Unit 4 Momentum & Energy

Content Area: **Science**
Course(s):
Time Period: **December**
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Topic Outline

The Impulse-Momentum Change Theorem

- Momentum / Momentum and Impulse Connection / Real-World Applications

The Law of Momentum Conservation

- The Law of Action-Reaction (Revisited) / Momentum Conservation Principle
- Using Equations as a "Recipe" for Algebraic Problem-Solving & a Guide to Thinking
- Momentum Conservation in Explosions

Basic Terminology and Concepts

- Definition and Mathematics of Work / Calculating the Amount of Work Done by Forces
- Potential Energy / Kinetic Energy / Mechanical Energy / Power

The Work-Energy Relationship

- Internal vs. External Forces / Analysis of Situations Involving External Forces
- Analysis of Situations in Which Mechanical Energy is Conserved
- Application and Practice Questions / Bar Chart Illustrations

Unit Summary

How is energy transferred and conserved?

In this unit of study, students *develop and use models, plan and carry out investigations, use computational thinking and design solutions* as they make sense of the disciplinary core idea. The disciplinary core idea of *Energy* is broken down into subcore 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. 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.

updated from 11.19.15

Enduring Understandings

- There are different types of energies and these energies may change over time.
- Ideas can be represented in numerous ways such as graphs, mathematical formulas, drawings, bar charts, etc.
- "Energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems."
- Mechanical energy can be classified as kinetic and potential.
- We use energy from a diversity of sources in various forms.
- An isolated/closed system is a collection of objects isolated from outside forces and to/from which no net energy flows.
- Total energy in a closed system is conserved.

Essential Questions

- How does losing and gaining weight relate to energy transformations?
- Why and how is energy conserved?
- If energy is conserved, why do people talk about an energy crisis?
- How can one explain and predict interactions between objects and within systems of objects?
- Why are humans dependent on transformations of energy?
- Why does society spend a lot of resources on controlling thermal energy?

Student Learning Objectives (PE, SEP, DCI, CCC) & Aligned Standards

(+ Honors Only Skills)

- Students at the honors level will derive equations with less support than the students at the CP level.
- The honors level will quantitatively examine energy losses due to frictional forces.
- The honors students may derive gravitational potential energy and kinetic energy mathematical representations (math reps) from the kinematic math reps.
- The honors students will examine problems where the angle between the force and displacement is not equal to 0 degrees, 180 degrees, or 90 degrees.

Performance Expectations

Identify and quantify the various types of energies within a system of objects in a well-defined state, such as elastic potential energy, gravitational potential energy, kinetic energy, and thermal energy and represent how these energies may change over time. (PS3.A and PS3.B)

Calculate changes in kinetic energy and gravitational potential energy of a system using representations of that system. (PS3.A)

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.]* **(HS-PS3-2)**

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.]* **(HS-PS3-1)**

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.]* **(HS-PS3-3)**

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

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. (HS-ETS1-2)

Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. (HS-ETS1-3)

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. (HS-ETS1-4)

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

Evaluate or refine a technological solution that reduces impacts of human activities on climate change and other natural systems. (HS-ESS3-4)

Science and Engineering Practices

Developing and Using Models

- Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS3-2)

Using Mathematics and Computational Thinking

- Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS-PS3-1)
- 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)

Constructing Explanations and Designing Solutions

- 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)

Disciplinary Core Ideas

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)

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)

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 an Engineering Problem

- 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)*

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)

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)

- 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)

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)

ESS3.A: Natural Resources

- Resource availability has guided the development of human society. (HS-ESS3-1)
- 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)

ESS3.C: Human Impacts on Earth Systems

- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-4)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS3-1)

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)
- 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)
- 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-ESS3-6)

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)
- 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)

Stability and Change

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-3),(HS-ESS3-5)
- Feedback (negative or positive) can stabilize or destabilize a system. (HS-ESS3-4)

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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)
- 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) (HS-ETS1-3)

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)

Science is a Human Endeavor

- Science is a result of human endeavors, imagination, and creativity. (HS-ESS3-3)

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)

CCC.1.1	students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. They use mathematical representations to identify certain patterns and analyze patterns of

	performance in order to reengineer and improve a designed system.
	Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
CCC.2.1	students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects.
	Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
CCC.5.1	students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.
	For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.
CCC.7.1	students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.
SCI.9-12.1.3	Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.
SCI.9-12.1.4	Mathematical representations are needed to identify some patterns.
SCI.9-12.1.5	Empirical evidence is needed to identify patterns.
SCI.9-12.2.2	Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.
SCI.9-12.2.3	Systems can be designed to cause a desired effect.
SCI.9-12.2.4	Changes in systems may have various causes that may not have equal effects.
SCI.9-12.5.2	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.
SCI.9-12.5.3	Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.
SCI.9-12.5.4	Energy drives the cycling of matter within and between systems.
SCI.9-12.7.2	Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.
SCI.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.
SCI.HS-PS2-2	Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
SCI.HS-PS2-3	Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

SCI.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.
SCI.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).

Concepts & Formative Assessment

Part A: I have heard about it since kindergarten but what is energy?

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.
- Energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems.

Formative Assessment

Students who understand the concepts are able to:

- 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.

Part B: How can we use mathematics to prove what happens in an abiotic and biotic systems?

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.

Formative Assessment

Students who understand the concepts are able to:

- 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.

Part C: Superstorm Sandy devastated the New Jersey Shore and demonstrated to the public how vulnerable our infrastructure is. Using your understandings of energy, design a low technology system that would insure the availability of energy to residents if catastrophic damage to the grid occurs again.

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.

Formative Assessment

Students who understand the concepts are able to:

- 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.

Part D: There are many different ways to obtain the energy we need to make our world function. Research the current methods and possible future methods and identify the pros and cons of each.

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).
- Energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems.
- 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.
- 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.

Formative Assessment

Students who understand the concepts are able to:

- 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.

- 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.
- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.
- Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.b., trade-offs), constraints, and ethical issues.
- Communicate scientific and/or technical information or 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).

Resources

Energy Skate Park: Basics: Using this Phet resource, learn about conservation of energy with a skater gal! Explore different tracks and view the kinetic energy, potential energy and friction as she moves. Build your own tracks, ramps, and jumps for the skater.

Work and Energy Workbook Labs (12 total): These physics classroom labs describe the question and purpose of each lab and provide a short description of what should be included in the student lab report.

Build a Solar House: Construct and measure the energy efficiency and solar heat gain of a cardboard model house. Use a light bulb heater to imitate a real furnace and a temperature sensor to monitor and regulate the internal temperature of the house. Use a bright bulb in a gooseneck lamp to model sunlight at different times of the year, and test the effectiveness of windows for passive solar heating.

Hot Mess "How We Make Energy" video about the different ways humans transform energy (https://www.youtube.com/watch?v=Y1b3-BnKwA4).

Actively Learn "Renewable Energy Might Be Able to Green a Desert" (https://reader.activelylearn.com/authoring/preview/981380/notes)

Actively Learn" Ocean Energy Could Be the Wave of the Future" (https://reader.activelylearn.com/authoring/preview/976215/notes)

Our World in Data (https://ourworldindata.org/)

The Science Classroom

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).

Kinetic Energy	$\mathbf{KE = {}^{1}/_{2}mv^{2}}$
Potential Energy	$\mathbf{PE_{gravitational} = mgh}$
Work	$\mathbf{W = Fd}$

In these kinds of investigations, students should understand how to obtain the original potential energy of the object. They should know that when work is done on an object, the energy of the object changes, such as when the wrecking ball of a demolition machine is raised. Work can be calculated (□=□□□), 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. For example, kinetic energy is transferred 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. 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.

calculate the time at each individual height in the table where □ is the distance fallen from start	$\mathbf{d = 1/2\ gt^2}$
potential energy of springs where *k* is spring constant and is the amount of compression relative to the equilibrium position	$\mathbf{PE_{spring} = 1/2\ kx^2}$

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. 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.

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.

Connecting with English Language Arts Literacy and Mathematics

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.

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).
- 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 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.

- 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.

Modifications

Teacher Note: Teachers identify the modifications that they will use in the unit. The unneeded modifications can then be deleted from the list.

- Restructure lesson using UDL principals (http://www.cast.org/our-work/about-udl.html#.VXmoXcfD_UA)
- Structure lessons around questions that are authentic, relate to students' interests, social/family background and knowledge of their community.
- Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling).
- Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies).
- Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds and cultures (e.g. multiple representation and multimodal experiences).
- Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings.
- Use project-based science learning to connect science with observable phenomena.
- Structure the learning around explaining or solving a social or community-based issue.
- Provide ELL students with multiple literacy strategies.
- Collaborate with after-school programs or clubs to extend learning opportunities.

Research on Student Learning

Students rarely think energy is measurable and quantifiable. Students' alternative conceptualizations of energy influence their interpretations of textbook representations of energy.

Students tend to think that energy transformations involve only one form of energy at a time. Although they develop some skill in identifying different forms of energy, in most cases their descriptions of energy-change focus only on forms which have perceivable effects. The transformation of motion to heat seems to be difficult for students to accept, especially in cases with no temperature increase. Finally, it may not be clear to students that some forms of energy, such as light, sound, and chemical energy, can be used to make things happen.

The idea of energy conservation seems counterintuitive to students who hold on to the everyday use of the term energy, but teaching heat dissipation ideas at the same time as energy conservation ideas may help alleviate this difficulty. Even after instruction, however, students do not seem to appreciate that energy conservation is a useful way to explain phenomena. A key difficulty students have in understanding conservation appears to derive from not considering the appropriate system and environment. In addition, high-school students tend to use their conceptualizations of energy to interpret energy conservation ideas. For example, some students interpret the idea that "energy is not created or destroyed" to mean that energy is stored up in the system and can even be released again in its original form. Or, students may believe that no energy remains at the end of a process, but may say that "energy is not lost" because an effect was caused during the process (for example, a weight was lifted). Although teaching approaches which accommodate students' difficulties about energy appear to be more successful than traditional science instruction, the main deficiencies outlined above remain despite these approaches (NSDL, 2015)

Prior Learning

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.
- 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.

Earth and space science

- 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.

Connections to Other Courses

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.

References

Adapted from the New Jesery NGSS Science Model Curriclum

Connections to NJSLS

English Language Arts/Literacy

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) **RST.11-12.1**

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

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),(HS-ETS1-3) **WHST.9-12.5**

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),(HS-ETS1-1),(HS-ETS1-3) **WHST.9-12.7**

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),(HS-ETS1-3),(HS-ETS1-1),(HS-ETS1-3) **WHST.11-12.8**

Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS1-3),(HS-ETS1-1),(HS-ETS1-3) **WHST.9-12.9**

Mathematics

Reason abstractly and quantitatively. (HS-ETS1-1),(HS-ETS1-3),(HS-ETS1-4) **MP.2**

Model with mathematics. (HS-ETS1-1),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4) **MP.4**

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),(HS-PS1-3) **HSN-Q.A.1**

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) **SL.11-12.5**