Chemistry, Unit 1

Structure and Properties of Matter

Overview

Unit abstract

Students are expected to develop understanding of the substructure of atoms and to provide more mechanistic explanations of the properties of substances. Chemical reactions, including rates of reactions and energy changes, can be understood by students at this level in terms of the collisions of molecules and the rearrangements of atoms. Students are able to use the periodic table as a tool to explain and predict the properties of elements. Students are expected to communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

The crosscutting concepts of structure and function, patterns, energy and matter, and stability and change are called out as organizing concepts for these disciplinary core ideas. In the PS1 performance expectations, students are expected to demonstrate proficiency in developing and using models, planning and conducting investigations, using mathematical thinking, and constructing explanations and designing solutions. In PS2-6, students are expected to communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Essential questions

- How can one explain the structure, properties, and interactions of matter?

Written Curriculum

Next Generation Science Standards*

HS. Structure and Properties of Matter

Students who demonstrate understanding can:

HS-PS1-1. **Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.** [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ▪ Use a model to predict the relationships between systems or between components of a system. (HS-PS1-1)	**PS1.A: Structure and Properties of Matter** ▪ Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1) ▪ The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1) **PS2.B: Types of Interactions** ▪ Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. *(secondary to HS-PS1-1)*	**Patterns** ▪ Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-1)

Connections to other DCIs in this grade-band: **HS.LS1.C** (HS-PS1-1)

Articulation to DCIs across grade-bands: **MS.PS1.A** (HS-PS1-1); **MS.PS1.B** (HS-PS1-1)

Common Core State Standards Connections:

ELA/Literacy –

RST.9-10.7 Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. *(HS-PS1-1)*

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HS. Chemical Reactions

Students who demonstrate understanding can:

HS-PS1-2. **Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.** [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-PS1-2)	**PS1.A: Structure and Properties of Matter** ▪ The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-2) *(Note: This Disciplinary Core Idea is also addressed by HS-PS1-1.)* **PS1.B: Chemical Reactions** ▪ The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2)	**Patterns** ▪ Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-2)

Connections to other DCIs in this grade-band: **HS.LS1.C** (HS-PS1-2); **HS.ESS2.C** (HS-PS1-2)

Articulation to DCIs across grade-bands: **MS.PS1.A** (HS-PS1-2); **MS.PS1.B** (HS-PS1-2)

Common Core State Standards Connections:

ELA/Literacy –

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS1-2)

WHST.9-12.5 Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-PS1-2)

Mathematics –

HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS1-2)

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-2)*

HS. Structure and Properties of Matter

Students who demonstrate understanding can:

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ▪ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS1-3)	**PS1.A: Structure and Properties of Matter** ▪ The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3) **PS2.B: Types of Interactions** ▪ Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. *(secondary to HS-PS1-3)*	**Patterns** ▪ Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-3)

Connections to other DCIs in this grade-band: **HS.ESS2.C** (HS-PS1-3)

Articulation to DCIs across grade-bands: **MS.PS1.A** (HS-PS1-3); **MS.PS2.B** (HS-PS1-3)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS1-3)

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS1-3)

WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS1-3)

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research. *(HS-PS1-3)*

Mathematics –

HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(HS-PS1-3)*

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-3)*

HS.Structure and Properties of Matter		
Students who demonstrate understanding can: **HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*** [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices **Obtaining, Evaluating, and Communicating Information** Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs. ▪ Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-PS2-6)	**Disciplinary Core Ideas** **PS1.A: Structure and Properties of Matter** ▪ The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. *(secondary to HS-PS2-6)* **PS2.B: Types of Interactions** ▪ Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (HS-PS2-6)	**Crosscutting Concepts** **Structure and Function** ▪ Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-PS2-6)
Connections to other DCIs in this grade-band: N/A		
Articulation to DCIs across grade-bands: **MS.PS1.A** (HS-PS2-6); **MS.PS2.B** (HS-PS2-6)		
Common Core State Standards Connections: *ELA/Literacy –* **RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-PS2-6)* **WHST.9-12.2** Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-PS2-6)* *Mathematics –* **HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(HS-PS2-6)* **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling. *(HS-PS2-6)* **HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS2-6)*		

HS.Engineering Design

Students who demonstrate understanding can:

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.

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. ▪ Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	**ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)	***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** ▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-3)

Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:
Physical Science: HS-PS2-3, HS-PS3-3
Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:
Earth and Space Science: HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6
Connections to HS-ETS1.C: Optimizing the Design Solution include:
Physical Science: HS-PS1-6, HS-PS2-3

Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-3); **MS.ETS1.B** (HS-ETS1-3)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-ETS1-3)*

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ETS1-3)

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. *(HS-ETS1-3)*

Mathematics –

MP.2 Reason abstractly and quantitatively. *(HS-ETS1-3)*

MP.4 Model with mathematics.(HS-ETS1-3)

HS.Engineering Design		
Students who demonstrate understanding can: **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.**		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4)	**ETS1.B: Developing Possible Solutions** ▪ Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)	**Systems and System Models** ▪ Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. (HS-ETS1-4)
Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include: **Physical Science:** HS-PS2-3, HS-PS3-3 *Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:* **Earth and Space Science:** HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6 *Connections to HS-ETS1.C: Optimizing the Design Solution include:* **Physical Science:** HS-PS1-6, HS-PS2-3		
Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-4); **MS.ETS1.B** (HS-ETS1-4); **MS.ETS1.C** (HS-ETS1-4)		
Common Core State Standards Connections: *Mathematics –* **MP.2** Reason abstractly and quantitatively. *(HS-ETS1-4)* **MP.4** Model with mathematics. (HS-ETS1-4)		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- Substances are made from different types of atoms, which combine with one another in various ways.
- Atoms form molecules that range in size from two atoms to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.

- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others.
- In a gas, they are widely spaced except when they happen to collide.
- In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.
- Solids may be formed from molecules or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- Substances react chemically in characteristic ways.
- In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.
- The total number of each type of atom is conserved, and thus the mass does not change.
- Some chemical reactions release energy, others store energy.
- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics.
- These physical and chemical properties include water's exceptional capacity to absorb, store, and release large amounts of energy; transmit sunlight; expand upon freezing; dissolve and transport materials; and lower the viscosities and melting point of rocks.

Progression of current learning

Driving question 1
How can the periodic table be used to predict the relative properties of elements?

Concepts

- Different patterns may be observed at each of the scales at which a system is studied, and these patterns can provide evidence for causality in explanations of phenomena.
- Each atom has a charged substructure.
- An atom's nucleus is made of protons and neutrons and is surrounded by electrons.
- The periodic table orders elements horizontally by number of protons in the nucleus of each element's atoms and places elements with similar chemical properties in columns.
- The repeating patterns of this table reflect patterns of outer electron states.

Practices

- Use the periodic table as a model to provide evidence for relative properties of elements at different scales based on the patterns of electrons in the outermost energy level of atoms in main group elements.
- 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 in main group elements.

- Patterns of electrons in the outermost energy level of atoms can provide evidence for the relative properties of elements at different scales.
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

Driving question 2
How can the outcome of a simple chemical reaction be explained?

Concepts

- The periodic table orders elements horizontally by number of protons in the nucleus of each element's atoms and places elements with similar chemical properties in columns.
- The repeating patterns of the periodic table reflect patterns of outer electron states.
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- Different patterns may be observed at each of the scales at which a system is studied, and these patterns can provide evidence for causality in explanations of phenomena.

Practices

- Use valid and reliable evidence (obtained from students' own investigations, models, theories, simulations, and peer review) showing the outermost electron states of atoms, trends in the periodic table, and patterns of chemical properties to construct and revise an explanation for the outcome of a simple chemical reaction.
- Use the assumption that theories and laws that describe the outcome of simple chemical reactions operate today as they did in the past and will continue to do so in the future.
- Observe patterns in the outermost electron states of atoms, trends in the periodic table, and chemical properties.
- Use the conservation of atoms and the chemical properties of the elements involved to describe and predict the outcome of a chemical reaction.

Driving question 3
What is the relationship between the structure of substances at the bulk scale and the strength of electrical forces between particles?

Concepts

- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- Attraction and repulsion between electric charges at the atomic scale explain the

Practices

- Plan and conduct an investigation individually and collaboratively to produce data that can serve as the basis for evidence for comparing the structure of substances at the bulk scale to infer the strength of structure, properties, and transformations of matter, as well as the contact forces between material objects.

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

electrical forces between particles; in the investigation design, decide on types, how much, and accuracy of data needed to produce reliable measurements; consider limitations on the precision of the data (e.g., number of trials, cost, risk, time); and refine the design accordingly.

- Use patterns in the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Driving question 4
Why is the molecular-level structure important in the functioning of designed materials?

Concepts

- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.
- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, aesthetics, and to consider social, cultural, and environmental impacts.
- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.
- Models (e.g., physical, mathematical, computer models) can be used to simulate why the molecular-level structure is important in the functioning of designed materials.

Practices

- Communicate scientific and technical information about why the molecular - level structure is important in the functioning of designed materials.
- Evaluate a solution to a complex real-world problem based on scientific knowledge, student generated sources of evidence, prioritized criteria, and tradeoffs considerations to determine why the molecular level structure is important in the functioning of designed materials.
- Use mathematical models and/or computer simulations to show why the molecular-level structure is important in the functioning of designed materials.
- Communication scientific and technical information about the attractive and repulsive forces that determine the functioning of the material.
- Use mathematical models and/or computer simulations to show the attractive and repulsive forces that determine the functioning of the material.
- Examine in detail the properties of designed materials, the structure of the components of designed materials, and the connections of the components to reveal the function.

- Use models (e.g., physical, mathematical, computer models) to simulate systems of designed materials and interactions--including energy, matter, and information flows--within and between designed materials at different scales.

Integration of content, practices, and crosscutting concepts

In order to understand how the periodic table can be used as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms, students must first understand the idea that atoms have a charged substructure consisting of a nucleus that is composed of protons and neutrons surrounded by electrons. Students should use a variety of models to understand the structure of an atom. Examples may include computer simulations, drawings, and kits. Students can create models of atoms by calculating protons, neutrons, and electrons in any given atom, isotope, or ion.

In order to understand the predictive power of the periodic table, students should write electron configurations for main group elements, paying attention to patterns of electrons in the outermost energy level. Students should annotate the periodic table to determine its arrangement horizontally by number of protons in the atom's nucleus and its vertical arrangement by the placement of elements with similar chemical properties in columns. Students should also be able to translate information about patterns in the periodic table into words that describe the importance of the outermost electrons in atoms.

Students will use the ideas of attraction and repulsion (i.e., charges—cations/anions) at the atomic scale to explain the structure of matter, such as in ion formation, and to explain the properties of matter such as density, luster, melting point, boiling point, etc.

Students will also use the ideas of attraction and repulsion (charges—cations/anions) at the atomic scale to explain transformations of matter—for example, reaction with oxygen, reactivity of metals, types of bonds formed, and number of bonds formed. Students will explain bonding through the patterns in outermost electrons, periodic trends, and chemical properties.

To explain the outcomes of chemical reactions using the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties, students should use investigations, simulations, and models of chemical reactions to prove that atoms are conserved. For example, students might observe simple reactions in a closed system and measure the mass before and after the reaction as well as count atoms in reactants and products in chemical formulas. Students should also construct chemical formulas involving main group elements in order to model that atoms are conserved in chemical reactions (the Law of Conservation of Mass). Students will need to describe and predict simple chemical reactions, including combustion, involving main group elements. Students should use units when modeling the outcome of chemical reactions. When reporting quantities, students should choose a level of accuracy appropriate to limitations on measurement.

Students should also be able to write a rigorous explanation of the outcome of simple chemical reactions, using data from their own investigations, models, theories, and simulations. They should strengthen their explanations by drawing and citing evidence from informational text.

In order to address how the substructure of substances at the bulk scale infers the strength of electrical forces between particles, emphasis should be on the importance of outermost electrons in bulk physical properties, bonding, and stability. *Students need to realize that valence electrons are important.*

Students should plan and conduct investigations to show that structure and interactions of matter at the bulk scale are dependent on electrical forces within and between atoms. For example, students could test conductivity, relative melting point, and solubility. In investigations, students must decide on the types, amount, and accuracy of data required to produce reliable information and consider limitations on the precision of the data.

Students should also plan and conduct investigations using attraction and repulsion (charges—cations/anions) at the atomic scale to explain the structure of matter at the bulk scale. For example, students could investigate how the strength of forces between particles is dependent on particle type (ions, atoms, molecules, networked materials [allotropes]). Students should examine crystal structures and amorphous structures.

Students should also plan and conduct investigations using attraction and repulsion (charges—cations/anions) at the atomic scale to explain the properties of matter at the bulk scale—for example, investigating melting point, boiling point, vapor pressure, and surface tension. Students might also plan and conduct an investigation using attraction and repulsion (charges—cations/anions) at the atomic scale to explain transformations of matter at the bulk scale—for example, collecting data to create cooling and heating curves.

Students might also conduct short or more sustained research projects to compare the structure of substances at the bulk scale and use this research to infer the strength of electrical forces between particles. Information should be gathered from multiple reliable sources and used to support claims. Any data reported should include appropriate units and limitations on measurements should be considered.

As students consider communicating scientific and technical information about why the molecular-level structure is important in the functioning of designed materials, focus should be on attractive and repulsive forces. Students might research information about Life Cycle Analysis (LCA), which examines every part of the production, use, and final disposal of a product. LCA requires that students examine the inputs (raw materials and energy) required to manufacture products, as well as the outputs (atmospheric emissions, waterborne wastes, solid wastes, coproducts, and other resources). This will allow them to make connections between molecular-level structure and product functionality. Students should evaluate the LCA process and communicate a solution to a real-world problem, such as the environmental impact of different types of grocery bags (paper or plastic/reusable vs. disposable), cold drink containers (plastic, glass, or aluminum), or hot drink containers (paper, Styrofoam, or ceramic). They will base their solution to their chosen real-world problem 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.

Students should then use technology to present a life-cycle-stage model that considers the LCA and typical inputs and outputs measured for their real-world problem. Students will need to consider the properties of various materials (e.g. Molar mass, solubility, bonding) to decide what materials to use for what purposes. When students have properties appropriate for the final use, they will be able to consider material uses in LCAs to determine if they are environmentally appropriate. For further reference see ChemMatters, February 2014, “It’s Not Easy Being Green, Or Is It?,” at www.acs.org/content/acs/en/education/resources/highschool/chemmatters.html.

Integration of engineering

In this unit, students consider communicating scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. HS-ETS1-3 and HS-ETS1-4 have been identified as appropriate engineering connections. Students might evaluate a solution to a complex real-world problem, such as electrically conductive materials made of metal, plastics made of organic polymers, or pharmaceuticals designed for specific biological targets, and then use a computer simulation to model the impact of that solution.

<u>*Integration of mathematics and English language arts/literacy*</u>

Mathematics

- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing periodic trends for main group elements based on patterns of electrons in the outermost energy level of atoms.
- Considering the outermost energy level of atoms, define appropriate quantities for descriptive modeling of periodic trends for main group elements based on patterns of electrons in outermost energy levels.
- Use units as a way to understand the outcome of a simple chemical reaction involving main group elements based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. Choose and interpret units consistently in chemical reactions. Choose and interpret the scale and origin in graphs and data displays representing patterns of chemical properties, outer electron states of atoms, trends in the periodic table, and patterns of chemical properties.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities of simple chemical reactions.
- Use units as a simple way to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. Choose and interpret units comparing the structure of substances at the bulk scale to infer the strength of electrical forces between particles. Choose and interpret the scale and origin in graphs and data displays comparing the structure of substances and the bulk scale and electrical forces between particles.
- Choose a level of accuracy appropriate to limitations on measurements of the strength of electrical forces between particles.

English language arts/literacy

- Translate information from the periodic table about the patterns of electrons in the outermost energy level of atoms into words that describe the relative properties of elements.
- Write 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 of elements using well-chosen, relevant, and sufficient facts; extended definitions; and concrete details from students' own investigations, models, theories, simulations, and peer review.
- Develop and strengthen explanations for the outcome of a simple chemical reaction by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties of elements.
- Draw evidence from informational texts about the outermost electron states of atoms, trends in the periodic table, and patterns of chemical properties of elements to construct a rigorous explanation of the outcome of a simple chemical reaction.
- Cite specific textual evidence comparing the structure of substances at the bulk scale to infer the strength of electrical forces between particles.
- Conduct short as well as more sustained research projects to compare the structure of substances at the bulk scale and use this research to infer the strength of electrical forces between particles.

- Gather applicable information from multiple reliable sources to support the claim that electrical forces between particles can be used to explain the structure of substances at the bulk scale.
- Develop evidence comparing the structure of substances at the bulk scale and the strength of electrical forces between particles.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Life science

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: Their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used, for example, to form new cells.
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another.
- Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles.
- Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.

Earth and space science

- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks.

Number of Instructional Days

Recommended number of instructional days: 40 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were consulted during the writing of this unit:

- Next Generation Science Standards Appendices L and M
- *A Framework for K–12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science, & Technical Subjects*

Chemistry, Unit 2

Energy and Its Applications (Nonliving)

Overview

Unit abstract

In this unit of study, students will understand energy as a quantitative property of a system—a property that depends on the motion and interactions of matter and radiation within that system. They will also understand that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Students develop an understanding that energy, at both the macroscopic and the atomic scales, can be accounted for as motions of particles or as energy associated with the configurations (relative positions) of particles.

Students understand the role that water plays in affecting weather. Students can examine the ways that human activities cause feedback that create changes to other systems. In the HS Earth's Systems performance expectations, students are expected to demonstrate proficiency in developing and using models, planning and carrying out investigations, analyzing and interpreting data, engaging in argument from evidence, and using these practices to demonstrate understanding of core ideas.

Students understand the complex and significant interdependencies between humans and the rest of Earth's systems through the impacts of natural hazards, our dependencies on natural resources, and environmental impacts of human activities.

Developing possible solutions for major global problems begins by breaking these problems into smaller problems that can be tackled with engineering methods. To evaluate potential solutions, students are expected not only to consider a wide range of criteria, but also to recognize that criteria need to be prioritized.

Improving designs at the high school level may involve sophisticated methods, such as using computer simulations to model proposed solutions. Students are expected to use such methods to take into account a range of criteria and constraints, to try to anticipate possible societal and environmental impacts, and to test the validity of their simulations by comparison to the real world.

Essential questions

- How is energy transferred and conserved?
- How do the major Earth systems interact?
- How do the properties and movements of water shape Earth's surface and affect its systems?
- How do humans depend on Earth's resources?
- How do people model and predict the effects of human activities on Earth's climate?

Written Curriculum

Next Generation Science Standards

HS. Energy

Students who demonstrate understanding can:

HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ▪ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS3-4)	**PS3.B: Conservation of Energy and Energy Transfer** ▪ Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-4) ▪ Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4) **PS3.D: Energy in Chemical Processes** ▪ Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-4)	**Systems and System Models** ▪ When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-PS3-4)

Connections to other DCIs in this grade-band: **HS.ESS1.A** (HS-PS3-4); **HS.ESS2.A** (HS-PS3-4); **HS.ESS2.D** (HS-PS3-4)

Articulation to DCIs across grade-bands: **MS.PS3.B** (HS-PS3-4)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-PS3-4)*
WHST.9-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS3-4)
WHST.11-12.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS3-4)

WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *(HS-PS3-4)*
Mathematics –	
MP.2	Reason abstractly and quantitatively. (HS-PS3-4)
MP.4	Model with mathematics. *(HS-PS3-4)*

HS. Earth's Systems

Students who demonstrate understanding can:

HS-ESS2-5. Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ▪ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-ESS2-5)	**ESS2.C: The Roles of Water in Earth's Surface Processes** ▪ The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. (HS-ESS2-5)	**Structure and Function** ▪ The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. (HS-ESS2-5)

Connections to other DCIs in this grade-band: **HS.PS1.A** (HS-ESS2-5); **HS.PS1.B** (HS-ESS2-5); **HS.PS3.B** (HS-ESS2-5); **HS.ESS3.C** (HS-ESS2-5)

Articulation of DCIs across grade-bands: **MS.PS1.A** (HS-ESS2-5); **MS.PS4.B** (HS-ESS2-5); **MS.ESS2.A** (HS-ESS2-5); **MS.ESS2.C** (HS-ESS2-5); **MS.ESS2.D** (HS-ESS2-5)

Common Core State Standards Connections:

ELA/Literacy –	
WHST.9-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-ESS2-5)
Mathematics –	
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS2-5)

HS. Human Sustainability

Students who demonstrate understanding can:

HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.* [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. • Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations). (HS-ESS3-2)	**ESS3.A: Natural Resources** ▪ All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2) **ETS1.B. Designing Solutions to Engineering Problems** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary to HS-ESS3-2)*	***Connections to Engineering, Technology, and Applications of Science*** **Influence of Engineering, Technology, and Science on Society and the Natural World** ▪ Engineers continuously modify these systems to increase benefits while decreasing costs and risks. (HS-ESS3-2) ▪ Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ESS3-2) --- ***Connections to Nature of Science*** **Science Addresses Questions About the Natural and Material World** ▪ Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. (HS-ESS3-2) ▪ Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. (HS-ESS3-2) ▪ Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. (HS-ESS3-2)

Connections to other DCIs in this grade-band: **HS.PS3.B** (HS-ESS3-2); **HS.PS3.D** (HS-ESS3-2); **HS.LS2.A** (HS-ESS3-2); **HS.LS2.B** (HS-ESS3-2); **HS.LS4.D** (HS-ESS3-2); **HS.ESS2.A** (HS-ESS3-2)

Articulation of DCIs across grade-bands: **MS.PS3.D** (HS-ESS3-2); **MS.LS2.A** (HS-ESS3-2); **MS.LS2.B** (HS-ESS3-2); **MS.LS4.D** (HS-ESS3-2); **MS.ESS3.A** (HS-ESS3-2); **MS.ESS3.C** (HS-ESS3-2)

Common Core State Standards Connections:	
ELA/Literacy –	
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(*(HS-ESS3-2)
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ESS3-2)
Mathematics –	
MP.2	Reason abstractly and quantitatively. (HS-ESS3-2)

HS. Engineering Design

Students who demonstrate understanding can:

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.

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. ▪ Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	**ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)	***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** ▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-3)

Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:
Physical Science: HS-PS2-3, HS-PS3-3
Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:
Earth and Space Science: HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6
Connections to HS-ETS1.C: Optimizing the Design Solution include:
Physical Science: HS-PS1-6, HS-PS2-3

Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-3); **MS.ETS1.B** (HS-ETS1-3)

Common Core State Standards Connections:	
ELA/Literacy –	
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-ETS1-3)*
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ETS1-3)
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. *(HS-ETS1-3)*
Mathematics –	
MP.2	Reason abstractly and quantitatively. *(HS-ETS1-3)*
MP.4	Model with mathematics.(HS-ETS1-3)

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two atoms to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.
- Solids may be formed from molecules or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- When light shines on an object, it is reflected from, absorbed by, or transmitted through the object, depending on the object's material and the frequency (color) of the light.
- The path that light travels can be traced as a straight line, except at surfaces between different transparent materials (e.g., air and water, air and glass), where the light path bends.
- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave like sound or water waves.

Life science

- Organisms and populations of organisms are dependent on their environmental interactions with other living things and with nonliving factors.
- In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction.
- Growth of organisms and population increases are limited by access to resources.
- Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions between organisms may, in contrast, become so

interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.

- Food webs are models that demonstrate how matter and energy are transferred among producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.

Earth and space science

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.
- The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.
- Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land.
- The complex patterns of the changes and movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns.
- Global movements of water and its changes in form are propelled by sunlight and gravity.
- Variations in density due to variations in temperature and salinity drive a global pattern of interconnected ocean currents.
- Water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations.
- Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns.
- Because these patterns are so complex, weather can only be predicted probabilistically.
- The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents.
- Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.
- Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things.
- Typically, as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.

Progression of current learning

Driving question 1

How does energy distribution change among the components of a closed system when two components of different temperature are combined?

Concepts

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Uncontrolled systems always move toward more stable states—that is, toward a more uniform energy distribution.
- Although energy cannot be destroyed, it can be converted into less useful forms—for example, to thermal energy in the surrounding environment.

Practices

- Plan and conduct an investigation individually or collaboratively to produce data on transfer of thermal energy in a closed system that can serve as a basis for evidence of uniform energy distribution among components of a system when two components of different temperatures are combined.
- Use models to describe a system and define its boundaries, initial conditions, inputs, and outputs.
- Design an investigation to produce data on transfer of thermal energy in a closed system that can serve as a basis for evidence of uniform energy distribution among components of a system when two components of different temperatures are combined, considering types, how much, and the accuracy of data needed to produce reliable measurements.
- Consider the limitations of the precision of the data collected and refine the design accordingly.

Driving question 2

What are the properties of water and what are its effects on Earth materials and surface processes?

Concepts

- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics.
- The functions and properties of water and water systems can be inferred from the overall structure, the way the components are shaped and used, and the molecular substructure.

Practices

- Plan and conduct an investigation individually and collaboratively of the properties of water and its effects on Earth materials and surface processes.
- Use models to describe a hydrological system and define its boundaries, initial conditions, inputs, and outputs.
- Design an investigation considering the types, how much, and accuracy of data needed to produce reliable measurements.

- These properties include water's exceptional capacity to absorb, store, and release large amounts of energy; transmit sunlight; expand upon freezing; dissolve and transport materials; and lower the viscosities and melting points of rocks.

- Consider the limitations on the precision of the data collected and refine the design accordingly.

Driving question 3

How can energy and mineral resources be developed, managed, and utilized?

Concepts

- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.
- Models can be used to simulate systems and interactions, including energy, matter, and information flows, within and between systems at different scales.
- Engineers continuously modify design solutions to increase benefits while decreasing costs and risks.
- Analysis of costs and benefits is a critical aspect of decisions about technology.
- Scientific knowledge indicates what can happen in natural systems, not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.
- New technologies can have deep impacts on society and the environment, including some that were not anticipated.
- Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
- Many decisions are made not using science alone, but instead relying on social and cultural contexts to resolve issues.

Practices

- Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios, scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, and ethical considerations).
- Use models to evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost–benefit ratios, scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, and ethical considerations).

Integration of content, practices, and crosscutting concepts

In this unit of study, students begin by building their understanding of the law of conservation of energy by planning and conducting investigations of thermal energy transfer. Students should investigate and describe a system focusing specifically on thermal energy transfer in a closed system. These investigations will provide opportunities for students to use models that can be made of a variety of materials, such as student-generated drawings and/or digital simulations, such as those available from PhET. These models can be used to describe a system, and define its boundaries, initial conditions, inputs, and outputs.

Students should have the opportunity to ask and refine questions, using specific textual evidence, about the energy distribution in a system. Students should collect relevant data from several sources, including their own investigations, and synthesize their findings into a coherent understanding.

Using the knowledge that energy cannot be created or destroyed, students should create computational or mathematical models to calculate the change in the energy in one component of a system when the change in energy of the other component(s) and energy flows in and out of the systems are known. In order to do this, students should manipulate variables in specific heat calculations. For example, students can use data collected from simple Styrofoam calorimeters to investigate the mixing of water at different initial temperatures or the adding of objects at different temperatures to water to serve as a basis for evidence of uniform energy distribution among components of a system. Students might conduct an investigation using different materials such as various metals, glass, and rock samples. Using the specific heat values for these substances, students could create mathematical models to represent the energy distribution in a system, identify important quantities in energy distribution, map relationships, and analyze those relationships mathematically to draw conclusions.

These investigations will allow students to collect data to show that energy is transported from one place to another or transferred between systems, and that uncontrolled systems always move toward more stable states with more uniform energy distribution. Students should also observe during investigations that energy can be converted into less useful forms, such as thermal energy released to the surrounding environment. During the design and implementation of investigations, students must consider the precision and accuracy appropriate to limitations on measurement of the data collected and refine their design accordingly.

This unit will also focus on the planning and conducting of mechanical and chemical investigations of water. Properties to be investigated should include water's exceptional capacity to absorb, store, and release large amounts of energy; transmit sunlight; expand upon freezing; dissolve and transport materials; and lower the viscosities and melting points of rocks. This focus is particularly important since water's abundance on Earth's surface, and its unique combination of physical and chemical properties, are central to the planet's dynamics. The functions and properties of water and water systems can be inferred from the overall structure, the way components are shaped and used, and the molecular substructure. Investigations will emphasize the mechanical and chemical processes involved in the interactions between the hydrological cycle and solid materials. Examples of mechanical investigations include stream transportation and deposition, erosion, and frost wedging. Examples of chemical investigations include chemical weathering, recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids). When investigating the properties of water and their effects on Earth materials and surface processes, students should report quantities using a level of accuracy appropriate to limitations on measurement.

To gain a more complete understanding, students might conduct short or more sustained research projects to determine how the properties of water affect Earth materials and surface processes.

Once students have an understanding of the conservation of energy and the properties of water that allow it to absorb, store, and release large amounts of energy, the unit will transition to an engineering design problem. Working from the premise that all forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs, risks, and benefits, students will use cost–benefit ratios to evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources.

For example, students might investigate the real-world technique of using hydraulic fracturing to extract natural gas from shale deposits versus other traditional means of acquiring energy from natural resources. Students will synthesize information from a range of sources into a coherent understanding of competing design solutions for extracting and utilizing energy and mineral resources. As students evaluate competing design solutions, they should consider that new technologies could have deep impacts on society and the environment, including some that were not anticipated. Some of these impacts could raise ethical issues for which science does not provide answers or solutions. In their evaluations, students should make sense of quantities and relationships associated with developing, managing, and utilizing energy and mineral resources. Mathematical models can be used to explain their evaluations. Students might represent their understanding by conducting a Socratic seminar as a way to present opposing views. Students should consider and discuss decisions about designs in scientific, social, and cultural contexts.

Integration of engineering

The engineering performance expectation HS-ESS3-2 specifically identifies a connection to HS-ETS1-3. This requires students to evaluate a solution to a complex real-world problem. In this unit, students will use cost–benefit ratios to evaluate competing designs for developing, managing, and utilizing energy and mineral resources.

Integration of DCI from prior units within this grade level

Using prior knowledge from Unit 1 about properties and transformations of matter, students will now study the transfer of energy using water as the model.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Use symbols to represent energy distribution in a system when two components of different temperature are combined, and manipulate the representing symbols. Make sense of quantities and relationships in the energy distribution in a system when two components of different temperature are combined.
- Use a mathematical model to describe energy distribution in a system when two components of different temperature are combined. Identify important quantities in energy distribution in a system when two components of different temperature are combined and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities of the properties of water and their effects on Earth materials and surface processes.
- Use symbols to represent an explanation of the best of multiple design solutions for developing, managing, and utilizing energy and mineral resources and manipulate the representing symbols. Make sense of quantities and relationships in cost–benefit ratios for multiple design solutions for developing, managing, and utilizing energy and mineral resources symbolically and manipulate the representing symbols.
- Use a mathematical model to explain the evaluation of multiple design solutions for developing, managing, and utilizing energy and mineral resources. Identify important quantities in cost–benefit ratios for multiple design solutions for developing, managing, and utilizing energy and mineral resources and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

English language arts/literacy

- Ask and refine questions to support uniform energy distribution among the components in a system when two components of different temperature are combined, using specific textual evidence.
- Conduct short as well as more sustained research projects to determine energy distribution in a system when two components of different temperature are combined.
- Collect relevant data across a broad spectrum of sources about the distribution of energy in a system and assess the strengths and limitations of each source.
- Synthesize findings from experimental data into a coherent understanding of energy distribution in a system.
- Conduct short as well as more sustained research projects to determine how the properties of water affect Earth materials and surface processes.
- Cite specific textual evidence to evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost–benefit ratios.
- Evaluate the hypotheses, data, analysis, and conclusions of competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost–benefit ratios, verifying the data when possible and corroborating or challenging conclusions with other design solutions.
- Integrate and evaluate multiple design solutions for developing, managing, and utilizing energy and mineral resources based on cost–benefit ratios in order to reveal meaningful patterns and trends.
- Evaluate the hypotheses, data, analysis, and conclusions of competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost–benefit ratios, verifying the data when possible and corroborating or challenging conclusions with other design solutions.
- Synthesize data from multiple sources of information in order to create data sets that inform design decisions and create a coherent understanding of developing, managing, and utilizing energy and mineral resources.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- Each atom has a charged substructure consisting of a nucleus made of protons and neutrons and surrounded by electrons.
- The periodic table orders elements horizontally by the number of protons in the nucleus of each element's atoms and places elements with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- A stable molecule has less energy than does the same set of atoms separated; at least this much energy is required in order to take the molecule apart.
- Chemical processes, their rates, and whether or not they store or release energy can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
- The fact that atoms are conserved in chemical reactions, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the energy stored in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
- The availability of energy limits what can occur in any system.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

Life science

- Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.
- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.
- Humans depend on the living world for resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.

Earth and space science

- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.
- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.
- The Big Bang theory is supported by observations of distant galaxies receding from our own, by the measured composition of stars and nonstellar gases, and by the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.
- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, and a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and the gravitational movement of denser materials toward the interior.
- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.
- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.
- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

Number of Instructional Days

Recommended number of instructional days: 40 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were consulted during the writing of this unit:

- Next Generation Science Standards appendices I, L, and M
- *A Framework for K-12 Science Education*
- Common Core State Standards appendices (Mathematics and ELA/Literacy)

Chemistry Unit 3

Bonding and Chemical Reactions

Overview

Unit abstract

In this unit of study, students are expected to develop understanding of the substructure of atoms and to provide more mechanistic explanations of the properties of substances. Chemical reactions, including rates of reactions and energy changes, can be understood by students at this level in terms of the collisions of molecules and the rearrangements of atoms. Students are also able to apply an understanding of the process of optimization and engineering design to chemical reaction systems.

The crosscutting concepts of patterns, energy and matter, and stability and change are the organizing concepts for these disciplinary core ideas. In the PS1 performance expectations, students are expected to demonstrate proficiency in developing and using models, planning and conducting investigations, using mathematical thinking, and constructing explanations and designing solutions.

Essential questions

- How can one explain the structure, properties, and interactions of matter?
- How is energy transferred and conserved?
- How do substances combine or change (react) to make new substances?
- How does one explain reactions and make predictions about them?

Written Curriculum

Next Generation Science Standards

HS. Chemical Reactions

Students who demonstrate understanding can:

HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical representations of phenomena to support claims. (HS-PS1-7)	**PS1.B: Chemical Reactions** ▪ The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-7)	**Energy and Matter** ▪ The total amount of energy and matter in closed systems is conserved. (HS-PS1-7) ▪ Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS1-4) --------------------------------------- ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** ▪ Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS1-7)

Connections to other DCIs in this grade-band: **HS.PS3.B** (HS-PS1-7); **HS.LS1.C** (HS-PS1-7); **HS.LS2.B** (HS-PS1-7)

Articulation to DCIs across grade-bands: **MS.PS1.A** (HS-PS1-7); **MS.PS1.B** (HS-PS1-7); **MS.LS1.C** (HS-PS1-7); **MS.LS2.B** (HS-PS1-7); **MS.ESS2.A** (HS-PS1-7)

Common Core State Standards Connections:

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-PS1-7)
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS1-7)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-PS1-7)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-7)*

HS. Chemical Reactions

Students who demonstrate understanding can:

HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ▪ Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS1-4)	**PS1.A: Structure and Properties of Matter** ▪ A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. (HS-PS1-4) **PS1.B: Chemical Reactions** ▪ Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-4)	**Energy and Matter** ▪ Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS1-4)

Connections to other DCIs in this grade-band: **HS.PS3.A** (HS-PS1-4); **HS.PS3.B** (HS-PS1-4); **HS.PS3.D** (HS-PS1-4); **HS.LS1.C** (HS-PS1-4)

Articulation to DCIs across grade-bands: **MS.PS1.A** (HS-PS1-4); **MS.PS1.B** (HS-PS1-4); **MS.PS2.B** (HS-PS1-4); **MS.PS3.D** (HS-PS1-4); **MS.LS1.C** (HS-PS1-4)

Common Core State Standards Connections:

ELA/Literacy –

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-PS1-4)*

Mathematics –

MP.4 Model with mathematics. *(HS-PS1-4)*

HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(HS-PS1-4)*

HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-4)

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-4)*

HS. Chemical Reactions

Students who demonstrate understanding can:

HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (HS-PS1-5)	**PS1.B: Chemical Reactions** ▪ Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-5)	**Patterns** ▪ Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-5)

Connections to other DCIs in this grade-band: **HS.PS3.A** (HS-PS1-5)

Articulation to DCIs across grade-bands: **MS.PS1.A** (HS-PS1-5); **MS.PS1.B** (HS-PS1-5); **MS.PS2.B** (HS-PS1-5); **MS.PS3.A** (HS-PS1-5); **MS.PS3.B** (HS-PS1-5)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS1-5)

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-PS1-5)*

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-PS1-5)

HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(HS-PS1-5)*

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-5)*

HS. Chemical Reactions

Students who demonstrate understanding can:

HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* [Clarification Statement: Emphasis is on the application of Le Chatlier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS1-6)	**PS1.B: Chemical Reactions** ▪ In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6) **ETS1.C: Optimizing the Design Solution** ▪ Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. *(secondary to HS-PS1-6)*	**Stability and Change** ▪ Much of science deals with constructing explanations of how things change and how they remain stable. (HS-PS1-6)

Connections to other DCIs in this grade-band: **HS.PS3.B** (HS-PS1-6)

Articulation to DCIs across grade-bands: **MS.PS1.B** (HS-PS1-6)

Common Core State Standards Connections:

ELA/Literacy –

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. *(HS-PS1-6)*

HS. Engineering Design		
Students who demonstrate understanding can: **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.**		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. ▪ Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2)	**ETS1.C: Optimizing the Design Solution** ▪ Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	N/A
Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include: **Physical Science:** HS-PS2-3, HS-PS3-3 *Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:* **Earth and Space Science:** HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6 *Connections to HS-ETS1.C: Optimizing the Design Solution include:* **Physical Science:** HS-PS1-6, HS-PS2-3		
Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-2); **MS.ETS1.B** (HS-ETS1-2); **MS.ETS1.C** (HS-ETS1-2)		
Common Core State Standards Connections: *Mathematics –* **MP.4** Model with mathematics. (HS-ETS1-2)		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using models of matter. Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change. Some chemical reactions release energy; others store energy.
- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun.
- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object or a ball, respectively).
- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- A system of objects may also contain stored (potential) energy, depending on their relative positions.
- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.

Life science

- Plants, algae (including phytoplankton), and many microorganisms use energy from light to make sugars (food) from carbon dioxide from the atmosphere and water, through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use.
- Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules to support growth or to release energy.
- Food webs are models that demonstrate how matter and energy are transferred among producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.

Earth and space science

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.
- The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.

Progression of current learning

Driving question 1
How is mass is conserved during a chemical reaction?

Concepts

- The fact that atoms are conserved, together with the knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- The total amount of energy and matter in closed systems is conserved.
- The total amount of energy and matter in a chemical reaction system is conserved.
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.
- Changes of energy and matter in a chemical reaction system can be described in terms of energy and matter flows into, out of, and within that system.

Practices

- Use mathematical representations of chemical reaction systems to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
- Use mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale, using the mole as the conversion from the atomic to the macroscopic scale.
- Use the fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, to describe and predict chemical reactions.

- Describe changes of energy and matter in a chemical reaction system in terms of energy and matter flows into, out of, and within that system.

Driving question 2
What is the relationship between the release or absorption of energy from a chemical reaction system and the changes in total bond energy?

Concepts

- A stable molecule has less energy than the same set of atoms separated; at least this much energy must be provided in order to take the molecule apart.
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.
- Changes of energy and matter in a chemical reaction system can be described in terms of collisions of molecules and the rearrangements of atoms into new molecules, with subsequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

Practices

- Explain the idea that a stable molecule has less energy than the same set of atoms separated.
- Describe changes of energy and matter in a chemical reaction system in terms of energy and matter flows into, out of, and within that system.
- Describe chemical processes, their rates, and whether or not they store or release energy in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- Develop a model based on evidence to illustrate the relationship between the release or absorption of energy from a chemical reaction system and the changes in total bond energy.

Driving question 3
What are the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs?

Concepts

- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.
- Patterns in the effects of changing the temperature or concentration of the reacting particles can be used to provide evidence for causality in the rate at which a reaction occurs.

Practices

- Use the number and energy of collisions between molecules (particles) to explain the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use patterns in the effects of changing the temperature or concentration of the reactant particles to provide evidence for causality in the rate at which a reaction occurs.
- Apply scientific principles and multiple and independent student-generated sources of evidence to provide an explanation of the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

Driving question 4
What changes in conditions would produce increased amounts of products at equilibrium?

Concepts

- Much of science deals with constructing explanations of how things change and how they remain stable.
- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others may be needed.
- Explanations can be constructed explaining how chemical reaction systems can change and remain stable.

Practices

- Construct explanations for how chemical reaction systems change and how they remain stable.
- Design a solution to specify a change in conditions that would produce increased amounts of products at equilibrium in a chemical system based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
- Break down and prioritize criteria for increasing amounts of products in a chemical system at equilibrium.
- Refine the design of a solution to specify a change in conditions that would produce increased amounts of products at equilibrium in a chemical system based on

scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Integration of content, practices, and crosscutting concepts

Unit 3 ties together concepts learned in Unit 1 and Unit 2 (how to describe and predict chemical reactions, and energy flow and conservation within a system). Students will develop an understanding that the total amount of energy and matter in a closed system (including chemical reaction systems) is conserved and that changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. Using this knowledge, and knowledge of the chemical properties of elements, students should be able to describe and predict simple chemical reactions in terms of mass and energy.

The mole concept and stoichiometry are used to show proportional relationships between masses of reactants and products. Students should be able to use balanced equations to show mass relationships between reactants and products. Students should also gain an understanding of the use of dimensional analysis to perform mass to mole conversions that demonstrate how mass is conserved during chemical reactions. Focus should be on students' use of mathematics to demonstrate their thinking about proportional relationships among masses of reactants and products and to make connections between the atomic and macroscopic world. Students should use units appropriately and consistently, considering limitations on measurement, for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.

This unit also expands student understanding of the conservation of energy within a system by emphasizing the key idea that a stable molecule has less energy than the same set of atoms when separated. To support this concept, students might look at the change in energy when bonds are made and broken in a reaction system. Students might also analyze molecular-level drawings and tables showing energies in compounds with multiple bonds to show that energy is conserved in a chemical reaction.

In addition to conservation of energy, students should explore energy flow into, out of, and within systems (including chemical reaction systems). Students might be given data and asked to graph the relative energies of reactants and products to determine whether energy is released or absorbed. They should also conduct simple chemical reactions that allow them to apply the law of conservation of energy by collecting data from their own investigations. Students should be able to determine whether reactions are endothermic and exothermic, constructing explanations in terms of energy changes. These experiences will allow them to develop a model that relates energy flow to changes in total bond energy. Examples of models might include molecular-level drawings, energy diagrams, and graphs.

Students should expand their study of bond energies by relating this concept to kinetic energy. This can be understood in terms of the collisions of molecules and the rearrangement of atoms into new molecules as a function of their kinetic energy content. Students should also study the effect on reaction rates of changing the temperature and/or concentration of a reactant (Le Chatelier's principle). Students might explore the concept of equilibrium through investigations, which may include manipulations of variables such as temperature and concentration. Examples of these investigations may include the iodine clock reaction, the ferrous cyanide complex, as well as computer simulations such as those located at www.harpercollege.edu/tm-ps/chm/100/dgodambe/thedisk/equil/equil.htm. Using results from these investigations, students should develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs and on equilibrium. Students should be able cite evidence from text to support their explanations after conducting research.

Finally, in order to meet the engineering requirement for Unit 3, students should design a solution to specify a change in conditions that would produce increased amounts of products at equilibrium. As they consider their design, students should keep in mind that much of science deals with constructing explanations for how things change and how they remain stable. Through investigations and practice in changing reaction conditions (as mentioned above), as well as through teacher demonstrations such as MOM to the Rescue/Acid–Base Reaction (Flinn Scientific), students should come to understand that in many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the number of all types of molecules present. Examples of designs that students could refine might include different ways to increase product formation. Designs should include methods such as adding reactants or removing products as a means to change equilibrium. Students will base these design solutions on scientific knowledge, student-generated sources of evidence from prior investigations, prioritized criteria, and tradeoff considerations. They will do this in order to produce the greatest amount of product from a reaction system.

Integration of engineering

The engineering performance expectation HS-PS1-1 calls specifically for a connection to HS-ETS1.C. To meet this requirement, HS-ETS1-2 has been identified as appropriate for this unit, since it directs students to design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. Students will design a solution to specify a change in conditions that would produce increased amounts of products at equilibrium.

Integration of DCI from prior units within this grade level

In this unit, students will use prior knowledge of how to describe and predict chemical reactions to show proportional relationships between masses of reactants and products with stoichiometry. Students must continue to construct chemical formulas involving main group elements to model conservation of energy in chemical reactions. Student will then use previously learned explanations of bonding to explore bond energy, as well as energy flow into, within, and out of chemical reaction systems. During the engineering design process of this unit, students will continue to consider limitations of empirical data to design and refine solutions to problems.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the

translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.

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

English language arts/literacy

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

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position) of the particles. In some cases, the relative position of energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

Life science

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: Their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells.
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.

- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

Number of Instructional Days

Recommended number of instructional days: 30 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were during the writing of this unit:

- NGSS Appendices F, I, L, and M
- *A Framework for K-12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*

Chemistry Unit 4

Energy and Its Applications (Living)

Overview

Unit abstract

In this unit of study, students can construct explanations for the role of energy in the cycling of matter in organisms. They can apply mathematical concepts to develop evidence to support explanations of the interactions of photosynthesis and cellular respiration and develop models to communicate these explanations. The crosscutting concept of matter and energy provides students with insights into the structures and processes of organisms.

Essential questions

- How is energy transferred and conserved?
- How do organisms obtain and use the energy they need to live and grow?

Written Curriculum

Next Generation Science Standards

HS. Matter and Energy in Organisms and Ecosystems		
Students who demonstrate understanding can: **HS-LS1-5.** **Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.** [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [Assessment Boundary: Assessment does not include specific biochemical steps.]		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ▪ Use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-LS1-5)	**LS1.C: Organization for Matter and Energy Flow in Organisms** ▪ The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5)	**Energy and Matter** ▪ Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-LS1-5)
Connections to other DCIs in this grade-band: **HS.PS1.B** (HS-LS1-5); **HS.PS3.B** (HS-LS1-5)		
Articulation across grade-bands: **MS.PS1.B** (HS-LS1-5); **MS.PS3.D** (HS-LS1-5); **MS.LS1.C** (HS-LS1-5); **MS.LS2.B** (HS-LS1-5)		

Common Core State Standards Connections: *ELA/Literacy –*	
SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-LS1-5)*

HS. Matter and Energy in Organisms and Ecosystems

Students who demonstrate understanding can:

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. [Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ▪ Use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-LS1-7)	**LS1.C: Organization for Matter and Energy Flow in Organisms** ▪ As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-7) ▪ As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. (HS-LS1-7)	**Energy and Matter** ▪ Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems.(HS-LS1-7)

Connections to other DCIs in this grade-band: **HS.PS1.B** (HS-LS1-7); **HS.PS2.B** (HS-LS1-7); **HS.PS3.B** (HS-LS1-7)

Articulation across grade-bands: **MS.PS1.B** (HS-LS1-7); **MS.PS3.D** (HS-LS1-7); **MS.LS1.C** (HS-LS1-7); **MS.LS2.B** (HS-LS1-7)

Common Core State Standards Connections: *ELA/Literacy –*	
SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-LS1-7)*

HS. Matter and Energy in Organisms and Ecosystems		
Students who demonstrate understanding can: **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.** [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.]		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices **Constructing Explanations and Designing Solutions** Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS1-6)	**Disciplinary Core Ideas** **LS1.C: Organization for Matter and Energy Flow in Organisms** ▪ The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6) ▪ As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6)	**Crosscutting Concepts** **Energy and Matter** ▪ Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-LS1-6)
Connections to other DCIs in this grade-band: **HS.PS1.B** (HS-LS1-6)		
Articulation across grade-bands: **MS.PS1.A** (HS-LS1-6); **MS.PS1.B** (HS-LS1-6); **MS.PS3.D** (HS-LS1-6); **MS.LS1.C** (HS-LS1-6); **MS.ESS2.E** (HS-LS1-6)		
Common Core State Standards Connections: *ELA/Literacy –* **RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS1-6) **WHST.9-12.2** Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS1-6) **WHST.9-12.5** Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-LS1-6) **WHST.9-12.9** Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS1-6)		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.
- Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change.
- Some chemical reactions release energy, others store energy.
- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.
- The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends.
- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

Life science

- Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use.
- Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy.
- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.

- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

Progression of current learning

Driving question 1
How does photosynthesis transform light energy into stored chemical energy?

Concepts

- The process of photosynthesis converts light energy to stored energy by converting carbon dioxide plus water into sugars plus released oxygen.
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within a system.

Practices

- Use a model based on evidence to illustrate how photosynthesis transforms light energy into stored chemical energy.
- Use a model to illustrate the inputs and outputs of matter and the transformation of energy in photosynthesis.

Driving question 2
How does cellular respiration result in a net transfer of energy?

Concepts

- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another.
- Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles.

Practices

- Use a model based on evidence 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.
- Use a model based on evidence to illustrate the inputs and outputs of the process of cellular respiration.

- Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.
- Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems.

Driving question 3
How do elements of a sugar molecule combine with other elements and what molecules are formed?

Concepts

- Sugar molecules contain carbon, hydrogen, and oxygen: Their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells.
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Practices

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) 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.
- Construct and revise an explanation, based on valid and reliable evidence from a variety of sources (including models, theories, simulations, peer review) and on the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, 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.
- Use evidence from models and simulations to support explanations 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.

Integration of content, practices, and crosscutting concepts

This unit of study continues looking at energy flow and matter but with emphasis on photosynthesis, cellular respiration, and polymerization. Students should use models such as diagrams, chemical equations, and conceptual models to illustrate how matter and energy flow through different organizational levels of living systems, from microscale to macroscale.

In particular, both photosynthesis and cellular respiration will be the reactions used to emphasize that the reactants (inputs) and products (outputs) show the transfer of matter and energy from one system of interacting molecules to another. In developing models to represent how photosynthesis transforms light energy into stored chemical energy and the inputs and outputs of cellular respiration, students might use digital media in presentations to enhance understanding. Specifically, the focus is on the basic inputs and outputs rather than the specific biological steps of the Calvin cycle, Glycolysis, and Kreb cycle.

Developing an understanding of photosynthesis and respiration will allow students to model radiant energy transferred from a macrosystem, such as the ocean, to a microsystem, such as an individual organism like plankton. In photosynthesis, light energy is converted to stored energy when carbon dioxide and water are converted into sugars. Oxygen is released in this process. The organism then converts the chemical energy into a usable form (A.T.P) on the cellular level through the process of cellular respiration. This process gives organisms the energy needed to maintain life functions. An example is how some organisms need energy to maintain body temperature despite ongoing energy transfer to the surrounding environment.

Models should use evidence to illustrate how photosynthesis transforms light energy into stored chemical energy; how 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; and to illustrate the inputs and outputs of matter and the transformations of energy in both processes. Models could include chemical equations, flow diagrams, manipulatives, and conceptual models. Models should also illustrate that energy cannot be created or destroyed, and that it moves only between one place and another, between objects, or between systems.

At the same time, students will be taking an in-depth look at the polymerization of sugar; they should research and investigate how simple sugars (made from carbon, hydrogen, and oxygen) are combined and recombined in different structures with specific functions. Students will construct and revise explanations for how simple sugars help form hydrocarbon backbones (amino acids) or carbon-based backbones (protein, DNA, new organism). Explanations should be supported and revised using evidence from multiple sources of text, models, theories, simulations, students' own investigations, and peer review. Students' explanations should describe the formation of amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA) that can be used, for example, to form new cells. It is important to remember that students are only required to conceptually understand the process, not the specific chemical reactions or the identification of macromolecules such as amino acids and DNA.

Integration of DCI from prior units within this grade level

This unit of study continues looking at the content of energy flow and matter discussed in units 1, 2, and 3; however it approaches the content from a life science standpoint. Students will use their understanding of energy flow and conservation of energy to support their learning as they model photosynthesis and cellular respiration. Previous work with chemical reactions will help students develop explanations for the formation of amino acids and other large, carbon-based molecules. Also, students continue developing and using models, constructing explanations and designing solutions, and obtaining, evaluating, and communicating information.

Integration of English language arts/literacy

- Make strategic use of digital media in presentations to enhance understanding of how photosynthesis transforms light energy into stored chemical energy.
- Use digital media in presentations to enhance understanding of the inputs and outputs of the process of cellular respiration.
- Cite specific textual evidence to support how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large, carbon-based molecules.
- Use evidence from multiple sources to clearly communicate an explanation 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.
- Revise an explanation 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 by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant.
- Draw evidence from informational texts to describe how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large, carbon-based molecules.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.
- Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change.
- Some chemical reactions release energy, others store energy.
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

Life science

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: Their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells.
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.
- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

Number of Instructional Days

Recommended number of instructional days: 12 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

- NGSS Appendices F, I, L, and M
- *A Framework for K-12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*

Chemistry Unit 5

Nuclear Energy

Overview

Unit abstract

In this unit of study, energy and matter are studied further by investigating the processes of nuclear fusion and fission that govern the formation, evolution, and workings of the solar system in the universe. Some concepts studied are fundamental to science and demonstrate scale, proportion, and quantity, such as understanding how the matter of the world formed during the Big Bang and within the cores of stars over the cycle of their lives. In addition, an important aspect of Earth and space sciences involves understanding the concept of stability and change while making inferences about events in Earth's history based on a data record that is increasingly incomplete the farther one goes back in time. A mathematical analysis of radiometric dating is used to comprehend how absolute ages are obtained for the geologic record.

High school students are expected to demonstrate proficiency in developing and using models; constructing explanations and designing solutions; using mathematical and computational thinking; and obtaining, evaluating, and communicating information; and they are expected to use these practices to demonstrate understanding of the core ideas. The crosscutting concepts of energy and matter; scale, proportion, and quantity; and stability and change are called out as organizing concepts for this unit.

Essential questions

- How do substances combine or change (react) to make new substances?
- What is the universe and what goes on in stars?
- What is the universe, and what is Earth's place in it?

Written Curriculum

Next Generation Science Standards

HS. Structure and Properties of Matter

Students who demonstrate understanding can:

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. [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ▪ Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS1-8)	**PS1.C: Nuclear Processes** ▪ Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HS-PS1-8)	**Energy and Matter** ▪ In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-PS1-8)

Connections to other DCIs in this grade-band: **HS.PS3.A** (HS-PS1-8); **HS.PS3.B** (HS-PS1-8); **HS.PS3.C** (HS-PS1-8); **HS.PS3.D** (HS-PS1-8); **HS.ESS1.A** (HS-PS1-8); **HS.ESS1.C** (HS-PS1-8)

Articulation to DCIs across grade-bands: **MS.PS1.A** (HS-PS1-8); **MS.PS1.B** (HS-PS1-8); **MS.PS1.C** (HS-PS1-8); **MS.ESS2.A** (HS-PS1-8)

Common Core State Standards Connections:

Mathematics –

MP.4	Model with mathematics. *(HS-PS1-8)*
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS1-8)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-8)
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-8)*

HS. Space Systems

Students who demonstrate understanding can:

HS-ESS1-3. **Communicate scientific ideas about the way stars, over their life cycle, produce elements.** [Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.] [Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.]

The performance expectations above were developed using the following elements from the NRC document A Framework for K-12 Science Education:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. ▪ Communicate scientific ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-ESS1-3)	**ESS1.A: The Universe and Its Stars** • The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. (HS-ESS1-3) • Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. (HS-ESS1-3)	**Energy and Matter** • In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-ESS1-3)

Connections to other DCIs in this grade-band: **HS.PS1.A** (HS-ESS1-3); **HS.PS1.C** (HS-ESS1-3)

Articulation of DCIs across grade-bands: **MS.PS1.A** (HS-ESS1-3); **MS.ESS1.A** (HS-ESS1-3)

Common Core State Standards Connections:

ELA/Literacy –

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-ESS1-3)*

SL.11-12.4 Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. *(HS-ESS1-3)*

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-ESS1-3)

HS. Space Systems

Students who demonstrate understanding can:

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. [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). ▪ Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-ESS1-1)	**ESS1.A: The Universe and Its Stars** • The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years. (HS-ESS1-1) **PS3.D: Energy in Chemical Processes and Everyday Life** • Nuclear Fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. *(secondary to HS-ESS1-1)*	**Scale, Proportion, and Quantity** • The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-ESS1-1)

Connections to other DCIs in this grade-band: **HS.PS1.C** (HS-ESS1-1); **HS.PS3.A** (HS-ESS1-1)

Articulation of DCIs across grade-bands: **MS.PS1.A** (HS-ESS1-1); **MS.PS4.B** (HS-ESS1-1); **MS.ESS1.A** (HS-ESS1-1); **MS.ESS2.A** (HS-ESS1-1); **MS.ESS2.D** (HS-ESS1-1)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-ESS1-1)*

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-ESS1-1)
MP.4	Model with mathematics. (HS-ESS1-1)
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-ESS1-1)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. (HS-ESS1-1)
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS1-1)
HSA-SSE.A.1	Interpret expressions that represent a quantity in terms of its context. *(HS-ESS1-1)*
HSA-CED.A.2	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. *(HS-ESS1-1)*
HSA-CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *(HS-ESS1-1)*

HS. Space Systems

Students who demonstrate understanding can:

HS-ESS1-2. Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe. [Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-ESS1-2)

Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. (HS-ESS1-2)

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. (HS-ESS1-2)
- The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe. (HS-ESS1-2)
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. (HS-ESS1-2)

PS4.B Electromagnetic Radiation

- Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. *(secondary to HS-ESS1-2)*

Crosscutting Concepts

Energy and Matter

- Energy cannot be created or destroyed–only moved between one place and another place, between objects and/or fields, or between systems. (HS-ESS1-2)

Connection to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. (HS-ESS1-2)

Connection to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. (HS-ESS1-2)
- Science assumes the universe is a vast single system in which basic laws are consistent. (HS-ESS1-2)

Connections to other DCIs in this grade-band: **HS.PS1.A** (HS-ESS1-2); **HS.PS1.C** (HS-ESS1-2); **HS.PS3.A** (HS-ESS1-2); **HS.PS3.B** (HS-ESS1-2); **HS.PS4.A** (HS-ESS1-2)

Articulation of DCIs across grade-bands: **MS.PS1.A** (HS-ESS1-2); **MS.PS4.B** (HS-ESS1-2); **MS.ESS1.A** (HS-ESS1-2)

Common Core State Standards Connections:	
ELA/Literacy –	
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-ESS1-2)*
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-ESS1-2)
Mathematics –	
MP.2	Reason abstractly and quantitatively. (HS-ESS1-2)
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-ESS1-2)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-ESS1-2)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS1-2)
HSA-SSE.A.1	Interpret expressions that represent a quantity in terms of its context. *(HS-ESS1-2)*
HSA-CED.A.2	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. *(HS-ESS1-2)*
HSA-CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *(HS-ESS1-2)*

HS. History of Earth

Students who demonstrate understanding can:

HS-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history. [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-ESS1-6) -- ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ▪ A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. (HS-ESS1-6) ▪ Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. (HS-ESS1-6)	**ESS1.C: The History of Planet Earth** ▪ Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. (HS-ESS1-6) **PS1.C: Nuclear Processes** ▪ Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. *(secondary to HS-ESS1-6)*	**Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS1-6)

Connections to other DCIs in this grade-band: **HS.PS2.A** (HS-ESS1-6); **HS.PS2.B** (HS-ESS1-6)	
Articulation of DCIs across grade-bands: **MS.PS2.B** (HS-ESS1-6); **MS.ESS1.B** (HS-ESS1-6); **MS.ESS1.C** (HS-ESS1-6); **MS.ESS2.A** (HS-ESS1-6); **MS.ESS2.B** (HS-ESS1-6)	
Common Core State Standards Connections:	
ELA/Literacy –	
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-ESS1-6)*
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ESS1-6)
WHST.9-12.1	Write arguments focused on *discipline-specific content.* (HS-ESS1-6)
Mathematics –	
MP.2	Reason abstractly and quantitatively. (HS-ESS1-6),
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-ESS1-6)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling *(HS-ESS1-6)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities (HS-ESS1-6)
HSF-IF.B.5	Relate the domain of a function to its graph and, where applicable, to the quantitative relationship it describes. *(HS-ESS1-6)*
HSS-ID.B.6	Represent data on two quantitative variables on a scatter plot, and describe how those variables are related. *(HS-ESS1-6)*

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.
- Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.
- The total number of each type of atom is conserved, and thus the mass does not change.
- Some chemical reactions release energy, others store energy.
- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.

- The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends.
- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

Earth and space science

- Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.
- Earth and its solar system are part of the Milky Way Galaxy, which is one of many galaxies in the universe.
- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.
- The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.
- Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns.
- Because these patterns are so complex, weather can only be predicted probabilistically.
- The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents.

Progression of current learning

Driving question 1
What are the changes in the composition of the nucleus of the atom during the processes of fission, fusion, and radioactive decay?

Concepts

- Nuclear processes, including fusion, fission, and radioactive decay of unstable nuclei, involve release or absorption of energy.
- The total number of neutrons plus protons does not change in any nuclear process.
- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Practices

- Develop models based on evidence to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
- Use simple qualitative models based on evidence to illustrate the scale of energy released in nuclear processes relative to other kinds of transformations.
- Develop models based on evidence to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of alpha, beta, and gamma radioactive decays.

Driving question 2
How do stars produce elements?

Concepts

- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.
- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Practices

- Communicate scientific ideas in multiple formats (including orally, graphically, textually, and mathematically) about the way stars, over their life cycles, produce elements.
- Communicate scientific ideas about the way nucleosynthesis, and therefore the different elements it creates, vary as a function of the mass of a star and the stage of its lifetime.
- Communicate scientific ideas about how in nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Driving question 3
What is the life span of the sun and what results from nuclear fusion in the sun's core?

Concepts

- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.
- Nuclear fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation.
- The significance of the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth is dependent on the scale, proportion, and quantity at which it occurs.

Practices

- 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 in releasing energy that eventually reaches Earth in the form of radiation.
- Develop a model based on evidence to illustrate the relationships between nuclear fusion in the sun's core and radiation that reaches Earth.

Driving question 4
What evidence can be used to support the Big Bang theory?

Concepts

- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.

Practices

- Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.

- The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and nonstellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.
- Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities.
- Energy cannot be created or destroyed, only moved between one place and another place, between objects and/or fields, or between systems.
- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.
- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and will continue to do so in the future.
- Science assumes the universe is a vast single system in which basic laws are consistent.
- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

- Construct an explanation of the Big Bang theory based on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars).
- Construct an explanation based on valid and reliable evidence that energy in the universe cannot be created or destroyed, only moved between one place and another place, between objects and/or fields, or between systems.

Driving question 5
What is the relationship of ancient Earth materials, meteorites, and other planetary surfaces to the early history of Earth?

Concepts

- Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.
- Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials.
- Much of science deals with constructing explanations of how things change and how they remain stable.

Practices

- Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.
- Use available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago.
- Apply scientific reasoning to link evidence from ancient Earth materials, meteorites, and other planetary surfaces to claims about Earth's formation and early history, and assess the extent to which the reasoning and data support the explanation or conclusion.
- Use available evidence within the solar system to construct explanations for how Earth has changed and how it remains stable.

Integration of content, practices, and crosscutting concepts

This unit of study continues looking at energy flow and matter but with a new emphasis on Earth and space science in relation to the history of Earth starting with the Big Bang theory. Students will also explore the production of elements in stars and radioactive decay. Students should develop and use models to illustrate the processes of fission, fusion, and radioactive decay and the scale of energy released in nuclear processes relative to other kinds of transformations, such as chemical reactions. Models should be qualitative, based on evidence, and might include depictions of radioactive decay series such as Uranium-238, chain reactions such as the fission of Uranium-235 in reactors, and fusion within the core of stars. Students could also explore the PhET nuclear fission inquiry lab and create foldables and graphs to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of alpha, beta, and gamma radioactive decays. When modeling nuclear processes, students should depict that atoms are not conserved, but the total number of protons plus neutrons is conserved. Models should include changes in the composition of the nucleus of atoms and the scale of energy released in nuclear processes.

The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. Other than hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. Because atoms of each element emit and absorb characteristic frequencies of light, the presence of an element can be detected in stars and interstellar gases. Students should develop an understanding of how analysis of light spectra gives us information about the composition of stars and interstellar gases. Communication of scientific ideas about how stars produce elements should be done in multiple formats, including orally, graphically, textually, and mathematically. The conservation of the total number of protons plus neutrons is important in their explanations, and students should cite supporting evidence from text.

Students should also use the sun as a model for the lifecycle of a star. This model should also illustrate the relationship between nuclear fusion in the sun's core and energy that reaches the Earth in the form of radiation. Students could construct a mathematical model of nuclear fusion in the sun's core, identifying important quantities and factors that affect the life span of the sun. They should also be able to use units and consider limitations on measurement when describing energy from nuclear fusion in the sun's core that reaches the Earth. For example, students should be able to quantify the amounts of energy in joules when comparing energy sources. In this way, students will develop an understanding of how our sun changes and how it will burn out over a lifespan of approximately 10 billion years.

This unit continues with a study of how astronomical evidence ("red shift/blue shift," wavelength relationships to energy, and universe expansion) can be used to support the Big Bang theory. Students should construct an explanation of the Big Bang theory based on evidence of light spectra, motion of distant galaxies, and composition of matter in the universe. Students should explore and cite evidence from text of distant galaxies receding from our own, of the measured composition of stars and nonstellar gases, and of the maps of spectra of primordial radiation that still fills the universe. The concept of conservation of energy should be evident in student explanations. Students should also be aware that a scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. Students should also know that if new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of the new evidence.

Students should be able to cite specific evidence from text to support their explanations of the life cycle of stars, the role of nuclear fusion in the sun's core, and the Big Bang theory. In their explanations, they should discuss the idea that science assumes the universe is a vast single system in which laws are consistent.

This unit concludes with the application of scientific reasoning and the use of evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of the Earth's formation and early history. For example, students will use examples of spontaneous radioactive decay as a tool to determine the ages of rocks or other materials (K-39 to Ar-40). Students should make claims about Earth's formation and early history supported by data while considering appropriate units, quantities and limitations on measurement. Students might construct graphs showing data on the absolute ages and composition of Earth's rocks, lunar rocks, and meteorites. Using available evidence within the solar system, students should construct explanations for how the earth has changed and how it has remained stable in its 4.6 billion year history.

Integration of DCI from prior units within this grade level

This unit of study continues looking at energy flow and matter discussed in Units 1 through 3; however it approaches the content from an Earth and space science standpoint. Students will expand their knowledge of energy to include nuclear processes as they develop an understanding of nuclear transformations, the life cycle of stars, and the how fusion in the sun releases energy that reaches the Earth. Also, students continue developing and using models, constructing explanations and designing solutions, and obtaining, evaluating, and communicating information.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Represent the life span of the sun and the role of nuclear fusion in the sun's core in releasing energy that eventually reaches Earth in the form of radiation symbolically, and manipulate the representing symbols. Make sense of quantities and relationships about the life span of the sun and the role of nuclear fusion in the sun's core in releasing energy that eventually reaches Earth in the form of radiation symbolically, and manipulate the representing symbols.

- Use a mathematical model to explain 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. Identify important quantities in factors that affect the life span of the sun and the role of nuclear fusion in the sun's core in releasing energy that eventually reaches Earth in the form of radiation and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand energy transfer mechanisms that allow energy from nuclear fusion in the sun’s core to reach Earth. Choose and interpret units consistently in formulas representing energy transfer mechanisms that allow energy from nuclear fusion in the sun’s core to reach Earth; choose and interpret the scale and the origin in graphs and data displays representing the life span of the sun and energy transfer mechanisms that allow energy from nuclear fusion in the sun’s core to reach Earth.
- Define appropriate quantities for the purpose of descriptive modeling of the life span of the sun and the role of nuclear fusion in the sun's core in releasing energy that eventually reaches Earth in the form of radiation.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the life span of the sun and the role of nuclear fusion in the sun's core in releasing energy that eventually reaches Earth in the form of radiation.
- Create equations in two or more variables to represent relationships between the role of nuclear fusion in the sun's core and the release of energy that eventually reaches Earth in the form of radiation.
- Manipulate nuclear equations to highlight a quantity of interest when representing the role of nuclear fusion in the sun's core and the release of energy that eventually reaches Earth in the form of radiation, using the same reasoning as in solving equations.
- Represent symbolically an explanation for the Big Bang theory in terms of astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe, and manipulate the representing symbols. Make sense of quantities and relationships between light spectra, motion of distant galaxies, and composition of matter in the universe symbolically, and manipulate the representing symbols.
- Define appropriate quantities representing light spectra, motion of distant galaxies, and composition of matter in the universe for the purpose of descriptive modeling of the Big Bang theory.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing light spectra, motion of distant galaxies, and composition of matter in the universe.
- Interpret expressions that represent light spectra, motion of distant galaxies, and composition of matter in the universe in terms of the Big Bang theory.
- Create equations in two or more variables to represent relationships between light spectra, motion of distant galaxies, and composition of matter in the universe; graph equations on coordinate axes with labels and scales.
- Rearrange formulas representing light spectra, motion of distant galaxies, and composition of matter in the universe to highlight a quantity of interest, using the same reasoning as in solving equations.
- Represent symbolically an explanation for the way stars, over their life cycles, produce elements, and manipulate the representing symbols. Using symbols, make sense of quantities and relationships about

nucleosynthesis and the different elements it creates and the mass of a star and the stage of its lifetime, and manipulate the representing symbols.

- Use a mathematical model 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. Identify important quantities in the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay; choose and interpret units consistently in formulas representing the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay; choose and interpret the scale and origin in graphs and data displays representing the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
- Define appropriate quantities for the purpose of descriptive modeling of the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
- Represent symbolically an explanation for the absolute ages of ancient materials, and manipulate the representing symbols. Using symbols, make sense of quantities and relationships about the ages of ancient materials, and manipulate the representing symbols.
- Use units as a way to understand problems and to guide the solution of multistep problems about the ages of ancient materials; choose and interpret units consistently in formulas representing the ages of ancient materials; choose and interpret the scale and the origin in graphs and data displays representing the ages of ancient materials.
- Define appropriate quantities for the purpose of descriptive modeling of Earth's formation and early history.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the ages of ancient materials.
- Relate the domain of a function representing the ages of ancient materials to its graph and, where applicable, to the quantitative relationship between the ages of ancient materials and Earth's formation and early history.
- Represent data on two quantitative variables representing the ages of ancient materials on a scatter plot and describe how those variables are related in terms of Earth's formation and early history.

English language arts/literacy

- Cite specific textual evidence to support analysis of science and technical texts describing evidence of the life span of the sun and the role of nuclear fusion in the sun's core in releasing energy that eventually reaches Earth in the form of radiation, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

- Cite specific textual evidence to support an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Write informative/explanatory texts explaining the Big Bang theory in terms of astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.
- Write informative/explanatory texts, including narration of the way stars, over their life cycles, produce elements.
- Present claims and findings about the way stars, over their life cycled, produce elements, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places elements with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.
- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.
- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
- The availability of energy limits what can occur in any system.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).

- When two objects interacting through a field change relative position, the energy stored in the field is changed.
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.
- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.
- Photoelectric materials emit electrons when they absorb light of a high-enough frequency.

Earth and space science

- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.
- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.
- The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and nonstellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.
- Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old.
- Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.

Number of Instructional Days

Recommended number of instructional days: 16 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

- NGSS Appendices F, L, and M
- *A Framework for K-12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*

Chemistry Unit 6
Human Impact

Overview

Unit abstract

In this unit of study, students use cause and effect to develop models and explanations for the ways that feedbacks among different Earth systems control the appearance of Earth's surface. Central to this is the tension between internal systems, which are largely responsible for creating land at Earth's surface (e.g., volcanism and mountain building), and the sun-driven surface systems that tear down the land through weathering and erosion. Students begin to examine the ways that human activities cause feedbacks that create changes to other systems. Students understand the system interactions that control weather and climate, with a major emphasis on the mechanisms and implications of climate change. Students model the flow of energy and matter between different components of the weather system and how this affects chemical cycles such as the carbon cycle. Engineering and technology figure prominently here, as students use mathematical thinking and the analysis of geoscience data to examine and construct solutions to the many challenges facing long-term human sustainability on Earth. Here students will use these geoscience data to explain climate change over a wide range of timescales, including over one to ten years: large volcanic eruption, ocean circulation; ten to hundreds of years: changes in human activity, ocean circulation, solar output; tens of thousands to hundreds of thousands of years: changes to Earth's orbit and the orientation of its axis; and tens of millions to hundreds of millions of years: long-term changes in atmospheric composition).

Essential question

- How do Earth's surface processes and human activities affect each other?

Written Curriculum

Next Generation Science Standards

HS. Weather and Climate

Students who demonstrate understanding can:

HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). ▪ Use a model to provide mechanistic accounts of phenomena. (HS-ESS2-4) --------------------------- ***Connections to Nature of Science*** **Scientific Knowledge is Based on Empirical Evidence** ▪ Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-ESS2-4)	**ESS1.B: Earth and the Solar System** ▪ Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. *(secondary to HS-ESS2-4)* **ESS2.A: Earth Materials and Systems** ▪ The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (HS-ESS2-4) **ESS2.D: Weather and Climate** ▪ The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. (HS-ESS2-4), *(secondary to HS-ESS2-2)* ▪ Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.(HS-ESS2-4)	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS2-4)

Connections to other DCIs in this grade-band: **HS.PS3.A** (HS-ESS2-4); **HS.PS3.B** (HS-ESS2-4); **HS.LS2.C** (HS-ESS2-4); **HS.ESS1.C** (HS-ESS2-4); **HS.ESS3.C** (HS-ESS2-4); **HS.ESS3.D** (HS-ESS2-4)

Articulation of DCIs across grade-bands: **MS.PS3.A** (HS-ESS2-4); **MS.PS3.B** (HS-ESS2-4); **MS.PS3.D** (HS-ESS2-4); **MS.PS4.B** (HS-ESS2-4); **MS.LS1.C** (HS-ESS2-4); **MS.LS2.B** (HS-ESS2-4); **MS.LS2.C** (HS-ESS2-4); **MS.ESS2.A** (HS-ESS2-4); **MS.ESS2.B** (HS-ESS2-4); **MS.ESS2.C** (HS-ESS2-4); **MS.ESS2.D** (HS-ESS2-4); **MS.ESS3.C** (HS-ESS2-4); **MS.ESS3.D** (HS-ESS2-4)

Common Core State Standards Connections:

ELA/Literacy –

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-ESS2-4)*

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-ESS2-4)

MP.4 Model with mathematics. (HS-ESS2-4)

HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-ESS2-4)

HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. (HS-ESS2-4)

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS2-4)

HS. Earth's Systems		
Students who demonstrate understanding can: **HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.** [Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.]		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). ▪ Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-ESS2-6)	**ESS2.D: Weather and Climate** ▪ Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-6) ▪ Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-6)	**Energy and Matter** ▪ The total amount of energy and matter in closed systems is conserved. (HS-ESS2-6)
Connections to other DCIs in this grade-band: **HS.PS1.A** (HS-ESS2-6); **HS.PS1.B** (HS-ESS2-6); **HS.PS3.D** (HS-ESS2-6); **HS.LS1.C** (HS-ESS2-6); **HS.LS2.B** (HS-ESS2-6); **HS.ESS3.C** (HS-ESS2-6); **HS.ESS3.D** (HS-ESS2-6)		
Articulation of DCIs across grade-bands: **MS.PS1.A** (HS-ESS2-6); **MS.PS3.D** (HS-ESS2-6); **MS.PS4.B** (HS-ESS2-6); **MS.LS2.B** (HS-ESS2-6); **MS.ESS2.A** (HS-ESS2-6); **MS.ESS2.B** (HS-ESS2-6); **MS.ESS2.C** (HS-ESS2-6); **MS.ESS3.C** (HS-ESS2-6); **MS.ESS3.D** (HS-ESS2-6)		
Common Core State Standards Connections: *Mathematics –* **MP.2** Reason abstractly and quantitatively. (HS-ESS2-6) **MP.4** Model with mathematics. (HS-ESS2-6) **HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-ESS2-6) **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling. (HS-ESS2-6) **HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS2-6)		

HS. Engineering Design

Students who demonstrate understanding can:

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.

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. ▪ Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1)	**ETS1.A: Defining and Delimiting Engineering Problems** ▪ Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) ▪ Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)	***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** ▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1)

Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:
Physical Science: HS-PS2-3, HS-PS3-3
Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:
Earth and Space Science: HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6
Connections to HS-ETS1.C: Optimizing the Design Solution include:
Physical Science: HS-PS1-6, HS-PS2-3

Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-1)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-ETS1-1)
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. *(HS-ETS1-1)*
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-ETS1-1)

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-ETS1-1)
MP.4	Model with mathematics. (HS-ETS1-1)

HS. Engineering Design		
Students who demonstrate understanding can: **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.**		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. ▪ Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2)	**ETS1.C: Optimizing the Design Solution** ▪ Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	N/A
Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include: **Physical Science:** HS-PS2-3, HS-PS3-3 *Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:* **Earth and Space Science:** HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6 *Connections to HS-ETS1.C: Optimizing the Design Solution include:* **Physical Science:** HS-PS1-6, HS-PS2-3		
Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-2); **MS.ETS1.B** (HS-ETS1-2); **MS.ETS1.C** (HS-ETS1-2)		
Common Core State Standards Connections: *Mathematics –* **MP.4** Model with mathematics. (HS-ETS1-2)		

HS. Engineering Design

Students who demonstrate understanding can:

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.

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. ▪ Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	**ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)	***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** ▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-3)

Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:
Physical Science: HS-PS2-3, HS-PS3-3
Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:
Earth and Space Science: HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6
Connections to HS-ETS1.C: Optimizing the Design Solution include:
Physical Science: HS-PS1-6, HS-PS2-3

Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-3); **MS.ETS1.B** (HS-ETS1-3)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-ETS1-3)*

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ETS1-3)

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. *(HS-ETS1-3)*

Mathematics –

MP.2 Reason abstractly and quantitatively. *(HS-ETS1-3)*

MP.4 Model with mathematics.(HS-ETS1-3)

HS. Engineering Design		
Students who demonstrate understanding can: **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.**		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4)	**ETS1.B: Developing Possible Solutions** ▪ Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)	**Systems and System Models** ▪ Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. (HS-ETS1-4)
Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include: **Physical Science:** HS-PS2-3, HS-PS3-3 *Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:* **Earth and Space Science:** HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6 *Connections to HS-ETS1.C: Optimizing the Design Solution include:* **Physical Science:** HS-PS1-6, HS-PS2-3		
Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-4); **MS.ETS1.B** (HS-ETS1-4); **MS.ETS1.C** (HS-ETS1-4)		
Common Core State Standards Connections: *Mathematics –* **MP.2** Reason abstractly and quantitatively. *(HS-ETS1-4)* **MP.4** Model with mathematics. (HS-ETS1-4)		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.
- Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- A system of objects may also contain stored (potential) energy, depending on the objects' relative positions.
- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.
- The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends.
- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

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Life science

- Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use.
- Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth or to release energy.
- Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.
- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.
- A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.
- Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.

Earth and space science

- Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes.
- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, and a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and the gravitational movement of denser materials toward the interior.
- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.
- The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.
- Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust.
- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks.
- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.
- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.
- Resource availability has guided the development of human society.
- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.
- Natural hazards and other geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations.

- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.
- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.
- Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.
- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.

Progression of current learning

Driving question 1
What is the relationship between energy flow into and out of Earth's systems and changes in climate?

Concepts

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.
- Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes.
- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

Practices

- Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
- Use empirical evidence to differentiate between how variations in the flow of energy into and out of Earth's systems result in climate changes.
- Use multiple lines of evidence to support how variations in the flow of energy into and out of Earth's systems result in climate changes.

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

Driving question 2
How does carbon cycle among the hydrosphere, atmosphere, geosphere, and biosphere?

Concepts

- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.
- The total amount of energy and matter in closed systems is conserved.
- The total amount of carbon cycling among and between the hydrosphere, atmosphere, geosphere, and biosphere is conserved.

Practices

- Develop a model based on evidence to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- Develop a model based on evidence to illustrate the biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere, providing the foundation for living organisms.

Integration of content, practices, and crosscutting concepts

This unit of study continues looking at matter and energy, with a focus on weather and climate, carbon cycling, and the cause-and-effect relationships between human activity and Earth's systems. Students will examine causes of variations in the flow of energy into and out of Earth's systems and how climate is affected by these variations. They will also determine how the amount of carbon cycling in Earth's systems has changed over time, and how humans are influenced by resource availability, natural hazards, and climate change.

Students should develop an understanding of how the foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. They should also examine how cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the Earth. These phenomena cause a cycle of ice ages and other gradual climate changes. Students might conduct research to locate and analyze data sets showing these phenomena.

In order to determine how changes in the atmosphere due to human activity have increased the carbon dioxide concentrations and affected climate, students should look at cycles of differing timescales and their effects on climate. Geoscience data should be used to explain climate change over a wide-range of timescales, including one to ten years: large volcanic eruptions, ocean circulation; ten to hundreds of years: changes in human activity, ocean circulation, solar output; tens of thousand to hundreds of thousands of years: changes to Earth's orbit and the orientation of its axis; and tens of millions to hundreds of millions of years: long-term changes in atmospheric composition. Students might also explore Earth's climate history through an analysis of datasets such as the Keeling Curve or Vostok ice core data. Students can use a jigsaw activity to examine data for an assigned timescale and event to show cause-and-effect relationships among energy flow into and out of Earth's systems and the resulting in changes in climate.

Students should use models to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. Models should be supported by multiple lines of evidence, and students should use digital media in presentations to enhance understanding. Students might use mathematical models, and they should identify important quantities and map relationships using charts and graphs. Mathematical models should include appropriate units and limitations on measurement should be considered.

Students will continue their study of Earth's systems by examining the history of the atmosphere. Students should research the early atmospheric components and the changes that occurred due to plants and other organisms removing carbon dioxide and releasing oxygen. By studying the carbon cycle, students should revisit the idea that matter and energy within a closed system are conserved among the hydrosphere, atmosphere, geosphere, and biosphere. Students should extend their understanding of how human activity affects the concentration of carbon dioxide in the environment and therefore climate. Students' experiences should include synthesizing information from multiple sources and developing quantitative models based on evidence to describe the cycling of carbon among the ocean, atmosphere, soil, and biosphere. Students should understand how biogeochemical cycles provide the foundation for living organisms. Once again, students might use a jigsaw activity to illustrate the relationships between these systems.

Finally, making a connection to engineering, students will investigate the cause-and-effect relationships between the interdependence of human activities and Earth's systems. Students should construct an explanation based on evidence for relationships between human activity and changes in climate. Students can revisit the idea of renewable and nonrenewable resources touched upon in unit 4, and further investigate their availability. Examples of key natural resources should include access to fresh water, fertile soil, and high concentrations of minerals and fossil fuels. Students should also examine natural hazards including interior processes (volcanic eruptions and earthquakes); surface processes (tsunamis, mass wasting, and soil erosion); and severe weather (hurricanes, floods, and droughts). Additionally, other geologic events that have driven the development of human history (including populations and migrations) should also be researched. These geologic events include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised. Students must use empirical evidence to identify differences between cause and correlation in the relationship between climate changes and human activity. Students should also use empirical evidence to make claims about causes and effects of these interactions. The influence of major technological systems on modern civilizations should be emphasized.

Because all the scientific and engineering practices and crosscutting concepts are necessary for mastery of the scientific content in this unit, it is an opportunity for students to engage in problem solving using the complete engineering design cycle. Research and examination of data to determine relationships between global change and human activity will allow students to identify and analyze a major global challenge. Students should take into account possible qualitative and quantitative criteria and constraints for solutions and examine the needs of society in response to the identified major global challenge. The students could then design a solution to this real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. They must then evaluate their solution based on prioritized criteria and tradeoffs (e.g., cost, safety, reliability, aesthetics, and possible social, cultural, and environmental impacts). Finally, students might use computer simulations along with mathematics and computational thinking to model the impact of their proposed solution. Their simulation must take into account the numerous criteria and constraints on interactions within and between systems relevant to the problem. For example, major global challenges might include ozone depletion, melting glaciers, rising sea levels, changes in climate and extreme weather, ocean acidification, aerosols and smog, melting permafrost, destruction of rainforests, and biome migration. Some local challenges students might consider include fishing industry quotas vs. economic impact on local fishing fleets (i.e., New Bedford, Galilee, Jerusalem); flood plain construction vs. housing restrictions on ocean beach fronts (i.e., Carpenter's beach, Misquamicut beach); design of possible solutions to retard or prevent further beach erosion; and response to recent flooding in Rhode Island and flood plain restoration.

Integration of engineering

The standards in this unit do not identify a connection to engineering; however, the nature of the content lends itself to real-world problem identification and solution design, testing, and modification. Students can use their understanding of energy and matter and system interactions from the previous units to guide their thinking about climate change, its effects on humans, the adverse effects of human activities, and potential solutions to contemporary issues regarding climate change. In this unit, students have the opportunity to complete the entire engineering cycle (ETS1-1, ETS1-2, ETS1-3, and ETS1-4) by analyzing a major global challenge related to climate change and human activity, designing and evaluating a possible solution to this problem, and further using a computer simulation to model the impact of the proposed solution.

Integration of DCI from prior units within this grade level

This unit of study continues looking at energy flow and matter discussed in previous units; however, as in Unit 5, this unit approaches the content from an Earth and space science standpoint, specifically looking at weather and climate, carbon cycling, and cause and effect in the interdependence of human impact and the Earth's systems. In regard to engineering practices, students have the opportunity to once again evaluate solutions to complex real-world problems, as they had in units 1 and 2. In unit 3, students had the opportunity to design a solution to a complex real-world problem, and in unit 1, students were introduced to the use of computer simulations to model the impact of proposed solutions.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Represent symbolically an explanation for how variations in the flow of energy into and out of Earth's systems result in changes in climate, and manipulate the representing symbols. Make Use symbols to make sense of quantities and relationships about how variations in the flow of energy into and out of Earth's systems result in changes in climate, symbolically and manipulate the representing symbols.
- Use a mathematical model to explain how variations in the flow of energy into and out of Earth's systems result in changes in climate. Identify important quantities in variations in the flow of energy into and out of Earth's systems result in changes in climate and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand problems and to guide the solution of multistep problems about how variations in the flow of energy into and out of Earth's systems result in changes in climate; choose and interpret units consistently in formulas representing how variations in the flow of energy into and out of Earth's systems result in changes in climate; choose and interpret the scale and the origin in graphs and data displays representing how variations in the flow of energy into and out of Earth's systems result in changes in climate.
- Define appropriate quantities for the purpose of descriptive modeling of how variations in the flow of energy into and out of Earth's systems result in changes in climate.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

- Represent symbolically the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere, and manipulate the representing symbols. Make sense of quantities and relationships in the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- Use a mathematical model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. Identify important quantities in the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere; choose and interpret units consistently in formulas representing the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere; choose and interpret the scale and the origin in graphs and data displays representing the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- Define appropriate quantities for the purpose of descriptive modeling of the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities showing the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- Represent symbolically how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity, and manipulate the representing symbols. Make sense of quantities and relationships among availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.
- Use units as a way to understand the relationships among availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity. Choose and interpret units consistently in formulas to determine relationships among availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity. Choose and interpret the scale and the origin in graphs and data displays representing relationships among availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.
- Define appropriate quantities for the purpose of descriptive modeling of relationships among availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities showing relationships among availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.

English language arts/literacy

- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations describing how variations in the flow of energy into and out of Earth's systems result in changes in climate to enhance understanding of findings, reasoning, and evidence and to add interest.
- Cite specific textual evidence of the availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.
- Use empirical evidence to write an explanation for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those elements with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.
- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases, the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.

- The availability of energy limits what can occur in any system.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

Life science

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: Their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells.
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.
- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.
- A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, the ecosystem may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.
- Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.

Earth and space science

- Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old.
- Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth’s formation and early history.
- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.
- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.
- Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.
- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.

Number of Instructional Days

Recommended number of instructional days: 20 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

- NGSS Appendices F, I, L, and M
- *A Framework for K–12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*