Physics Unit 4

Energy

Overview

Unit abstract

In this unit of study, the disciplinary core idea PS3 is broken down into sub-core ideas: definitions of energy, conservation of energy and energy transfer, and the relationship between energy and forces. Energy is understood as a quantitative property of a system that depends on the motion and interactions of matter, and the total change of energy in any system is equal to the total energy transferred into and out of the system. Students also demonstrate their understanding of engineering principles when they design, build, and refine devices associated with the conversion of energy. The crosscutting concepts of cause and effect, systems and systems models, energy and matter, and the influence of science, engineering, and technology on society and the natural world are further developed in the performance expectations associated with PS3. In these performance expectations, students are expected to demonstrate proficiency in developing and using models, planning and carry out investigations, using computational thinking and designing solutions, and they are expected to use these practices to demonstrate understanding of core ideas.

Essential question

- How is energy transferred and converted?

Written Curriculum

Next Generation Science Standards

HS. Energy

Students who demonstrate understanding can:

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]

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 and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS3-2)	**PS3.A: Definitions of Energy** ▪ Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. 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. (HS-PS3-2) ▪ At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) ▪ These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)	**Energy and Matter** ▪ Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2)

Connections to other DCIs in this grade-band: **HS.PS1.A** (HS-PS3-2); **HS.PS1.B** (HS-PS3-2); **HS.PS2.B** (HS-PS3-2); **HS.ESS2.A** (HS-PS3-2)

Articulation to DCIs across grade-bands: **MS.PS1.A** (HS-PS3-2); **MS.PS2.B** (HS-PS3-2); **MS.PS3.A** (HS-PS3-2); **MS.PS3.C** (HS-PS3-2)

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-PS3-2)*
Mathematics –	
MP.2	Reason abstractly and quantitatively. (HS-PS3-2)
MP.4	Model with mathematics. (HS-PS3-2)

HS. Energy

Students who demonstrate understanding can:

HS-PS3-1 **Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.** [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]

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. ▪ Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS-PS3-1)	**PS3.A: Definitions of Energy** ▪ Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. 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. (HS-PS3-1) **PS3.B: Conservation of Energy and Energy Transfer** ▪ Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1) ▪ Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1) ▪ Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1) ▪ The availability of energy limits what can occur in any system. (HS-PS3-1)	**Systems and System Models** ▪ Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. (HS-PS3-1) -- ***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-PS3-1)

Connections to other DCIs in this grade-band: **HS.PS1.B** (HS-PS3-1); **HS.LS2.B** (HS-PS3-1); **HS.ESS1.A** (HS-PS3-1); **HS.ESS2.A** (HS-PS3-1)
Articulation to DCIs across grade-bands: **MS.PS3.A** (HS-PS3-1); **MS.PS3.B** (HS-PS3-1); **MS.ESS2.A** (HS-PS3-1)
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-PS3-1)* *Mathematics –* **MP.2** Reason abstractly and quantitatively. (HS-PS3-1) **MP.4** Model with mathematics. (HS-PS3-1) **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-PS3-1) **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling. (HS-PS3-1) **HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS3-1)

HS. Energy

Students who demonstrate understanding can:

HS-PS3-3. **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*** [Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency. Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials 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
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, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS3-3)	**PS3.A: Definitions of Energy** ▪ At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-3) **PS3.D: Energy in Chemical Processes** ▪ Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3) **ETS1.A: Defining and Delimiting Engineering Problems** ▪ Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary to HS-PS3-3)*	**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-PS3-3) --------------------------------------- ***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** ▪ Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS3-3)

Connections to other DCIs in this grade-band: **HS.ESS3.A** (HS-PS3-3)

Articulation to DCIs across grade-bands: **MS.PS3.A** (HS-PS3-3); **MS.PS3.B** (HS-PS3-3); **MS.ESS2.A** (HS-PS3-3)

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-PS3-3)*

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-PS3-3)

MP.4 Model with mathematics. (HS-PS3-3)

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-PS3-3)

HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. (HS-PS3-3)
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS3-3)

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)

<table>
<tr><td colspan="3">HS. Engineering Design</td></tr>
<tr><td colspan="3">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.</td></tr>
<tr><td colspan="3">The performance expectations above were developed using the following elements from the NRC document A Framework for K-12 Science Education:</td></tr>
<tr><td>Science and Engineering Practices
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)</td><td>Disciplinary Core Ideas
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)</td><td>Crosscutting Concepts
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)</td></tr>
<tr><td colspan="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</td></tr>
<tr><td colspan="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)</td></tr>
<tr><td colspan="3">Common Core State Standards Connections:
Mathematics –
MP.2 Reason abstractly and quantitatively. (HS-ETS1-4)
MP.4 Model with mathematics. (HS-ETS1-4)</td></tr>
</table>

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

- 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.
- 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.
- 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—for example, 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).
- 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.
- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.

Earth and space science

- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- 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
What are the relationships between energy at the macroscopic scale, energy associated with the motions of particles (objects), and energy associated with the relative position of particles (objects)?

Concepts

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system.
- 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).
- Radiation is a phenomenon in which energy stored in fields moves across spaces.

Practices

- Develop and use models based on evidence to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects).
- Develop and use models based on evidence to illustrate that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems.
- Use mathematical expressions to quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compressions of a spring) and how kinetic energy depends on mass and speed.
- Use mathematical expressions and the concept of conservation of energy to predict and describe system behavior.

- 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 2
How can the change in the energy of one component in a system be determined?

Concepts

- 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.
- The availability of energy limits what can occur in any system.
- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximation inherent in models.
- Science assumes that the universe is a vast single system in which basic laws are consistent.

Practices

- Use basic algebraic expressions or computations to create a computational model to calculate the change in the energy of one component in a system (limited to two or three components) when the change in energy of the other component(s) and energy flows in and out of the system are known.
- Explain the meaning of mathematical expressions used to model the change in the energy of one component in a system (limited to two or three components) when the change in energy of the other component(s) and out of the system are known.

Driving question 3
How can one form of energy be converted into another form of energy?

Concepts

- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.
- 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.
- Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.
- News 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.
- 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.
- Humanity faces major global challenges today, such as the need for supplies of clean water or for energy sources that minimize pollution, that can be addressed through engineering. These global challenges also may have manifestations in local communities.

Practices

- Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
- Analyze a device to convert one form of energy into another form of energy by specifying criteria and constraints for successful solutions.
- Use mathematical models and/or computer simulations to predict the effects of a device that converts one form of energy into another form of energy.

Integration of content, practices, and crosscutting concepts

In this unit of study, students will develop an understanding that energy is a quantitative property. They will explore energy in systems as a function of the motion and interactions of matter and radiation within systems. Energy can be detected and measured at the macroscopic scale as the phenomena of motion, sound, light, and thermal energy. Students will also learn that these forms of energy can be modeled in terms of the energy associated with the motion of particles or the energy stored in fields (gravitational, electric, magnetic,) that mediate interactions between particles.

Students should ultimately be able to develop models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles, or objects, and energy associated with the relative position of particles, or objects. In some cases, the relative position energy can be thought of as stored in fields. Students should be able to qualitatively show that an object in a gravitational field has a greater amount of potential energy as it is put into higher and higher locations in that field. An example of this could be investigating how an object, such as a ball, when released from successively higher and higher positions hits the ground at greater and greater velocities (kinetic energy, KE= $\frac{1}{2}mv^2$).

In these kinds of investigations, students should understand how to obtain the original potential energy ($PE_{gravitational} = mgh$) of the object. They should know that when work is done on an object, the energy of the object changes, such when the wrecking ball of a demolition machine is raised. Work can be calculated ($W = Fd$), appreciated, and understood as a concept. Students should recognize the relationship between the work done on an object and the potential energy of objects. Considering an object that collides with the ground, students should be able to list a variety of ways the kinetic energy is transferred upon impact, such as kinetic energy to thermal energy or to sound. Emphasis on the law of conservation of energy should be evident at all points of this discussion. Energy cannot be created or destroyed. It only moves between one place and another, between objects and/or fields, or between systems. Students should demonstrate their understanding of energy conservation and transfer using models. Models should be evidence based and illustrate the relationship between energy at the bulk scale and motion and position at the particle scale. Models should also illustrate conservation of energy. Examples of models might include diagrams, drawings, written descriptions, or computer simulations. Modeling should include strategic use of digital media in presentations to enhance understanding.

Students should understand that changes of energy in a system are described in terms of energy flows into, out of, and within the system. They should also be able to describe the components of a system. Basic algebraic expressions or computations should be used to model the energy of one component of a system (limited to two or three components) when the change in energy of the other components is known. Students should be given opportunities to quantitatively calculate an object's gravitational potential energy based on its height (near the surface of the Earth). Students should also be able to calculate the potential and kinetic energy of an object simultaneously as the object falls through a gravitational field. Calculations might be displayed in table format. At this point, the law of conservation of energy should be evident numerically through analysis of the calculated data in the table.

Students should have an understanding that kinetic energy depends on mass and speed. As an enrichment activity, students might calculate the time at each individual height in the table (using $d = \frac{1}{2}gt^2$,where d is distance fallen from start). Students could then graph the potential and kinetic energy versus height on one graph, and both the potential and kinetic energy versus time on another. Analysis of the energy versus height graph will demonstrate that as an object falls, the potential energy will linearly decrease as the kinetic energy linearly increases. Analysis of the energy versus time graph should demonstrate that the potential energy exponentially decreases as the kinetic energy exponentially increases. In all data representations and calculations, students should define quantities, use units, and choose a level of accuracy appropriate to limitations on measurement.

Students should conduct short as well as more sustained research to describe energy conversions and energy flows within and between systems. They should evaluate and compare multiple sources of information to enhance understanding. When exploring systems, they should be limited to two or three components and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electrical fields. Examples of systems students might consider include a boulder rolling down a hill, a coasting bicyclist moving up a hill, the interaction between two like poles of magnets, thermal convection in a glass tube, and a small motor made out of a battery, permanent magnet, and coil of wire.

Students also should use mathematical expressions to quantify how stored energy in a system depends on configuration—for example, the stretching or compression of a spring. Students might calculate the potential energy of springs using $PE_{spring} = 0.5kx^2$, where k is spring constant and x is amount of compression relative to the equilibrium position. Students should also consider how stored energy depends on configuration in terms of relative positions of charged particles. Students might perform investigations with capacitors. They should also know that the availability of energy limits what can occur in any system.

Another way for students to illustrate that, in systems, energy can be transformed into various types of energy (both potential and kinetic) is to describe and diagram the changes in energy that occur in systems. For example, students could diagram steps showing the transformations of energy that occur when a student uses a yo-yo or the transformations of energy that occur in a burning candle. Ultimately, students might also diagram the steps showing transformations of energy, from fusion in the sun to the food that we eat. Students should include the phenomenon of radiation, in which energy stored in fields can move across spaces, when appropriate.

In this unit, students will also design, build, and refine a device that works within given constraints to convert one form of energy into another based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. They should also use mathematical models or computer simulations to predict the effects of a device that converts one form of energy into another.

To fulfill the engineering component of this unit as described above, students might be assigned a rollercoaster project to explore energy transformation and conservation. This could be a computer simulation, practical model, or model with Excel-calculated formulae to verify expected results. Students could also design and build a Rube Goldberg apparatus to perform a given task. After conducting research, students could make claims or defend arguments about various green energy sources. Properties of dams, solar cells, solar ovens, generators, and turbines could be explored through simulations. Evaluations of devices should be both qualitative and quantitative, and analysis of costs and benefits is a critical aspect of design decisions.

When focusing on engineering, students should keep in mind that modern civilization depends on major technological systems, and that engineers continuously modify these systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Students should also develop an understanding that new technologies can have deep impacts on society and the environment, including some that were not anticipated.

Integration of engineering

This unit allows for the opportunity to apply one or more engineering practices at the teacher's discretion. ETS1-1 is specifically called for in the engineering performance expectation of this unit. Because of the requirement to design, build, and refine a device to convert one form of energy into another, students have the opportunity to experience the complete engineering cycle. All ETS1 performance expectations have been included. Some examples of activities might include, but are not limited to, designing roller coasters, Rube Goldberg machines, or exploring systems represented by wind-up toys, green energy conservation devices, or solar energy storage devices that perform useful work.

Integration of DCI from prior units within this grade level

In Unit 2, students used mathematical representations of Newton's law of gravitation and Coulomb's law to describe and predict the gravitational and electrostatic forces between objects. This understanding will support them in the current unit as they describe energy in fields in terms of the motion of particles or as stored in fields (gravitational, electric, magnetic) that mediate interactions between particles.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Represent symbolically an explanation about the notion that energy is a quantitative property of a system and that the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known, and manipulate the representing symbols. Make sense of quantities and relationships about the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known symbolically, and manipulate the representing symbols.
- Use a mathematical model to explain the notion that energy is a quantitative property of a system and that the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known. Identify important quantities in energy of components in systems 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 how the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known; choose and interpret units consistently in formulas representing how the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known; choose and interpret the scale and the origin in graphs and data displays representing that the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known.
- Define appropriate quantities for the purpose of descriptive modeling of how the quantitative change in energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing how the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known.
- Represent symbolically that energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects), and manipulate the representing symbols. Make sense of quantities and relationships between the energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects).
- Use a mathematical model of how energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects). Identify important quantities representing how the energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects), 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 the conversion of one form of energy into another symbolically, considering criteria and constraints, and manipulate the representing symbols. Make sense of quantities and relationships in the conversion of one form of energy into another.
- Use a mathematical model to describe the conversion of one form of energy into another and to predict the effects of the design on systems and/or interactions between systems. Identify important quantities in the conversion of one form of energy into another 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 conversion of one form of energy into another; choose and interpret units consistently in formulas representing energy conversions as energy flows into, out of, and within systems; choose and interpret the scale and the origin in graphs and data displays representing energy conversions as energy flows into, out of, and within systems.
- Define appropriate quantities for the purpose of descriptive modeling of a device to convert one form of energy into another form of energy.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities of energy conversions as energy flows into, out of, and within systems.

English language art/literacy

- Make strategic use of digital media in presentations to enhance understanding of the notion that energy is a quantitative property of a system and that the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known.
- Make strategic use of digital media in presentations to support the claim that energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects).
- Conduct short as well as more sustained research projects to describe energy conversions as energy flows into, out of, and within systems.
- Integrate and evaluate multiple sources of information presented in diverse formats and media to describe energy conversions as energy flows into, out of, and within systems.
- Evaluate scientific text regarding energy conversions to determine the validity of the claim that although energy cannot be destroyed, it can be converted into less useful forms.
- Compare different sources of information describing energy conversions to create a coherent understanding of energy flows into, out of, within, and between systems.

Connected learning

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

Physical science

- 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.
- 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; at least this much energy must be provided 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 number 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.
- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space; these fields can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.
- Attraction and repulsion between electrical charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

Life science

- 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.

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.
- 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 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.
- 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.

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 consulted during the writing of this unit:

- NGSS appendices 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*
- Next Generation Science Standards, www.nextgenscience.org/next-generation-science-standards
- The Physics Classroom, www.physicsclassroom.com/
- PhET Interactive Simulations, https://phet.colorado.edu/en/simulations/category/physics