



PISCATAWAY TOWNSHIP SCHOOLS

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AP Chemistry

Content Area: Science

Grade Span: 11-12

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Approval date: August 12, 2021

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COURSE OVERVIEW

Description		
<p>The AP Chemistry is a full year, 7.5 credit lab science course that is aligned with the College Board standards and requirements. It is an advanced course in theoretical and practical chemistry for students who have successfully completed a first year Academic or Honors chemistry course. This is a college-level course that includes a study of kinetics, equilibrium, electro-chemistry, thermodynamics, quantum mechanics, descriptive chemistry, and some organic chemistry. AP Chemistry is structured around two essential components which are science practices and course content. The science practices are central to the study and practice of chemistry. Students should develop and apply the described practices on a daily basis. The course content is grounded in big ideas, which are cross cutting concepts that build conceptual understanding and spiral throughout the course. Laboratory investigations are coupled with lecture concepts. Formal Labs interspersed throughout the year are designed to explore the six Science Practices and four Big Ideas, offering students a real-life experience for the theory they learn in class. Labs also afford students a chance to develop their data collecting and technical skills in the lab. Concluding each lab activity, is the formal write-up; which serves to show students how scientists record their experiments, their data and ultimately their findings and conclusions. Lab reports serve as an opportunity for students to engage in peer review, a common practice in the scientific community. In May, students will take the Chemistry Advanced Placement Exam administered by the College Boards.</p>		
Goals		
<p>With the ever-changing field of Chemistry, scientific literacy is crucial for all students, regardless of future profession in or outside of the sciences. Throughout the year, real-life phenomena are connected to fundamental chemistry concepts, showcasing Chemistry's importance for everyone. This course is designed to prepare students for the AP Chemistry Exam in May, and also prepares students for the first and second semester of Chemistry in college, should they choose to take those courses at the college level. Following the AP exam, students spend the remainder of the year working on various chemical projects or developing posters to showcase a topic in Chemistry which appealed to them, but was not explicitly covered in the course. At the end of the year, students will share their work with one another.</p>		
Scope and Sequence		
Unit	Topic(s)	Length
Unit 0	Review of Matter, Energy and Measurements; Atoms, molecules and ions; Chemical Reactions and stoichiometry; and Basic Redox	Summer Academy /Independent study
Unit 1	Reactions in Aqueous Solutions	9-10 Blocks
Unit 2	Thermochemistry	8-9 Blocks
Unit 3	Electronic Structure of Atoms	7-8 Blocks
Unit 4	Periodic Properties of the Elements	6-7 Blocks
Unit 5	Basic Concept of Chemical Bonding	4-5 Blocks
Unit 6	Molecular Geometry and Bonding Theories	5-6 Blocks
Unit 7	Gases	7-8 Blocks
Unit 8	Liquids and Intermolecular Forces, Solids and Modern Materials	10-11 Blocks
Unit 9	Properties of Solutions	5-6 Blocks
Unit 10	Chemical Kinetics	10-11 Blocks
Unit 11	Chemical Equilibrium	6-7 Blocks

Unit 12	Acid Base Equilibria	7-8 Blocks
Unit 13	Additional Aspects of Aqueous Equilibria	9-10 Blocks
Unit 14	Chemical Thermodynamics	5-6 Blocks
Unit 15	Electrochemistry	5-6 Blocks
Resources		
<p>Core Text: Theodore E. Brown, et al., <i>Chemistry: The Central Science</i>, 14th Edition. Pearson. New York, NY, 2018</p> <p>Suggested Resources: Trout, Laura, editor. <i>POGIL Activities for AP Chemistry</i>. Flinn Scientific & The POGIL Project. Batavia, IL, 2015</p>		

ALL UNITS: INSTRUCTIONAL FOCUS

College Board AP Chemistry Science Practices	
Practice 1	Models and Representations - Describe models and representations, including across scales.
Practice 2	Question and Method - Determine scientific questions and methods.
Practice 3	Representing Data and Phenomena - Create representations or models of chemical phenomena.
Practice 4	Model Analysis - Analyze and interpret models and representations on a single scale or across multiple scales.
Practice 5	Mathematical Routines - Solve problems using mathematical relationships.
Practice 6	Argumentation - Develop an explanation or scientific argument.
College Board AP Chemistry Big Ideas	
Big Idea 1	Scale, Proportion, and Quantity (SPQ) - Quantities in chemistry are expressed at both the macroscopic and atomic scale. Explanations, predictions, and other forms of argumentation in chemistry require understanding the meaning of these quantities, and the relationship between quantities at the same scale and across scales.
Big Idea 2	Structure and Properties (SAP) - Properties of substances observable at the macroscopic scale emerge from the structures of atoms and molecules and the interactions between them. Chemical reasoning moves in both directions across these scales. Properties are predicted from known aspects of the structures and interactions at the atomic scale. Observed properties are used to infer aspects of the structures and interactions.
Big Idea 3	Transformations (TRA) - At its heart, chemistry is about the rearrangement of matter. Understanding the details of these transformations requires reasoning at many levels as one must quantify what is occurring both macroscopically and at the atomic level during the process. This reasoning can be as simple as monitoring amounts of products made or as complex as visualizing the intermolecular forces among the species in a mixture. The rate of a transformation is also of interest, as particles must move and collide to initiate reaction events.
Big Idea 4	Energy (ENE) - Energy has two important roles in characterizing and controlling chemical systems. The first is accounting for the distribution of energy among the components of a system and the ways that heat exchanges, chemical reactions, and phase transitions redistribute this energy. The second is in considering the enthalpic and entropic driving forces for a chemical process. These are closely related to the dynamic equilibrium present in many chemical systems and the ways in which changes in experimental conditions alter the positions of these equilibria.

UNIT 0: INTRODUCTION -
Matter, Energy, and Measurement
Atoms, Molecules and Ions
Chemical Reactions and Reaction Stoichiometry
Basic Redox

Summary and Rationale

Summer Sneak Peek: Students will review key concepts addressed in the first year Chemistry course prior to the start of the year.

Introduction: Matter, Energy, and Measurement

- Subunit 1 – The Study of Chemistry
- Subunit 2 – Classification of Matter
- Subunit 3 – Properties of Matter
- Subunit 4 – The Nature of Energy
- Subunit 5 – Units of Measurement
- Subunit 6 – Uncertainty in Measurement
- Subunit 7 – Dimensional Analysis

Atoms, Molecules and Ions

- Subunit 1 – The Atomic Theory of Matter
- Subunit 2 – The Discovery of Atomic Structure
- Subunit 3 – The Modern View of Atomic Structure
- Subunit 4 – Atomic Weights
- Subunit 5 – The Periodic Table
- Subunit 6 – Molecules and Molecular Compounds
- Subunit 7 – Ions and Ionic Compounds
- Subunit 8 – Naming Inorganic Compounds
- Subunit 9 – Some Simple Organic Compounds

Chemical Reactions and Reaction Stoichiometry

- Subunit 1 – Chemical Equations
- Subunit 2 – Simple Patterns of Chemical Reactivity
- Subunit 3 – Formula Weights
- Subunit 4 – Avogadro's Number
- Subunit 5 – Empirical Formulas from Analysis
- Subunit 6 – Quantitative Information from Balanced Equations
- Subunit 7 – Limiting Reactants

Electrochemistry

- Subunit 1 – Oxidation States and Oxidation-Reduction Reactions
- Subunit 2 – Balancing Redox Equations

Recommended Pacing

One Week (Summer Academy)

College Board AP Chemistry Big Ideas

Big Idea 1: Scale, Proportion, and Quantity (SPQ)

Big Idea 2: Structure and Properties (SAP)

Big Idea 3: Transformations (TRA)

Instructional Focus

Enduring Understanding

SPQ - 1 The mole allows different units to be compared

SPQ - 2 Chemical formulas identify substances by their unique combination of atoms.

SAP - 2 The periodic table shows patterns in electronic structure and trends in atomic properties.

TRA - 1 A substance that changes its properties, or that changes into a different substance, can be represented by chemical equations.

SPQ - 4 When a substance changes into a new substance, or when its properties change, no mass is lost or gained.

TRA - 2 A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it.

Unit Essential Questions

- What is Chemistry?
- Why is Chemistry important?
- How to characterize and differentiate physical versus chemical properties.
- What is energy, and its many forms?
- What are the traditional units of measurement in Chemistry and how to switch between them with dimensional analysis?
- How are atoms structured?
- How was the atom discovered and its various models?
- How is the Periodic Table a helpful tool for scientists and everyday people alike?
- What are molecules and ions and how to name various compounds?
- How to write and balance a chemical equation?
- What is the significance of the mole and Avogadro's number?
- How to determine the limiting reactant in a reaction?

Learning Objective

SPQ - 1.A Calculate quantities of a substance or its relative number of particles using dimensional analysis and the mole concept.

SPQ - 1.B Explain the quantitative relationship between the mass spectrum of an element and the masses of the element's isotopes.

SPQ - 2.A Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance.

SPQ - 2.B Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture.

SAP-2.B Explain the relationship between trends in the reactivity of elements and periodicity.

TRA-1.A Identify evidence of chemical and physical changes in matter.

TRA-1.B Represent changes in matter with a balanced chemical or net ionic equation:

- a. For physical changes.
- b. For given information about the identity of the reactants and/or product.
- c. For ions in a given chemical reaction.

TRA-1.C Represent a given chemical reaction or physical process with a consistent particulate model.

TRA-1.D Explain the relationship between macroscopic characteristics and bond interactions for:

a. Chemical processes.

b. Physical processes.

SPQ-4.A Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process.

TRA-2.A Identify a reaction as acid base, oxidation-reduction, or precipitation.

TRA-2.C Represent a balanced redox reaction equation using half-reactions.

Essential Knowledge

SPQ – 1.A.1 One cannot count particles directly while performing laboratory work. Thus, there must be a connection between the masses of substances reacting and the actual number of particles undergoing chemical changes.

SPQ - 1.A.2 Avogadro's number ($N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$) 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.

SPQ - 1.A.3 Expressing the mass of an individual atom or molecule in atomic mass units (amu) is useful because the average mass in amu of one particle (atom or molecule) or formula unit of a substance will always be numerically equal to the molar mass of that substance in grams. Thus, there is a quantitative connection between the mass of a substance and the number of particles that the substance contains.

$$\text{EQN: } n = m/M$$

SPQ - 1.B.1 The mass spectrum of a sample containing a single element can be used to determine the identity of the isotopes of that element and the relative abundance of each isotope in nature.

SPQ - 1.B.2 The average atomic mass of an element can be estimated from the weighted average of the isotopic masses using the mass of each isotope and its relative abundance.

SPQ - 2.A.1 Some pure substances are composed of individual molecules, while others consist of atoms or ions held together in fixed proportions as described by a formula unit.

SPQ - 2.A.2 According to the law of definite proportions, the ratio of the masses of the constituent elements in any pure sample of that compound is always the same.

SPQ - 2.A.3 The chemical formula that lists the lowest whole number ratio of atoms of the elements in a compound is the empirical formula.

SPQ - 2.B.1 While pure substances contain molecules or formula units of a single type, mixtures contain molecules or formula units of two or more types, whose relative proportions can vary.

SPQ - 2.B.2 Elemental analysis can be used to determine the relative numbers of atoms in a substance and to determine its purity.

SAP-2.B.1 The likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of elements.

SAP-2.B.2 Elements in the same column of the periodic table tend to form analogous compounds.

SAP-2.B.3 Typical charges of atoms in ionic compounds are governed by their location on the periodic table and the number of valence electrons.

TRA-1.A.1 A physical change occurs when a substance undergoes a change in properties but not a change in composition. Changes in the phase of a substance (solid, liquid, gas) or formation/separation of mixtures of substances are common physical changes.

TRA-1.A.2 A chemical change occurs when substances are transformed into new substances, typically with different compositions. Production of heat or light, formation of a gas, formation of a precipitate, and/or color change provide possible evidence that a chemical change has occurred.

TRA-1.B.1 All physical and chemical processes can be represented symbolically by balanced equations.

TRA-1.B.2 Chemical equations represent chemical changes. These changes are the result of a rearrangement of atoms into new combinations; thus, any representation of a chemical change must contain equal numbers of atoms of every element before and after the change occurred. Equations thus demonstrate that mass is conserved

in chemical reactions.

TRA-1.B.3 Balanced molecular, complete ionic, and net ionic equations are differing symbolic forms used to represent a chemical reaction. The form used to represent the reaction depends on the context in which it is to be used.

TRA-1.C.1 Balanced chemical equations in their various forms can be translated into symbolic particulate representations.

TRA-1.D.1 Processes that involve the breaking and/or formation of chemical bonds are typically classified as chemical processes. Processes that involve only changes in intermolecular interactions, such as phase changes, are typically classified as physical processes.

TRA-1.D.2 Sometimes physical processes involve the breaking of chemical bonds. For example, plausible arguments could be made for the dissolution of a salt in water, as either a physical or chemical process, involves breaking of ionic bonds, and the formation of ion-dipole interactions between ions and solvent.

SPQ-4.A.1 Because atoms must be conserved during a chemical process, it is possible to calculate product amounts by using known reactant amounts, or to calculate reactant amounts given known product amounts.

SPQ-4.A.2 Coefficients of balanced chemical equations contain information regarding the proportionality of the amounts of substances involved in the reaction. These values can be used in chemical calculations involving the mole concept.

SPQ-4.A.3 Stoichiometric calculations can be combined with the ideal gas law and calculations involving molarity to quantitatively study gases and solutions.

TRA-2.A.2 Oxidation-reduction reactions involve transfer of one or more electrons between chemical species, as indicated by changes in oxidation numbers of the involved species. Combustion is an important subclass of oxidation-reduction reactions, in which a species reacts with oxygen gas. In the case of hydrocarbons, carbon dioxide and water are products of complete combustion.

TRA-2.A.3 In a redox reaction, electrons are transferred from the species that are oxidized to the species that are reduced.

TRA-2.A.4 Oxidation numbers may be assigned to each of the atoms in the reactants and products; this is often an effective way to identify the oxidized and reduced species in a redox reaction.

TRA-2.C.1 Balanced chemical equations for redox reactions can be constructed from half-reactions.

College Board AP Chemistry Science Practices

Practice 1 - Models and Representations

Practice 2 – Question and Method

Practice 3 – Representing Data and Phenomena

Practice 4 – Model Analysis

Practice 5 – Mathematical Routines

Practice 6 – Argumentation

Instructional Focus

Skills

- 5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.
- 5.D Identify information presented graphically to solve a problem.
- 2.A Identify a testable scientific question based on an observation, data, or a model.
- 5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).
- 4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.
- 2.B Formulate a hypothesis or predict the results of an experiment.
- 5.E Determine a balanced chemical equation for a given chemical phenomenon.
- 3.B Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).
- 6.B Support a claim with evidence from experimental data.
- 5.C Explain the relationship between variables within an equation when one variable changes.
- 1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic level properties.
- 5.E Determine a balanced chemical equation for a given chemical phenomenon.

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 2-119 and 848-856.

UNIT 1: REACTIONS IN AQUEOUS SOLUTIONS

Summary and Rationale

In this unit, students will expand on their use and understanding of stoichiometry while learning about the physical and chemical properties of such solutions. Simple reactions will be covered and serve as the foundation for complex reactions as well as explaining phenomena which are explored in other sciences: biology, geology, oceanography and others.

- Subunit 1 – General Properties of Aqueous Solutions
- Subunit 2 – Precipitation Reactions
- Subunit 3 – Acids, Bases, and Neutralization Reactions
- Subunit 4 – Oxidation-Reduction Reactions
- Subunit 5 – Concentration of Solutions
- Subunit 6 – Solution Stoichiometry and Chemical Analysis

Recommended Pacing

9-10 blocks

College Board AP Chemistry Big Ideas

Big Idea 1: Scale, Proportion, and Quantity (SPQ)

Big Idea 3: Transformations (TRA)

Instructional Focus

Enduring Understanding

TRA – 1 A substance that changes its properties, or that changes into a different substance, can be represented by chemical equations.

SPQ – 4 When a substance changes into a new substance, or when its properties change, no mass is lost or gained.

TRA – 2 A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it.

Essential Questions

- What is the composition and organization of matter?
- How and why do particles rearrange during a chemical and physical change?
- How is it possible to predict, given thermodynamic parameters, quantitative energy changes and the favored direction of thermodynamic changes?

Learning Objective

TRA-1.A Identify evidence of chemical and physical changes in matter.

TRA-1.B Represent changes in matter with a balanced chemical or net ionic equation:

- a. For physical changes.
- b. For given information about the identity of the reactants and/or product.
- c. For ions in a given chemical reaction.

TRA-1.C Represent a given chemical reaction or physical process with a consistent particulate model.

TRA-1.D Explain the relationship between macroscopic characteristics and bond interactions for:

- a. Chemical processes.

b. Physical processes.

SPQ-4.A Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process.

SPQ-4.B Identify the equivalence point in a titration based on the amounts of the titrant and analyte, assuming the titration reaction goes to completion.

TRA-2.A Identify a reaction as acid base, oxidation-reduction, or precipitation.

TRA-2.B Identify species as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species.

TRA-2.C Represent a balanced redox reaction equation using half-reactions.

Essential Knowledge

TRA-1.A.1 A physical change occurs when a substance undergoes a change in properties but not a change in composition. Changes in the phase of a substance (solid, liquid, gas) or formation/separation of mixtures of substances are common physical changes.

TRA-1.A.2 A chemical change occurs when substances are transformed into new substances, typically with different compositions. Production of heat or light, formation of a gas, formation of a precipitate, and/or color change provide possible evidence that a chemical change has occurred.

TRA-1.B.1 All physical and chemical processes can be represented symbolically by balanced equations.

TRA-1.B.2 Chemical equations represent chemical changes. These changes are the result of a rearrangement of atoms into new combinations; thus, any representation of a chemical change must contain equal numbers of atoms of every element before and after the change occurred. Equations thus demonstrate that mass is conserved in chemical reactions.

TRA-1.B.3 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.

TRA-1.C.1 Balanced chemical equations in their various forms can be translated into symbolic particulate representations.

TRA-1.D.1 Processes that involve the breaking and/or formation of chemical bonds are typically classified as chemical processes. Processes that involve only changes in intermolecular interactions, such as phase changes, are typically classified as physical processes.

TRA-1.D.2 Sometimes physical processes involve the breaking of chemical bonds. For example, plausible arguments could be made for the dissolution of a salt in water, as either a physical or chemical process, involves breaking of ionic bonds, and the formation of ion-dipole interactions between ions and solvent.

SPQ-4.A.1 Because atoms must be conserved during a chemical process, it is possible to calculate product amounts by using known reactant amounts, or to calculate reactant amounts given known product amounts.

SPQ-4.A.2 Coefficients of balanced chemical equations contain information regarding the proportionality of the amounts of substances involved in the reaction. These values can be used in chemical calculations involving the mole concept.

SPQ-4.A.3 Stoichiometric calculations can be combined with the ideal gas law and calculations involving molarity to quantitatively study gases and solutions.

SPQ-4.B.1 Titrations may be used to determine the concentration of an analyte in solution. The titrant has a known concentration of a species that reacts specifically and quantitatively with the analyte. The equivalence point of the titration occurs when the analyte is totally consumed by the reacting species in the titrant. The equivalence point is often indicated by a change in a property (such as color) that occurs when the equivalence point is reached. This observable event is called the endpoint of the titration.

TRA-2.A.1 Acid-base reactions involve transfer of one or more protons between chemical species.

TRA-2.A.2 Oxidation-reduction reactions involve transfer of one or more electrons between chemical species, as indicated by changes in oxidation numbers of the involved species. Combustion is an important subclass of oxidation-reduction reactions, in which a species reacts with oxygen gas. In the case of hydrocarbons, carbon dioxide and water are products of complete combustion.

TRA-2.A.3 In a redox reaction, electrons are transferred from the species that are oxidized to the species that are reduced.

TRA-2.A.4 Oxidation numbers may be assigned to each of the atoms in the reactants and products; this is often an effective way to identify the oxidized and reduced species in a redox reaction.

TRA-2.A.5 Precipitation reactions frequently involve mixing ions in aqueous solution to produce an insoluble or sparingly soluble ionic compound. All sodium, potassium, ammonium, and nitrate salts are soluble in water.

TRA-2.B.1 By definition, a Brønsted-Lowry acid is a proton donor and a Brønsted-Lowry base is a proton acceptor.

TRA-2.B.2 Only in aqueous solutions, water plays an important role in many acid-base reactions, as its molecular structure allows it to accept protons from and donate protons to dissolved species.

TRA-2.B.3 When an acid or base ionizes in water, the conjugate acid-base pairs can be identified and their relative strengths compared.

TRA-2.C.1 Balanced chemical equations for redox reactions can be constructed from half-reactions.

College Board AP Chemistry Science Practices

Practice 1 - Models and Representations

Practice 2 – Question and Method

Practice 3 – Representing Data and Phenomena

Practice 5 – Mathematical Routines

Practice 6 – Argumentation

Instructional Focus

Skills

2.B Formulate a hypothesis or predict the results of an experiment.

5.E Determine a balanced chemical equation for a given chemical phenomenon.

3.B Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).

6.B Support a claim with evidence from experimental data.

5.C Explain the relationship between variables within an equation when one variable changes.

3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.

1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic level properties.

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 120-161.

UNIT 2: THERMOCHEMISTRY

Summary and Rationale

In this unit, students will delve into chemical reactions and how energy plays a key role in whether a reaction occurs. Students will explore energy and its transformations into alternate forms.

- Subunit 1 – The Nature of Chemical Energy
- Subunit 2 – The First Law of Thermodynamics
- Subunit 3 – Enthalpy
- Subunit 4 – Enthalpies of Reactions
- Subunit 5 – Calorimetry
- Subunit 6 – Hess' Law
- Subunit 7 – Enthalpies of Formation
- Subunit 8 – Bond Enthalpies
- Subunit 9 Foods and Fuels

Recommended Pacing

8-9 Blocks

College Board AP Chemistry Big Ideas

Big Idea 4: Energy (ENE)

Instructional Focus

Enduring Understanding

ENE-2 Changes in a substance's properties or change into a different substance requires an exchange of energy.
ENE-3 The energy exchanged in a chemical transformation is required to break and form bonds.

Unit Essential Questions

- How and why do particles rearrange during a chemical and physical change?
- How is it possible to predict, given thermodynamic parameters, quantitative energy changes and the favored direction of thermodynamic changes?

Learning Objective

ENE-2.A Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation.

ENE-2.B Represent a chemical or physical transformation with an energy diagram.

ENE-2.C Explain the relationship between the transfer of thermal energy and molecular collisions.

ENE-2.D Calculate the heat q absorbed or released by a system undergoing heating/cooling based on the amount of the substance, the heat capacity, and the change in temperature.

ENE-2.E Explain changes in the heat q absorbed or released by a system undergoing a phase transition based on the amount of the substance in moles and the molar enthalpy of the phase transition.

ENE-2.F Calculate the heat q absorbed or released by a system undergoing a chemical reaction in relationship to the amount of the reacting substance in moles and the molar enthalpy of reaction.

ENE-3.A Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction.

ENE-3.B Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation.

ENE-3.C Represent a chemical or physical process as a sequence of steps.

ENE-3.D Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual steps.

Essential Knowledge

ENE-2.A.1 Temperature changes in a system indicate energy changes.

ENE-2.A.2 Energy changes in a system can be described as endothermic and exothermic processes such as the heating or cooling of a substance, phase changes, or chemical transformations.

ENE-2.A.3 When a chemical reaction occurs, the energy of the system either decreases (exothermic reaction), increases (endothermic reaction), or remains the same. For exothermic reactions, the energy lost by the reacting species (system) is gained by the surroundings, as heat transfer from or work done by the system. Likewise, for endothermic reactions, the system gains energy from the surroundings by heat transfer to or work done on the system.

ENE-2.A.4 The formation of a solution may be an exothermic or endothermic process, depending on the relative strengths of intermolecular/interparticle interactions before and after the dissolution process.

ENE-2.B.1 A physical or chemical process can be described with an energy diagram that shows the endothermic or exothermic nature of that process.

ENE-2.C.1 The particles in a warmer body have a greater average kinetic energy than those in a cooler body.

ENE-2.C.2 Collisions between particles in thermal contact can result in the transfer of energy. This process is called “heat transfer,” “heat exchange,” or “transfer of energy as heat.”

ENE-2.C.3 Eventually, thermal equilibrium is reached as the particles continue to collide. At thermal equilibrium, the average kinetic energy of both bodies is the same, and hence, their temperatures are the same.

ENE-2.D.1 The heating of a cool body by a warmer body is an important form of energy transfer between two systems. The amount of heat transferred between two bodies may be quantified by the heat transfer equation:
EQN: $q = mc\Delta T$.

Calorimetry experiments are used to measure the transfer of heat.

ENE-2.D.2 The first law of thermodynamics states that energy is conserved in chemical and physical processes.

ENE-2.D.3 The transfer of a given amount of thermal energy will not produce the same temperature change in equal masses of matter with differing specific heat capacities.

ENE-2.D.4 Heating a system increases the energy of the system, while cooling a system decreases the energy of the system.

ENE-2.D.5 The specific heat capacity of a substance and the molar heat capacity are both used in energy calculations.

ENE-2.D.6 Chemical systems change their energy through three main processes: heating/cooling, phase transitions, and chemical reactions.

ENE-2.E.1 Energy must be transferred to a system to cause a substance to melt (or boil). The energy of the system therefore increases as the system undergoes a solid-to-liquid (or liquid to gas) phase transition. Likewise, a system releases energy when it freezes (or condenses). The energy of the system decreases as the system undergoes a liquid-to-solid (or gas to liquid) phase transition. The temperature of a pure substance remains constant during a phase change.

ENE-2.E.2 The energy absorbed during a phase change is equal to the energy released during a complementary phase change in the opposite direction. For example, the molar heat of condensation of a substance is equal to the

negative of its molar heat of vaporization.

ENE-2.F.1 The enthalpy change of a reaction gives the amount of heat energy released (for negative values) or absorbed (for positive values) by a chemical reaction at constant pressure.

ENE-3.A.1 During a chemical reaction, bonds are broken and/or formed, and these events change the potential energy of the system.

ENE-3.A.2 The average energy required to break all of the bonds in the reactant molecules can be estimated by adding up the average bond energies of all the bonds in the reactant molecules. Likewise, the average energy released in forming the bonds in the product molecules can be estimated. If the energy released is greater than the energy required, the reaction is exothermic. If the energy required is greater than the energy released, the reaction is endothermic.

ENE-3.B.1 Tables of standard enthalpies of formation can be used to calculate the standard enthalpies of reactions.

EQN: $\Delta H^\circ_{\text{reaction}} = \sum \Delta H_f^\circ \text{products} - \sum \Delta H_f^\circ \text{reactants}$

ENE-3.C.1 Although the concept of “state function” is not required for the course, two principles of Hess’s law should be understood. First, when a reaction is reversed, the enthalpy change stays constant in magnitude but becomes reversed in mathematical sign. Second, when two (or more) reactions are added to obtain an overall reaction, the individual enthalpy changes of each reaction are added to obtain the net enthalpy of the overall reaction.

ENE-3.D.1 When the products of a reaction are at a different temperature than their surroundings, they exchange energy with the surroundings to reach thermal equilibrium. Thermal energy is transferred to the surroundings from the products of an exothermic reaction. Thermal energy is transferred from the surroundings to the products of an endothermic reaction.

College Board AP Chemistry Science Practices

Practice 1 - Models and Representations

Practice 2 – Question and Method

Practice 3 – Representing Data and Phenomena

Practice 4 – Model Analysis

Practice 5 – Mathematical Routines

Practice 6 – Argumentation

Instructional Focus

Skills

6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.

3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.

6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.

2.D Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.

1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic level properties.

4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.

5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 162- 211.

UNIT 3: ELECTRONIC STRUCTURE OF ATOMS

Summary and Rationale

In this unit, students explore quantum theory and its importance in chemistry, understanding the nature of light along with tools in quantum mechanics used to describe atoms and their structure at the subatomic level. As students do so, they will better understand how the arrangement of the Periodic Table of Elements came to be and why it is arranged as it is today.

- Subunit 1 – The Wave Nature of Light
- Subunit 2 – Quantized Energy and Photons
- Subunit 3 – Line Spectra and the Bohr Model
- Subunit 4 – The Wave Behavior of Matter
- Subunit 5 – Quantum Mechanics and Atomic Orbitals
- Subunit 6 – Representation of Orbitals
- Subunit 7 – Many-Electron Atoms
- Subunit 8 – Electron Configurations
- Subunit 9 – Electron Configurations and the Periodic Table

Recommended Pacing

7-8 Blocks

College Board AP Chemistry Big Ideas

Big Idea 2: Structure and Properties (SAP)

Instructional Focus

Enduring Understanding

SAP - 1 Atoms and molecules can be identified by their electron distribution and energy.

SAP – 8 Spectroscopy can determine the structure and concentration in a mixture of a chemical species.

Unit Essential Questions

- What is the composition and organization of matter?

Learning Objective

SAP-1.A Represent the electron configuration of an element or ions of an element using the Aufbau principle.

SAP-1.B Explain the relationship between the photoelectron spectrum of an atom or ion and:

- a. The electron configuration of the species.
- b. The interactions between the electrons and the nucleus.

SAP-8.B Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.

Essential Knowledge

SAP - 1.A.1 The atom is composed of negatively charged electrons and a positively charged nucleus that is made of protons and neutrons.

SAP-1.A.2 Coulomb's law is used to calculate the force between two charged particles.

EQN: $F_{coulombic} = \frac{q_1q_2}{r^2}$

SAP-1.A.3 In atoms and ions, the electrons can be thought of as being in “shells (energy levels)” and “subshells (sublevels),” as described by the electron configuration. Inner electrons are called core electrons, and outer electrons are called valence electrons. The electron configuration is explained by quantum mechanics, as delineated in the Aufbau principle and exemplified in the periodic table of the elements.

SAP-1.A.4 The relative energy required to remove an electron from different subshells of an atom or ion or from the same subshell in different atoms or ions (ionization energy) can be estimated through a qualitative application of Coulomb’s law. This energy is related to the distance from the nucleus and the effective (shield) charge of the nucleus.

SAP-1.B.1 The energies of the electrons in a given shell can be measured experimentally with photoelectron spectroscopy (PES). The position of each peak in the PES spectrum is related to the energy required to remove an electron from the corresponding subshell, and the height of each peak is (ideally) proportional to the number of electrons in that subshell

SAP-8.B.1 When a photon is absorbed (or emitted) by an atom or molecule, the energy of the species is increased (or decreased) by an amount equal to the energy of the photon.

SAP-8.B.2 The wavelength of the electromagnetic wave is related to its frequency and the speed of light by the equation: EQN: $c = \lambda\nu$.

The energy of a photon is related to the frequency of the electromagnetic wave through Planck’s equation ($E = h\nu$).

College Board AP Chemistry Science Practices

Practice 1 - Models and Representations

Practice 4 – Model Analysis

Practice 5 – Mathematical Routines

Instructional Focus

Skills

1.A Describe the components of and quantitative information from models and representations that illustrate particulate-level properties only.

4.B Explain whether a model is consistent with chemical theories.

5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 212-255.

UNIT 4: PERIODIC PROPERTIES OF THE ELEMENTS

Summary and Rationale

In this unit, students will explore several fundamental characteristics of the elements. We see how these change as one moves across the table, either down a group, or across a period. By doing so, students can make predictions regarding the physical and chemical properties of elements and compounds made from them.

- Subunit 1 – Development of the Periodic Table
- Subunit 2 – Effective Nuclear Charge
- Subunit 3 – Sizes of Atoms and Ions
- Subunit 4 – Ionization Energy
- Subunit 5 – Electron Affinity
- Subunit 6 – Metals, Nonmetals, and Metalloids
- Subunit 7 – Trends for Group 1A and Group 2A Metals
- Subunit 8 – Trends for Selected Nonmetals

Recommended Pacing

6-7 Blocks

College Board AP Chemistry Big Ideas

Big Idea 2: Structure and Properties (SAP)

Instructional Focus

Enduring Understanding

SAP- 2 The periodic table shows patterns in electronic structure and trends in atomic properties.

Unit Essential Questions

- What is the composition and organization of matter?
- By what mechanism does particle charge and arrangement give rise to the chemical and physical properties of substances?

Learning Objective

SAP-2.A Explain the relationship between trends in atomic properties of elements and electronic structure and periodicity.

SAP-2.B Explain the relationship between trends in the reactivity of elements and periodicity.

Essential Knowledge

SAP-2.A.1 The organization of the periodic table is based on the recurring properties of the elements and explained by the pattern of electron configurations and the presence of completely or partially filled shells (and subshells) of electrons in atoms.

SAP-2.A.2 Trends in atomic properties within the periodic table (periodicity) can be qualitatively understood through the position of the element in the periodic table, Coulomb's law, the shell model, and the concept of

shielding/effective nuclear charge. These properties include:

- a. Ionization energy
- b. Atomic and ionic radii
- c. Electron affinity
- d. Electronegativity.

SAP-2.A.3 The periodicity (in SAP-2.A.2) is useful to predict /estimate values of properties in the absence of data.

SAP-2.B.1 The likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of elements.

SAP-2.B.2 Elements in the same column of the periodic table tend to form analogous compounds.

SAP-2.B.3 Typical charges of atoms in ionic compounds are governed by their location on the periodic table and the number of valence electrons.

College Board AP Chemistry Science Practices

Practice 4 – Model Analysis

Instructional Focus

Skills

4.A Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.

4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 256-297.

UNIT 5: BASIC CONCEPTS OF CHEMICAL BONDING

Summary and Rationale

In this unit, students will review the electronic structure of atoms and compounds and how to represent these in pictorial form. Students will then learn about the different types of bonds, what makes them different and what requirements must be fulfilled to form a bond; be it nonpolar, polar covalent or ionic.

- Subunit 1 – Lewis Symbols and the Octet Rule
- Subunit 2 – Ionic Bonding
- Subunit 3 – Covalent Bonding
- Subunit 4 – Bond Polarity and Electronegativity
- Subunit 5 – Drawing Lewis Structures
- Subunit 6 – Resonance Structures
- Subunit 7 – Exceptions to the Octet Rule
- Subunit 8 – Strengths and Lengths of Covalent Bonds

Recommended Pacing

4-5 Blocks

College Board AP Chemistry Big Ideas

Big Idea 2: Structure and Properties (SAP)

Enduring Understanding

SAP-3 Atoms or ions bond due to interactions between them, forming molecules.

SAP-4 Molecular compounds are arranged based on Lewis diagrams and Valence Shell Electron Pair Repulsion (VSEPR) theory.

Unit Essential Questions

- What is the composition and organization of matter?
- By what mechanism does particle charge and arrangement give rise to the chemical and physical properties of substances?

Learning Objective

SAP-3.A Explain the relationship between the type of bonding and the properties of the elements participating

SAP-3.B Represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength

SAP-3.C Represent an ionic solid with a particulate model that is consistent with Coulomb's law and the properties of the constituent ions.

SAP-4.A Represent a molecule with a Lewis diagram.

SAP-4.B Represent a molecule with a Lewis diagram that accounts for resonance between equivalent structures or that uses formal charge to select between nonequivalent structures.

Essential Knowledge

SAP-3.A.1 Electronegativity values for the representative elements increase going from left to right across a period and decrease going down a group. These trends can be understood qualitatively through the electronic structure of the atoms, the shell model, and Coulomb's law.

SAP-3.A.2 Valence electrons shared between atoms of similar electronegativity constitute a nonpolar covalent bond. For example, bonds between carbon and hydrogen are effectively nonpolar even though carbon is slightly more electronegative than hydrogen.

SAP-3.A.3 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.

SAP-3.A.4 The difference in electronegativity is not the only factor in determining if a bond should be designated as ionic or covalent. Generally, bonds between a metal and nonmetal are ionic, and bonds between two nonmetals are covalent. Examination of the properties of a compound is the best way to characterize the type of bonding.

SAP-3.A.5 In a metallic solid, the valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom.

SAP-3.B.1 A graph of potential energy versus the distance between atoms is a useful representation for describing the interactions between atoms. Such graphs illustrate both the equilibrium bond length (the separation between atoms at which the potential energy is lowest) and the bond energy (the energy required to separate the atoms).

SAP-3.B.2 In a covalent bond, the bond length is influenced by both the size of the atom's core and the bond order (i.e., single, double, triple). Bonds with a higher order are shorter and have larger bond energies.

SAP-3.B.3 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.

SAP-3.C.1 The cations and anions in an ionic crystal are arranged in a systematic, periodic 3-D array that maximizes the attractive forces among cations and anions while minimizing the repulsive forces.

SAP-4.A.1 Lewis diagrams can be constructed according to an established set of principles.

SAP-4.B.1 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.

SAP-4.B.2 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.

SAP-4.B.3 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.

College Board AP Chemistry Science Practices

Practice 3 – Representing Data and Phenomena

Practice 4 – Model Analysis

Practice 6 – Argumentation

Instructional Focus
Skills
<p>6.A Make a scientific claim.</p> <p>3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.</p> <p>4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.</p> <p>3.B Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).</p> <p>6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.</p>
Resources
<p>Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 298-337.</p>

UNIT 6: MOLECULAR GEOMETRY

Summary and Rationale

In this unit, students will be able to determine the geometric shape of a molecule based on its components, including lone pairs of electrons and specific atoms. Students will be able to explain how this shape affects the molecule's ability to interact with different compounds.

Subunit 1 – Molecular Shapes

Subunit 2 – The VESPR Model

Subunit 3 – Molecular Shape and Molecular Polarity

Subunit 4 - Covalent Bonding and Orbital Overlap

Subunit 5 – Hybrid Orbitals

Subunit 6 – Multiple Bonds

Subunit 7 – Molecular Orbitals

Subunit 8 – Bonding in Period 2 Diatomic Molecules

Recommended Pacing

5-6 Blocks

College Board AP Chemistry Big Ideas

Big Idea 2: Structure and Properties (SAP)

Instructional Focus

Enduring Understanding

SAP-3 Atoms or ions bond due to interactions between them, forming molecules.

SAP-4 Molecular compounds are arranged based on Lewis diagrams and Valence Shell Electron Pair Repulsion (VSEPR) theory.

Unit Essential Questions

- By what mechanism does particle charge and arrangement give rise to the chemical and physical properties of substances?

Learning Objective

SAP-3.A Explain the relationship between the type of bonding and the properties of the elements participating

SAP-3.B Represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength

SAP-4.A Represent a molecule with a Lewis diagram.

SAP-4.B Represent a molecule with a Lewis diagram that accounts for resonance between equivalent structures or that uses formal charge to select between nonequivalent structures.

SAP-4.C Based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities:

- a. Explain structural properties of molecules.
- b. Explain electron properties of molecules.

Essential Knowledge

SAP-3.A.1 Electronegativity values for the representative elements increase going from left to right across a period and decrease going down a group. These trends can be understood qualitatively through the electronic structure of the atoms, the shell model, and Coulomb's law.

SAP-3.A.2 Valence electrons shared between atoms of similar electronegativity constitute a nonpolar covalent bond. For example, bonds between carbon and hydrogen are effectively nonpolar even though carbon is slightly more electronegative than hydrogen

SAP-3.A.3 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.

SAP-3.A.4 The difference in electronegativity is not the only factor in determining if a bond should be designated as ionic or covalent. Generally, bonds between a metal and nonmetal are ionic, and bonds between two nonmetals are covalent. Examination of the properties of a compound is the best way to characterize the type of bonding.

SAP-3.A.5 In a metallic solid, the valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom.

SAP-3.B.1 A graph of potential energy versus the distance between atoms is a useful representation for describing the interactions between atoms. Such graphs illustrate both the equilibrium bond length (the separation between atoms at which the potential energy is lowest) and the bond energy (the energy required to separate the atoms).

SAP-3.B.2 In a covalent bond, the bond length is influenced by both the size of the atom's core and the bond order (i.e., single, double, triple). Bonds with a higher order are shorter and have larger bond energies.

SAP-3.B.3 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.

SAP-4.A.1 Lewis diagrams can be constructed according to an established set of principles.

SAP-4.B.1 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.

SAP-4.B.2 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.

SAP-4.B.3 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.

SAP-4.C.1 VSEPR theory uses the Coulombic repulsion between electrons as a basis for predicting the arrangement of electron pairs around a central atom.

SAP-4.C.2 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
- Bond angles
- Relative bond energies based on bond order
- Relative bond lengths (multiple bonds, effects of atomic radius)

- e. Presence of a dipole moment
- f. Hybridization of valence orbitals of the molecule

SAP-4.C.3 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° .

SAP-4.C.4 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 structural isomers.

College Board AP Chemistry Science Practices

Practice 3 – Representing Data and Phenomena

Practice 4 – Model Analysis

Practice 6 – Argumentation

Instructional Focus

Skills

6.A Make a scientific claim.

3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.

4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.

3.B Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).

6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 340-393.

UNIT 7: GASES

Summary and Rationale

In this unit, students will examine the physical properties of gases, what is atmospheric pressure, how gases respond to changes in temperature, pressure and concentration. Students will learn about ideal gases, and how real gases differ from them and why this is significant.

- Subunit 1 – Characteristics of Gases
- Subunit 2 – Pressure
- Subunit 3 – The Gas Laws
- Subunit 4 – The Ideal-Gas Equation
- Subunit 5 – Further Applications of the Ideal-Gas Equation
- Subunit 6 – Gas Mixtures and Partial Pressures
- Subunit 7 – The Kinetic-Molecular Theory of Gases
- Subunit 8 – Molecular Effusion and Diffusion
- Subunit 9 – Real Gases: Deviations from Ideal Behavior

Recommended Pacing

7-8 Blocks

College Board AP Chemistry Big Ideas

Big Idea 2: Structure and Properties (SAP)

Instructional Focus

Enduring Understanding

SAP-6 Matter exists in three states: solid, liquid, and gas, and their differences are influenced by variances in spacing and motion of the molecules.

SAP-7 Gas properties are explained macroscopically—using the relationships among pressure, volume, temperature, moles, gas constant—and molecularly by the motion of the gas.

Unit Essential Questions

- What is the composition and organization of matter?
- By what mechanism does particle charge and arrangement give rise to the chemical and physical properties of substances?
- How and why do particles rearrange during a chemical and physical change?
- How is it possible to predict, given thermodynamic parameters, quantitative energy changes and the favored direction of thermodynamic changes?

Learning Objective

SAP-6.A Represent the differences between solid, liquid, and gas phases using a particulate level model.

SAP-7.A Explain the relationship between the macroscopic properties of a sample of gas or mixture of gases using the ideal gas law.

SAP-7.B Explain the relationship between the motion of particles and the macroscopic properties of gases with:

- The kinetic molecular theory (KMT).
- A particulate model.
- A graphical representation.

SAP-7.C Explain the relationship among non-ideal behaviors of gases, interparticle forces, and/or volumes.

Essential Knowledge

SAP-6.A.4 In the gas phase, the particles are in constant motion. Their frequencies of collision and the average spacing between them are dependent on temperature, pressure, and volume. Because of this constant motion, and minimal effects of forces between particles, a gas has neither a definite volume nor a definite shape.

SAP-7.A.1 The macroscopic properties of ideal gases are related through the ideal gas law: EQN: $PV = nRT$.

SAP-7.A.2 In a sample containing a mixture of ideal gases, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the total pressure of the sample is the sum of the partial pressures.

$$\text{EQN: } P_A = P_{\text{total}} \times X_A,$$

where X_A = moles A/total moles;

$$\text{EQN: } P_{\text{total}} = P_A + P_B + P_C + \dots$$

SAP-7.A.3 Graphical representations of the relationships between P , V , T , and n are useful to describe gas behavior.

SAP-7.B.1 The kinetic molecular theory (KMT) relates the macroscopic properties of gases to motions of the particles in the gas. The Maxwell-Boltzmann distribution describes the distribution of the kinetic energies of particles at a given temperature.

SAP-7.B.2 All the particles in a sample of matter are in continuous, random motion. The average kinetic energy of a particle is related to its average velocity by the equation:

$$\text{EQN: } KE = \frac{1}{2} mv^2.$$

SAP-7.B.3

The Kelvin temperature of a sample of matter is proportional to the average kinetic energy of the particles in the sample.

SAP-7.B.4 The Maxwell-Boltzmann distribution provides a graphical representation of the energies/velocities of particles at a given temperature.

SAP-7.C.1 The ideal gas law does not explain the actual behavior of real gases. Deviations from the ideal gas law may result from interparticle attractions among gas molecules, particularly at conditions that are close to those resulting in condensation. Deviations may also arise from particle volumes, particularly at extremely high pressures.

College Board AP Chemistry Science Practices

Practice 3 – Representing Data and Phenomena

Practice 4 – Model Analysis

Practice 5 – Mathematical Routines

Practice 6 – Argumentation

Instructional Focus
Skills
<p>3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).</p> <p>5.C Explain the relationship between variables within an equation when one variable changes.</p> <p>4.A Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.</p> <p>6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.</p>
Resources
<p>Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 394-433.</p>

UNIT 8: LIQUIDS AND INTERMOLECULAR FORCES

Summary and Rationale

In this unit, students will learn about the various forces through which molecules may interact with one another. Students will connect how the geometry and composition of these molecules dictates the type of forces exhibited and be able to explain why they occur. Students will then learn to connect these intermolecular forces to physical properties exhibited by these compounds.

- Subunit 1 – A Molecular Comparison of Gases, Liquids, and Solids
- Subunit 2 – Intermolecular Forces
- Subunit 3 – Select Properties of Liquids
- Subunit 4 – Phase Changes
- Subunit 5 – Vapor Pressure
- Subunit 6 – Phase Diagrams
- Subunit 7 – Liquid Crystals

Solids and Modern Materials: In this unit, students will learn about the properties of the three main groups of solids: insulators, semi-conductors and conductors. Students will learn about the electrical properties of each and learn about the bonds which hold solids together including covalent, ionic and metallic.

- Subunit 1 – Classification of Solids
- Subunit 2 – Structures of Solids
- Subunit 3 – Metallic Solids
- Subunit 4 – Metallic Bonding
- Subunit 5 – Ionic Solids
- Subunit 6 – Molecular Solids
- Subunit 7 – Covalent-Network Solids
- Subunit 8 – Polymers
- Subunit 9 – Nanomaterials

Recommended Pacing

10-11 Blocks

College Board AP Chemistry Big Ideas

Big Idea 2: Structure and Properties (SAP)

Instructional Focus

Enduring Understanding

SAP- 5 Intermolecular forces can explain the physical properties of a material.

SAP-6 Matter exists in three states: solid, liquid, and gas, and their differences are influenced by variances in spacing and motion of the molecules.

SAP-3 Atoms or ions bond due to interactions between them, forming molecules.

Unit Essential Questions

- By what mechanism does particle charge and arrangement give rise to the chemical and physical properties of substances?
- How is it possible to predict, given thermodynamic parameters, quantitative energy changes and the favored direction of thermodynamic changes?

Learning Objective

SAP-5.A Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when:

- The molecules are of the same chemical species.
- The molecules are of two different chemical species.

SAP-5.B Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.

SAP-6.A Represent the differences between solid, liquid, and gas phases using a particulate level model.

SAP-3.D Represent a metallic solid and/or alloy using a model to show essential characteristics of the structure and interactions present in the substance.

Essential Knowledge

SAP-5.A.1 London dispersion forces are a result of the Coulombic interactions between temporary, fluctuating dipoles. London dispersion forces are often the strongest net intermolecular force between large molecules.

- 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.”

SAP-5.A.2 The dipole moment of a polar molecule leads to additional interactions with other chemical species.

- Dipole-induced dipole interactions are present between a polar and nonpolar molecule. These forces are always attractive. The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule.
- 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.

SAP-5.A.3 The relative strength and orientation dependence of dipole-dipole and ion-dipole forces can be understood qualitatively by considering the sign of the partial charges responsible for the molecular dipole moment, and how these partial charges interact with an ion or with an adjacent dipole.

SAP-5.A.4 Hydrogen bonding is a strong type of intermolecular interaction that exists when hydrogen atoms covalently bonded to the highly electronegative atoms (N, O, and F) are attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a different molecule, or a different part of the same molecule.

SAP-5.A.5 In large biomolecules, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule.

SAP-5.B.1 Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present. Because intermolecular interactions are broken when a substance vaporizes, the vapor pressure and boiling point are directly related to the strength of those interactions. Melting points also tend to correlate with interaction strength, but because the interactions are only rearranged, in melting, the relations can be more subtle.

SAP-5.B.2 Particulate-level representations, showing multiple interacting chemical species, are a useful means to

communicate or understand how intermolecular interactions help to establish macroscopic properties.

SAP-5.B.3 Due to strong interactions between ions, ionic solids tend to have low vapor pressures, high melting points, and high boiling points. They tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer. They conduct electricity only when the ions are mobile, as when the ionic solid is melted or dissolved in water or another solvent.

SAP-5.B.4 In covalent network solids, the atoms are covalently bonded together into a three-dimensional network (e.g., diamond) or layers of two-dimensional networks (e.g., graphite). These are only formed from nonmetals: elemental (e.g., diamond, graphite) or binary compounds of two nonmetals (e.g., silicon dioxide and silicon carbide). Due to the strong covalent interactions, covalent solids have high melting points. Three-dimensional network solids are also rigid and hard, because the covalent bond angles are fixed. However, graphite is soft because adjacent layers can slide past each other relatively easily.

SAP-5.B.5 Molecular solids are composed of distinct, individual units of covalently-bonded molecules attracted to each other through relatively weak intermolecular forces. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. They do not conduct electricity because their valence electrons are tightly held within the covalent bonds and the lone pairs of each constituent molecule. Molecular solids are sometimes composed of very large molecules or polymers.

SAP-5.B.6 Metallic solids are good conductors of electricity and heat, due to the presence of free valence electrons. They also tend to be malleable and ductile, due to the ease with which the metal cores can rearrange their structure. In an interstitial alloy, interstitial atoms tend to make the lattice more rigid, decreasing malleability and ductility. Alloys typically retain a sea of mobile electrons and so remain conducting.

SAP-5.B.7 In large biomolecules or polymers, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule. The functionality and properties of such molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions.

SAP-6.A.1 Solids can be crystalline, where the particles are arranged in a regular three-dimensional structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. In both cases, the motion of the individual particles is limited, and the particles do not undergo overall translation with respect to each other. The structure of the solid is influenced by interparticle interactions and the ability of the particles to pack together.

SAP-6.A.2 The constituent particles in liquids are in close contact with each other, and they are continually moving and colliding. The arrangement and movement of particles are influenced by the nature and strength of the forces (e.g., polarity, hydrogen bonding, and temperature) between the particles.

SAP-6.A.3 The solid and liquid phases for a particular substance typically have similar molar volume because, in both phases, the constituent particles are in close contact at all times.

SAP-6.A.4 In the gas phase, the particles are in constant motion. Their frequencies of collision and the average spacing between them are dependent on temperature, pressure, and volume. Because of this constant motion, and minimal effects of forces between particles, a gas has neither a definite volume nor a definite shape.

SAP-3.D.1 Metallic bonding can be represented as an array of positive metal ions surrounded by delocalized valence electrons (i.e., a “sea of electrons”).

SAP-3.D.2 Interstitial alloys form between atoms of different radii, where the smaller atoms fill the interstitial spaces between the larger atoms (e.g., with steel in which carbon occupies the interstices in iron).

SAP-3.D.3 Substitutional alloys form between atoms of comparable radius, where one atom substitutes for the other in the lattice. (In certain brass alloys, other elements, usually zinc, substitute for copper.)

College Board AP Chemistry Science Practices

Practice 3 – Representing Data and Phenomena

Practice 4 – Model Analysis

Instructional Focus

Skills

3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).

4.A Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.

4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 434-523.

UNIT 9: PROPERTIES OF SOLUTIONS

Summary and Rationale
<p>In this unit, students will learn about the properties of homogeneous mixtures of solids, liquids and gases, along with their components: the solvent and solute.</p> <ul style="list-style-type: none">• Subunit 1 – The Solution Process• Subunit 2 – Saturated Solutions and Solubility• Subunit 3 – Factors Affecting Solubility• Subunit 4 – Expressing Solution Concentration• Subunit 5 – Colligative Properties• Subunit 6 – Colloids
Recommended Pacing
5-6 Blocks
College Board AP Chemistry Big Ideas
Big Idea 1: Scale, Proportion, and Quantity (SPQ) Big Idea 2: Structure and Properties (SAP)
Instructional Focus
Enduring Understanding
SPQ - 3 Interactions between intermolecular forces influence the solubility and separation of mixtures. SAP – 8 Spectroscopy can determine the structure and concentration in a mixture of a chemical species.
Unit Essential Questions
<ul style="list-style-type: none">• What is the composition and organization of matter?• By what mechanism does particle charge and arrangement give rise to the chemical and physical properties of substances?• How and why do particles rearrange during a chemical and physical change?
Learning Objective
SPQ-3.A Calculate the number of solute particles, volume, or molarity of solutions. SPQ-3.B Using particulate models for mixtures: <ul style="list-style-type: none">a. Represent interactions between components.b. Represent concentrations of components. SPQ-3.C Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles. SAP-8.A Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region. SAP-8.C Explain the amount of light absorbed by a solution of molecules or ions in relationship to the concentration, path length, and molar absorptivity
Essential Knowledge

SPQ-3.A.1 Solutions, also sometimes called homogeneous mixtures, can be solids, liquids, or gases. In a solution, the macroscopic properties do not vary throughout the sample. In a heterogeneous mixture, the macroscopic properties depend on location in the mixture.

SPQ-3.A.2 Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory. EQN: $M = n_{\text{solute}}/L_{\text{solution}}$

SPQ-3.B.1 Particulate representations of solutions communicate the structure and properties of solutions, by illustration of the relative concentrations of the components in the solution and drawings that show interactions among the components.

SPQ-3.C.1 The components of a liquid solution cannot be separated by filtration. They can, however, be separated using processes that take advantage of differences in the intermolecular interactions of the components.

a. Chromatography (paper, thin-layer, and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components of the solution (the mobile phase) and with the surface components of the stationary phase.

b. Distillation separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components and the effects these interactions have on the vapor pressures of the components in the mixture.

SPQ-3.C.2 Substances with similar intermolecular interactions tend to be miscible or soluble in one another.

SAP-8.A.1 Differences in absorption or emission of photons in different spectral regions are related to the different types of molecular motion or electronic transition:

a. Microwave radiation is associated with transitions in molecular rotational levels.

b. Infrared radiation is associated with transitions in molecular vibrational levels.

c. Ultraviolet/visible radiation is associated with transitions in electronic energy levels.

SAP-8.C.1 The Beer-Lambert law relates the absorption of light by a solution to three variables according to the equation: EQN: $A = Ebc$.

The molar absorptivity E describes how intensely a sample of molecules or ions absorbs light of a specific wavelength. The path length b and concentration c are proportional to the number of absorbing species.

SAP-8.C.2 In most experiments the path length and wavelength of light are held constant. In such cases, the absorbance is proportional only to the concentration of absorbing molecules or ions.

College Board AP Chemistry Science Practices

Practice 2 – Question and Method

Practice 3 – Representing Data and Phenomena

Practice 4 – Model Analysis

Practice 5 – Mathematical Routines

Instructional Focus

Skills

5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).

2.C Identify experimental procedures that are aligned to a scientific question (which may include a sketch of a

lab setup).

4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.

5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

2.E Identify or describe potential sources of experimental error.

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 524-567.

UNIT 10: CHEMICAL KINETICS

Summary and Rationale

In this unit, students will learn about what factors can slow or speed up a reaction's progression or rate. Students will be able to derive the rate, rate constant, the order and concentration of reactants using experimentally derived data and application.

- Subunit 1 – Factors That Affect Reaction Rates
- Subunit 2 – Reaction Rates
- Subunit 3 – Concentration of Rate Laws
- Subunit 4 – The Change in Concentration with Time
- Subunit 5 – Temperature and Rate
- Subunit 6 – Reaction Mechanisms
- Subunit 7 – Catalysis

Recommended Pacing

10-11 Blocks

College Board AP Chemistry Big Ideas

Big Idea 3: Transformations (TRA)

Big Idea 4: Energy (ENE)

Instructional Focus

Enduring Understanding

TRA-3 Some reactions happen quickly, while others happen more slowly and depend on reactant concentrations and temperature.

TRA-4 There is a relationship between the speed of a reaction and the collision frequency of particle collisions.

TRA-5 Many chemical reactions occur through a series of elementary reactions. These elementary reactions when combined form a chemical equation.

ENE-1 The speed at which a reaction occurs can be influenced by a catalyst.

Unit Essential Questions

- What factors affect the rate of a chemical reaction?
- For a given system, what factors determine the factors favored by reversible change, if a favored direction exists?
- If the system is perturbed, how will it respond?

Learning Objective

TRA-3.B Represent experimental data with a consistent rate law expression.

TRA-3.C Identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time.

TRA-4.A Represent an elementary reaction as a rate law expression using stoichiometry.

TRA-4.B Explain the relationship between the rate of an elementary reaction and the frequency, energy, and orientation of molecular collisions.

TRA-4.C Represent the activation energy and overall energy change in an elementary reaction using a reaction energy profile.

TRA-5.A Identify the components of a reaction mechanism.

TRA-5.B Identify the rate law for a reaction from a mechanism in which the first step is rate limiting.

TRA-5.C Identify the rate law for a reaction from a mechanism in which the first step is not rate limiting.

TRA-5.D Represent the activation energy and overall energy change in a multistep reaction with a reaction energy profile.

ENE-1.A Explain the relationship between the effect of a catalyst on a reaction and changes in the reaction mechanism.

Essential Knowledge

TRA-3.B.1 Experimental methods can be used to monitor the amounts of reactants and/or products of a reaction and to determine the rate of the reaction.

TRA-3.B.2 The rate law expresses the rate of a reaction as proportional to the concentration of each reactant raised to a power.

TRA-3.B.3 The power of each reactant in the rate law is the order of the reaction with respect to that reactant. The sum of the powers of the reactant concentrations in the rate law is the overall order of the reaction.

TRA-3.B.4 The proportionality constant in the rate law is called the rate constant. The value of this constant is temperature dependent and the units reflect the overall reaction order.

TRA-3.B.5 Comparing initial rates of a reaction is a method to determine the order with respect to each reactant.

TRA-3.C.1 The order of a reaction can be inferred from a graph of concentration of reactant versus time.

TRA-3.C.2 If a reaction is first order with respect to a reactant being monitored, a plot of the natural log (ln) of the reactant concentration as a function of time will be linear.

TRA-3.C.3 If a reaction is second order with respect to a reactant being monitored, a plot of the reciprocal of the concentration of that reactant versus time will be linear.

TRA-3.C.4 The slopes of the concentration versus time data for zeroth, first, and second order reactions can be used to determine the rate constant for the reaction.

Zeroth order: EQN: $[A]_t - [A]_0 = -kt$ First order: EQN: $\ln[A]_t - \ln[A]_0 = -kt$ Second order: EQN: $1/[A]_t - 1/[A]_0 = kt$

TRA-3.C.5 Half-life is a critical parameter for first order reactions because the half-life is constant and related to the rate constant for the reaction by the equation: EQN: $t_{1/2} = 0.693/k$.

TRA-3.C.6 Radioactive decay processes provide an important illustration of first order kinetics.

TRA-4.A.1 The rate law of an elementary reaction can be inferred from the stoichiometry of the molecules participating in a collision.

TRA-4.A.2 Elementary reactions involving the simultaneous collision of three or more particles are rare.

TRA-4.B.1 For an elementary reaction to successfully produce products, reactants must successfully collide to initiate bond-breaking and bond-making events.

TRA-4.B.2 In most reactions, only a small fraction of the collisions leads to a reaction. Successful collisions have both sufficient energy to overcome energy barriers and orientations that allow the bonds to rearrange in the required manner.

TRA-4.B.3 The Maxwell-Boltzmann distribution curve describes the distribution of particle energies; this distribution can be used to gain a qualitative estimate of the fraction of collisions with sufficient energy to lead to a reaction, and also how that fraction depends on temperature.

TRA-4.C.1 Elementary reactions typically involve the breaking of some bonds and the forming of new ones.

TRA-4.C.2 The reaction coordinate is the axis along which the complex set of motions involved in rearranging reactants to form products can be plotted.

TRA-4.C.3 The energy profile gives the energy along the reaction coordinate, which typically proceeds from reactants, through a transition state, to products. The energy difference between the reactants and the transition state is the activation energy for the forward reaction.

TRA-4.C.4 The Arrhenius equation relates the temperature dependence of the rate of an elementary reaction to the activation energy needed by molecular collisions to reach the transition state.

TRA-5.A.1 A reaction mechanism consists of a series of elementary reactions, or steps, that occur in sequence. The components may include reactants, intermediates, products, and catalysts.

TRA-5.A.2 The elementary steps when combined should align with the overall balanced equation of a chemical reaction.

TRA-5.A.3 A reaction intermediate is produced by some elementary steps and consumed by others, such that it is present only while a reaction is occurring.

TRA-5.A.4 Experimental detection of a reaction intermediate is a common way to build evidence in support of one reaction mechanism over an alternative mechanism.

TRA-5.B.1 For reaction mechanisms in which each elementary step is irreversible, or in which the first step is rate limiting, the rate law of the reaction is set by the molecularity of the slowest elementary step (i.e., the rate-limiting step).

TRA-5.C.1 If the first elementary reaction is not rate limiting, approximations (such as steady state) must be made to determine a rate law expression.

TRA-5.D.1 Knowledge of the energetics of each elementary reaction in a mechanism allows for the construction of an energy profile for a multistep reaction.

ENE-1.A.1 In order for a catalyst to increase the rate of a reaction, the addition of the catalyst must increase the number of effective collisions and/or provide a reaction path with a lower activation energy relative to the original reaction coordinate.

ENE-1.A.2 In a reaction mechanism containing a catalyst, the net concentration of the catalyst is constant. However, the catalyst will frequently be consumed in the rate-determining step of the reaction, only to be regenerated in a subsequent step in the mechanism.

ENE-1.A.3 Some catalysts accelerate a reaction by binding to the reactant(s). The reactants are either oriented more favorably or react with lower activation energy. There is often a new reaction intermediate in which the catalyst is bound to the reactant(s). Many enzymes function in this manner.

ENE-1.A.4 Some catalysts involve covalent bonding between the catalyst and the reactant(s). An example is acid-base catalysis, in which a reactant or intermediate either gains or loses a proton. This introduces a new reaction intermediate and new elementary reactions involving that intermediate.

ENE-1.A.5 In surface catalysis, a reactant or intermediate binds to, or forms a covalent bond with, the surface. This introduces elementary reactions involving these new bound reaction intermediate(s).

College Board AP Chemistry Science Practices

Practice 1 - Models and Representations

Practice 3 – Representing Data and Phenomena

Practice 5 – Mathematical Routines

Practice 6 – Argumentation

Instructional Focus

Skills

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

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 568-621.

UNIT 11: CHEMICAL EQUILIBRIUM

Summary and Rationale

In this unit, students will learn about equilibrium, the state of a reaction where products and reactants are both being formed at the same time. Students will learn about the factors which may affect the dynamic equilibrium of reactions and favor either the products, or the reactants.

- Subunit 1 – The Concept of Equilibrium
- Subunit 2 – The Equilibrium Constant
- Subunit 3 – Understanding and Working with Equilibrium Constants
- Subunit 4 – Heterogeneous Equilibria
- Subunit 5 – Calculating Equilibrium Constants
- Subunit 6 – Applications of Equilibrium Constants
- Subunit 7 – Le Chatelier Principle

Recommended Pacing

6-7 Blocks

College Board AP Chemistry Big Ideas

Big Idea 3: Transformations (TRA)

Instructional Focus

Enduring Understanding

TRA-6 Some reactions can occur in both forward and reverse directions, sometimes proceeding in each direction simultaneously.

TRA-7 A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and equilibrium constant K .

TRA-8 Systems at equilibrium respond to external stresses to offset the effect of the stress.

Unit Essential Questions

- For a given system, what factors determine the factors favored by reversible change, if a favored direction exists?
- If the system is perturbed, how will it respond?

Learning Objective

TRA-6.A Explain the relationship between the occurrence of a reversible chemical or physical process, and the establishment of equilibrium, to experimental observations.

TRA-6.B Explain the relationship between the direction in which a reversible reaction proceeds and the relative rates of the forward and reverse reactions.

TRA-7.A Represent the reaction quotient Q_c or Q_p , for a reversible reaction, and the corresponding equilibrium expressions $K_c = Q_c$ or $K_p = Q_p$.

TRA-7.B Calculate K_c or K_p based on experimental observations of concentrations or pressures at equilibrium

TRA-7.C Explain the relationship between very large or very small values of K and the relative concentrations of

chemical species at equilibrium.

TRA-7.D Represent a multistep process with an overall equilibrium expression, using the constituent K expressions for each individual reaction.

TRA-7.E Identify the concentrations or partial pressures of chemical species at equilibrium based on the initial conditions and the equilibrium constant.

TRA-7.F Represent a system undergoing a reversible reaction with a particulate model.

TRA-8.A Identify the response of a system at equilibrium to an external stress, using Le Châtelier's principle.

TRA-8.B Explain the relationships between Q , K , and the direction in which a reversible reaction will proceed to reach equilibrium.

Essential Knowledge

TRA-6.A.1 Many observable processes are reversible. Examples include evaporation and condensation of water, absorption and desorption of a gas, or dissolution and precipitation of a salt. Some important reversible chemical processes include the transfer of protons in acid-base reactions and the transfer of electrons in redox reactions.

TRA-6.A.2 When equilibrium is reached, no observable changes occur in the system. Reactants and products are simultaneously present, and the concentrations or partial pressures of all species remain constant.

TRA-6.A.3 The equilibrium state is dynamic. The forward and reverse processes continue to occur at equal rates, resulting in no net observable change.

TRA-6.A.4 Graphs of concentration, partial pressure, or rate of reaction versus time for simple chemical reactions can be used to understand the establishment of chemical equilibrium.

TRA-6.B.1 If the rate of the forward reaction is greater than the reverse reaction, then there is a net conversion of reactants to products. If the rate of the reverse reaction is greater than that of the forward reaction, then there is a net conversion of products to reactants. An equilibrium state is reached when these rates are equal.

TRA-7.A.1 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 pressures as Q_p . The reaction quotient tends toward the equilibrium constant such that at equilibrium $K_c = Q_c$ and $K_p = Q_p$. As examples, for the reaction $aA + bB \rightleftharpoons cC + dD$ the equilibrium expression for (K_c , Q_c) is EQN: $K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$ And that for (K_p , Q_p) is EQN:

$$K_p = \frac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b}$$

TRA-7.A.2 The reaction quotient does not include substances whose concentrations (or partial pressures) are independent of the amount, such as for solids and pure liquids.

TRA-7.B.1 Equilibrium constants can be determined from experimental measurements of the concentrations or partial pressures of the reactants and products at equilibrium.

TRA-7.C.1 Some equilibrium reactions have very large K values and proceed essentially to completion. Others have very small K values and barely proceed at all.

TRA-7.D.1 When a reaction is reversed, K is inverted.

TRA-7.D.2 When the stoichiometric coefficients of a reaction are multiplied by a factor c , K is raised to the power c .

TRA-7.D.3 When reactions are added together, the K of the resulting overall reaction is the product of the K 's for the reactions that were summed.

TRA-7.D.4 Since the expressions for K and Q have identical mathematical forms, all valid algebraic manipulations of K also apply to Q .

TRA-7.E.1 The concentrations or partial pressures of species at equilibrium can be predicted given the balanced reaction, initial concentrations, and the appropriate K .

TRA-7.F.1 Particulate representations can be used to describe the relative numbers of reactant and product

particles present prior to and at equilibrium, and the value of the equilibrium constant.

TRA-8.A.1 Le Châtelier's principle can be used to predict the response of a system to stresses such as addition or removal of a chemical species, change in temperature, change in volume/pressure of a gas-phase system, or dilution of a reaction system.

TRA-8.A.2 Le Châtelier's principle can be used to predict the effect that a stress will have on experimentally measurable properties such as pH, temperature, and color of a solution.

TRA-8.B.1 A disturbance to a system at equilibrium causes Q to differ from K , thereby taking the system out of equilibrium. The system responds by bringing Q back into agreement with K , thereby establishing a new equilibrium state.

TRA-8.B.2 Some stresses, such as changes in concentration, cause a change in Q only. A change in temperature causes a change in K . In either case, the concentrations or partial pressures of species redistribute to bring Q and K back into equality.

College Board AP Chemistry Science Practices

Practice 3 – Representing Data and Phenomena

Practice 4 – Model Analysis

Practice 5 – Mathematical Routines

Practice 6 – Argumentation

Instructional Focus

Skills

6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.

4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.

3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.

5.C Explain the relationship between variables within an equation when one variable changes.

5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).

6.F Explain the connection between experimental results and chemical concepts, processes, or theories.

5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 622-663.

UNIT 12: ACID-BASE EQUILIBRIA

Summary and Rationale

In this unit, students will learn how to name and recognize various acids and bases. Students will identify and compare Arrhenius, Bronsted-Lowry and Lewis Acids and bases. Students will identify what makes an acid or a base, strong or weak.

- Subunit 1 – Arrhenius Acids and Bases
- Subunit 2 – Bronsted-Lowry Acids and Bases
- Subunit 3 – The Autoionization of Water
- Subunit 4 – The pH Scale
- Subunit 5 – Strong Acids and Bases
- Subunit 6 – Weak Acids
- Subunit 7 – Weak Bases
- Subunit 8 – Relationship between K_a and K_b
- Subunit 9 – Acid-Base Behavior and Chemical Structure
- Subunit 10 – Acid-Base Behavior and Chemical Structure
- Subunit 11 – Lewis Acids and Bases

Recommended Pacing

7-8 Blocks

College Board AP Chemistry Big Ideas

Big Idea 2: Structure and Properties (SAP)

Instructional Focus

Enduring Understanding

SAP-9 The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium concentrations being related to the strength of the acids and bases involved.

Unit Essential Questions

- How and why do particles rearrange during a chemical and physical change?
- For a given system, what factors determine the factors favored by reversible change, if a favored direction exists?
- If the system is perturbed, how will it respond?

Learning Objective

SAP-9.A Calculate the values of pH and pOH, based on K_w and the concentration of all species present in a neutral solution of water.

SAP-9.B Calculate pH and pOH based on concentrations of all species in a solution of a strong acid or a strong base.

SAP-9.C Explain the relationship among pH, pOH, and concentrations of all species in a solution of a monoprotic weak acid or weak base.

SAP-9.F Explain the relationship between the strength of an acid or base and the structure of the molecule or ion.

Essential Knowledge

SAP-9.A.1 The concentrations of hydronium ion and hydroxide ion are often reported as pH and pOH, respectively.

EQN: $\text{pH} = -\log[\text{H}_3\text{O}^+]$ EQN: $\text{pOH} = -\log[\text{OH}^-]$

The terms “hydrogen ion” and “hydronium ion” and the symbols $\text{H}^+(\text{aq})$ and $\text{H}_3\text{O}^+(\text{aq})$ are often used interchangeably for the aqueous ion of hydrogen. Hydronium ion and $\text{H}_3\text{O}^+(\text{aq})$ are preferred, but $\text{H}^+(\text{aq})$ is also accepted on the AP Exam.

SAP-9.A.2 Water autoionizes with an equilibrium constant K_w . EQN: $K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$ at 25°C

SAP-9.A.3 In pure water, $\text{pH} = \text{pOH}$ is called a neutral solution. At 25°C , $\text{p}K_w = 14.0$ and thus $\text{pH} = \text{pOH} = 7.0$.

EQN: $\text{p}K_w = 14 = \text{pH} + \text{pOH}$ at 25°C

SAP-9.A.4 The value of K_w is temperature dependent, so the pH of pure, neutral water will deviate from 7.0 at temperatures other than 25°C .

SAP-9.B.1 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. 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.

SAP-9.B.2 When dissolved in solution, strong bases (e.g., group I and II hydroxides) completely dissociate to produce hydroxide ions. As such, the concentration of OH^- in a strong base solution is equal to the initial concentration of the strong base, and thus the pOH (and pH) of the strong base solution is easily calculated.

SAP-9.C.1 Weak acids react with water to produce hydronium ions. However, molecules of a weak acid will only partially ionize in this way. In other words, only a small percentage of the molecules of a weak acid are ionized in a solution. Thus, the concentration of H_3O^+ is much less than the initial concentration of the molecular acid, and the vast majority of the acid molecules remain un-ionized.

SAP-9.C.2 A solution of a weak acid involves equilibrium between an un-ionized acid and its conjugate base. The equilibrium constant for this reaction is K_a , often reported as $\text{p}K_a$. The pH of a weak acid solution can be determined from the initial acid concentration and the $\text{p}K_a$. EQN: $K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$ EQN: $\text{p}K_a = -\log K_a$

SAP-9.C.3 Weak bases react with water to produce hydroxide ions in solution. However, ordinarily just a small percentage of the molecules of a weak base in solution will ionize in this way. Thus, the concentration of OH^- in the solution does not equal the initial concentration of the base, and the vast majority of the base molecules remain un-ionized.

SAP-9.C.4 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 $\text{p}K_b$. The pH of a weak base solution can be determined from the initial base concentration and the $\text{p}K_b$. EQN: $K_b = \frac{[\text{OH}^-][\text{HB}^+]}{[\text{B}]}$ EQN: $\text{p}K_b = -\log K_b$

SAP-9.C.5 The percent ionization of a weak acid (or base) can be calculated from its $\text{p}K_a$ ($\text{p}K_b$) and the initial concentration of the acid (base).

SAP-9.F.1 The protons on a molecule that will participate in acid-base reactions, and the relative strength of these protons, can be inferred from the molecular structure.

- 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 acid.
- Strong bases (such as group I and II hydroxides) have very weak conjugate acids.
- Common weak bases include nitrogenous bases such as ammonia as well as carboxylate ions.
- Electronegative elements tend to stabilize the conjugate base relative to the conjugate acid, and so increase acid strength.

College Board AP Chemistry Science Practices
Practice 5 – Mathematical Routines Practice 6 – Argumentation

Instructional Focus
Skills
5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem. 5.C Explain the relationship between variables within an equation when one variable changes. 6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.

Resources
Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 664- 715.

UNIT 13: ADDITIONAL ASPECTS OF AQUEOUS EQUILIBRIA

Summary and Rationale

In this unit, students will continue exploring factors which affect the properties of a solution and the solubility of compounds into solvents.

- Subunit 1 – The Common-Ion Effect
- Subunit 2 – Buffers
- Subunit 3 – Acid-Base Titrations
- Subunit 4 – Solubility Equilibria
- Subunit 5 – Factors That Affect Solubility
- Subunit 6 – Precipitation and Separation of Ions
- Subunit 7 – Qualitative Analysis for Metallic Elements

Recommended Pacing

9-10 Blocks

College Board AP Chemistry Big Ideas

Big Idea 1: Scale, Proportion, and Quantity (SPQ)

Big Idea 2: Structure and Properties (SAP)

Instructional Focus

Enduring Understanding

SPQ-5 The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.

SAP-9 The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium concentrations being related to the strength of the acids and bases involved.

SAP-10 A buffered solution resists changes to its pH when small amounts of acid or base are added.

Unit Essential Questions

- For a given system, what factors determine the factors favored by reversible change, if a favored direction exists?
- If the system is perturbed, how will it respond?

Learning Objective

SPQ-5.A Calculate the solubility of a salt based on the value of K_{sp} for the salt.

SPQ-5.B 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.

SPQ-5.C Identify the qualitative effect of changes in pH on the solubility of a salt.

SAP-9.D Explain the relationship among the concentrations of major species in a mixture of weak and strong acids and bases.

SAP-9.E Explain results from the titration of a mono- or polyprotic acid or base solution, in relation to the properties of the solution and its components.

SAP-10.A Explain the relationship between the predominant form of a weak acid or base in solution at a given pH and the pK_a of the conjugate acid or the pK_b of the conjugate base.

SAP-10.B Explain the relationship between the ability of a buffer to stabilize pH and the reactions that occur when

an acid or a base is added to a buffered solution.

SAP-10.C Identify the pH of a buffer solution based on the identity and concentrations of the conjugate acid-base pair used to create the buffer.

SAP-10.D Explain the relationship between the buffer capacity of a solution and the relative concentrations of the conjugate acid and conjugate base components of the solution.

Essential Knowledge

SPQ-5.A.1 The dissolution of a salt is a reversible process whose extent can be described by K_{sp} , the solubility-product constant.

SPQ-5.A.2 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.

SPQ-5.A.3 The solubility rules (see TRA-2.A.5) can be quantitatively related to K_{sp} , in which K_{sp} values >1 correspond to soluble salts.

SPQ-5.B.1 The solubility of a salt is reduced when it is dissolved into a solution that already contains one of the ions present in the salt. The impact of this “common-ion effect” on solubility can be understood qualitatively using Le Châtelier’s principle or calculated from the K_{sp} for the dissolution process.

SPQ-5.C.1 The solubility of a salt is pH sensitive when one of the constituent ions is a weak acid or base. These effects can be understood qualitatively using Le Châtelier’s principle.

SAP-9.D.1 When a strong acid and a strong base are mixed, they react quantitatively in a reaction represented by the equation: $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$. The pH of the resulting solution may be determined from the concentration of excess reagent.

SAP-9.D.2 When a weak acid and a strong base are mixed, they react quantitatively in a reaction represented by the equation: $HA(aq) + OH^-(aq) \ll A^-(aq) + H_2O(l)$. If the weak acid is in excess, then a buffer solution is formed, and the pH can be determined from the Henderson-Hasselbalch (H-H) equation (see SAP-10.C.1). If the strong base is in excess, then the pH can be determined from the moles of excess hydroxide ion and the total volume of solution. If they are equimolar, then the (slightly basic) pH can be determined from the equilibrium represented by the equation: $A^-(aq) + H_2O(l) \ll HA(aq) + OH^-(aq)$.

SAP-9.D.3 When a weak base and a strong acid are mixed, they will react quantitatively in a reaction represented by the equation: $B(aq) + H_3O^+(aq) \ll HB^+(aq) + H_2O(l)$. If the weak base is in excess, then a buffer solution is formed, and the pH can be determined from the H-H equation. If the strong acid is in excess, then the pH can be determined from the moles of excess hydronium ion and the total volume of solution. If they are equimolar, then the (slightly acidic) pH can be determined from the equilibrium represented by the equation: $HB^+(aq) + H_2O(l) \ll B(aq) + H_3O^+(aq)$.

SAP-9.D.4 When a weak acid and a weak base are mixed, they will react to an equilibrium state whose reaction may be represented by the equation: $HA(aq) + B(aq) \rightleftharpoons A^-(aq) + HB^+(aq)$.

SAP-9.E.1 An acid-base reaction can be carried out under controlled conditions in a titration. A titration curve, plotting pH against the volume of titrant added, is useful for summarizing results from a titration.

SAP-9.E.2 At the equivalence point, the number of moles of titrant added is equal to the number of moles of analyte originally present. This relationship can be used to obtain the concentration of the analyte. This is the case for titrations of strong acids/bases and weak acids/bases.

SAP-9.E.3 For titrations of weak acids/bases, it is useful to consider the point halfway to the equivalence point, that is, the half-equivalence point. At this point, there are equal concentrations of each species in the conjugate acid-base pair, for example, for a weak acid $[HA] = [A^-]$. Because $pH = pK_a$ 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.

SAP-9.E.4 For polyprotic acids, titration curves can be used to determine the number of acidic protons. In doing so, the major species present at any point along the curve can be identified, along with the pK_a associated with each proton in a weak polyprotic acid.

SAP-10.A.1 The protonation state of an acid or base (i.e., the relative concentrations of HA and A^-) can be predicted by comparing the pH of a solution to the pK_a of the acid in that solution. When solution $pH < acid\ pK_a$, the acid form has a higher concentration than the base form. When solution $pH > acid\ pK_a$, the base form has a higher concentration than the acid form.

SAP-10.A.2 Acid-base indicators are substances that exhibit different properties (such as color) in their protonated versus deprotonated state, making that property respond to the pH of a solution.

SAP-10.B.1 A buffer solution contains a large concentration of both members in a conjugate acid-base pair. The conjugate acid reacts with added base and the conjugate base reacts with added acid. These reactions are responsible for the ability of a buffer to stabilize pH.

SAP-10.C.1 The pH of the buffer is related to the pK_a 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. EQN: $pH = pK_a + -\log([A^-]/[HA])$

SAP-10.D.1 Increasing the concentration of the buffer components (while keeping the ratio of these concentrations constant) keeps the pH of the buffer the same but increases the capacity of the buffer to neutralize added acid or base.

SAP-10.D.2 When a buffer has more conjugate acid than base, it has a greater buffer capacity for addition of added base than acid. When a buffer has more conjugate base than acid, it has a greater buffer capacity for addition of added acid than base.

College Board AP Chemistry Science Practices

Practice 2 – Question and Meth
Practice 5 – Mathematical Routines
Practice 6 – Argumentation

Instructional Focus

Skills

5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.

2.F Explain how modifications to an experimental procedure will alter results.

2.D Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.

5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

5.D Identify information presented graphically to solve a problem.

6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.

6.G Explain how potential sources of experimental error may affect the experimental results.

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 716- 765.

UNIT 14: CHEMICAL THERMODYNAMICS

Summary and Rationale

In this unit, students will work to answer fundamental questions: how fast will a reaction progress and how far does it proceed? In this unit, students will bring together earlier topics of chemical kinetics, chemical equilibrium and enthalpy/entropy to determine an answer to the above questions.

- Subunit 1 – Spontaneous Processes
- Subunit 2 – Entropy and the Second Law of Thermodynamics
- Subunit 3 – The Molecular Interpretation of Entropy and the Third Law of Thermodynamics
- Subunit 4 – Entropy Changes in Chemical Reactions
- Subunit 5 – Gibbs Free Energy
- Subunit 6 – Free Energy and Temperature
- Subunit 7 – Free Energy and the Equilibrium Constant

Recommended Pacing

5-6 Blocks

College Board AP Chemistry Big Ideas

Big Idea 4: Energy (ENE)

Big Idea 1: Scale, Proportion, and Quantity (SPQ)

Instructional Focus

Enduring Understanding

ENE-4 Some chemical or physical processes cannot occur without intervention.

ENE-5 The relationship between ΔG° and K can be used to determine favorability of a chemical or physical transformation.

SPQ-5 The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.

Unit Essential Questions

- How is it possible to predict, given thermodynamic parameters, quantitative energy changes and the favored direction of thermodynamic changes?
- For a given system, what factors determine the factors favored by reversible change, if a favored direction exists?
- If the system is perturbed, how will it respond?

Learning Objective

ENE-4.A Identify the sign and relative magnitude of the entropy change associated with chemical or physical processes.

ENE-4.B Calculate the entropy change for a chemical or physical process based on the absolute entropies of the species involved in the process.

ENE-4.C Explain whether a physical or chemical process is thermodynamically favored based on an evaluation of ΔG° .

ENE-4.D Explain, in terms of kinetics, why a thermodynamically favored reaction might not occur at a measurable

rate.

ENE-5.A Explain whether a process is thermodynamically favored using the relationships between K , ΔG° , and T .

ENE-5.B Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes.

SPQ-5.D Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process.

Essential Knowledge

ENE-4.A.1 Entropy increases when matter becomes more dispersed. For example, the phase change from solid to liquid or from liquid to gas results in a dispersal of matter as the individual particles become freer to move and generally occupy a larger volume. Similarly, for a gas, the entropy increases when there is an increase in volume (at constant temperature), and the gas molecules are able to move within a larger space. For reactions involving gas-phase reactants or products, the entropy generally increases when the total number of moles of gas-phase products is greater than the total number of moles of gas-phase reactants.

ENE-4.A.2 Entropy increases when energy is dispersed. According to kinetic molecular theory (KMT), the distribution of kinetic energy among the particles of a gas broadens as the temperature increases. As a result, the entropy of the system increases with an increase in temperature.

ENE-4.B.1 The entropy change for a process can be calculated from the absolute entropies of the species involved before and after the process occurs. EQN: $\Delta S^\circ_{\text{reaction}} = \sum S^\circ_{\text{products}} - \sum S^\circ_{\text{reactants}}$

ENE-4.C.1 The Gibbs free energy change for a chemical process in which all the reactants and products are present in a standard state (as pure substances, as solutions of 1.0 M concentration, or as gases at a pressure of 1.0 atm (or 1.0 bar)) is given the symbol ΔG° .

ENE-4.C.2 The standard Gibbs free energy change for a chemical or physical process is a measure of thermodynamic favorability. Historically, the term “spontaneous” has been used to describe processes for which $\Delta G^\circ < 0$. 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.

ENE-4.C.3 The standard Gibbs free energy change for a physical or chemical process may also be determined from the standard Gibbs free energy of formation of the reactants and products.

EQN: $\Delta G^\circ_{\text{reaction}} = \sum \Delta G_f^\circ_{\text{products}} - \sum \Delta G_f^\circ_{\text{reactants}}$

ENE-4.C.4 In some cases, it is necessary to consider both enthalpy and entropy to determine if a process will be thermodynamically favored. The freezing of water and the dissolution of sodium nitrate are examples of such phenomena.

ENE-4.C.5 Knowing the values of ΔH° and ΔS° for a process at a given temperature allows ΔG° to be calculated directly. EQN: $\Delta G^\circ = \Delta H^\circ - T \Delta S^\circ$

ENE-4.C.6 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° as shown in the table below:

ΔH°	ΔS°	Symbols	$\Delta G^\circ < 0$, favored at:
< 0	> 0	< >	all T
> 0	< 0	> <	no T
> 0	> 0	> >	high T
< 0	< 0	< <	low T

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 ($\Delta G^\circ > 0$).

ENE-4.D.1 Many processes that are thermodynamically favored do not occur to any measurable extent, or they

occur at extremely slow rates.

ENE-4.D.2 Processes that are thermodynamically favored, but do not proceed at a measurable rate, are under “kinetic control.” High activation energy is a common reason for a process to be under kinetic control. The fact that a process does not proceed at a noticeable rate does not mean that the chemical system is at equilibrium. If a process is known to be thermodynamically favored, and yet does not occur at a measurable rate, it is reasonable to conclude that the process is under kinetic control.

ENE-5.A.1 The phrase “thermodynamically favored” ($\Delta G^\circ < 0$) means that the products are favored at equilibrium ($K > 1$).

ENE-5.A.2 The equilibrium constant is related to free energy by the equations EQN: $K = e^{-\Delta G^\circ/RT}$ And EQN: $\Delta G^\circ = -RT \ln K$.

ENE-5.A.3 Connections between K and ΔG° can be made qualitatively through estimation. When ΔG° is near zero, the equilibrium constant will be close to 1. When ΔG° is much larger or much smaller than RT , the value of K deviates strongly from 1.

ENE-5.A.4 Processes with $\Delta G^\circ < 0$ favor products (i.e., $K > 1$) and those with $\Delta G^\circ > 0$ favor reactants (i.e., $K < 1$).

ENE-5.B.1 An external source of energy can be used to make a thermodynamically unfavorable process occur. Examples include:

- Electrical energy to drive an electrolytic cell or charge a battery.
- Light to drive the overall conversion of carbon dioxide to glucose in photosynthesis.

ENE-5.B.2 A desired product can be formed by coupling a thermodynamically unfavorable reaction that produces that product to a favorable reaction (e.g., the conversion of *ATP* to *ADP* in biological systems). In the coupled system, the individual reactions share one or more common intermediates. The sum of the individual reactions produces an overall reaction that achieves the desired outcome and has $\Delta G^\circ < 0$.

SPQ-5.D.1 The free energy change (ΔG°) for dissolution of a substance reflects a number of factors: the breaking of the intermolecular interactions that hold the solid together, the reorganization of the solvent around the dissolved species, and the interaction of the dissolved species with the solvent. It is possible to estimate the sign and relative magnitude of the enthalpic and entropic contributions to each of these factors. However, making predictions for the total change in free energy of dissolution can be challenging due to the cancellations among the free energies associated with the three factors cited.

College Board AP Chemistry Science Practices

Practice 4 – Model Analysis

Practice 5 – Mathematical Routines

Practice 6 – Argumentation

Instructional Focus

Skills

6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.

5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.

6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.
4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 806- 847.

UNIT 15: ELECTROCHEMISTRY

Summary and Rationale

In this unit, students will focus on the relationship between electricity and chemical reactions. In these reactions, one species gains electrons and is reduced, while the other gives up electrons and is oxidized. The tendency for such a reaction to occur depends on the reactants used, the environment the reaction occurs and if voltage and electrical conditions are altered.

- Subunit 1 - Oxidation States and Oxidation-Reduction Reactions
- Subunit 2 – Balancing Redox Reactions
- Subunit 3 – Voltaic Cells
- Subunit 4 – Cell Potentials under Standard Conditions
- Subunit 5 – Free Energy and Redox Reactions
- Subunit 6 – Cell Potentials under Nonstandard Conditions
- Subunit 7 – Batteries and Fuel Cells
- Subunit 8 – Corrosion
- Subunit 9 – Electrolysis

Recommended Pacing

5-6 Blocks

College Board AP Chemistry Big Ideas

Big Idea 3: Transformations (TRA)

Big Idea 4: Energy (ENE)

Instructional Focus

Enduring Understanding

TRA – 2 A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it.

ENE-6 Electrical energy can be generated by chemical reactions.

Unit Essential Questions

- How and why do particles rearrange during a chemical and physical change?

Learning Objective

TRA-2.A Identify a reaction as acid base, oxidation-reduction, or precipitation.

TRA-2.C Represent a balanced redox reaction equation using half-reactions.

ENE-6.A Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.

ENE-6.B Explain whether an electrochemical cell is thermodynamically favored, based on its standard cell potential and the constituent half-reactions within the cell.

ENE-6.C Explain the relationship between deviations from standard cell conditions and changes in the cell potential.

ENE-6.D Calculate the amount of charge flow based on changes in the amounts of reactants and products in an electrochemical cell.

Essential Knowledge

TRA-2.A.1 Acid-base reactions involve transfer of one or more protons between chemical species.

TRA-2.A.2 Oxidation-reduction reactions involve transfer of one or more electrons between chemical species, as indicated by changes in oxidation numbers of the involved species. Combustion is an important subclass of oxidation-reduction reactions, in which a species reacts with oxygen gas. In the case of hydrocarbons, carbon dioxide and water are products of complete combustion.

TRA-2.A.3 In a redox reaction, electrons are transferred from the species that are oxidized to the species that are reduced.

TRA-2.A.4 Oxidation numbers may be assigned to each of the atoms in the reactants and products; this is often an effective way to identify the oxidized and reduced species in a redox reaction.

TRA-2.A.5 Precipitation reactions frequently involve mixing ions in aqueous solution to produce an insoluble or sparingly soluble ionic compound. All sodium, potassium, ammonium, and nitrate salts are soluble in water.

TRA-2.C.1 Balanced chemical equations for redox reactions can be constructed from half-reactions.

ENE-6.A.1 Each component of an electrochemical cell (electrodes, solutions in the half-cells, salt bridge, voltage/current measuring device) plays a specific role in the overall functioning of the cell. The operational characteristics of the cell (galvanic vs. electrolytic, direction of electron flow, reactions occurring in each half-cell, change in electrode mass, evolution of a gas at an electrode, ion flow through the salt bridge) can be described at both the macroscopic and particulate levels.

ENE-6.A.2 Galvanic, sometimes called voltaic, cells involve a thermodynamically favored reaction, whereas electrolytic cells involve a thermodynamically unfavored reaction. Visual representations of galvanic and electrolytic cells are tools of analysis to identify where half-reactions occur and in what direction current flows.

ENE-6.A.3 For all electrochemical cells, oxidation occurs at the anode and reduction occurs at the cathode.

ENE-6.B.1 Electrochemistry encompasses the study of redox reactions that occur within electrochemical cells. The reactions are either thermodynamically favored (resulting in a positive voltage) or thermodynamically unfavored (resulting in a negative voltage and requiring an externally applied potential for the reaction to proceed).

ENE-6.B.2 The standard cell potential of electrochemical cells can be calculated by identifying the oxidation and reduction half-reactions and their respective standard reduction potentials.

ENE-6.B.3 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. EQN: $\Delta G^\circ = -nFE^\circ$

ENE-6.C.1 In a real system under nonstandard conditions, the cell potential will vary depending on the concentrations of the active species. The cell potential is a driving force toward equilibrium; the farther the reaction is from equilibrium, the greater the magnitude of the cell potential.

ENE-6.C.2 Equilibrium arguments such as Le Châtelier's principle do not apply to electrochemical systems, because the systems are not in equilibrium.

ENE-6.C.3 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.

ENE-6.C.4 Algorithmic calculations using the Nernst equation are insufficient to demonstrate an understanding of

electrochemical cells under nonstandard conditions. However, students should qualitatively understand the effects of concentration on cell potential and use conceptual reasoning, including the qualitative use of the Nernst equation: EQN: $E = E^\circ - (RT/nF) \ln Q$ to solve problems.

ENE-6.D.1 Faraday's laws can be used to determine the stoichiometry of the redox reaction occurring in an electrochemical cell with respect to the following:

- a. Number of electrons transferred
- b. Mass of material deposited on or removed from an electrode
- c. Current
- d. Time elapsed
- e. Charge of ionic species

EQN: $I = q/t$

College Board AP Chemistry Science Practices

Practice 1 - Models and Representations

Practice 2 – Question and Method

Practice 5 – Mathematical Routines

Practice 6 – Argumentation

Instructional Focus

Skills

1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic level properties.

5.E Determine a balanced chemical equation for a given chemical phenomenon.

2.F Explain how modifications to an experimental procedure will alter results.

5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.

5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.

Resources

Core Text: Chemistry: The Central Science, Brown, Et. Al. 2018, pgs. 848-899.