 - Reaction Rate and Absorbance activity
 - Determining Rate Order Lab
 - Connecting Rate Order to Mechanisms Activity
 - Reaction Coordinate Diagrams Activity
- Instruction on vocabulary, concepts, and problem solving techniques following gradual release framework.
- Collaborative and independent practice of foundational skills.
- Collaborative and independent practice breaking down and answering College Board MCQ and FRQ style questions.

<i>RESOURCES</i>

Teacher Resources:

- AP Classroom
- AP Chemistry Lab Manual
- Textbook: Zumdahl, Steven S., Zumdahl, Susan A., DeCoste, Donald J. *Chemistry*, 10th Edition.

Equipment Needed:

- Projection and computer equipment
- Group whiteboards and dry erase materials
- Poster and individual periodic tables
- Calculators
- Laboratory equipment and chemicals for labs, activities, and demonstrations
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UNIT 6 OVERVIEW

Content Area: Science

Unit Title: Thermochemistry

Target Course/Grade Level: Advanced Placement Chemistry/Grades 11-12

Unit Summary: 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. Thermochemistry 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.

Approximate Length of Unit: 3 weeks

LEARNING TARGETS

NJ Student Learning Standards:

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

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

HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).

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).

Career Readiness, Life Literacies, and Key Skills:

9.3.ST.2 Use technology to acquire, manipulate, analyze and report data.

9.3.ST.3 Describe and follow safety, health and environmental standards related to science, technology, engineering and mathematics (STEM) workplaces.

9.3 ST.4 Understand the nature and scope of the Science, Technology, Engineering & Mathematics Career Cluster and the role of STEM in society and the economy.

9.3.ST-ET.1 Use STEM concepts and processes to solve problems involving design and/or production.

9.3.ST-ET.5 Apply the knowledge learned in STEM to solve problems.

9.3.ST-SM.3 Analyze the impact that science and mathematics has on society.

9.3.ST-SM.4 Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.

9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas.

- 9.4.12.CI.3** Investigate new challenges and opportunities for personal growth, advancement, and transition.
- 9.4.12.CT.1** Identify problem-solving strategies used in the development of an innovative product or practice.
- 9.4.12.CT.2** Explain the potential benefits of collaborating to enhance critical thinking and problem solving.
- 9.4.12.CT.4** Participate in online strategy and planning sessions for course-based, school-based, or other project and determine the strategies that contribute to effective outcomes.
- 9.4.12.IML.3** Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions.
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Interdisciplinary Connections and Standards:

ELA

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Mathematics

- N.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
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- A.SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
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- F.BF.A.1** Write a function that describes a relationship between two quantities.
- S.ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that...

- As we are part of the surroundings for most systems under study, a change in temperature we feel/measure is not directly indicative of the change in energy for the system under study.
- The availability or disposition of energy plays a role in virtually all observed chemical processes.
- 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.

Unit Essential Questions:

- Why is energy released when liquid water becomes an ice cube?
- Why does your skin feel cold when water evaporates off of it?
- How does a thermal energy transfer affect temperature, states of matter, and chemical bonds?
- How can energy changes be tracked and measured when energy can't be seen?
- Why do combustion reactions that form carbon dioxide release energy?

Knowledge and Skills:

Students will know...

Subtopic 6.1 Endothermic and Exothermic Processes

- Temperature changes in a system indicate energy changes.
- Energy changes in a system can be described as endothermic and exothermic processes, such as the heating or cooling of a substance, phase changes, or chemical transformations.
- When a chemical reaction occurs, the energy of the system either decreases (exothermic reaction), increases (endothermic reaction), or remains the same. For exothermic reactions, the energy lost by the reacting species (system) is gained by the surroundings, as heat transfer from or work done by the system. Likewise, for endothermic reactions, the system gains energy from the surroundings by heat transfer to or work done on the system.
- The formation of a solution may be an exothermic or endothermic process, depending on the relative strengths of intermolecular/interparticle interactions before and after the dissolution process.

Subtopic 6.2 Energy Diagrams

- A physical or chemical process can be described with an energy diagram that shows the endothermic or exothermic nature of that process.

Subtopic 6.3 Heat Transfer and Thermal Equilibrium

- The particles in a warmer body have a greater average kinetic energy than those in a cooler body.
- Collisions between particles in thermal contact can result in the transfer of energy. This process is called "heat transfer," "heat exchange," or "transfer of energy as heat."
- Eventually, thermal equilibrium is reached as the particles continue to collide. At thermal equilibrium, the average kinetic energy of both bodies is the same, and hence, their temperatures are the same.

Subtopic 6.4 Heat Capacity and Calorimetry

- The heating of a cool body by a warmer body is an important form of energy transfer between two systems. The amount of heat transferred between two bodies may be quantified by the heat transfer equation
- Calorimetry experiments are used to measure the transfer of heat.
- The first law of thermodynamics states that energy is conserved in chemical and physical processes.
- The transfer of a given amount of thermal energy will not produce the same temperature change in equal masses of matter with differing specific heat capacities.
- Heating a system increases the energy of the system, while cooling a system decreases the energy of the system.

- The specific heat capacity of a substance and the molar heat capacity are both used in energy calculations.
- Chemical systems change their energy through three main processes: heating/cooling, phase transitions, and chemical reactions.
- In calorimetry experiments involving dissolution, temperature changes of the mixture within the calorimeter can be used to determine the direction of energy flow. If the temperature of the mixture increases, thermal energy is released by the dissolution process (exothermic). If the temperature of the mixture decreases, thermal energy is absorbed by the dissolution process (endothermic).

Subtopic 6.5 Energy of Phase Changes

- Energy must be transferred to a system to cause a substance to melt (or boil). The energy of the system, therefore, increases as the system undergoes a solid-to-liquid (or liquid-to-gas) phase transition. Likewise, a system releases energy when it freezes (or condenses). The energy of the system decreases as the system undergoes a liquid-to-solid (or gas-to-liquid) phase transition. The temperature of a pure substance remains constant during a phase change.
- The energy absorbed during a phase change is equal to the energy released during a complementary phase change in the opposite direction. For example, the molar enthalpy of condensation of a substance is equal to the negative of its molar enthalpy of vaporization. Similarly, the molar enthalpy of fusion can be used to calculate the energy absorbed when melting a substance and the energy released when freezing a substance.

Subtopic 6.6 Introduction to Enthalpy of Reaction

- The enthalpy change of a reaction gives the amount of heat energy released (for negative values) or absorbed (for positive values) by a chemical reaction at constant pressure.
- When the products of a reaction are at a different temperature than their surroundings, they exchange energy with the surroundings to reach thermal equilibrium. Thermal energy is transferred to the surroundings as the reactants convert to products in an exothermic reaction. Thermal energy is transferred from the surroundings as the reactants convert to products in an endothermic reaction.
- The chemical potential energy of the products of a reaction is different from that of the reactants because of the breaking and forming of bonds. The energy difference results in a change in the kinetic energy of the particles, which manifests as a temperature change.

Subtopic 6.7 Bond Enthalpies

- During a chemical reaction, bonds are broken and/or formed, and these events change the potential energy of the system.
- The average energy required to break all of the bonds in the reactant molecules can be estimated by adding up the average bond energies of all the bonds in the reactant molecules. Likewise, the average energy released in forming the bonds in the product molecules can be estimated. If the energy released is greater than the energy required, the reaction is exothermic. If the energy required is greater than the energy released, the reaction is endothermic.

Subtopic 6.8 Enthalpy of Formation

- Tables of standard enthalpies of formation can be used to calculate the standard enthalpies of reactions.

Subtopic 6.9 Hess's Law

- Many processes can be broken down into a series of steps. Each step in the series has its own energy change.
- Because total energy is conserved (first law of thermodynamics), and each individual reaction in a sequence transfers thermal energy to or from the surroundings, the net thermal energy transferred in the sequence will be equal to the sum of the thermal energy transfers in each of the steps. These thermal energy transfers are the result of potential energy changes among the species in the reaction sequence; thus, at constant pressure, the enthalpy change of the overall process is equal to the sum of the enthalpy changes of the individual steps.

- The following are essential principles of Hess's law:
 - When a reaction is reversed, the enthalpy change stays constant in magnitude but becomes reversed in mathematical sign.
 - When a reaction is multiplied by a factor c , the enthalpy change is multiplied by the same factor c .
 - When two (or more) reactions are added to obtain an overall reaction, the individual enthalpy changes of each reaction are added to obtain the net enthalpy change of the overall reaction.

Students will be able to...

Subtopic 6.1 Endothermic and Exothermic Processes

- Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation.

Subtopic 6.2 Energy Diagrams

- Represent a chemical or physical transformation with an energy diagram.

Subtopic 6.3 Heat Transfer and Thermal Equilibrium

- Explain the relationship between the transfer of thermal energy and molecular collisions.

Subtopic 6.4 Heat Capacity and Calorimetry

- 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.

Subtopic 6.5 Energy of Phase Changes

- 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.

Subtopic 6.6 Introduction to Enthalpy of Reaction

- 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

Subtopic 6.7 Bond Enthalpies

- Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction

Subtopic 6.8 Enthalpy of Formation

- Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation.

Subtopic 6.9 Hess's Law

- Represent a chemical or physical process as a sequence of steps.
- Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual steps.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- A mix of conceptual, representation-based, math-based, and data analysis questions will be used to gather formative data through:
 - Do now questions, exit tickets, and independent classwork/homework.
 - Group whiteboarding problems, card sort activities, and exploratory analysis activities.
 - AP Classroom Topic Questions

- Summative data will be collected through:
 - AP Classroom Progress Check
 - Analysis and CER conclusions of labs such as:
 - Heat of Dissolution and Neutralization
 - Hess's Law

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Inquiry investigations and labs including:
 - Heat of Dissolution and Neutralization Lab
 - Hess's Law Lab
 - Produce a Temperature Change Lab
 - Exothermic vs Endothermic Think Pair Share
 - Calorimetry Activity
 - Specific Heat Capacity POGIL
 - Bond Enthalpy Think Pair Share
- Instruction on vocabulary, concepts, and problem solving techniques following gradual release framework.
- Collaborative and independent practice of foundational skills.
- Collaborative and independent practice breaking down and answering College Board MCQ and FRQ style questions.

RESOURCES

Teacher Resources:

- AP Classroom
- AP Chemistry Lab Manual
- Textbook: Zumdahl, Steven S., Zumdahl, Susan A., DeCoste, Donald J. *Chemistry*, 10th Edition.

Equipment Needed:

- Projection and computer equipment
- Group whiteboards and dry erase materials
- Poster and individual periodic tables
- Calculators
- Laboratory equipment and chemicals for labs, activities, and demonstrations
- Student copies of textbook

UNIT 7 OVERVIEW

Content Area: Science

Unit Title: Equilibrium

Target Course/Grade Level: Advanced Placement Chemistry/Grades 11-12

Unit Summary: Chemical equilibrium is a dynamic state in which opposing processes occur at the same rate. In this unit, students learn that any bond or intermolecular attraction that can be formed can be broken. These two processes are in a dynamic competition, sensitive to initial conditions and external perturbations. A change in conditions, such as addition of a chemical species, change in temperature, or change in volume, can cause the rate of the forward and reverse reactions to fall out of balance. Le Châtelier's principle provides a means to reason qualitatively about the direction of the shift in an equilibrium system resulting from various possible stresses. The expression for the equilibrium constant, K , is a mathematical expression that describes the equilibrium state associated with a chemical change. An analogous expression for the reaction quotient, Q , describes a chemical reaction at any point, enabling a comparison to the equilibrium state. The dissolution of a solid in a solvent can also be understood by applying the principles of chemical equilibrium because it is a reversible reaction. The relationships between salt solubility, pH, and free energy will be encountered in subsequent units. Subsequent units will also explore equilibrium constants that arise from acid-base chemistry.

Approximate Length of Unit: 5 weeks

LEARNING TARGETS

NJ Student Learning 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.

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

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

Career Readiness, Life Literacies, and Key Skills:

9.3.ST.2 Use technology to acquire, manipulate, analyze and report data.

9.3.ST.3 Describe and follow safety, health and environmental standards related to science, technology, engineering and mathematics (STEM) workplaces.

9.3 ST.4 Understand the nature and scope of the Science, Technology, Engineering & Mathematics Career Cluster and the role of STEM in society and the economy.

9.3.ST-ET.1 Use STEM concepts and processes to solve problems involving design and/or production.

9.3.ST-ET.5 Apply the knowledge learned in STEM to solve problems.

9.3.ST-SM.3 Analyze the impact that science and mathematics has on society.

9.3.ST-SM.4 Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.

9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas.

- 9.4.12.CI.3** Investigate new challenges and opportunities for personal growth, advancement, and transition.
- 9.4.12.CT.1** Identify problem-solving strategies used in the development of an innovative product or practice.
- 9.4.12.CT.2** Explain the potential benefits of collaborating to enhance critical thinking and problem solving.
- 9.4.12.CT.4** Participate in online strategy and planning sessions for course-based, school-based, or other project and determine the strategies that contribute to effective outcomes.
- 9.4.12.IML.3** Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions.
- 9.4.12.IML.5** Evaluate, synthesize, and apply information on climate change from various sources appropriately.
- 9.4.12.IML.7** Develop an argument to support a claim regarding a current workplace or societal/ethical issue such as climate change.
- 9.4.12.TL.1** Assess digital tools based on features such as accessibility options, capacities, and utility for accomplishing a specified task.
- 9.4.12.TL.2** Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.
- 9.4.12.TL.4** Collaborate in online learning communities or social networks or virtual worlds to analyze and propose a resolution to a real-world problem.

Interdisciplinary Connections and Standards:

ELA

- RI.CR.11–12.1** Accurately cite a range of thorough textual evidence and make relevant connections to strongly support a comprehensive analysis of multiple aspects of what an informational text says explicitly and inferentially, as well as interpretations of the text.
- RI.MF.11–12.6** Synthesize complex information across multiple sources and formats to develop ideas, resolve conflicting information, or develop an interpretation that goes beyond explicit text information (e.g., express a personal point of view, new interpretation of the concept).
- W.AW.11–12.1** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
- W.SE.11–12.6** 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 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.
- SL.UM.11–12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Mathematics

- N.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- N.Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- A.SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- A.SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- A.CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- A.CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- F.IF.C.7** Graph functions are expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
- F.BF.A.1** Write a function that describes a relationship between two quantities.
- S.ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that...

- Chemical equilibrium is a dynamic state in which opposing processes occur at the same rate.
- A change in conditions, such as addition of a chemical species, change in temperature, or change in volume, can cause the rate of the forward and reverse reactions to fall out of balance.
- Le Chatelier's Principle is a qualitative tool for examining equilibrium, while the equilibrium constant and reaction quotient are mathematical tools for examining equilibrium.

Unit Essential Questions:

- How are the rates of forward and reverse reactions related to the direction that a reversible reaction proceeds?
- How can the composition of a mixture at equilibrium be predicted?
- How can an equilibrium system be manipulated to maximize product yield?
- Why do paramedics administer pure oxygen to people with carbon monoxide poisoning?
- What factors influence the degree to which a salt will dissolve?

Knowledge and Skills:

Students will know...

Subtopic 7.1 Introduction to Equilibrium

- Many observable processes are reversible. Examples include evaporation and condensation of water, absorption and desorption of a gas, or dissolution and precipitation of a salt. Some important reversible chemical processes include the transfer of protons in acid-base reactions and the transfer of electrons in redox reactions.
- When equilibrium is reached, no observable changes occur in the system. Reactants and products are simultaneously present, and the concentrations or partial pressures of all species remain constant.
- The equilibrium state is dynamic. The forward and reverse processes continue to occur at equal rates, resulting in no net observable change.
- Graphs of concentration, partial pressure, or rate of reaction versus time for simple chemical reactions can be used to understand the establishment of chemical equilibrium.

Subtopic 7.2 Direction of Reversible Reactions

- If the rate of the forward reaction is greater than the reverse reaction, then there is a net conversion of reactants to products. If the rate of the reverse reaction is greater than that of the forward reaction, then there is a net conversion of products to reactants. An equilibrium state is reached when these rates are equal.

Subtopic 7.3 Reaction Quotient and Equilibrium Constant

- The reaction quotient Q_c describes the relative concentrations of reaction species at any time. For gas phase reactions, the reaction quotient may instead be written in terms of partial pressures as Q_p . The reaction quotient tends toward the equilibrium constant such that at equilibrium $K_c = Q_c$ and $K_p = Q_p$.
- The reaction quotient does not include substances whose concentrations (or partial pressures) are independent of the amount, such as for solids and pure liquids

Subtopic 7.4 Calculating the Equilibrium Constant

- Equilibrium constants can be determined from experimental measurements of the concentrations or partial pressures of the reactants and products at equilibrium.

Subtopic 7.5 Magnitude of the Equilibrium Constant

- Some equilibrium reactions have very large K values and proceed essentially to completion. Others have very small K values and barely proceed at all.

Subtopic 7.6 Properties of the Equilibrium Constant

- When a reaction is reversed, K is inverted.

- When the stoichiometric coefficients of a reaction are multiplied by a factor c , K is raised to the power c .
- When reactions are added together, the K of the resulting overall reaction is the product of the K 's for the reactions that were summed.
- Since the expressions for K and Q have identical mathematical forms, all valid algebraic manipulations of K also apply to Q .

Subtopic 7.7 Calculating Equilibrium Concentrations

- The concentrations or partial pressures of species at equilibrium can be predicted given the balanced reaction, initial concentrations, and the appropriate K .
- When $Q < K$, the reaction will proceed with a net consumption of reactants and generation of products. When $Q > K$, the reaction will proceed with a net consumption of products and generation of reactants. When $Q = K$, the system is at dynamic equilibrium; both forward and reverse reactions proceed at the same rate, and the proportion of reactants and products remains constant.

Subtopic 7.8 Representations of Equilibrium

- Particulate representations can be used to describe the relative numbers of reactant and product particles present prior to and at equilibrium, and the value of the equilibrium constant.

Subtopic 7.9 Introduction to Le Chatelier's Principle

- Le Châtelier's principle can be used to predict the response of a system to stresses such as addition or removal of a chemical species, change in temperature, change in volume/pressure of a gas-phase system, or dilution of a reaction system.
- Le Châtelier's principle can be used to predict the effect that a stress will have on experimentally measurable properties such as pH, temperature, and color of a solution.

Subtopic 7.10 Reaction Quotient and Le Chatelier's Principle

- A disturbance to a system at equilibrium causes Q to differ from K , thereby taking the system out of equilibrium. The system responds by bringing Q back into agreement with K , thereby establishing a new equilibrium state.
- Some stresses, such as changes in concentration, cause a change in Q only. A change in temperature causes a change in K . In either case, the concentrations or partial pressures of species redistribute to bring Q and K back into equality.

Subtopic 7.11 Introduction to Solubility Equilibria

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

Subtopic 7.12 Common-Ion Effect

- The solubility of a salt is reduced when it is dissolved into a solution that already contains one of the ions present in the salt. The impact of this "common-ion effect" on solubility can be understood qualitatively using Le Châtelier's principle or calculated from the K_{sp} for the dissolution process.

Students will be able to...

Subtopic 7.1 Introduction to Equilibrium

- Explain the relationship between the occurrence of a reversible chemical or physical process, and the establishment of equilibrium, to experimental observations.

Subtopic 7.2 Direction of Reversible Reactions

- Explain the relationship between the direction in which a reversible reaction proceeds and the relative rates of the forward and reverse reactions.

Subtopic 7.3 Reaction Quotient and Equilibrium Constant

- Represent the reaction quotient Q_c or Q_p for a reversible reaction, and the corresponding equilibrium expressions

Subtopic 7.4 Calculating the Equilibrium Constant

- Calculate K_c or K_p based on experimental observations of concentrations or pressures at equilibrium.

Subtopic 7.5 Magnitude of the Equilibrium Constant

- Explain the relationship between very large or very small values of K and the relative concentrations of chemical species at equilibrium.

Subtopic 7.6 Properties of the Equilibrium Constant

- Represent a multistep process with an overall equilibrium expression, using the constituent K expressions for each individual reaction.

Subtopic 7.7 Calculating Equilibrium Concentrations

- Identify the concentrations or partial pressures of chemical species at equilibrium based on the initial conditions and the equilibrium constant.

Subtopic 7.8 Representations of Equilibrium

- Represent a system undergoing a reversible reaction with a particulate model.

Subtopic 7.9 Introduction to Le Chatelier's Principle

- Identify the response of a system at equilibrium to an external stress, using Le Châtelier's principle.

Subtopic 7.10 Reaction Quotient and Le Chatelier's Principle

- Explain the relationships between Q , K , and the direction in which a reversible reaction will proceed to reach equilibrium

Subtopic 7.11 Introduction to Solubility Equilibria

- Calculate the solubility of a salt based on the value of K_{sp} for the salt.

Subtopic 7.12 Common-Ion Effect

- Identify the solubility of a salt, and/or the value of K_{sp} for the salt, based on the concentration of a common ion already present in solution.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- A mix of conceptual, representation-based, math-based, and data analysis questions will be used to gather formative data through:
 - Do now questions, exit tickets, and independent classwork/homework.
 - Group whiteboarding problems, card sort activities, and exploratory analysis activities.
 - AP Classroom Topic Questions
- Summative data will be collected through:
 - AP Classroom Progress Check
 - Analysis and CER conclusions of labs such as:
 - Le Chatelier's Principle
 - Milk of Magnesia

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Inquiry investigations and labs including:
 - Le Chatelier's Principle Lab
 - Milk of Magnesia Lab
 - Manipulative Modeling Equilibrium Activity
 - Writing Expressions Activity
 - Lead Solubility Activity
- Instruction on vocabulary, concepts, and problem solving techniques following gradual release framework.
- Collaborative and independent practice of foundational skills.
- Collaborative and independent practice breaking down and answering College Board MCQ and FRQ style questions.

<i>RESOURCES</i>

Teacher Resources:

- AP Classroom
- AP Chemistry Lab Manual
- Textbook: Zumdahl, Steven S., Zumdahl, Susan A., DeCoste, Donald J. *Chemistry*, 10th Edition.

Equipment Needed:

- Projection and computer equipment
- Group whiteboards and dry erase materials
- Poster and individual periodic tables
- Calculators
- Laboratory equipment and chemicals for labs, activities, and demonstrations
- Student copies of textbook

UNIT 8 OVERVIEW

Content Area: Science

Unit Title: Acids and Bases

Target Course/Grade Level: Advanced Placement Chemistry/Grades 11-12

Unit Summary: This unit builds on the content about chemical equilibrium studied in Unit 7. 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. In the final unit, the equilibrium constant is related to temperature and the difference in Gibbs free energy between the reactants and products.

Approximate Length of Unit: 5 weeks

LEARNING TARGETS

NJ Student Learning 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.

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

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

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

Career Readiness, Life Literacies, and Key Skills:

9.3.ST.2 Use technology to acquire, manipulate, analyze and report data.

9.3.ST.3 Describe and follow safety, health and environmental standards related to science, technology, engineering and mathematics (STEM) workplaces.

9.3 ST.4 Understand the nature and scope of the Science, Technology, Engineering & Mathematics Career Cluster and the role of STEM in society and the economy.

9.3.ST-ET.1 Use STEM concepts and processes to solve problems involving design and/or production.

9.3.ST-ET.5 Apply the knowledge learned in STEM to solve problems.

9.3.ST-SM.3 Analyze the impact that science and mathematics has on society.

9.3.ST-SM.4 Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.

9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas.

9.4.12.CI.3 Investigate new challenges and opportunities for personal growth, advancement, and transition.

9.4.12.CT.1 Identify problem-solving strategies used in the development of an innovative product or practice.

9.4.12.CT.2 Explain the potential benefits of collaborating to enhance critical thinking and problem solving.

- 9.4.12.CT.4** Participate in online strategy and planning sessions for course-based, school-based, or other project and determine the strategies that contribute to effective outcomes.
- 9.4.12.IML.3** Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions.
- 9.4.12.IML.5** Evaluate, synthesize, and apply information on climate change from various sources appropriately.
- 9.4.12.IML.7** Develop an argument to support a claim regarding a current workplace or societal/ethical issue such as climate change.
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- 9.4.12.TL.2** Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.
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Interdisciplinary Connections and Standards:

ELA

- RI.CR.11–12.1** Accurately cite a range of thorough textual evidence and make relevant connections to strongly support a comprehensive analysis of multiple aspects of what an informational text says explicitly and inferentially, as well as interpretations of the text.
- RI.MF.11–12.6** Synthesize complex information across multiple sources and formats to develop ideas, resolve conflicting information, or develop an interpretation that goes beyond explicit text information (e.g., express a personal point of view, new interpretation of the concept).
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Mathematics

- N.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- N.Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- A.SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- A.SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- A.CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- A.CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- F.IF.C.7** Graph functions are expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
- F.BFA.1** Write a function that describes a relationship between two quantities.
- S.ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that...

- Chemical equilibrium is a dynamic state in which opposing processes occur at the same rate.

- A change in conditions, such as addition of a chemical species, change in temperature, or change in volume, can cause the rate of the forward and reverse reactions to fall out of balance.
- Le Chatelier's Principle is a qualitative tool for examining equilibrium, while the equilibrium constant and reaction quotient are mathematical tools for examining 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.

Unit Essential Questions:

- How is pH related to the concentration and strength of an acid, a base, or a mixture of them?
- How does acid or base strength relate to the concentrations of reactants and products when a system reaches equilibrium?
- Why are some acids stronger than others?
- How does your body maintain pH balance?

Knowledge and Skills:

Students will know...

Subtopic 8.1 Introduction to Acids and Bases

- The concentrations of hydronium ion and hydroxide ion are often reported as pH and pOH, respectively.
- The terms "hydrogen ion" and "hydronium ion" and the symbols H^+ (aq) and H_3O^+ (aq) are often used interchangeably for the aqueous ion of hydrogen.
- Water autoionizes with an equilibrium constant K_w .
- In pure water, $pH = pOH$ is called a neutral solution. At $25^\circ C$, $pK_w = 14.0$ and thus $pH = pOH = 7.0$.
- The value of K_w is temperature dependent, so the pH of pure, neutral water will deviate from 7.0 at temperatures other than $25^\circ C$.

Subtopic 8.2 pH and pOH of Strong Acids and Bases

- Molecules of a strong acid (e.g., HCl, HBr, HI, $HClO_4$, H_2SO_4 , and HNO_3) will completely ionize in aqueous solution to produce hydronium ions and the conjugate base of the acid. As such, the concentration of H_3O^+ in a strong acid solution is equal to the initial concentration of the strong acid, and thus the pH of the strong acid solution is easily calculated.
- When dissolved in solution, strong bases (e.g., group I and II hydroxides) completely dissociate to produce hydroxide ions. As such, the concentration of OH^- in a strong base solution is equal to the initial concentration of a group I hydroxide and double the initial concentration of a group II hydroxide, and thus the pOH (and pH) of the strong base solution is easily calculated.

Subtopic 8.3 Weak Acid and Base Equilibria

- Weak acids react with water to produce hydronium ions. However, only a small percentage of molecules of a weak acid will ionize in this way. Thus, the concentration of H_3O^+ is much less than the initial concentration of the molecular acid, and the vast majority of the acid molecules remain un-ionized.
- A solution of a weak acid involves equilibrium between an un-ionized acid and its conjugate base. The equilibrium constant for this reaction is K_a , often reported as pK_a . The pH of a weak acid solution can be determined from the initial acid concentration and the pK_a .
- Weak bases react with water to produce hydroxide ions in solution. However, ordinarily, just a small percentage of the molecules of a weak base in solution will ionize in this way. Thus, the concentration of OH^- in the solution does not equal the initial concentration of the base, and the vast majority of the base molecules remain un-ionized.
- A solution of a weak base involves equilibrium between an un-ionized base and its conjugate acid. The equilibrium constant for this reaction is K_b , often reported as pK_b . The pH of a weak base solution can be determined from the initial base concentration and the pK_b .

- The percent ionization of a weak acid (or base) can be calculated from its pK_a (pK_b) and the initial concentration of the acid (base). The percent ionization can also be calculated from the initial concentration of the acid (base) and the equilibrium concentration of any of the species in the equilibrium expression.
- For any conjugate acid-base pair, the acid ionization constant and base ionization constant are related by K_w .

Subtopic 8.4 Acid-Base Reactions and Buffers

- When a strong acid and a strong base are mixed, they react quantitatively. The pH of the resulting solution may be determined from the concentration of excess reagent.
- When a weak acid and a strong base are mixed, they react quantitatively. If the weak acid is in excess, then a buffer solution is formed, and the pH can be determined from the Henderson-Hasselbalch (H-H) equation. If the strong base is in excess, then the pH can be determined from the moles of excess hydroxide ion and the total volume of solution. If they are equimolar, then the (slightly basic) pH can be determined from the equilibrium.
- When a weak base and a strong acid are mixed, they will react quantitatively. If the weak base is in excess, then a buffer solution is formed, and the pH can be determined from the H-H equation. If the strong acid is in excess, then the pH can be determined from the moles of excess hydronium ions and the total volume of solution. If they are equimolar, then the (slightly acidic) pH can be determined from the equilibrium.
- When a weak acid and a weak base are mixed, they will react to an equilibrium state.

Subtopic 8.5 Acid-Base Titrations

- An acid-base reaction can be carried out under controlled conditions in a titration. A titration curve, plotting pH against the volume of titrant added, is useful for summarizing results from a titration.
- At the equivalence point for titrations of monoprotic acids or bases, the number of moles of titrant added is equal to the number of moles of analyte originally present. This relationship can be used to obtain the concentration of the analyte. This is the case for titrations of strong acids/bases and weak acids/bases.
- For titrations of weak acids/bases, it is useful to consider the point halfway to the equivalence point, that is, the half-equivalence point. At this point, there are equal concentrations of each species in the conjugate acid-base pair, for example, for a weak acid $[HA] = [A^-]$. Because $pH = pK_a$ when the conjugate acid and base have equal concentrations, the pK_a can be determined from the pH at the half equivalence point in a titration.
- At the equivalence point, pH is determined by the major species in solution. Strong acid and strong base titrations result in neutral pH at the equivalence point. However, in titrations of weak acids (weak bases), the conjugate base of the weak acid (conjugate acid of the weak base) is present at the equivalence point and can undergo proton-transfer reactions with the surrounding water, producing basic (acidic) solutions.
- For polyprotic acids, titration curves can be used to determine the number of acidic protons. In doing so, the major species present at any point along the curve can be identified, along with the pK_a associated with each proton in a weak polyprotic acid.

Subtopic 8.6 Molecular Structure of Acids and Bases

- The protons on a molecule that will participate in acid-base reactions, and the relative strength of these protons, can be inferred from the molecular structure.
- Strong acids (such as HCl, HBr, HI, $HClO_4$, H_2SO_4 , and HNO_3) have very weak conjugate bases that are stabilized by electronegativity, inductive effects, resonance, or some combination thereof.
- Carboxylic acids are one common class of weak acids.
- Strong bases (such as group I and II hydroxides) have very weak conjugate acids.
- Common weak bases include nitrogenous bases such as ammonia as well as carboxylate ions.
- Electronegative elements tend to stabilize the conjugate base relative to the conjugate acid, and so increase acid strength.

Subtopic 8.7 pH and pKa

- The protonation state of an acid or base (i.e., the relative concentrations of HA and A⁻) can be predicted by comparing the pH of a solution to the pKa of the acid in that solution. When solution pH < acid pKa, the acid form has a higher concentration than the base form. When solution pH > acid pKa, the base form has a higher concentration than the acid form.
- Acid-base indicators are substances that exhibit different properties (such as color) in their protonated versus deprotonated state, making that property respond to the pH of a solution.
- To ensure accurate results in a titration experiment, acid-base indicators should be selected that have a pKa close to the pH at the equivalence point.

Subtopic 8.8 Properties of Buffers

- A buffer solution contains a large concentration of both members in a conjugate acid-base pair. The conjugate acid reacts with added base and the conjugate base reacts with added acid. These reactions are responsible for the ability of a buffer to stabilize pH.

Subtopic 8.9 Henderson-Hasselbalch Equation

- The pH of the buffer is related to the pKa of the acid and the concentration ratio of the conjugate acid-base pair. This relation is a consequence of the equilibrium expression associated with the dissociation of a weak acid, and is described by the Henderson-Hasselbalch equation. Adding small amounts of acid or base to a buffered solution does not significantly change the ratio of [A⁻]/[HA] and thus does not significantly change the solution pH. The change in pH in addition of acid or base to a buffered solution is therefore much less than it would have been in the absence of the buffer.

Subtopic 8.10 Buffer Capacity

- Increasing the concentration of the buffer components (while keeping the ratio of these concentrations constant) keeps the pH of the buffer the same but increases the capacity of the buffer to neutralize added acid or base.
- When a buffer has more conjugate acid than base, it has a greater buffer capacity for addition of added base than acid. When a buffer has more conjugate base than acid, it has a greater buffer capacity for addition of added acid than base.

Subtopic 8.11 pH and Solubility

- The solubility of a salt is pH sensitive when one of the constituent ions is a weak acid, a weak base, or the hydroxide ion. These effects can be understood qualitatively using Le Châtelier's principle.

Students will be able to...

Subtopic 8.1 Introduction to Acids and Bases

- Calculate the values of pH and pOH, based on Kw and the concentration of all species present in a neutral solution of water.

Subtopic 8.2 pH and pOH of Strong Acids and Bases

- Calculate pH and pOH based on concentrations of all species in a solution of a strong acid or a strong base.

Subtopic 8.3 Weak Acid and Base Equilibria

- Explain the relationship among pH, pOH, and concentrations of all species in a solution of a monoprotic weak acid or weak base.

Subtopic 8.4 Acid-Base Reactions and Buffers

- Explain the relationship among the concentrations of major species in a mixture of weak and strong acids and bases.

Subtopic 8.5 Acid-Base Titrations

- Explain results from the titration of a monoprotic or polyprotic acid or base solution, in relation to the properties of the solution and its components.

Subtopic 8.6 Molecular Structure of Acids and Bases

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

Subtopic 8.7 pH and pKa

- Explain the relationship between the predominant form of a weak acid or base in solution at a given pH and the pKa of the conjugate acid or the pKb of the conjugate base.

Subtopic 8.8 Properties of Buffers

- 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.

Subtopic 8.9 Henderson-Hasselbalch Equation

- Identify the pH of a buffer solution based on the identity and concentrations of the conjugate acid-base pair used to create the buffer.

Subtopic 8.10 Buffer Capacity

- 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.

Subtopic 8.11 pH and Solubility

- Identify the qualitative effect of changes in pH on the solubility of a salt.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly “understand”?

- End of Unit Common Assessment - See folder for assessment links.
- A mix of conceptual, representation-based, math-based, and data analysis questions will be used to gather formative data through:
 - Do now questions, exit tickets, and independent classwork/homework.
 - Group whiteboarding problems, card sort activities, and exploratory analysis activities.
 - AP Classroom Topic Questions
- Summative data will be collected through:
 - AP Classroom Progress Check
 - Analysis and CER conclusions of labs such as:
 - Acid in Soda
 - Comparative Titration Curves

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Inquiry investigations and labs including:
 - Acid in Soda Lab
 - Comparative Titration Curves Lab
 - Comparing Strong and Weak Acids Activity
 - Buffer Capacity Activity
 - Developing a Buffer Activity
- Instruction on vocabulary, concepts, and problem solving techniques following gradual release framework.
- Collaborative and independent practice of foundational skills.
- Collaborative and independent practice breaking down and answering College Board MCQ and FRQ style questions.

RESOURCES

Teacher Resources:

- AP Classroom
- AP Chemistry Lab Manual
- Textbook: Zumdahl, Steven S., Zumdahl, Susan A., DeCoste, Donald J. *Chemistry*, 10th Edition.

Equipment Needed:

- Projection and computer equipment
- Group whiteboards and dry erase materials
- Poster and individual periodic tables
- Calculators
- Laboratory equipment and chemicals for labs, activities, and demonstrations
- Student copies of textbook

UNIT 9 OVERVIEW

Content Area: Science

Unit Title: Thermodynamics and Electrochemistry

Target Course/Grade Level: Advanced Placement Chemistry/Grades 11-12

Unit Summary: This unit allows students to connect principles and calculations across Units 1–8. The thermodynamics of a chemical reaction is connected to both the structural aspects of the reaction and the macroscopic outcomes of the reaction. All changes in matter involve some form of energy change. One key determinant of chemical transformations is the change in potential energy that results from changes in electrostatic forces. Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions. Applying the laws of thermodynamics will allow students to describe the essential role of energy and explain and predict the direction of changes in matter.

Approximate Length of Unit: 3 weeks

LEARNING TARGETS

NJ Student Learning Standards:

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

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

HS-PS3-4 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).

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

Career Readiness, Life Literacies, and Key Skills:

9.3.ST.2 Use technology to acquire, manipulate, analyze and report data.

9.3.ST.3 Describe and follow safety, health and environmental standards related to science, technology, engineering and mathematics (STEM) workplaces.

9.3 ST.4 Understand the nature and scope of the Science, Technology, Engineering & Mathematics Career Cluster and the role of STEM in society and the economy.

9.3.ST-ET.1 Use STEM concepts and processes to solve problems involving design and/or production.

9.3.ST-ET.5 Apply the knowledge learned in STEM to solve problems.

9.3.ST-SM.3 Analyze the impact that science and mathematics has on society.

9.3.ST-SM.4 Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.

9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas.

9.4.12.CI.3 Investigate new challenges and opportunities for personal growth, advancement, and transition.

- 9.4.12.CT.1** Identify problem-solving strategies used in the development of an innovative product or practice.
- 9.4.12.CT.2** Explain the potential benefits of collaborating to enhance critical thinking and problem solving.
- 9.4.12.CT.4** Participate in online strategy and planning sessions for course-based, school-based, or other project and determine the strategies that contribute to effective outcomes.
- 9.4.12.IML.3** Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions.
- 9.4.12.IML.5** Evaluate, synthesize, and apply information on climate change from various sources appropriately.
- 9.4.12.IML.7** Develop an argument to support a claim regarding a current workplace or societal/ethical issue such as climate change.
- 9.4.12.TL.1** Assess digital tools based on features such as accessibility options, capacities, and utility for accomplishing a specified task.
- 9.4.12.TL.2** Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.
- 9.4.12.TL.4** Collaborate in online learning communities or social networks or virtual worlds to analyze and propose a resolution to a real-world problem.

Interdisciplinary Connections and Standards:

ELA

- RI.CR.11–12.1** Accurately cite a range of thorough textual evidence and make relevant connections to strongly support a comprehensive analysis of multiple aspects of what an informational text says explicitly and inferentially, as well as interpretations of the text.
- RI.MF.11–12.6** Synthesize complex information across multiple sources and formats to develop ideas, resolve conflicting information, or develop an interpretation that goes beyond explicit text information (e.g., express a personal point of view, new interpretation of the concept).
- W.AW.11–12.1** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
- W.SE.11–12.6** 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 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.
- SL.UM.11–12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Mathematics

- N.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- N.Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- A.SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- A.SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- A.CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- A.CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- F.IF.C.7** Graph functions are expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
- F.BF.A.1** Write a function that describes a relationship between two quantities.
- S.ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that...

- 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 changes substances experience depend on the interactions between particles; impacting these interactions will impact the rate of the change.
- Attractive forces can explain the result of many changes/reactions. Often, the most likely result/product will bring particles with the strongest attraction closer together.

Unit Essential Questions:

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

Knowledge and Skills:

Students will know...

Subtopic 9.1 Introduction to Entropy

- Entropy increases when matter becomes more dispersed. For example, the phase change from solid to liquid or from liquid to gas results in a dispersal of matter as the individual particles become freer to move and generally occupy a larger volume. Similarly, for a gas, the entropy increases when there is an increase in volume (at constant temperature), and the gas molecules are able to move within a larger space. For reactions involving gas-phase reactants or products, the entropy generally increases when the total number of moles of gas-phase products is greater than the total number of moles of gas-phase reactants.
- Entropy increases when energy is dispersed. According to kinetic molecular theory (KMT), the distribution of kinetic energy among the particles of a gas broadens as the temperature increases. As a result, the entropy of the system increases with an increase in temperature.

Subtopic 9.2 Absolute Entropy and Entropy Change

- The entropy change for a process can be calculated from the absolute entropies of the species involved before and after the process occurs.

Subtopic 9.3 Gibbs Free Energy and Thermodynamic Favorability

- The Gibbs free energy change for a chemical process in which all the reactants and products are present in a standard state (as pure substances, as solutions of 1.0 M concentration, or as gases at a pressure of 1.0 atm (or 1.0 bar)) is given the symbol ΔG° .
- The standard Gibbs free energy change for a chemical or physical process is a measure of thermodynamic favorability. Historically, the term “spontaneous” has been used to describe processes for which $\Delta G^\circ < 0$. The phrase “thermodynamically favored” is preferred instead so that common misunderstandings (equating “spontaneous” with “suddenly” or “without cause”) can be avoided. When $\Delta G^\circ < 0$ for the process, it is said to be thermodynamically favored.
- The standard Gibbs free energy change for a physical or chemical process may also be determined from the standard Gibbs free energy of formation of the reactants and products.
- In some cases, it is necessary to consider both enthalpy and entropy to determine if a process will be thermodynamically favored. The freezing of water and the dissolution of sodium nitrate are examples of such phenomena.
- Knowing the values of ΔH° and ΔS° for a process at a given temperature allows ΔG° to be calculated directly.
- In general, the temperature conditions for a process to be thermodynamically favored ($\Delta G^\circ < 0$) can be predicted from the signs of ΔH° and ΔS°

- In cases where $\Delta H^\circ < 0$ and $\Delta S^\circ > 0$, no calculation of ΔG° is necessary to determine that the process is thermodynamically favored ($\Delta G^\circ < 0$). In cases where $\Delta H^\circ > 0$ and $\Delta S^\circ < 0$, no calculation of ΔG° is necessary to determine that the process is thermodynamically unfavored ($\Delta G^\circ > 0$).

Subtopic 9.4 Thermodynamic and Kinetic Control

- Many processes that are thermodynamically favored do not occur to any measurable extent, or they occur at extremely slow rates.
- Processes that are thermodynamically favored, but do not proceed at a measurable rate, are under “kinetic control.” High activation energy is a common reason for a process to be under kinetic control. The fact that a process does not proceed at a noticeable rate does not mean that the chemical system is at equilibrium. If a process is known to be thermodynamically favored, and yet does not occur at a measurable rate, it is reasonable to conclude that the process is under kinetic control.

Subtopic 9.5 Free Energy and Equilibrium

- The phrase “thermodynamically favored” ($\Delta G^\circ < 0$) means that the products are favored at equilibrium ($K > 1$) under standard conditions.
- The equilibrium constant is related to free energy.
- Connections between K and ΔG° can be made qualitatively through estimation. When ΔG° is near zero, the equilibrium constant will be close to 1. When ΔG° is much larger or much smaller than RT , the value of K deviates strongly from 1.
- Processes with $\Delta G^\circ < 0$ favor products (i.e., $K > 1$) and those with $\Delta G^\circ > 0$ favor reactants (i.e., $K < 1$).

Subtopic 9.6 Free Energy of Dissolution

- The free energy change (ΔG°) for dissolution of a substance reflects a number of factors: the breaking of the intermolecular interactions that hold the solid together, the reorganization of the solvent around the dissolved species, and the interaction of the dissolved species with the solvent. It is possible to estimate the sign and relative magnitude of the enthalpic and entropic contributions to each of these factors. However, making predictions for the total change in free energy of dissolution can be challenging due to the cancellations among the free energies associated with the three factors cited.

Subtopic 9.7 Coupled Reactions

- An external source of energy can be used to make a thermodynamically unfavorable process occur.
- A desired product can be formed by coupling a thermodynamically unfavorable reaction that produces that product to a favorable reaction (e.g., the conversion of ATP to ADP in biological systems). In the coupled system, the individual reactions share one or more common intermediates. The sum of the individual reactions produces an overall reaction that achieves the desired outcome and has $\Delta G^\circ < 0$.

Subtopic 9.8 Galvanic (Voltaic) and Electrolytic Cells

- Each component of an electrochemical cell (electrodes, solutions in the half-cells, salt bridge, voltage/current measuring device) plays a specific role in the overall functioning of the cell. The operational characteristics of the cell (galvanic vs. electrolytic, direction of electron flow, reactions occurring in each half-cell, change in electrode mass, evolution of a gas at an electrode, ion flow through the salt bridge) can be described at both the macroscopic and particulate levels.
- Galvanic, sometimes called voltaic, cells involve a thermodynamically favored reaction, whereas electrolytic cells involve a thermodynamically unfavored reaction. Visual representations of galvanic and electrolytic cells are tools of analysis to identify where half-reactions occur and in what direction current flows.
- For all electrochemical cells, oxidation occurs at the anode and reduction occurs at the cathode.

Subtopic 9.9 Cell Potential and Free Energy

- Electrochemistry encompasses the study of redox reactions that occur within electrochemical cells. The reactions are either thermodynamically favored (resulting in a positive voltage) or thermodynamically unfavored (resulting in a negative voltage and requiring an externally applied potential for the reaction to proceed).
- The standard cell potential of electrochemical cells can be calculated by identifying the oxidation and reduction half-reactions and their respective standard reduction potentials.
- ΔG° (standard Gibbs free energy change) is proportional to the negative of the cell potential for the redox reaction from which it is constructed. Thus, a cell with a positive E° involves a thermodynamically favored reaction, and a cell with a negative E° involves a thermodynamically unfavored reaction.

Subtopic 9.10 Cell Potential Under Nonstandard Conditions

- In a real system under nonstandard conditions, the cell potential will vary depending on the concentrations of the active species. The cell potential is a driving force toward equilibrium; the farther the reaction is from equilibrium, the greater the magnitude of the cell potential.
- Equilibrium arguments such as Le Châtelier's principle do not apply to electrochemical systems, because the systems are not in equilibrium.
- The standard cell potential E° corresponds to the standard conditions of $Q = 1$. As the system approaches equilibrium, the magnitude (i.e., absolute value) of the cell potential decreases, reaching zero at equilibrium (when $Q = K$). Deviations from standard conditions that take the cell further from equilibrium than $Q = 1$ will increase the magnitude of the cell potential relative to E° . Deviations from standard conditions that take the cell closer to equilibrium than $Q = 1$ will decrease the magnitude of the cell potential relative to E° . In concentration cells, the direction of spontaneous electron flow can be determined by considering the direction needed to reach equilibrium.
- Algorithmic calculations using the Nernst equation are insufficient to demonstrate an understanding of electrochemical cells under nonstandard conditions. However, students should qualitatively understand the effects of concentration on cell potential and use conceptual reasoning, including the qualitative use of the Nernst equation

Subtopic 9.11 Electrolysis and Faraday's Law

- Faraday's laws can be used to determine the stoichiometry of the redox reaction occurring in an electrochemical cell with respect to the following: number of electrons transferred, mass of material deposited on or removed from an electrode (as in electroplating), current, time elapsed, and charge of ionic species

Students will be able to...

Subtopic 9.1 Introduction to Entropy

- Identify the sign and relative magnitude of the entropy change associated with chemical or physical processes.

Subtopic 9.2 Absolute Entropy and Entropy Change

- Calculate the standard entropy change for a chemical or physical process based on the absolute entropies (standard molar entropies) of the species involved in the process.

Subtopic 9.3 Gibbs Free Energy and Thermodynamic Favorability

- Explain whether a physical or chemical process is thermodynamically favored based on an evaluation of ΔG° .

Subtopic 9.4 Thermodynamic and Kinetic Control

- Explain, in terms of kinetics, why a thermodynamically favored reaction might not occur at a measurable rate.

Subtopic 9.5 Free Energy and Equilibrium

- Explain whether a process is thermodynamically favored using the relationships between K , ΔG° , and T .

Subtopic 9.6 Free Energy of Dissolution

- Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process.

Subtopic 9.7 Coupled Reactions

- Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes.

Subtopic 9.8 Galvanic (Voltaic) and Electrolytic Cells

- Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.

Subtopic 9.9 Cell Potential and Free Energy

- Explain whether an electrochemical cell is thermodynamically favored, based on its standard cell potential and the constituent half-reactions within the cell.

Subtopic 9.10 Cell Potential Under Nonstandard Conditions

- Explain the relationship between deviations from standard cell conditions and changes in the cell potential.

Subtopic 9.11 Electrolysis and Faraday's Law

- Calculate the amount of charge flow based on changes in the amounts of reactants and products in an electrochemical cell.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly “understand”?

- End of Unit Common Assessment - See folder for assessment links.
- A mix of conceptual, representation-based, math-based, and data analysis questions will be used to gather formative data through:
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Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

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 - Make a Battery Lab
 - Thermodynamic Favorability Think Pair Share
 - Electroplating Activity
- Instruction on vocabulary, concepts, and problem solving techniques following gradual release framework.
- Collaborative and independent practice of foundational skills.
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RESOURCES

Teacher Resources:

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- Group whiteboards and dry erase materials
- Poster and individual periodic tables
- Calculators
- Laboratory equipment and chemicals for labs, activities, and demonstrations
- Student copies of textbook