Part II
Teaching Next Generation Science Standards with *World of Chemistry*: Chapter-by-Chapter

Fulfilling NGSS Performance Expectations with *World of Chemistry*

High school physical science performance expectations connected to the topics of Matter and Its Interactions, Energy, and Waves and their Applications in Technologies for Information Transfer are met throughout the text as listed below. Performance expectations are fully met by combined chapter content. Some performance expectations are distributed across several chapters according to the performance expectation's integration of multiple chemistry topics.

Performance Expectation	**Chapter**
HS-PS1-1	4, 11, 12, 18, 20
HS-PS1-2	5, 8, *15*, 16, 18, 20
HS-PS1-3	4, 11, 12, 13, 14, 15, 20, 21
HS-PS1-4	*7*, 10
HS-PS1-5	11, 17
HS-PS1-6	*16*, 17
HS-PS1-7	6, 7, 9, *15*
HS-PS1-8	19
HS-PS2-6	*8*, 12, 13, 14, 18
HS-PS3-1	10
HS-PS3-2	10, 13, 14
HS-PS3-3	10, *19*
HS-PS3-4	10
HS-PS4-3	11
HS-PS4-4	11, 19
HS-PS4-5	*11*, 19

Chapters 1, 2, and 3: The Practices of Science and Engineering

NGSS Science and Engineering Practices	
Asking Questions and Defining Problems	Constructing Explanations and Designing Solutions
Planning and Carrying Out Investigations	Engaging in Argument from Evidence
Analyzing and Interpreting Data	Using Mathematics and Computational Thinking
Developing and Using Models	Obtaining, Evaluating, and Communicating Information

The first three chapters of World of Chemistry reacquaint students with the practices of science and engineering. **Chapter 1, "Chemistry: An Introduction,"** begins by describing the importance of scientific thinking and the study of chemistry in particular. In **Section 1.2, "Using Science to Solve Problems,"** the eight practices are first presented using the real-world example of National Geographic Explorer Imogen Napper's marine microplastics studies, then defined in detail. **Systems and system models** are also described in this section. **Section 1.3, "Using Chemistry to Solve Problems,"** describes the practices of engineering, and explains how the core engineering design ideas of **defining and delimiting engineering problems**, **developing possible solutions**, and **optimizing the design solution** are employed by chemical engineers. Features throughout the chapter can also be connected with core ideas from Earth Science performance expectations.

Chapter 2, "Matter," introduces atoms, molecules, compounds, and elements and discusses the states of matter; students then **develop and use models** to explain the differences between related concepts. Using empirical evidence, they **analyze and interpret data** and **construct explanations** of liquid and gas behavior. To practice separating and classifying matter, students **plan and carry out investigations** and **communicate information** about their processes and results. Several chapter features tie closely to standards associated with performance expectations for Earth and Human Activity and Engineering Design.

Throughout **Chapter 3, "Measurements and Calculations,"** students **use mathematics and computational thinking** to calculate quantities derived from measurements and solve problems using scientific notation and unit conversion factors. Students identify relevant units and apply concepts of uncertainty by recognizing significant figures as they **plan and carry out investigations,** such as finding the densities of various substances, and when they **analyze and interpret data** to determine whether and to what degree they are meaningful.

NGSS Engineering Design Performance Expectations
HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can solved through engineering.
HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Chapter 4: Chemical Foundations: Elements, Atoms, and Ions

<table>
<tr><th colspan="2">NGSS Physical Science and Engineering Standards</th></tr>
<tr><td colspan="2">Performance Expectations
HS-PS1-1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
HS-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.</td></tr>
<tr><td>Science and Engineering Practices
Developing and Using Models
Planning and Carrying Out Investigations
Constructing Explanations</td><td>Crosscutting Concepts
Patterns
Structure and Function
Cause and Effect
Systems and System Models

Disciplinary Core Ideas
PS1.A Structure and Properties of Matter
PS2.B Types of Interactions</td></tr>
</table>

Together with **Chapter 11**, "Modern Atomic Theory," Chapter 4 provides students with a vocabulary and framework for understanding how patterns in atomic structure, particularly with regard to electrons, give rise to trends in chemical bonding and contribute to the structure and properties of a bulk substance. The first three sections of this chapter present the basic notation for identifying chemical elements, including chemical symbols, atomic number, and mass number, in the context of describing early models of the atom. **Section 4.3** introduces the concept that the number of electrons in a given atom greatly affects its interactions with other atoms; the arrangement of the periodic table based on similarities in chemical properties is then detailed in **Section 4.4**. Students practice one aspect of the physical science performance expectation **HS-PS1-1** in **Section 4.5**, where they learn to predict the charge of the ion(s) formed by each element based on its location on the periodic table, and thus determine which elements will form ionic bonds with each other. The **Chapter Investigation** carried out at the end of this chapter can be used as a starting point for students to plan their own investigations to meet physical science performance expectation **HS-PS1-3** using concepts gathered throughout the remainder of the course.

Explorers at Work: Using Chemical Tracers to Model Geologic Processes

This feature highlights the application of chemistry to volcanology, relating the concept of isotopes to Earth science disciplinary idea **ESS2.A** (**HS-ESS2-1**, **HS-ESS2-3**). The article describes how Kenneth Warren Sims uses isotopic variations in samples of volcanic material obtained from different locations around the world to determine the compositions of their magma sources within Earth's interior. By using chemical data to model **stability and change** in volcanic behavior over time, he hopes to be able to identify patterns that can predict future volcanic eruptions.

Case Study: Earth's Helium Resources

Helium can be used as an example to illustrate the Earth science disciplinary idea **ESS3.A** (**HS-ESS3-2**). This case study discusses the availability and management of helium as a natural resource, including efforts to find new sources, maintain reserves, and recycle and reuse helium. For helium or other elemental resources, students can examine the **cause-and-effect** relationships that drive their geographical occurrence and their subsequent availability and cost.

Investigation: Electric Solutions

In this investigation, students measure the electrical conductivity of various solutions with the purpose of determining whether the solutions contain ions. To extend this investigation further, students can test the model they developed via molecular-level diagrams by formulating a question that relates the strength of the inter-particle forces in a substance to its bulk structure and properties. Students should then **plan and carry out** their proposed investigation (**HS-PS1-3**). This activity makes a good cumulative assessment, as investigative questions will likely arise from what students learn about the motion of electrons in later chapters.

Some examples that students might pursue include investigations of ionic substances: *How does the conductivity of an ionic solid compare to that of an aqueous solution? How does the concentration of a solution affect its conductivity? How does the solubility of a substance relate to its electrical conductivity?* These investigations would be informed by studying the process of dissolution in **Section 8.1** and solution composition in **Sections 15.1 and 15.2**.

Alternatively, students may wish to investigate the effects of different types of chemical bonding on bulk properties; for example, they could ask a question such as *How does the type of chemical bonding in a substance affect its melting or boiling point?* Concepts from **Chapters 12 and 14** will be useful in planning these investigations.

Have students use the results of their investigations to refine their initial molecular-level models as needed in order to explain the relationship between inter-particle electrical forces and the bulk structure or property they investigated.

Additional NGSS Connections

Performance Expectations

HS-ESS2-1 Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.

HS-ESS2-3 Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.

HS-ESS3-2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*

Science and Engineering Practices

Scientific Knowledge is Based on Empirical Evidence

Engaging in Argument from Evidence

Crosscutting Concepts

Stability and Change

Energy and Matter

Influence of Science, Engineering, and Technology on Society and the Natural World

Disciplinary Core Ideas

ESS2.B Plate Tectonics and Large-Scale Interactions

ESS3.A Natural Resources

Chapter 5: Nomenclature

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.	
Science and Engineering Practices Constructing Explanations and Designing Solutions Using Mathematics and Computational Thinking Developing and Using Models	**Crosscutting Concepts** Patterns **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS1.B Chemical Reactions

This chapter provides students with the vocabulary and conventions for names and formulas for chemical compounds. Students use naming **patterns** that indicate ion charge or number of atoms to predict the results of chemical reactions. This skill is typically required to fulfill physical science performance expectation **HS-PS1-2**.

Exploring Engineering: Cleaning the Air with Ions Using Environmental Engineering and Design

Ionic air scrubbers were engineered to remove particulate matter from air (**HS-ESS3-4**). The teacher notes address two aspects of the public health issue of air pollution; **Real-World Issues** highlights global impacts and relates outdoor air quality to climate change (**ETS1.A**), and **Engineering Practices: Defining Criteria and Constraints** suggests questions for students to consider in evaluating the public awareness campaign as a problem-solving strategy (**HS-ETS1-1**).

Case Study: Compound Semiconductors

Some elements used in electronics can be very expensive, rare, difficult to work with, or even toxic. As discussed in the **In Your Community** teacher note, the improper disposal of such substances causes environmental hazards (**ESS3.C**).

Investigation: Forming and Naming Ionic Compounds

In this investigation, students observe whether reactions occur between assorted ionic solutions and write the names and formulas of the products, a necessary step in explaining the outcomes of reactions (**HS-PS1-2**).

Additional NGSS Connections	
Performance Expectations HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems. HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.	
Science and Engineering Practices Asking Questions and Defining Problems	**Crosscutting Concepts** Influence of Science, Engineering, and Technology on Society and the Natural World **Disciplinary Core Ideas** ESS3.C Human Impacts on Earth Systems ETS1.A Defining and Delimiting Engineering Problems

Chapter 6: Chemical Composition

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.	
Science and Engineering Practices Analyzing and Interpreting Data Developing and Using Models Using Mathematics and Computational Thinking	**Crosscutting Concepts** Energy and Matter Scientific Knowledge Assumes an Order and Consistency in Natural Systems Scale, Proportion, and Quantity **Disciplinary Core Ideas** PS1.B Chemical Reactions

This chapter first introduces the idea that chemical composition can be defined in terms of mass in preparation for the mathematical representation of chemical reactions in **Chapter 7**, "Chemical Reactions: An Introduction," and the use of chemical equations to solve stoichiometry problems in **Chapter 9**, "Chemical Quantities." Taken together, these chapters fulfill the physical science performance expectation **HS-PS1-7**.

Counting Coins and Penny Composition

The ENGAGE feature for Chapter 6 explains how coins can be sorted and counted based on their masses, a concept analogous to the quantification of particles in terms of atomic and molecular mass and moles. You may want to begin this segment of coursework by delving directly into the **Hands-on Chemistry** feature in Section 6.1, **"Counting Pennies Without Counting"**; this feature gives students hands-on macroscopic experience with the concept of counting by mass. You can then ask students how they can apply these concepts to their understanding of the unique properties of elements.

Explorers at Work: Gathering Data in the Wild

The chapter's Explorers at Work feature depicts the real-world application of quantitative composition analysis in tracking the origins of timber. The timber tracking project may be used as an Investigative Phenomenon to frame the lesson: *How are researchers able to identify the components of chemical samples and determine their relative amounts?* Tie this to the chapter's **Case Study** on the measurement of biomass for a big-picture program integrated with Earth and life science disciplinary ideas.

The feature describes other work performed by Adventure Scientists, an organization that connects scientists with outdoor adventurers to collect data at various scales from hard-to-reach places, demonstrating how scientific investigations make use of diverse methods to obtain data. The work of National Geographic Explorer Gregg Treinish can be used to discuss ideas around the sustainability of human populations and biodiversity (**HS-ESS3-3**).

Hands-on Chemistry: Relative Masses

The Hands-on Chemistry "Relative Masses" activity in Section 6.2 is another opportunity for students to **use models** to explain how atomic masses are figured and used in computational chemistry problems. You may want to have students perform this exercise as an Investigative Phenomenon prior to exploring the concepts of molar mass and Avogadro's number, using the activity as an engaging way to spark interest in the content before developing explanations. Instead of using cotton balls, paper clips, and rubber stoppers, you may want to substitute coins of various denominations and tie this activity to the Section 6.1 Hands-on Chemistry activity, "Counting Pennies Without Counting."

Case Study: Measuring the Mass of Life on Earth

This feature uses different mathematical representations to model the distribution of biomass on Earth and the change in that distribution over time, similarly to the methods for counting particles by mass explored in the chapter. The law of conservation of mass is used to support the claim that biomass carbon is locked up inside an organism when it is alive, and the carbon is gradually released back into the biosphere when it dies and begins to decay. When humans burn the biomass of plants or fossil fuels, a significant amount of the biomass is rapidly converted to atmospheric carbon (**HS-LS2-4**). The feature describes the cycling of carbon between the biosphere (including humans) and the atmosphere, when discussing the burning of biomass (**HS-ESS2-6**).

<table>
<tr><th colspan="2">Additional NGSS Connections</th></tr>
<tr><td colspan="2">Performance Expectations
HS-LS2-4 Use mathematical representations to support claims for the cycling of matter and flow of energy in aerobic and anaerobic conditions.
HS-ESS2-6 Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
HS-ESS3-3 Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.</td></tr>
<tr><td>Science and Engineering Practices
Constructing Explanations and Designing Solutions</td><td>Crosscutting Concepts
Influence of Engineering, Technology, and Science on Society and the Natural World
Society is a Human Endeavor

Disciplinary Core Ideas
LS2.B Cycles of Matter and Energy Transfer in Ecosystems
ESS3.C Human Impacts on Earth Systems</td></tr>
</table>

Chapter 7: Chemical Reactions: An Introduction

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. *HS-PS1-4 Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.* HS-ETS1-3 Evaluate a solution to a real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.	
Science and Engineering Practices Developing and Using Models Using Mathematics and Computational Thinking	**Crosscutting Concepts** Energy and Matter Scientific Knowledge Assumes an Order and Consistency in Natural Systems **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS1.B Chemical Reactions ETS1.B Developing Possible Solutions ETS1.C Optimizing the Design Solution

Together with **Chapter 6**, "Chemical Composition," and **Chapter 9**, "Chemical Quantities," this chapter provides a foundation for the physical science performance expectation **HS-PS1-7**. In this chapter, students use **mathematics and computational thinking** to investigate the basic format of chemical equations and how they are systematically balanced using an understanding of the concept of conservation of mass. The concept of changes in energy associated with chemical reactions is also introduced in this chapter, laying a foundation for the fulfillment of the physical science performance expectation **HS-PS1-4**.

Bioluminescence

Chapter 7's ENGAGE feature describes the glowing headlight beetles of Emas National Park in Brazil. Use this feature to introduce the concepts covered in Section 7.1, "Evidence for a Chemical Reaction," supporting the idea that one indicator that a chemical reaction has taken place is a change in energy (**HS-PS1-4**)—in this case, the release of energy in the form of light. You may also use this feature as an opportunity to tie in life science concepts, and in particular the crosscutting concepts of **energy and matter** and **structure and function**.

Exploring Engineering: Designing Commercial Chemical Reactions

This chapter's Exploring Engineering feature describing the production of synthetic diamonds focuses on the concepts of process design and engineering and how chemical engineers seek to optimize production by limiting waste, improving efficiency, and minimizing cost, largely based on understanding of chemical mass balances and energy output (**HS-PS1-7**, **HS-PS1-4**). The feature discusses the availability of a natural resource (natural diamonds) and how it has influenced human activity (the "growing" of synthetic diamonds comparable to gem-quality natural stones). Chemical engineers look for ways to make lab-grown diamonds in a more eco-friendly manner than mined diamonds (**HS-ESS3-1**). The feature also describes the process that engineers go through to evaluate and refine their technological solutions to lab-grown diamond production in order to reduce their impact on natural systems (**HS-ESS3-4**). Chemical engineers evaluate solutions based on prioritized criteria and trade-offs, such as slowing down the production process in order to increase purity and reduce color. They consider a range of constraints such as cost, safety, reliability, aesthetics, and environmental impacts (**HS-ETS1-3**).

Chemistry in Your World: The Bombardier Beetle

This feature describes a system of specialized cells within the bombardier beetle that helps it defend itself, an essential function of life. It shoots a boiling stream of toxic chemicals at its enemy, resulting from the release of energy during a chemical reaction (**HS-PS1-4**). The balanced chemical reaction (**HS-PS1-7**),

$$C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow C_6H_4O_2(aq) + 2H_2O(l)$$

is also used in a **Connect to Biology** teacher note in **Chapter 10** to demonstrate Hess's law. Special structures within the beetle's body allow the chemicals to be stored safely and then mixed together and released at the right time (**HS-LS1-1**).

Case Study: Neurotransmitters: The Body's Chemical Messengers

This feature discusses large carbon-based molecules called neurotransmitters, which are produced by the brain and body. The carbon, hydrogen, and oxygen in neurotransmitter molecules ultimately come from sugar molecules, and those elements combine with other elements, such as nitrogen, to from different neurotransmitter molecules (**HS-LS1-6**). Teaching notes suggest that students consider the **cause-and-effect** relationships in the activity of neurotransmitters and, particularly, how difficult they are to untangle.

<table>
<tr><th colspan="2">Additional NGSS Connections</th></tr>
<tr><td colspan="2">Performance Expectations
HS-LS1-1 Construct an explanation based on scientific evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.
HS-LS1-6 Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.
HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
HS-ESS3-4 Evaluate or refine a technological solution that reduces the impacts of human activities on natural systems.*</td></tr>
<tr><td>Science and Engineering Practices
Constructing Explanations and Designing Solutions</td><td>Crosscutting Concepts
Structure and Function
Cause and Effect</td></tr>
</table>

Chapter 8: Reactions in Aqueous Solutions

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. *HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.** HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.	
Science and Engineering Practices Planning and Carrying Out Investigations Constructing Explanations and Designing Solutions Engaging in Argument from Evidence Obtaining, Evaluating, and Communicating Information	**Crosscutting Concepts** Patterns Structure and Function Influence of Science, Engineering, and Technology on Society and the Natural World **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS1.B Chemical Reactions ETS1.B Developing Possible Solutions

Chapter 8 picks up the exploration of chemical reactions initiated in **Chapter 7**. In this chapter, students learn how aqueous reactions can be classified based on **patterns** of chemical behavior, beginning with precipitation reactions and a discussion of solubility rules. Additional types of reactions, such as acid–base reactions and simple oxidation–reduction reactions, are also defined, supporting the physical science performance expectation **HS-PS1-2**.

Respiration and Energy Production

This chapter's ENGAGE feature uses the real-world phenomenon of respiration and metabolism as an example of an oxidation–reduction reaction to spark students' interest. This example can be used as an Investigative Phenomenon, requiring students to gather evidence to help explain respiration as a chemical process and develop a model for the reaction (**HS-PS1-2**, **HS-LS1-7**).

Explorers at Work: Investigating the Okavango

The Okavango Wilderness Project team has deployed sensors at sites throughout the delta and its source rivers to gather data on the water's salinity, acidity, dissolved oxygen, and conductivity (**HS-PS1-2**, **HS-ESS2-5**). This feature discusses how the availability of natural resources has influenced the human activity upstream from the delta and how that, in turn, has influenced the delta (**HS-ESS3-1**). The Okavango Wilderness Project team use the data they collect to inform solutions for reducing the impacts of human activity on the environment and biodiversity (**HS-LS2-7**).

Chemical Engineering: Treating Wastewater

This feature describes two solutions to the complex real-world problem of removing excess phosphorus from wastewater. Water treatment engineers must consider the trade-offs between the two solutions, taking into account a range of constraints including cost and reliability (**HS-ETS1-3**).

Case Study: The Flint Water Crisis

The Chapter 8 Case Study describes in detail why molecular-level structure is important in the functioning of designed materials, like the lead pipes in the city of Flint, Michigan. The feature explains the various chemical reactions that happen between the chemicals in tap water and the lead in pipes (**HS-PS2-6**). The water crisis shows how modern civilization depends on major technological systems, such as the water system of a city, and how a modification to this system (to decrease costs) can deeply affect society (**HS-ETS1-3**).

Investigation: Unknown Solutions

This student-designed investigation allows students to synthesize the concepts they have explored throughout the chapter and apply them to the determination of unknown solutions based on their chemical behavior (**HS-PS1-2**). This is an excellent opportunity for students to **plan and carry out an investigation** using the core ideas they learned throughout the chapter and to demonstrate their mastery of these concepts by **arguing from evidence**.

Additional NGSS Connections

Performance Expectations

HS-LS1-7 Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.

HS-LS2-7 Design, evaluate, and refine a solution for reducing the impact of human activities on the environment and biodiversity.

HS-ESS2-5 Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

Science and Engineering Practices

Developing and Using Models

Crosscutting Concepts

Energy and Matter
Stability and Change
Cause and Effect

Disciplinary Core Ideas

LS1.C Organization for Matter and Energy Flow in Organisms
LS2.C Ecosystem Dynamics, Functioning, and Resilience
LS4.D Biodiversity and Humans
ESS2.C The Roles of Water in Earth's Surface Processes

Chapter 9: Chemical Quantities

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. HS-ETS1-3 Evaluate a solution to a real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.	
Science and Engineering Practices Developing and Using Models Using Mathematics and Computational Thinking Designing Solutions Obtaining, Evaluating, and Communicating Information	**Crosscutting Concepts** Energy and Matter Scientific Knowledge Assumes an Order and Consistency in Natural Systems Scale, Proportion, and Quantity Systems and System Models **Disciplinary Core Ideas** PS1.B Chemical Reactions ETS1.B Developing Possible Solutions ETS1.C Optimizing the Design Solution

Chapter 9 builds upon the computational concepts in **Chapter 6**, "Chemical Composition," and **Chapter 7**, "Chemical Reactions: An Introduction" to investigate stoichiometric calculations based on balanced chemical equations. The sum of these chapters fulfills the physical science performance expectation **HS-PS1-7**. The large-scale project **"How can airbag inflation be optimized?"** in Part I of this guide addresses performance expectation HS-PS1-7 in the context of a real-world engineering problem involving stoichiometry.

Life Support on the International Space Station

The Chapter 9 ENGAGE feature describes various situations in which calculations based on chemical reactions and mass balances must be performed. The International Space Station's life support system is presented as an attention-getting real-world application of stoichiometry. You may want to use this example as an Investigative Phenomenon around which to build your curriculum. Students can research the average output of carbon dioxide and other substances from human respiration, then perform calculations based on a theoretical number of inhabitants of the space station to determine the system's minimum filtering capacity over time.

Exploring Engineering: Planning Large-Scale Reactions

This feature discusses the real-world problem of synthetic rubber production and how engineers consider the criteria and constraints associated with testing their processes, first on a smaller scale and then on the industrial scale (**HS-ETS1-3**). Using the concepts of **scale, proportion, and quantity**, engineers can model how a process at a pilot plant scale relates to the real-world application of the process at a much larger scale. In their designs, engineers must account for the flow of reactants into the system and the flow of products out. Even though the systems are more complex on the industrial scale, engineers can still apply the law of conservation of mass ensure that the mass of materials coming out equals the mass of materials going in (**HS-PS1-7**).

Hands-on Chemistry: The Nuts and Bolts of Stoichiometry

The Hands-on Chemistry activity in Section 9.3 presents an easy-to-understand model of stoichiometric calculations based on the ratios of species in a chemical reaction. You may want to use this activity early in your coverage of the concepts in this chapter to begin your exploration of stoichiometric mathematics. Allow students to draw their own conclusions and make comparisons between the model and particle-level computations.

Chemical Engineering: Reaction Engineering

This feature builds upon the **Exploring Engineering** feature for this chapter to describe how reaction engineers work to improve the yield of a reaction by determining the optimal reaction conditions. They evaluate their solutions based on prioritized criteria and trade-offs that account for a range of constraints, including cost and safety (**HS-ETS1-3**). The feature mentions that reaction engineers develop **system models** of their designs using process simulation software. If successful, their design is tested in a small-scale pilot plant before it is implemented in a full-scale industrial plant.

Case Study: Green Chemistry

This chapter's Case Study explores the concept of green chemistry. Green chemistry is a solution to the complex real-world problem of the adverse effects of certain chemicals on human health and the environment (**HS-ETS1-3**). The availability of natural resources, among other things, can and should influence human activity in this endeavor (**HS-ESS3-1**). One of the main goals of green chemistry is to **design, evaluate, and refine solutions** based on 12 design principles. These solutions aim to reduce the impact humans have (in terms of chemical production) on natural systems (**HS-ESS3-4**, **HS-LS2-7**).

<table>
<tr><th colspan="2">Additional NGSS Connections</th></tr>
<tr><td colspan="2">Performance Expectations
HS-LS2-7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*
HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
HS-ESS3-4 Evaluate or refine a technological solution that reduces the impacts of human activities on natural systems.*</td></tr>
<tr><td>Science and Engineering Practices
Constructing Explanations and Designing Solutions</td><td>Crosscutting Concepts
Stability and Change
Cause and Effect
Influence of Engineering, Technology, and Science on Society and the Natural World

Disciplinary Core Ideas
LS2.D Biodiversity and Humans
ESS3.A Natural Resources
ESS3.C Human Impacts on Earth Systems</td></tr>
</table>

Chapter 10: Energy

<table>
<tr><th colspan="2">NGSS Physical Science and Engineering Standards</th></tr>
<tr><td colspan="2">Performance Expectations
HS-PS1-4 Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.
HS-PS3-1 Create a computational model to calculate the change in energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*
HS-PS3-4 Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
HS-ETS1-3 Evaluate a solution to a real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.</td></tr>
<tr><td>Science and Engineering Practices
Developing and Using Models
Planning and Carrying Out Investigations
Analyzing and Interpreting Data
Using Mathematics and Computational Thinking
Constructing Explanations and Designing Solutions</td><td>Crosscutting Concepts
Energy and Matter
Systems and System Models
Scale, Proportion, and Quantity
Influence of Science, Engineering, and Technology on Society and the Natural World
Scientific Knowledge Assumes an Order and Consistency in Natural Systems

Disciplinary Core Ideas
PS1.A Structure and Properties of Matter
PS1.B Chemical Reactions
PS3.A Definitions of Energy
PS3.B Conservation of Energy and Energy Transfer
PS3.D Energy in Chemical Processes
ETS1.A Defining and Delimiting Engineering Problems</td></tr>
</table>

Students are first introduced to the phenomenon of changes in energy associated with chemical reactions in **Chapter 7**, "Chemical Reactions: An Introduction." The content in Chapter 10 fully addresses the physical science expectations **HS-PS1-4**, **HS-PS3-1**, **HS-PS3-2**, **HS-PS3-3**, and **HS-PS3-4**.

Sections 10.1–10.3 investigate the difference between kinetic and potential energy, the definition of temperature on a particle scale (**HS-PS3-2**), the concept of energy transfer, and basic thermochemical and thermodynamic principles, including application of **computational models** using Hess's law (**HS-PS1-4**, **HS-PS3-1**). The use of **systems and system models** in emphasized throughout the chapter.

Section 10.4, **"Using Energy in the Real World,"** provides an in-depth analysis of the degradation in the quality of energy when it is converted from one form to another, the primary energy sources utilized in the United States, and the benefits and drawbacks of various energy sources, especially regarding the issue of climate change (**HS-ESS3-5**). The "driving force" of entropy (**HS-PS3-4**) is also discussed at the end of this section.

The large-scale project **"What is the best design for a Meal, Ready to Eat?"** in Part I of this guide addresses all of the physical science performance expectations associated with this chapter, and the engineering-integrated expectation **HS-PS3-3** in particular, in the context of optimizing the energy output of a chemical system.

Alternative Energy Sources

This chapter's ENGAGE feature is a good way to get students to begin thinking about different types of energy, the differences between kinetic energy and potential energy, and the concepts of energy transfer and transformation (**HS-PS3-2**, **HS-PS3-4**). You can connect the search for reliable alternative energy sources with other chapter features, including the **Explorers at Work** feature and the **Case Study**, to address the disciplinary core ideas associated with these performance expectations.

Explorers at Work: Energizing Mali

This feature discusses Ibrahim Togola's work on renewable energy, environmental protection, and climate change issues in Mali. His organization designs solutions for developing, managing, and utilizing energy resources in order to make electricity more accessible in rural areas (**HS-ESS3-2**). They also provide many programs to train Mali citizens to operate and maintain energy resources within their communities, including replacing traditional wood-burning cookstoves with more environmentally-friendly stoves and encouraging agricultural forestry (**HS-ESS3-4**). The organization provides solutions to complex real-world problems based on prioritized criteria and trade-offs that account for a range of constraints (**HS-ETS1-3**).

Chemical Engineering: Heat Transfer

This feature explains how the principles of thermodynamics discussed in Chapter 10 are applied by engineers when designing reactors and other industrial processes. The flow of thermal energy is used to heat and cool components, and can even be used to generate other types of energy, such as electrical power (**HS-PS3-1**, **HS-PS3-2**, **HS-PS3-3**, **HS-PS3-4**, **HS-ETS1-3**).

Chemistry in Your World: Burning Calories

This feature connects the concepts of energy transformations with familiar life science phenomena: the changes in energy associated with respiration and metabolism (**HS-PS1-4**, **HS-LS1-7**). Differences in the amount of energy generated from different types of foods is discussed, and variation in the amount of energy in a food item based on **scale, proportion, and quantity** (due to variations in portion size and recipe amounts) can be related to the concepts of energy measurement discussed throughout the chapter.

Connect to Biology: The Bombardier Beetle

This teacher note relates the additive principles of Hess's law to a life science example students first explored in **Chapter 7**. Now that students are familiar with thermochemical concepts, you can explain the reaction that generates the bombardier beetle's protective spray and model the energy release using Hess's law (**HS-PS1-4**, **PS3.A**).

Chemistry in Your World: Farming the Wind

This feature returns to the topic of alternative energy sources described in the Chapter 10 ENGAGE feature, but also describes some of the hurdles engineers must consider before a large-scale switch to alternative energies is possible, such as issues with energy storage and the aging electrical grid (**HS-PS3-3**, **HS-ETS1-3**).

Case Study: Waste-to-Energy

This chapter's Case Study describes how, in order to lessen our dependence on fossil fuels of limited availability, different waste-to-energy approaches have been developed and used to generate energy from garbage (**HS-PS1-4**, **HS-PS3-3**). The feature evaluates different waste-to-energy solutions and looks at cost-benefit ratios (**HS-ETS1-3**, **HS-ESS3-2**). Teacher notes included with the feature encourage students to consider how a shift from fossil fuels to biofuels and waste-to-energy production methods influence society and the natural world with unintended consequences on the environment.

<table>
<tr><th colspan="2">Additional NGSS Connections</th></tr>
<tr><td colspan="2">Performance Expectations
HS-LS1-7 Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.
HS-ESS3-2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*
HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
HS-ESS3-5 Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.</td></tr>
<tr><td>Science and Engineering Practices
Engaging in Argument from Evidence</td><td>Crosscutting Concepts
Cause and Effect
Stability and Change
Science Addresses Questions About the Natural and Material World

Disciplinary Core Ideas
LS1.C Organization for Matter and Energy Flow in Organisms
ESS3.A Natural Resources
ESS3.C Human Impacts on Earth Systems
ESS3.D Global Climate Change
ETS1.B Developing Possible Solutions</td></tr>
</table>

Chapter 11: Modern Atomic Theory

<table>
<tr><th colspan="2">NGSS Physical Science and Engineering Standards</th></tr>
<tr><td colspan="2">Performance Expectations
HS-PS1-1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
HS-PS4-3 Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
HS-PS4-5 Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*
HS-PS4-4 Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.</td></tr>
<tr><td>Science and Engineering Practices
Developing and Using Models
Using Mathematics and Computational Thinking
Engaging in Argument from Evidence
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
Obtaining, Evaluating, and Communicating Information</td><td>Crosscutting Concepts
Patterns
Cause and Effect
Systems and System Models

Disciplinary Core Ideas
PS1.A Structure and Properties of Matter
PS4.A Wave Properties
PS4.B Electromagnetic Radiation</td></tr>
</table>

This chapter builds on the basic atomic structure established in **Chapter 4**, "Chemical Foundations: Elements, Atoms, and Ions" by discussing refinements to the model of the atom based on observations of photon emission from atoms in excited states. **Section 11.1** reviews the properties of waves outlined in physical science disciplinary idea **PS4.A**. **Sections 11.2 and 11.3** focus on developing the wave mechanical model of the atom, providing opportunities to meet physical science performance expectation **HS-PS4-3**. The Section 11.1 teacher notes, **Background Information: The Wave Nature of Light** and **Scientific Practices: Engaging in Argument from Evidence,** give supplementary information on phenomena that exhibit the wave and particle nature of electromagnetic radiation. Expanding on the concept of orbitals, **Section 11.4** examines **patterns** in valence-electron configurations as modeled by the periodic table and how these patterns manifest as trends in various properties of elements; students practice fulfilling performance expectation **HS-PS1-1** by explaining trends in atomic size and ionization energy. Additionally, the **Chapter Investigation** can be expanded to have students identify trends in flame color related to valence-electron configuration.

Investigation: Flame Tests

You may wish to demonstrate some flame tests such as those pictured in **Figure 11-10** and performed by students in this Chapter Investigation as an introductory Investigative Phenomenon to connect the Chapter 11 content to what students learned about electrons and ion formation in **Chapter 4** and to motivate further study of differences between element properties. Guidance for setting up this display is available in the **Demonstration: Burning Rainbows** teacher note in Section 11.1.

After students perform the Chapter Investigation themselves, they can explore how an element's flame test color correlates to its electron configuration by **planning and carrying out investigations** in which they observe flame tests of metals from other groups. For example, they might test compounds with transition metal ions or *p*-block cations; transition metal cations result in flames of various colors (or no color), and flame colors for *p*-block compounds tend to be blue or blue-green. Students can then **model** the outcomes using electron transition diagrams similar to those pictured in **Figures 11-17** and **11-18** to explain how the colors they observe result from the transitions between energy levels in a given atom (**HS-PS1-1**).

Explorers at Work: Modeling Dinosaur Color and Locomotion

In describing the multiple types of scanning technologies that Ryan Carney uses to develop sophisticated models of dinosaur appearance and movement, this feature provides several examples of devices that use wave interactions with matter to capture information and asks students to use what they learn throughout the chapter to give a basic explanation of how scanning technology works (**HS-PS4-5**).

Hands-on Chemistry: Making Waves

In this activity, students create and use wave diagrams to explain the relationships between wavelength, frequency, and energy (**HS-PS4-4**).

Chemical Engineering: Lasers

This feature describes how lasers are produced and explains how the sensitivity of drug-treated cancer cells to high-energy light enables laser treatment to kill cancerous cells without damaging surrounding normal cells (**PS4.B**).

Chemistry in Your World: A Magnetic Moment

In this feature, a live frog "floating" within in the hollow core of an electromagnet is used to illustrate how the phenomenon of diamagnetism results from a **cause-and-effect** interaction between electrons in the atoms of a nonmagnetic substance and an external magnetic field. (**HS-PS3-5**).

Case Study: Imaging Emission Lines

This Case Study defines emission and absorption spectra and describes how astronomers use them to study the composition of objects in space. Students are tasked with **obtaining information** about what NASA scientists hope to learn from the spectral data they gather using the Atmospheric Imaging Assembly (**HS-PS4-5**).

<table>
<tr><th colspan="2">Additional NGSS Connections</th></tr>
<tr><td colspan="2">Performance Expectations
HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.</td></tr>
<tr><td>Science and Engineering Practice
Developing and Using Models</td><td>Crosscutting Concept
Cause and Effect

Disciplinary Core Idea
PS3.C Relationship Between Energy and Forces</td></tr>
</table>

Chapter 12: Chemical Bonding

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. HS-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	
Science and Engineering Practices Developing and Using Models Planning and Carrying Out Investigations Obtaining, Evaluating, and Communicating Information Analyzing and Interpreting Data	**Crosscutting Concepts** Patterns Structure and Function **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS2.B Types of Interactions

This chapter expands on the **Chapter 11** discussion of probability maps to develop the concepts of bond polarity and electronegativity, a relative property of elements that shows trends modeled by the periodic table. In **Section 12.1**, students use electronegativity to predict the types of bonds elements will form with other elements, as required to meet physical science performance expectation **HS-PS1-1**; likewise, they use valence-electron configuration **patterns** and notation introduced in Chapter 11 to explain the relative sizes of atoms and their ions.

In **Section 12.3**, students **model** covalent bonds between atoms by drawing Lewis structures. In examining the structures of ionic compounds and molecules formed by covalent bonds, **Sections 12.2 and 12.4** address physical science disciplinary ideas **PS1.A** and **PS1.B** that support performance expectation **HS-PS1-3**. For example, the **Scientific Practices: Develop and Use Models** teacher note in Section 12.4 suggests that students analyze the structures of symmetric molecules to infer the strength of intermolecular forces in liquid forms of the molecular compounds. The Chapter 12 content regarding polarity and intermolecular forces forms a foundation for the coverage of intermolecular interactions and their effects on bulk structure and properties in **Chapter 14**, “Liquids and Solids.”

The **Explorers at Work**, **Chemical Engineering**, and **Case Study** features in this chapter provide examples of current modes of scientific research on atomic-level bonding that can be used to highlight the theme of physical science performance expectation **HS-PS2-6**, wherein students explore the connection between molecular-level **structure and function** in designed materials. The project “**What are the best materials for building temporary housing?”** in Part I of this guide poses a real-world engineering design problem that addresses performance expectations **HS-PS1-3** and **HS-PS2-6**.

Chemistry in the Visual Arts

The ENGAGE feature for Chapter 12 describes how chemical bonding influences the properties of several types of artistic media. You can use this concept along with the text’s photograph of a temple in Laos to motivate students to consider the chemistry behind materials they encounter in their everyday lives. Ask students to list properties of some artistic media that they are familiar with, such as paint color, graphite hardness, or clay plasticity. Then prompt students to think about how these substances are “designed” to have specific properties: *Can you mix paints of different types?* and *How would you choose what type of clay to use when sculpting an object that has a specific purpose?*

Explorers at Work: Self-Assembling Materials Based on Atomic Models

This article begins with a description of the 4D printing technique invented by Skylar Tibbits to produce self-assembling and programmable materials for novel products, manufacturing, and construction processes. The **In Your Community** teacher note for this feature presents opportunities for students to investigate the role of materials engineered to have specific structures and properties in product design (**HS-PS2-6**). To model the formation of matter from atoms via 4D printing, the MIT Self-Assembly Lab team designed spheres to represent carbon atoms, incorporating magnets and weights for the spheres to exert "interatomic bonding" forces on each other. Changing the energy in a system of spheres in a water-filled tank simulated the self-assembly of solid carbon structures and phase transitions. In the **Thinking Critically** activity, students are asked to explain carbon bonding patterns and describe how the electron arrangements of atoms in a molecule affects its three-dimensional structure (**HS-PS1-3**).

Hands-on Chemistry: Geometric Balloons

In this activity, students make figures out of balloons to **develop and use models** of molecular structures; the simple models they explore here are later refined using different methods and materials in the **Chapter 12 Investigation**. The Hands-on Chemistry teacher note describes a balloon demonstration that can be used to show the relationship between energy and molecular stability (**PS1.A**).

Chemical Engineering: Complex Molecular Models

This feature describes how scientists and engineers **use mathematical and computational thinking** to represent the repulsive forces between electron pairs and apply minimization algorithms to **develop models** of existing or new molecular systems. The associated teacher note suggests how students can be involved as citizen scientists in finding the best potential solutions for highly complex chemical structures.

Chemistry in Your World: Molecular Sieves

The use of molecular sieves as desiccants that trap water molecules to remove them from the surrounding air demonstrates that the molecular-level structure of a designed material is important to its functioning (**HS-PS2-6**). The teacher note illustrates physical science disciplinary idea **PS2.B** by detailing how molecular sieves are produced and how pore sizes can be varied by altering the starting compounds to change the atomic-scale electric forces that hold the material's network structure together.

Case Study: Looking at Molecular Bonds

During the 20th century, mathematical models were used to understand the nature of atomic bonds; however, modern imaging techniques now allow molecular structures to be examined at subatomic levels. This feature focuses on the technology behind atomic force microscopy, which uses electrical forces between the AFM tip and the atoms at the surface of the matter being scanned to generate information about the positions of atoms and charge in the material (**PS2.B, HS-PS1-3**). The **Scientific Practices: Analyzing and Interpreting Data** teacher note addresses issues involved in determining the meaning and relevance of data gathered at very small scales when comparing the empirical data to **computational models** of a material.

Investigation: Models of Molecules

This Investigation requires students to use two different methods—Lewis structures and three-dimensional figures made of toothpicks and clay—to **develop and use models** of specific molecular compounds. They **analyze and interpret data** from the shapes they have constructed to relate the repulsive forces between the electron pairs represented in their models to the electron arrangements and molecular structures of the given compounds (**HS-PS1-1**).

Chapter 13: Gases

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative position of particles (objects).	
Science and Engineering Practices Planning and Carrying Out Investigations Developing and Using Models Obtaining, Evaluating, and Communicating Information Constructing Explanations and Designing Solutions Using Mathematical and Computational Thinking	**Crosscutting Concepts** Patterns Energy and Matter Structure and Function Cause and Effect **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS3.A Definitions of Energy ETS1.B Developing Possible Solutions

Together with **Chapter 14**, "Liquids and Solids," Chapter 13 supports physical science performance expectation **HS-PS1-3** by describing the characteristic intermolecular forces for each of the three states of matter. This chapter illustrates that the insignificance of electrical forces between gas particles gives rise to bulk structure and properties that differ greatly from those of liquids and solids; teacher notes in Section 13.1, such as **Demonstration: Pressure and Volume**, **Demonstration: Helium Hot Air Balloon**, and **Scientific Practices: Constructing an Explanation** present activities in which students can observe several gas behaviors at the macroscopic level and **use models** to explain them. Throughout the chapter, students **use mathematical thinking** in recognizing the proportional relationships between gas parameters as described by the ideal gas law and by applying this law to perform gas stoichiometry calculations. The discussion of the kinetic molecular theory (KMT) of gases in **Section 13.3** equips students to practice physical science performance expectation **HS-PS3-2**. For example, the **Crosscutting Concepts: Patterns** teacher note in this section suggests a demonstration for which students use the KMT to **construct an explanation** for their observations, and the **Scientific Practices: Developing and Using Models** teacher note describes an activity in which students use a jar of small objects to **develop a model** of gas particle behavior.

To bookend the chapter content, you can use the **Exploring Engineering** feature and the large-scale project "**How can airbag inflation be optimized?**" in Part I of this guide as opportunities for students to **design solutions** and **communicate scientific and technical information** to fulfill performance expectation **HS-PS2-6**.

Full of Hot Air

The ENGAGE feature for Chapter 13 provides an opportunity for students to extend what they have learned about gas behavior in earlier grades to the high school level by encouraging them to take a closer look at the process by which a hot air balloon is inflated so that it can be made to float in the surrounding atmosphere. You can connect the phenomena that are visible in the photograph to the discussion of changes in the energy of a system in **Chapter 10**, "Energy"; defining the balloon and the air inside it as the system, have students identify whether any work is done on or by the system and determine the signs of heat q and the change in energy ΔE.

Exploring Engineering: Making Gases Work Using Pneumatic Technology

This article describes how the molecular-level behavior of gases enables them to do work within pneumatic devices. Devices powered by gas-producing chemical reactions are presented as a novel application of pneumatic technology; this method of generating pneumatic force is particularly helpful in the field of soft robotics, which can be safer and more convenient than conventional rigid robots for use around humans. In the **Applying Chemistry** activity, students use what they learn about the forces applied by gas molecules to design a simple pneumatic device (**HS-PS2-6**).

Hands-on Chemistry Minilab: The Cartesian Diver

Students **plan and carry out an investigation** of how a Cartesian diver works, choosing variables to for their experiments and **constructing explanations** of their observations.

Hands-on Chemistry: The Candle and the Tumbler

After observing the results of this procedure, students use their knowledge of the ideal gas law and the kinetic molecular theory to **construct an explanation** of the phenomena they observed.

Chemistry in Your World: What Puts the "Pop" in Popcorn?

In addition to describing the mechanism of popcorn popping in the context of the ideal gas law, this feature delves into how the molecular-level structure of the pericarp determines the "popability" of a corn kernel. In the teacher note for this feature and the related **Demonstration: The Scoop on Popcorn** teacher note, students **carry out investigations** in which they predict and compare the effects of factors such as moisture on the overall yield of popped corn (**HS-PS2-6**).

Chemistry in Your World: The Chemistry of Air Bags

The information provided here about the sodium azide reaction involved in the deployment of air bags can be used as an introduction to the "**How can airbag inflation be optimized?**" project, as it illustrates that designing a system requires examination of the **structures** of different components and the connections of components to reveal the system's **function** (**HS-PS2-6**). The teacher note for this feature details the effects of unused air bag disposal on natural systems and describes some possible solutions to this problem, thus providing an example relevant to Earth science disciplinary idea **ESS3.C** (**HS-ESS3-4**).

Chemical Engineering: Solids from Gases

This feature describes the process of chemical vapor deposition (CVD), in which atomic-scale interactions that occur in chemical reactions between different gases are used to produce thin layers of solids with specific structures and properties (**PS2.B**, **HS-PS2-6**).

Investigation: Masses of Gases

This investigation focuses on having students design an apparatus to measure the relative masses of various gas samples. As they **plan and carry out an investigation** to inform their design, students will need to consider how to compare the masses of very lightweight substances and identify variables they will need to control. To solve the problem of devising a measurement technique, they must examine the properties of gases and other materials, the **structures** of the components of their proposed system, and the connections between these components and how they **function**.

Chapter 14: Liquids and Solids

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative position of particles (objects). HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	
Science and Engineering Practices Planning and Carrying Out Investigations Developing and Using Models Obtaining, Evaluating, and Communicating Information Defining a Problem	**Crosscutting Concepts** Patterns Energy and Matter Structure and Function **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS2.B Types of Interactions PS3.A Definitions of Energy

Chapter 14 supports physical science performance expectation **HS-PS1-3** by describing intermolecular forces in liquids and solids and examining how these forces determine the bulk structures of substances. Students analyze the relationships between intermolecular interactions and properties of materials, such as vapor pressure and boiling point in liquids and thermal and electrical conductivity in solids. The **Scientific Practices: Planning and Conducting Investigations** teacher notes in Sections 14.2 and 14.3 offer activities in which students compare properties of substances in light of their structures and the characteristics of the intermolecular forces that they exhibit.

Phase changes in water are used to introduce the heating/cooling curve that models macroscopic changes in energy in a substance. Students meet physical science performance expectation **HS-PS3-2** by explaining **patterns** in heating/cooling curves in terms of particle-level motion and position, including the correlation of the relative magnitudes of molar heats of fusion and evaporation to the amount of energy required to overcome the types of intermolecular forces that hold solids or liquids together.

The large-scale project "**What are the best materials for building temporary housing?**" in Part I of this guide can be used in conjunction with Chapter 14 content to fulfill performance expectations **HS-PS1-3** and **HS-PS2-6**. This activity provides opportunities for students to **plan and carry out investigations** of the bulk structures and properties of materials, **design solutions** to a real-world engineering problem, and **communicate scientific and technical information** about their designs.

Penguin Power

To transition from the topic of gases in **Chapter 13** and the study of liquids and solids in Chapter 14, you can use the Chapter 14 ENGAGE feature that highlights a natural application of differences in intermolecular forces among the states of matter. Ask students to identify the gas, liquid, and solid elements in the penguin photograph and describe how these components interact. You can return to the photograph at relevant points throughout the chapter to discuss details about the penguin's launch mechanism, such as how releasing gas bubbles changes the density of the surrounding water and how friction (such as water resistance) results from forces between molecules on the contact surfaces of the substances involved (**PS1.A, PS2.B**).

Explorers at Work: Analyzing Sea Lion DNA

Sampling and **data analysis** techniques that Diego Peralta uses in his research on sea lions take advantage of the electrical nature of intermolecular forces between glue and hair, between positively-charged silica beads and negatively-charged DNA molecules, and on charged DNA molecules in gel electrophoresis. In the **Thinking Critically** activity, students use what they learn about intermolecular forces to explain how charged materials enable these research methods (**PS2.B, HS-PS2-6**).

Chemistry in Your World: Whales Need Changes of State

The feature describes how spermaceti melts or freezes in response to blood flow in a sperm whale's head and how the corresponding changes in the density of the spermaceti help the whale hover at different depths in the ocean. The teacher note for this feature supplies questions for extending the discussion of the bulk properties of the solid and liquid states to the effects of hydrogen bonding on the structure of water (**PS1.A, PS2.B**).

Hands-on Chemistry: Molecular Groupies

In this activity, students **use models** of pairs of molecular structures to infer the relative boiling points and vapor pressures of the associated liquids based on the size and polarity of the molecules and the type and strength of the intermolecular bonds (**HS-PS1-3**).

Chemistry in Your World: Metal with a Memory

Nitinol is a metal alloy that, if bent out of shape, returns to its original shape after a slight increase in temperature. The teacher note for this feature details the two solid structures between which nitinol switches depending on temperature or stress, exemplifying the active role of atomic-level structure in the functioning of this designed material (**HS-PS2-6**).

Case Study: Gecko-Inspired Adhesives

This feature describes biomimetic adhesives inspired by the elastic hairs on geckos' feet; both take advantage of attractive forces between molecules that enable materials to stick to each other. Scientists needed to alter the microscale surface structure of the adhesives to solve the problem of load distribution over larger areas, demonstrating the importance of molecular-level structure in designed materials.

In the **Model** activity for this feature, students are asked to identify an engineering application of the water-shedding property found in some plant and animal structures. To show an example of this property, you may wish to revisit the penguin feather functionality introduced in the **Penguin Power** ENGAGE feature at the beginning of the chapter. The Case Study teacher note recommends some organism-inspired criteria that students can consider as they formulate a biomimetic solution to a simple **defined problem** and delineate the physical criteria it must meet (**PS2.B**, **HS-PS2-6**).

Investigation: Heat of Fusion

This Investigation requires students to use temperature and mass measurements obtained by calorimetry to calculate the energy transferred from water to ice. To answer questions regarding how the experimental heat of fusion values would vary with hypothetical changes in procedure, students should understand the molecular model of heat transfer during changes of state. The **Something Extra** activity suggests that students **plan and carry out an investigation** to quantify the energy lost to the environment surrounding the calorimeter (**HS-PS3-2**).

Chapter 15: Solutions

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. *HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.* *HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.*	
Science and Engineering Practices Planning and Carrying Out Investigations Using Mathematics and Computational Thinking Constructing Explanations and Designing Solutions	**Crosscutting Concepts** Patterns Energy and Matter Scientific Knowledge Assumes an Order and Consistency in Natural Systems Cause and Effect **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS1.B Chemical Reactions

The content in Chapter 15 can be used primarily to support physical science performance expectation **HS-PS1-3**, and as a secondary support to **HS-PS1-2** and **HS-PS1-7**. A general survey of aqueous reactions and solubility patterns with a focus on macroscopic behavior is provided in **Chapter 8**, “Reactions in Aqueous Solutions.” The processes of dissolution and reaction in solution discussed in this chapter are also integral to the large-scale project **“What is the best design for a Meal, Ready to Eat?”** in Part I of this guide.

Blood Falls

The ENGAGE feature for Chapter 15 presents students with a real-world example of the processes of dissolution and how changes in concentration can cause large-scale observable effects. The example of Blood Falls in East Antarctica can also be used as a cross-discipline phenomenon to support performance expectation **HS-ESS2-5**.

Explorers at Work: Analysis of Lake Sediments

Neil Rose quantifies the effects of pollution through measurements of freshwater contaminant concentrations. Using this data, Rose and his team have been able to **construct explanations** as to the processes by which pollutants are dispersed through the environment and how climate change may exacerbate the problem. Rose’s team found, among other things, that the concentration of carbon-based products of fossil fuel combustion increased in freshwater bodies during the 20th century as part of the cycling of carbon among Earth’s systems, including the atmosphere and geosphere (**HS-ESS2-6**). His research shows that increased winter rainfall and the increased frequency of heavy rain (that is, the effects of climate change) promote soil erosion and can cause pollutants to be released into the lakes (**HS-ESS2-2**, **HS-ESS2-5**).

Case Study: Alternative Deicers

This Case Study explains how the colligative property of freezing-point depression makes rock salt useful as a road deicer. The salt used as deicer is a natural resource that can negatively affect the soil and drinking water and even corrode roads, cars, and bridges (**HS-ESS3-3**). Students are asked to examine data to identify **patterns** in the chloride concentrations of nearby water systems and explain how they relate to the use of road salt; this phenomenon can be further explored in your own community using the **Chapter 15 Investigation**. Other deicing substances, such as pickle juice and sugar beet juice, are also evaluated with the goal of reducing the impact of human activities on natural systems (**HS-ESS3-4**). A teacher note included with the feature also provides examples of unintended **cause-and-effect** consequences of the use of rock salt, such as increases in wildlife roadway fatalities.

Investigation: Chloride in Water

This chapter's Investigation builds upon the concepts discussed in the Explorers at Work and Case Study features, giving students an opportunity to measure chloride concentrations in water samples and to **analyze data** from local water sources. The use of titration as an analytical technique supports the law of conservation of mass as described by performance expectation **HS-PS1-7**. You may also use this procedure as the basis for a student-inquiry-driven investigation, explaining the technique of titration and allowing students to design their own experiment to evaluate a claim such as "Water samples from local tap water contain more chloride than bottled water" and support their argument with evidence.

<table>
<tr><th colspan="2">Additional NGSS Connections</th></tr>
<tr><td colspan="2">Performance Expectations
HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth Systems.
HS-ESS2-5 Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.
HS-ESS2-6 Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.</td></tr>
<tr><td>Science and Engineering Practices
Developing and Using Models
Analyzing and Interpreting Data</td><td>Crosscutting Concepts
Structure and Function
Stability and Change
Influence of Engineering, Technology, and Science on Society and the Natural World

Disciplinary Core Ideas
ESS2.A Earth Materials and Systems
ESS2.C The Roles of Water in Earth's Surface Processes
ESS2.D Weather and Climate</td></tr>
</table>

Chapter 16: Acids and Bases

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. *HS-PS1-6 Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.**	
Science and Engineering Practices Constructing Explanations and Designing Solutions	**Crosscutting Concepts** Patterns Stability and Change **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS1.B Chemical Reactions ETS1.C Optimizing the Design Solution

Chapter 16 builds upon the macroscopic **patterns** of reactions between strong acids and strong bases first discussed in **Chapter 8**, "Reactions in Aqueous Solutions," and can be used to support physical science performance expectation **HS-PS1-2**. This chapter also introduces the concepts of reversible reactions and equilibrium systems in the context of amphoteric behavior and the properties of weak acids and bases and buffered solutions, supporting performance expectation **HS-PS1-6**; these concepts are further developed in **Chapter 17**, "Equilibrium." The core ideas of this chapter serve as the foundation for the large-scale project **"Can acidification of aquatic environments be reversed?"** in Part I of this guide.

Sulfur Mining

The Chapter 16 ENGAGE feature describes the natural sulfur deposits in the Kawah Ijen volcano in Indonesia. The sulfur mined from the Kawah Ijan mines can be used to produce sulfuric acid through the contact process as described in the **Chapter 17 Exploring Engineering** feature. These features can be used in implementing Earth science performance expectations such as **HS-ESS3-1** and **HS-ESS3-2**.

Explorers at Work: Coral Reef Restoration

The Chapter 16 Explorers at Work feature describes how increased levels of carbon dioxide in the atmosphere have led to more carbon dioxide dissolved in the ocean, increasing its acidity. Ocean acidification contributes to coral bleaching and damage (**HS-ESS3-6**). Influenced by these changes, Rodríguez-Troncoso's team has studied different methods to promote the regrowth of coral (**HS-LS2-7**, **HS-ESS3-4**). Coral reef restoration is economically beneficial to regions that depend on the ecotourism that coral reefs draw; humans also depend on coral reefs as a source of food and as a buffer to protect coastal communities (**HS-ESS3-1**). The feature also highlights the relationship between coral reefs and other organisms that depend on the reefs for survival. This feature can be readily integrated into your classroom discussion for the large-scale project **"Can acidification of aquatic environments be reversed?"**

Hands-on Chemistry: Cabbage Juice Indicator

This simple minilab can be used to begin your discussion of indicators and the behavior of weak acids and bases. Students can experiment with substances of known acidity and **construct their own explanations** for how the color change occurs and why it can be reversed. After students make predictions based on their observations, they can explore the properties of acid–base indicators and reversible reactions.

Case Study: Neutralizing Acid Deposition

This Case Study investigates how pollution from burning coal in power plants can cause acid deposition, which is harmful to wildlife and structures. By law, power plants were required to reduce the pollution they released into the air in order to improve both air and water quality (**HS-LS2-7**, **HS-ESS3-1**, **HS-ESS3-4**, **HS-ESS3-6**). This feature ties directly into the **Chapter Investigation**, “Acid Rain,” which is also included as part of the large-scale project **“Can acidification of aquatic environments be reversed?”**

Investigation: Acid Rain

This investigation is included as one of the major Objectives in the large-scale project **“Can acidification of aquatic environments be reversed?”** Students can use this investigation to observe the effects of acid deposition on water in their own communities (**HS-ESS3-6**).

<table>
<tr><th colspan="2">Additional NGSS Connections</th></tr>
<tr><td colspan="2">Performance Expectations
HS-LS2-7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*
HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
HS-ESS3-2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*
HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*
HS-ESS3-6 Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.</td></tr>
<tr><td>Science and Engineering Practices
Using Mathematics and Computational Thinking
Engaging in Argument from Evidence</td><td>Crosscutting Concepts
Cause and Effect
Systems and System Models
Influence of Engineering, Technology, and Science on Society and the Natural World
Science Addresses Questions About the Natural and Material World

Disciplinary Core Ideas
LS2.C Ecosystem Dynamics, Functioning, and Resilience
LS4.D Biodiversity and Humans
ESS2.D Weather and Climate
ESS3.A Natural Resources
ESS3.B Natural Hazards
ESS3.D Global Climate Change
ETS1.B Developing Possible Solutions</td></tr>
</table>

Chapter 17: Equilibrium

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-5 Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. HS-PS1-6 Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can solved through engineering. HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.	
Science and Engineering Practices Planning and Carrying Out Investigations Constructing Explanations and Designing Solutions Optimizing the Design Solution	**Crosscutting Concepts** Patterns Stability and Change Influence of Science, Engineering, and Technology on the Natural World **Disciplinary Core Ideas** PS1.B Chemical Reactions ETS1.B Developing Possible Solutions ETS1.C Optimizing the Design Solution

Chapter 17 begins with an investigation of chemical kinetics and reaction mechanisms on the particle scale based on collision theory. This exploration of the effects of concentration and temperature on reaction rate fulfills physical science performance expectation **HS-PS1-5**.

The remainder of the chapter explains the concepts of chemical equilibrium and how equilibrium systems respond to shifting conditions according to Le Châtelier's principle, supporting performance expectation **HS-PS1-6**. Students will have already been introduced to the concept of reversible reactions in terms of amphoteric substances, weak acids and bases, and buffer systems in **Chapter 16**. Combined with the content in Chapter 16, the concepts and features in this chapter form the basis of large-scale project **"Can acidification of aquatic environments be reversed?"** in Part I of this guide.

Ecosystems in Equilibrium

The Chapter 17 ENGAGE feature describes an equilibrium system students are likely familiar with from coverage of world events in the media and prior academic exploration: the tangible large-scale example of ecosystem disruption. Use this example to investigate how the concept of **stability and change** is applicable at different scales and across disciplines. This feature can be used in conjunction with the Chapter 17 **Case Study**, "Carbon Sinks and Disruption of the Carbon Cycle," as a real-world Investigative Phenomenon for performance expectation **HS-PS1-6**.

Exploring Engineering: Manufacturing Sulfuric Acid

This chapter's Exploring Engineering feature describes how engineers solved design problems associated with the manufacture of sulfuric acid, taking into account possible unanticipated effects (**HS-ETS1-3**). For example, in the second step of the manufacturing process, engineers found that lowering the temperature increased yield but slowed the reaction (**HS-PS1-5**). To solve this problem, they used a catalyst. Based on trial and error, engineers were able to design a process that shifted equilibrium in favor of the desired product (**HS-PS1-6**).

Chemistry in Your World: Carbon Dioxide

This feature presents the carbon cycle as an equilibrium system that has fluctuated around a steady midpoint throughout Earth's past until the equilibrium was disrupted by human activity. Over the last century, the concentration of atmospheric carbon dioxide has far exceeded its highest historical levels (**HS-ESS3-6**), as previously described in Section 4 of **Chapter 10**, "Using Energy in the Real World." The increase in carbon dioxide in the atmosphere has had some unexpected effects. For example, plants grown in an atmosphere rich in carbon dioxide are starchy (high in carbon), but protein-poor (deficient in nitrogen). Studies have shown that when caterpillars eat these plants, their growth is slowed and they produce smaller butterflies (**HS-LS2-5**, **HS-ESS2-6**). You can use this feature along with the Chapter 17 **ENGAGE** feature and **Case Study** to support the large-scale project **"Can acidification of aquatic environments be reversed?"**

Chemical Engineering: The Haber–Bosch Process

This engineering-focused feature describes how the chemists Fritz Haber and Carl Bosch used the principles behind shifting equilibrium to solve various problems associated with producing ammonia on the industrial scale (**HS-PS1-5**, **HS-PS1-6**). Both took a systematic approach in optimizing their designs and in breaking down the problem into smaller problems that could be solved (**HS-ETS1-2**).

Case Study: Carbon Sinks and Disruption of the Carbon Cycle

The Chapter 17 Case Study describes how carbon moves through the biosphere, atmosphere, hydrosphere, and geosphere through the carbon cycle (**HS-ESS2-6**). The feature identifies regions such as forested areas and the world's oceans as carbon sinks (**HS-LS2-5**). The feature describes how changes in the amount of atmospheric carbon dioxide due to human activity have caused equilibrium systems in the ocean to shift, leading to ocean acidification, and thereby affecting marine organisms, such as those that use calcium carbonate to form shells and skeletal structures (**HS-PS1-6**, **HS-ESS3-6**). The **Evaluate** activity asks students to provide examples of how the problems associated with increased carbon dioxide may be reversed. Some solutions include the use of alternative carbon sinks (like planting more trees or growing more marine plants) or adding neutralizing acids to the ocean (**HS-ETS1-1**, **HS-ESS3-4**). This feature is included as part of the large-scale project **"Can acidification of aquatic environments be reversed?"** The Case Study can also be used with the Chapter 17 **ENGAGE** feature as an Investigative Phenomenon around which to frame the chapter's core ideas.

Investigation: Chemical Competition

This chapter's Investigation gives students an opportunity to **plan and carry out an investigation** using the principles of chemical equilibrium and changes in reactant concentration to produce a desired product (**HS-PS1-5**, **HS-PS1-6**). The activity is best performed once students have mastered the core ideas associated with the chapter, allowing them to apply their knowledge to design an experimental procedure and support their argument with evidence.

Additional NGSS Connections

Performance Expectations

HS-LS2-5 Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

HS-ESS2-6 Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*

HS-ESS3-6 Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Science and Engineering Practices

Asking Questions and Defining Problems
Developing and Using Models
Using Mathematics and Computational Thinking

Crosscutting Concepts

Systems and System Models
Energy and Matter
Science is a Human Endeavor

Disciplinary Core Ideas

LS2.B Cycles of Matter and Energy Transfer in Ecosystems
ESS2.D Weather and Climate
ESS3.C Human Impacts on Earth Systems
ESS3.D Global Climate Change
ETS1.A Defining and Delimiting Engineering Problems

Chapter 18: Oxidation–Reduction Reactions and Electrochemistry

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. HS-PS1-1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	
Science and Engineering Practices Developing and Using Models Planning and Carrying Out Investigations Obtaining, Evaluating, and Communicating Information Constructing Explanations and Designing Solutions	**Crosscutting Concepts** Patterns Structure and Function Stability and Change **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS1.B Chemical Reactions PS2.B Types of Interactions

Because they involve electron transfer, oxidation–reduction reactions provide numerous contexts for applying performance expectations involving patterns in valence electron configurations that give rise to periodic trends in chemical properties. This chapter introduces oxidation states and half-reactions; these tools enable students to determine the outcomes of redox reactions. To further fulfill physical science performance expectation **HS-PS1-2**, students explain how redox reactions result in directional current flow in batteries and use activity series to predict the occurrence of reactions involving metals. The **Scientific Practices: Developing and Using Models** and **Crosscutting Concepts: Patterns** teacher notes in Section 18.1 describe activities that help students meet physical science performance expectation **HS-PS1-1** by relating oxidation states to the properties of electronegativity and activity. The discussion of substances used in conventional batteries and newer battery technology is a useful theme by which students can compare how the molecular-level **structures and functions** of these materials are related, in order to meet physical science performance expectation **HS-PS2-6**.

Salty Stranded Ships

Rust formation on an unprotected iron or steel surface is a macroscopically visible phenomenon that occurs through a combination of oxidation–reduction reactions with atmospheric oxygen in the presence of water. The Chapter 18 ENGAGE question of why ships corrode faster in saltwater than in freshwater provides an Investigative Phenomenon that can be explored throughout the chapter via experimental observations. The Something Extra activity in the **Chapter Investigation** and the **Demonstration: Making a Galvanic Cell** and **Scientific Practices: Planning and Carry Out Investigations** teacher notes in Section 18.3 propose investigations that provide students with evidence to **construct their explanations**.

Explorers at Work: Microbial Photosynthesis and the Great Oxidation Event

Photosynthesis is a complex series of oxidation–reduction reactions. Billions of years ago, cyanobacterial photosynthesis resulted in a rapid increase in oxygen in the atmosphere that is thought to have enabled the evolution of more complex oxygen-breathing organisms. Anne D. Jungblut studies how microbial communities grow in polar habitats that model the harsh conditions that existed during the early development of life on Earth (**ESS2.D, ESS2.E**). In the **Thinking Critically** activity, students analyze oxidation–reduction reactions between oxygen and metals to explain how Earth's surface composition would have been affected by the Great Oxidation Event (**HS-ESS2-7**).

Investigation: Activity Series

To establish a progression from macroscopic to microscopic phenomena, you may wish to introduce the topic by having students **plan and carry out this investigation** to systematically compare the observable outcomes of many oxidation–reduction reactions between metals and solutions containing metal ions. This experience will prepare them to meet performance expectations **HS-PS1-1** and **HS-PS1-2** as they move to quantitatively analyzing electron transfer in redox reactions.

Chemical Engineering: Solid-State Batteries

With regard to the challenge of developing batteries for use in electric vehicles, this feature presents some qualitative criteria and constraints that account for societal needs and wants. For example, electric vehicle users typically require that the battery recharge quickly while storing enough energy to operate over long trips. Safety and environmental concerns also influence the general acceptance of new battery technologies (**HS-ETS1-1**). The teacher note for this feature describes the unique structure of a fast ion conductor and asks students to relate this **structure** to the material's **functional** benefits as a solid-state electrolyte in a battery (**HS-PS2-6**).

Case Study: Battery Farms

This article compares two methods of generating electricity—hydroelectric pumped-storage power plants and battery farms that store energy obtained using renewable energy sources—by identifying environmental and technological constraints that affect each method and highlighting trade-offs that would be made in choosing one of these methods (**HS-ESS3-2**). The **Analyze** activity asks students to define an engineering problem involving meeting the electric power demands of a rapidly growing population in an area (**ETS1.A, HS-ETS1-1**).

<table>
<tr><th colspan="2">Additional NGSS Connections</th></tr>
<tr><td colspan="2">Performance Expectations
HS-ESS2-7 Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.
HS-ESS3-2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*
HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.</td></tr>
<tr><td>Science and Engineering Practices
Engaging in Argument from Evidence
Asking Questions and Defining Problems</td><td>Crosscutting Concepts
Influence of Science, Engineering, and Technology on Society and the Natural World
Science Addresses Questions About the Natural and Material World

Disciplinary Core Ideas
ESS2.D Weather and Climate
ESS2.E Biogeology
ESS3.A Natural Resources
ETS1.A Defining and Delimiting Engineering Problems
ETS1.B Developing Possible Solutions</td></tr>
</table>

Chapter 19: Radioactivity and Nuclear Energy

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-8 Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. *HS-PS4-4 Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.*	
Science and Engineering Practices Developing and Using Models Obtaining, Evaluating, and Communicating Information	**Crosscutting Concepts** Energy and Matter Cause and Effect **Disciplinary Core Ideas** PS1.C Nuclear Processes PS4.B Electromagnetic Radiation

This chapter correlates completely to the physical science performance expectation **HS-PS1-8**. Starting in **Section 19.1**, students **develop and use models,** including diagrams and nuclear equations, to demonstrate how the numbers of neutrons or protons in an atom change during the processes of fission, fusion, and radioactive decay. To provide further detail for disciplinary idea **PS1.C**, this section introduces specific forms of **matter and energy** that are emitted or absorbed in nuclear processes.

Nuclear power is a prime example of the **influence of science, engineering, and technology on society and the natural world**. **Section 19.3** explains how energy released by nuclear fission is harnessed in nuclear reactors and converted to electricity in a nuclear power plant. The section's **In Your Community** and **Real-World Issues** teacher notes suggest that students **obtain, evaluate, and communicate information** about nuclear waste disposal and nuclear accidents; using this content, students can fulfill Earth science performance expectation **HS-ESS3-2** by comparing nuclear energy resources to other energy resources. **Section 19.3** also describes the damaging effects of radiation on organisms at a cellular scale, demonstrating the **cause-and-effect** relationships addressed in disciplinary idea **PS4.B**. Students can use this information to support efforts to meet physical science performance expectation **HS-PS4-4**.

Reactions in the Sun

Chapter 19's ENGAGE feature describes how the sun derives its energy from nuclear reactions. Use this point to introduce the concept of energy associated with changes occurring in the nucleus and start a discussion of how nuclear energy reaches Earth in the form of radiation (**HS-ESS1-1**).

Explorers at Work: Improving Nuclear Power

Leslie Dewan and her team conduct research to help engineers design novel nuclear energy technologies. In terms of waste product buildup, reaction efficiency, and safety, molten salt nuclear reactors may have advantages over conventional nuclear reactors that drive steam turbines. In the **Thinking Critically** activity, students evaluate the feasibility of nuclear power as a large-scale replacement for energy generation by fossil fuels (**HS-ESS3-2**). To inform their claims, the **In Your Community** teacher note for this feature suggests that students **obtain and evaluate information** about electrical energy sources used in the United States.

Hands-on Chemistry: Modeling Decay Rates

In this activity, students **use mathematics and computational thinking** to **model** radioactive decay rates with six-sided dice. The model illustrates the concept of half-life and allows students to estimate the half-life for their "sample." This activity ties closely to the **Chapter 19 Investigation**, which involves a different model of decay rates.

Chemical Engineering: Future Energy Sources

This feature describes how nuclear, wind, and solar energy technologies convert one form of energy into another and compares the economic and environmental effects of these forms of energy generation (**HS-ESS3-2**).

Chemistry in Your World: Making Elements in Stars

Nuclear fusion reactions in stars produced the chemical elements that make up all matter in the universe. This feature outlines the role of **matter and energy** interactions in forming elements and shaping the life cycles of stars (**PS3.D, ESS1.A**).

Investigation: Modeling Half-life

Students use pennies to **model** the probability of an atom decaying and **analyze and interpret data** to determine the half-life of the modeled radioactive isotope. At the completion of the investigation, you may wish to facilitate a discussion to compare this investigation's model and the **Hands-on Chemistry** model in terms of how well they illustrate radioactive decay.

<table>
<tr><th colspan="2">Additional NGSS Connections</th></tr>
<tr><td colspan="2">Performance Expectations
HS-ESS3-2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*
HS-ESS1-1 Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.</td></tr>
<tr><td>Science and Engineering Practices
Engaging in Argument from Evidence</td><td>Crosscutting Concepts
Science Addresses Questions About the Natural and Material World
Influence of Science, Engineering, and Technology on Society and the Natural World
Scale, Proportion, and Quantity

Disciplinary Core Ideas
ESS3.A Natural Resources
ESS1.A The Universe and Its Stars
PS3.D Energy in Chemical Processes and Everyday Life
ETS1.B Developing Possible Solutions</td></tr>
</table>

Chapter 20: Organic Chemistry

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. HS-PS1-1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. *HS-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.* HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.	
Science and Engineering Practices Developing and Using Models Constructing Explanations and Designing Solutions Planning and Carrying Out Investigations	**Crosscutting Concepts** Patterns Cause and Effect Energy and Matter Influence of Science, Engineering, and Technology on Society and the Natural World **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS1.B Chemical Reactions ETS1.B Developing Possible Solutions ETS1.C Optimizing the Design Solution

This chapter can be used to support the physical science performance expectations **HS-PS1-1**, **HS-PS1-2**, and **HS-PS1-3**, which students will have already covered extensively in previous chapters. This chapter allows students to explore the concepts of chemical reactions and the structure and function of matter as they apply to compounds and reactions in organic chemistry. Throughout this chapter, students relate the ubiquity and relevance of organic chemistry to human sustainability and designed materials.

Organic Materials

This chapter's ENGAGE feature gives students an opportunity to identify familiar materials that are made from organic substances. This may be the first time students will have learned that plastics are actually carbon compounds made from petrochemicals. You can use this feature to tie in with the Chapter 20 **Case Study**, which examines the impacts plastics have on the environments and attempts to engineer solutions that mitigate this problem (**HS-ESS3-4**).

Exploring Engineering: Designing Biocompatible Prosthetics

This article analyzes the challenge of designing biocompatible prosthetics to meet specific criteria and constraints (**HS-ETS1-3**). For example, the materials that are intended to function within or in contact with the human body must be sterilizable and hypoallergenic, must not degrade with use over time, and cannot be toxic. Analysis of costs and benefits is also a critical aspect of decisions related to prosthetics. Teacher notes suggest discussing some of the expenses related to prostheses and how engineering solutions have been applied to low-cost prosthetics that are suitable for users with limited resources.

Chemical Engineering: Cracking Hydrocarbons

This feature describes methods of breaking (or “cracking”) long-chain hydrocarbons into more desirable shorter-chain hydrocarbons. Over time, the method has been refined to include the use of catalysts, making it more efficient and cost-effective. This also reduces its impact on natural systems (**HS-ESS3-4**).

Chemistry in Your World: Livestock and Methane Production

This feature describes a couple solutions to reduce the amount of methane that livestock release into the atmosphere. This effort will reduce the impact of human activities (the raising of livestock for food) on natural systems, as methane is the second-biggest factor in greenhouse gas emissions (**HS-ESS3-4**).

Chemical Engineering: Renewable Methanol

This feature discusses the development of renewable methanol, a fuel with a minimal carbon imprint. While this fuel represents only a small portion of the fuel used by consumers and thus has a relatively small impact on the goal of reducing our dependency on fossil fuels, it is still a step in the right direction. This is an example of how a very complex real-world problem (greenhouse gas emissions from the burning of fossil fuels) can be broken down into smaller, more manageable problems that can be solved through engineering (**HS-ETS1-2**).

Case Study: Solving the Plastic Problem

This chapter’s Case Study analyzes the major global challenge of plastic pollution. The article illustrates how the availability and management of natural resources (for example, petroleum) have influenced the production of petroleum-based plastics (**HS-ESS3-1**). The production and use of petroleum-based plastics is not sustainable because plastic waste remains in the environment for a very long time. Various solutions are evaluated in the article, taking into account a range of constraints, including cost, safety, reliability, and aesthetics, as well as social and environmental impacts (**HS-ETS1-3**). For example, bioplastics are made from renewable biomass resources, but they have a much shorter shelf life, which makes them less useful. Still, solutions such as bioplastics and plastic-eating bacteria may reduce the impact of human activities on natural systems (**HS-ESS3-4**). The teacher notes suggest taking this idea of natural systems even further by describing the flow of carbon from photosynthetic organisms to petroleum to fossil fuel resources, plastics, and carbon dioxide. Emphasize that the amount of carbon—in the form of numerous organic, or carbon-based, compounds—in the entire Earth system does not change; it only changes form.

Investigation: Gluep

This chapter’s Investigation provides a hands-on opportunity for students to produce a polymer and explain how its bulk structure is a result of its particle-level structure (**HS-PS1-3**). You can also use the **Something Extra** prompt to emphasize the engineering practice of **optimizing the solution**; extrapolate this activity even further by assigning students different criteria, such as a firmer, bouncier, or looser product (**HS-ETS1-3**).

Additional NGSS Connections	
Performance Expectations HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*	
Science and Engineering Practices Using Mathematics and Computational Thinking	**Crosscutting Concepts** Stability and Change **Disciplinary Core Ideas** ESS3.A Natural Resources ESS3.C Human Impacts on Earth Systems

Chapter 21: Biochemistry

NGSS Physical Science and Engineering Standards	
Performance Expectations HS-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.	
Science and Engineering Practices Planning and Carrying Out Investigations Designing Solutions Developing and Using Models Obtaining, Evaluating, and Communicating Information	**Crosscutting Concepts** Patterns Structure and Function Influence of Science, Engineering, and Technology on Society and the Natural World **Disciplinary Core Ideas** PS1.A Structure and Properties of Matter PS2.B Types of Interactions ETS1.B Developing Possible Solutions

This chapter is considered a supplement to support the physical science performance expectation **HS-PS1-3**, which students will have already covered extensively in previous chapters. This chapter also builds on **Chapter 20**, "Organic Chemistry," in that certain groups of organic compounds are also important biochemical compounds, some of which students will explore in detail in this chapter. In **Section 21.1**, students **model** the primary, secondary, and tertiary structures of proteins, including enzymes, and evaluate the relationship between the **structure and function** of proteins. In **Section 21.2**, students investigate the **structure and function** of other classes of biologically important molecules: carbohydrates, nucleic acids, and lipids. This section also describes how the structure of DNA determines the structure of proteins (**HS-LS1-1**). Biomolecules consist of carbon, hydrogen, and oxygen, which come from molecules of sugar (a carbohydrate), and these elements combine with other elements, such as nitrogen, to form amino acids (the building blocks of proteins) and other large carbon-based molecules, such as nucleic acids and lipids (**HS-LS1-6**).

Spider Silk

This chapter's ENGAGE feature describes how the unique properties of spider silk can be attributed to the structures of the proteins from which it is made (**HS-PS1-3**, **HS-PS2-6**). You can use this feature along with the Chapter 21 **Case Study** to formulate an Investigative Phenomenon around which to frame the chapter content.

Explorers at Work: Studying Ancient DNA

The Explorers at Work feature describes the work of Beth Shapiro, who studies ancient DNA to envision the evolution of prehistoric species. She has also studied the genetics of current populations, including polar bears and RNA viruses. In all of her work, Shapiro **uses and develops models** of different varieties to illustrate relationships between systems or between components of a system. For example, she analyzes the gene sequences of fast-evolving RNA viruses from different patients over time and uses this information to model how the viruses are able to adapt so quickly. Such evidence can be used to develop better strategies for disease prevention.

Hands-on Chemistry: Colorful Milk

In this minilab, students conduct an experiment with whole milk to examine the relationships between **structure and function** in milk fat, food coloring, and dishwashing detergent. Students **construct explanations** as to why water-soluble food coloring does not spread in milk, which is a suspension of fat globules in water (**HS-PS1-3**). They also explain why the addition of soap to the center of a milk sample surface causes the food coloring to be “pushed away” from the center.

Case Study: Spider Silk and Manufactured Materials

The Case Study builds on this chapter’s **ENGAGE** feature, applying the understanding of the molecular structure of spider silk to the production of bulk designed materials leverage its strength, light weight, and other desirable characteristics (**HS-PS1-3**, **HS-PS2-6**). The article explains how engineers have developed a variety of products inspired by spider silk to satisfy various criteria and constraints (**HS-ETS1-3**).

Investigation: In a Lather

In this activity, students **carry out an investigation** to synthesize a soap of their choosing and test its properties in comparison to a commercial soap and a commercial detergent. Emphasize with students the relationship between molecular **structure and function** in soap. Have them compare and contrast the molecular structures of the three soap samples (their own soap and the commercial soap and detergent) (**HS-PS2-6**). After testing the soaps, have students relate the soaps’ structures to the test results and explain any differences. Invite students to compare their structures and properties at the bulk scale to infer the strength of the electrical forces between the particles involved (**HS-PS1-3**).

Additional NGSS Connections	
Performance Expectations HS-LS1-1 Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. HS-LS1-6 Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.	
Science and Engineering Practices Constructing Explanations	**Crosscutting Concepts** Energy and Matter **Disciplinary Core Ideas** LS1.A Structure and Function LS1.C Organization for Matter and Energy Flow in Organisms