SOUTH CAROLINA
DEPARTMENT OF EDUCATION

Physics Performance Targets

for the
South Carolina College- and Career-Ready Science Standards 2021

For use 2025-2026

July 2025

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State Superintendent of Education

Contents

Purpose and Use

Science is a way of understanding the physical universe using observation and experimentation to explain natural phenomena. Science also refers to an organized body of knowledge that includes core ideas to the disciplines and common themes that bridge the disciplines. As science educators we must take a 3-dimensional approach in facilitating student learning. By addressing content, science and engineering practices and crosscutting concepts, students can have relevant and evidence-based instruction that can help solve current and future problems.

This document is intended as a guide for discerning and describing features of students and their work who have met the stated Performance Expectation (PE). This document is not intended to be read from cover to cover, but to be used, when needed, to support teacher professional learning and curriculum decisions. This is not intended for student use and thus is not written in student-friendly language. This is not a curriculum or a means to limit instruction in the classroom. Although each PE states a dedicated Science and Engineering Practice (SEP) and Crosscutting Concept (CCC), students will need to use the whole range of SEPs and CCCs to achieve success by the end of instruction.

Three-dimensional science learning requires discipline specific communication skills. This means that effective science learning occurs when students are expected to speak, listen, read, and write in ways that are appropriate to science. With each Performance Target, there are question/sentence stems and terminology to support student discourse about phenomena to help teachers facilitate the acquisition of science discourse. Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding. The terms and stems in this section are intended to provide a baseline for teachers, neither list is exhaustive nor complete.

In addition to the doing (SEP), thinking (CCC), and learning of science knowledge (Disciplinary Core Ideas) outlined here, students will also require a working knowledge of grade-level appropriate tools and techniques of science. Students should know and recognize how scientists and engineers use these tools and techniques, not just identify them. Students should be able to use these tools to gather data, describe how these tools gather data, and/or interpret data sampled. Students will need to understand and apply the conventions of scientific notation when working with extremely large or small quantities of measurement and their calculations.

Document Updates

July 2025

- All Performance Expectation statements have been reformatted to call out each of the dimensions as follows:
  - Science and Engineering Practice – **bold**
  - Crosscutting Concept – *italicize*
  - Disciplinary Core Idea – regular
- The watermark from previous versions of this resource has been replaced with the wording "For use 2025-2026" on the title page and in the footer. This change was made to improve accessibility of this resource.
- Because scientific notation is no longer an expectation of the math standards, the following statement was added to the purpose and use page to support the teaching and understanding of scientific notation: "Students will need to understand and apply the conventions of scientific notation when working with extremely large or small quantities of measurement and their calculations."

June 2024

- Updated watermark to 2024-2025.
- Adjusted formatting and grammar.

PS2 – Motion and Stability: Forces and Interactions

P-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the *mathematical relationship among* the net force on a macroscopic object, its mass, and its acceleration.

> ***Clarification Statement:*** Examples of data could include tables or graphs of position or velocity of an object as a function of time. Examples of objects subjected to a net force could include objects in free-fall, objects sliding down a ramp, or moving objects pulled by a constant force.
> ***State Assessment Boundary:*** Assessment is limited to macroscopic objects moving in one-dimensional motion, at non-relativistic speeds.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Analyzing and Interpreting Data Analyzing data in 9-12 builds on K-8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. 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.	**PS2.A: Forces and Motion** Newton's second law accurately predicts changes in the motion of macroscopic objects (Fnet=ma).	**Cause and Effect** Empirical evidence is required to differentiate between cause and correlations and make claims about specific causes and effects.

Observable features of student performance by the end of the course:

1. **Organizing data**
    a. Students organize data that represent:
        i. net forces on a macroscopic object,
        ii. mass, and
        iii. acceleration (in the absence of other forces, gravitation).
2. **Identifying relationships**
    a. Students use tools, technologies, and/or models to analyze the data and identify relationships, including:
        i. When net force is constant, as object mass increases acceleration decreases.
        ii. When mass is constant, as net force increases acceleration increases.
        iii. Gravitation results in a constant acceleration on macroscopic objects (the ratio of net force to mass remains constant).

3. **Interpreting data**
    a. Students use the analyzed data to describe:
        i. The relationship between the observed quantities is accurately modeled across the range of data by the formula $a=F_{net}/m$.
        ii. The relationships linked by force, mass, and acceleration.

P-PS2-1 Academic Language

Question/Sentence Stems

- The evidence _______ presented in the scenario supports the claim that _______ causes _______.
- The fact that the data showed that _______ always happened [after/whenever] _______ occurred means that _______ causes _______ because _______.
- Even though I/we cannot see _______, it explains why the _______ pattern in the data is happening.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- acceleration ($a=F_{net}/m$)
- air resistance
- balanced forces
- directly proportional
- $F_{net}=ma$
- friction
- gravitational force
- impulse
- indirectly proportional
- macroscopic
- mass
- net force
- non-relativistic speed
- slope
- terminal velocity
- unbalanced forces
- vector
- velocity
- weight
- y-intercept

P-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*.

> ***Clarification Statement:*** Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.
> ***State Assessment Boundary:*** Assessment is limited to systems of two macroscopic bodies moving in one dimension.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 and 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, computational, and/or algorithmic representations of phenomena to describe and/or support claims and/or explanations.	**PS2.A: Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**Systems and System Models** When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.

Observable features of student performance by the end of the course:

1. **Representation**
    a. Students define the system of two interacting objects that is represented mathematically, including:
        i. boundaries and
        ii. initial conditions.
    b. Students develop/use mathematical and/or computational models to describe the momentum of each object in the system as a product of its mass and velocity, p=mv (p and v are restricted to one-dimensional vectors).
    c. Students develop/use mathematical and/or computational models to support the claim that the total momentum of a system of two interacting objects is constant if there is no net force on the system.

2. **Mathematical and/or computational modeling**
    a. Students develop/use mathematical and/or computational models of two interacting objects to characterize their physical interaction in terms of the change in momentum of each object as a result of the interaction.
    b. Students develop/use mathematical and/or computational models to characterize the total momentum of the system by calculating the vector sum of momenta of the two system objects.
3. **Analysis**
    a. Students develop/use and analyze mathematical and/or computational models:
        i. To support the claim that the momentum of the system is the same before and after the interaction between the objects in the system, so the momentum of the system is constant.
        ii. To support the claim that any change in momentum of one object is balanced by a change in momentum of the other objects, so the momentum of the system is constant.

P-PS2-2 Academic Language

Question/Sentence Stems

- In the system, _______ and _______ interact in _______ way.
- If you change _______ in the system, _______ will occur.
- As the momentum of one object ____, the momentum of a colliding object ____.
- The key assumptions to the model of my system are _______ this affects the reliability of the model because _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- acceleration
- closed system
- collision
- conversion
- elastic collision
- external
- final
- frame of reference
- friction
- inelastic collision
- inertial frame of reference
- initial
- internal
- isolated system
- Law of Conservation of Momentum (m1v1+m2v2=m1v1' +m2v2')
- mass
- momentum
- momentum (p=mv)
- negative acceleration
- net force
- Newton's Second Law
- transfer
- vector
- velocity
- $\Delta p=m\Delta v$

P-PS2-3. Apply scientific and engineering ideas to design, evaluate, and refine a device that *minimizes the effect* of a force on a macroscopic object during a collision.

> ***Clarification Statement:*** An example of evaluation could include determining the success of the device at protecting an object from damage. Examples of devices could include football helmets, parachutes, and car restraint systems, such as seatbelts and airbags. Refinement of the device could include modifying one or more parts or all of the device to improve performance of the device.
> ***State Assessment Boundary:*** Assessment is limited to qualitative evaluations, algebraic manipulations, or both.

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 refine a solution to a complex real-world problem, based on scientific knowledge, student generated sources of evidence, prioritized criteria, and trade off considerations.	**PS2.A: Forces and Motion** If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. **ETS1.A: Defining and Delimiting Engineering Problems** Criteria may include satisfying cost, safety, reliability, aesthetics requirements and taking into account constraints regarding social, cultural, and environmental impacts. **ETS1.B: Developing Possible Solutions** The aim of engineering is to design the best solution under clearly defined constraints and criteria, but there is often no one best solution. **ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically. Trade-offs among the criteria will need to be analyzed, and certain criteria may need to be prioritized over others.	**Cause and Effect** Systems can be designed to cause a desired effect.

Observable features of student performance by the end of the course:

1. **Using scientific knowledge to generate design solutions**
    a. Students design a solution to minimize the force on a macroscopic object during a collision, including:
        i. that for a given change in momentum, force in the direction of the change in momentum is decreased by increasing the time interval of the collision ($F\Delta t=m\Delta v$) and
        ii. using the principal above so the design solution reduces the net force applied to the object by extending the time the force is applied to the object during the collision.
    b. Students rationalize the materials and structure of the design solution.
2. **Describing criteria and constraints, including quantifications when appropriate**
    a. Students describe and quantify criteria.
    b. Students describe the design constraints and tradeoffs, which may include:
        i. availability and cost of materials,
        ii. environmental impact,
        iii. human needs,
        iv. mass,
        v. societal requirements for collision mitigation devices (for example: seatbelts, football helmets),
        vi. safety, and/or
        vii. time (for example: construction, function, etc.)
3. **Evaluating potential design solutions**
    a. Students evaluate the proposed solution for:
        i. cost,
        ii. design performance issues,
        iii. its ability to minimize force on the test object during a collision,
        iv. reliability, and/or
        v. safety.
4. **Refining/optimizing the design solution**
    a. Students refine the proposed solution by prioritizing the criteria and/or:
        i. extending impact time,
        ii. reducing device mass, and/or
        iii. considering cost-benefit analysis.

P-PS2-3 Academic Language

Question/Sentence Stems

- _______ caused the patterns I am observing. I know this because _______.
- If _______ happens, I/we predict that ________ will occur.
- In this situation, even a small change of _______ can cause a big effect of _______.
- The evidence _______ presented in the scenario supports the claim that _______ causes _______.
- In order to conclude that _____ caused _____, the following evidence is needed ____.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- acceleration
- active system
- actuator
- aesthetics
- aspect
- compressibility
- consequence
- consideration
- criteria
- critical
- crumple zone
- deformation
- development
- drag
- exert
- $F\Delta t=m\Delta v$
- force
- impact
- impulse
- inertia
- limitation
- macroscopic
- mass
- momentum
- negative acceleration
- Newton's First Law
- Newton's Second Law
- Newton's Third Law
- optimal
- passive system
- pneumatic system
- qualitative
- quantitative
- rationale
- representation
- risk
- safety
- shock absorber
- specification
- spring
- testable
- theoretical model
- time
- tradeoff
- velocity

P-PS2-4. Use mathematical representations of Newton's law of gravitation and Coulomb's law *to describe and predict* the gravitational and electrostatic forces between objects.

> ***Clarification Statement:*** Emphasis is on both quantitative and conceptual descriptions of interactions between masses in gravitational fields and electrical charges in electric fields.
> ***State Assessment Boundary:*** Assessment is limited to systems with two objects.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 and 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, computational, and/or algorithmic representations of phenomena to describe and/or support claims and/or explanations.	**PS2.B: Types of Interactions** 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 that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**Patterns** Different patterns may be observed at each of the scales at which a system is studied and can provide for causality in explanations of phenomena.

Observable features of student performance by the end of the course:

1. **Representation**
   a. Students define the system of two interacting objects that is represented mathematically, including:
      i. boundaries and
      ii. initial conditions.
   b. Students develop/use a mathematical and/or computational model to describe the gravitational attraction between two objects as the product of their masses divided by the separation distance squared ($F_g = -G\frac{m_1 m_2}{d^2}$), where a negative force is understood to be attractive.
   c. Students develop/use a mathematical and/or computational model to describe the electrostatic force between two objects as the product of their individual charges divided by the separation distance squared ($F_e = k\frac{q_1 q_2}{d^2}$), where a negative force is understood to be attractive.
2. **Mathematical and/or computational models**
   a. Students develop/use a mathematical and/or computational model to:
      i. predict the gravitational force between objects and/or
      ii. predict the electrostatic force between charged objects.
3. **Analysis**
   a. Students develop/use and analyze a mathematical and/or computational model to describe that the ratio between gravitational and electrostatic forces between objects with a given charge and mass is independent of distance.

P-PS2-4 Academic Language

Question/Sentence Stems

- The following predictions can be made about _______ when using the pattern of _______ found in the data.
- I/We can observe (notice) the pattern of _______ in the data presented.
- The pattern seen in the collected data allows me/us to conclude (know) that ______.
- As the _____ (increases/decreases), the gravitational force between two objects (increases/decreases).
- The observed pattern supports the conclusion that _______ is caused by _______, because _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- ampere
- attraction
- battery
- charged particle
- conductor
- conservation
- conversion
- Coulomb
- Coulomb's constant (k)
- Coulomb's Law
- direction
- electric charge
- electric field
- electric potential
- electromagnet
- electromagnetic field
- electromotive force
- electrostatic force ($F_e = k\frac{q_1q_2}{d^2}$)
- frequency
- $F_g = -G\,\frac{m_1m_2}{d^2}$
- gravitational force
- induced electric current
- induction
- insulator
- inverse-square relationship
- kinetic energy
- magnetic field
- magnetic field lines
- magnetic force
- magnitude
- mass
- negative charge
- Newton's Law of Gravitation
- permanent magnet
- permittivity of free space
- polarity
- positive charge
- potential energy
- repulsion
- resistance
- right-hand rule
- tesla
- universal gravitation constant (G)
- vectors
- voltage
- volts
- weight

P-PS2-5. Plan and conduct an investigation to provide evidence that an electric current *can produce* a magnetic field and that a changing magnetic field *can produce* an electric current.

> ***Clarification Statement:*** Examples could include current carrying wires and electromagnets/solenoids in motors, anti-shoplifting devices, junkyard magnets, metal detectors, and magnetic levitation in high-speed trains.
> ***State Assessment Boundary:*** Assessment is limited to planning and conducting investigations with provided materials and tools.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Planning and Carrying out Investigations Planning and carrying out investigations in 9- 12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence. During the planning process: decide on types, how much, and accuracy of data needed to produce reliable measurements, consider limitations on the precision of the data (such as number of trials, cost, risk, time), and refine the design accordingly.	**PS2.B: Types of Interactions** Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **PS3.A: Definitions of Energy** "Electrical Energy" may mean energy stored in battery or energy transmitted by electric current.	**Cause and Effect** Empirical evidence is required to differentiate between cause and correlations and make claims about specific causes and effects.

Observable features of student performance by the end of the course:

1. **Identifying the phenomenon under investigation**
    a. Students describe the purpose of the investigation, to collect evidence that an electric current produces a magnetic field and that a changing magnetic field produces an electric current.

2. **Identifying the evidence to address the purpose of the investigation**
    a. Students describe the data that will be collected to provide evidence that:
        i. an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit and
        ii. an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit.
3. **Planning the investigation**
    a. Students describe the investigation plan, including:
        i. the use of an electric circuit through which electric current can flow,
        ii. a source of electrical energy that can be placed in the circuit,
        iii. the shape and orientation of the wire,
        iv. the types and positions of detectors,
        v. a means to indicate or measure when electric current is flowing through the circuit,
        vi. a means to indicate or measure the presence of a local magnetic field near the circuit, and
        vii. a system to change the magnetic field in a nearby circuit and a means to indicate or measure when the magnetic field is changing.
4. **Collecting the data**
    a. Students measure and record electric currents and magnetic fields.
    b. Students evaluate collected data to determine whether the resulting evidence meets the goals of the investigation, including:
        i. accuracy and precision of the data collected,
        ii. limitations of the investigation, and
        iii. the reliability of the data.
    c. Students use the evaluated data to refine the investigation plan to produce more accurate, precise, and useful data.

P-PS2-5 Academic Language

Question/Sentence Stems

- _______ caused the patterns I am observing. I know this because _______.
- If _______ happens, I/we predict that ________ will occur.
- In this situation, even a small change of _______ can cause a big effect of _______.
- The evidence _______ presented in the scenario supports the claim that _______ causes _______.
- In order to conclude that _____ caused _____, the following evidence is needed ____.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- Amp
- ampere
- Ampere's Circuital Law
- charged particle
- conductor
- eddy current
- electric charge
- electric potential
- electrical circuit
- electrical current
- electrical energy
- electrodynamics
- electromagnet
- electromagnetic field
- electromotive force
- electrostatic
- Faraday's Law
- generator
- induced electric current
- induction
- insulator
- Lenz's Law
- magnetic field
- magnetic field lines
- magnitude
- motor
- Ohm (Ω)
- permanent magnet
- polarity
- resistance
- resistor
- right-hand rule
- solenoid
- tesla
- transformer
- vector
- voltage
- volts

P-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in *the functioning of designed materials*.

> ***Clarification Statement:*** Emphasis is on the attractive and repulsive forces that determine the functioning of the material, and transfer of electric charge. Examples of designed conductive materials could include wiring in phone chargers, wiring in car speakers, or computer chips. Examples of designed insulating materials could include polystyrene and fiberglass.
> ***State Assessment Boundary:*** Assessment is limited to molecular structures that are given or provided to students during instruction.

<table>
<tr><th>Science and Engineering Practices</th><th>Disciplinary Core Ideas</th><th>Crosscutting Concepts</th></tr>
<tr>
<td>Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 9-12 builds on K-8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs.

Communicate scientific and/or technical information about phenomena and performance of a proposed process or system.

Communication can be in multiple formats including orally, graphically, textually, and mathematically.</td>
<td>PS2.B: Types of Interactions

Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

ETS2.A: Interdependence of Science, Engineering, and Technology

Engineers continuously modify these technological systems by applying scientific knowledge. (secondary)

ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

Modern civilization depends on major technological systems which can have deep impacts on society and the environment. (secondary)</td>
<td>Structure and Function

Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.</td>
</tr>
</table>

Observable features of student performance by the end of the course:

1. **Communication**
    a. Students use and cite at least two different formats (for example: oral, graphical, textual, mathematical, etc.) to communicate scientific and technical information about the design, properties and structure of a chosen material.
2. **Connections**
    a. Students identify and communicate evidence for how molecular level structure determines the functioning of designed materials, including:
        i. how the structure, properties, and molecular interactions at the atomic scale determine the function of a designed material and
        ii. how the material's properties make it suitable for its intended use.
    b. Students identify the molecular structure of a designed material using appropriate representations for the communication format (for example: geometric shapes for drugs and receptors, ball and stick models for long-chain molecules, etc.).
    c. Students identify and describe the relationship between a designed material's function and its macroscopic properties (for example: material strength, conductivity, reactivity, state of matter, durability, etc.) and each of the following:
        i. molecular structure,
        ii. intermolecular forces and polarity,
        iii. ability of electrons to move relatively freely in metals, and
        iv. types of bonds between atoms.
    d. Students identify and describe the role of electrical forces (attractive and repulsive) between molecules in the arrangement of the molecules in a designed material (for example: state, network solid, polymer, etc.).
    e. Students identify and describe that, for all materials, electrostatic forces on the atomic and molecular scales result in contact forces (for example: friction, normal forces, stickiness, etc.) on the macroscopic scale.

P-PS2-6 Academic Language

Question/Sentence Stems

- The _______ structures help _______ to function because _______.
- _______ are the structures in the optimal solution. _______ is the function of the optimal solution. The important relationship of _______ between structure and function in the optimal solution makes it a successful design because _______.
- _______ behaviors in the testing of the design are results of _______ structures which function _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- charge
- charged particle
- chemical property
- conductor
- contact force
- covalent bond
- dipole dipole
- ductile
- electric charge
- electric potential
- electrical conductivity
- electromotive force
- electron sharing
- electron transfer
- electrostatic
- friction
- hydrogen bond
- insulator
- intermolecular forces
- ionic bond
- London dispersion forces
- long chained molecules
- macroscopic
- magnetic property
- malleable
- mechanical property
- microscopic
- monomer
- network material
- permanent magnet
- physical property
- polarity
- polymer
- reactivity
- resistance
- surface tension
- synthetic polymer
- van der Waals forces

PS3 – Energy

P-PS3-1. Create a computational model *to calculate the change* in the energy of one component in a system when the following are known: 1) the change in energy of the other component(s) and 2) the energy flowing *in and out of the system*.

> ***Clarification Statement:*** Emphasis is on explaining the calculations in the computational model. Examples of computational models could include diagrams, drawings, descriptions, mathematical equations, and computer simulations.
> ***State Assessment Boundary:*** Assessment is limited to basic algebraic equations, to systems of two or three components, and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 and 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. Create a computational model or simulation of a phenomenon, designed device, process, or system.	**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. A system's total energy is 1) conserved as energy is transferred within the system from one object to another and between its various possible forms and 2) always equal to the energy transferred into or out of the system. **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. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions allow the concept of conservation of energy to be used to predict and describe system behavior. Mathematical expressions quantify how the stored energy in a system depends on its configurations (such as relative positions of charged particles or compression of a spring) and how kinetic energy depends on mass and speed. The availability of energy limits what can occur in any system.	**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.

Observable features of student performance by the end of the course:

1. **Representation**
    a. Students develop/use a mathematical and/or computational model and describe the relevant components, including:
        i. system boundaries and the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero),
        ii. initial energies of the system components (for example: energy in fields, thermal energy, kinetic energy, energy stored in springs – expressed in Joules [J]),
        iii. energy flows in or out of the system, including quantification as an algebraic description with flow into the system defined as positive, and
        iv. final energies of the system components, including quantification in an algebraic description to calculate the total final energy of the system.
2. **Mathematical and/or computational modeling**
    a. Students develop/use algebraic descriptions of the initial and final energy state of the system, along with the energy flows, to create a computational model (for example: simple computer program, spreadsheet, simulation, etc.) that is based in the principle of the conservation of energy.
    b. Students develop/use a computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.
3. **Analysis**
    a. Students develop/use mathematical and/or computational models to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.
    b. Students identify and describe the limitations of the mathematical and/or computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.

P-PS3-1 Academic Language

Question/Sentence Stems

- In this system, energy is entering by _______, doing _______ in the system, and leaving the system by _______ as seen by the _____ pattern in the data.
- The flow of energy causes _____ to occur in the system as seen by ______ in the data.
- In the system, _______ and _______ interact in _______ way evidence for this claim is that _______.
- In the system, ______ is not shown in the model. This is not shown because _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- amp
- change in energy (Δe)
- chemical energy
- conduction
- conservation
- conservation of energy
- conservative force
- conversion
- electrical circuit
- electrical current
- electrical energy
- energy flow (Q)
- heat
- heat radiation
- inductor
- insulate
- kinetic energy
- Law of Conservation of Energy
- mechanical energy
- momentum
- nonconservative force
- Ohm’s law
- potential energy
- resistor
- thermal energy
- thermodynamics
- volt

P-PS3-2. Develop and use models to illustrate *that energy can be explained by the combination* of motion and position of objects at the macroscopic scale and the motion and position of particles at the microscopic scale.

> ***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 (as stored in fields), and the energy stored between two electrically charged plates. Examples of models could include diagrams, drawings, descriptions, or computer simulations.
> ***State Assessment Boundary:*** Assessment does not include quantitative calculations.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Developing and Using Models Modeling in 9-12 builds on K-8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components.	**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. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. Energy at the macroscopic level can be better understood, 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.	**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.

Observable features of student performance by the end of the course:

1. **Components of the model**
    a. Students develop/use a model (conceptual, graphical, physical, etc.) and identify the relevant components, including:
        i. components of the system and the surroundings,
        ii. energy flows between the system and surroundings,
        iii. a macroscopic representation of the system,
        iv. a microscopic/atomic-level representation of the system, and
        v. forms in which energy is manifested at the two different scales:
            1. macroscopic, such as motion, sound, light, thermal energy, potential energy, or energy in fields and
            2. molecular/atomic, such as motion (kinetic energy) or particles (for example: nuclei and electrons), the relative positions of particles in fields (potential energy), and energy in fields.
2. **Relationships**
    a. Students develop/use a model to describe the relationships between components, including:
        i. Changes in the relative position of object in gravitational, magnetic, or electrostatic fields can affect the energy of the fields (for example: charged objects moving away from each other change the field energy).
        ii. Thermal energy includes both kinetic and potential energy of particle vibrations in solids or molecules and the kinetic energy of freely moving particles (for example: inert gas atoms, molecules, etc.) in liquids and gases.
        iii. The total energy of the system and surroundings is conserved at a macroscopic and molecular/atomic level.
        iv. Chemical energy can be considered in terms of systems of nuclei and electrons in electrostatic fields (bonds).
        v. As one form of energy increases, others must decrease by the same amount as energy is transferred among and between objects and fields.
            1. This statement is true assuming no energy is lost to surroundings or due to nonconservative forces.

3. **Connections**
    a. Students develop/use a model to represent that in a closed system:
        i. energy is conserved on both the macroscopic and molecular and/or atomic scales,
        ii. as one form of energy changes, the total system energy remains constant, and
        iii. as evidenced by the other forms of energy changing by the same amount or changes only by the amount of energy that is transferred into or out of the system.
    b. Students develop/use a model to demonstrate that energy at the macroscopic scale can be accounted for as a combination of energy of the motions of particles/objects and energy of the relative positions of particles/objects at the macroscopic and microscopic scales.

P-PS3-2 Academic Language

Question/Sentence Stems

- The flow of energy causes _______ to occur in the system as seen with _______ as evidence from the investigation.
- _______ happens to _______ when you put it together with _______ because the energy is _______.
- The flow of energy between _______ and _______ drives the changes to the system as seen by _______during the investigation because _______.
- My/Our diagram shows the flow energy in our investigations as seen by _______ because _______.
- The investigation shows that _______ is the evidence that energy is being conserved in this system because _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- chemical reaction
- circuit
- conservation of energy
- conservative force
- current
- displacement
- distance
- electric field
- electrical charge
- exert
- force
- gravitational field
- heat
- heat conduction
- heat radiation
- kinetic energy
- Law of Conservation of Energy
- macroscopic scale
- magnetic field
- mechanical energy
- microscopic scale
- molecular energy
- nonconservative force
- particle motion
- particle position
- phase change
- potential energy
- store
- temperature
- thermal energy
- thermodynamics
- transfer
- work

P-PS3-3. **Design, build, and refine a device that works within given constraints** to convert one form of energy *into another form of energy*.

> ***Clarification Statement:*** Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, speakers, or generators. Examples of constraints placed on a device could include the cost of materials, types of materials available, having to use renewable energy, an efficiency threshold, and time to build and/or operate the device.
> ***State Assessment Boundary:*** Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.

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 refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations.	**PS3.A: Definitions of Energy** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. **PS3.D: Energy in Chemical Processes and Everyday Life** Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. **ETS1.A: Defining and Delimiting an Engineering Problem** Criteria may include satisfying cost, safety, reliability, aesthetics requirements and taking into account constraints regarding social, cultural, and environmental impacts. **ETS1.B: Developing Possible Solutions** The aim of engineering is to design the best solution under clearly defined constraints and criteria, but there is often no one best solution. **ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically. Trade-offs among the criteria will need to be analyzed, and certain criteria may need to be prioritized over others. **ETS2.A: Interdependence of Science, Engineering, and Technology** Engineers continuously modify these technological systems by applying scientific knowledge. **ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World** Modern civilization depends on major technological systems which can have deep impacts on society and the environment. (*secondary*)	**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.

Observable features of student performance by the end of the course:

1. **Using scientific knowledge to generate design solutions**
    a. Students design a device that converts one form of energy into another form of energy.
    b. Students develop a plan for the device, including:
        i. which scientific principles provide the basis for energy conversion,
        ii. identifying the forms of energy that will be converted,
        iii. identifying energy losses to the surrounding environment,
        iv. rational for choices of materials and structures of the device, and
        v. that this device is an example of how the application of scientific knowledge and engineering can increase benefits for modern civilization while decreasing costs and risks.
2. **Describing criteria and constraints, including quantification when appropriate**
    a. Students describe and quantify criteria of the device.
    b. Students describe the design constraints and tradeoffs, which may include:
        i. availability and cost of materials,
        ii. environmental impact,
        iii. human needs,
        iv. safety, and/or
        v. time (for example: construction, function, etc.).
3. **Evaluating potential solutions**
    a. Students build and test the device.
    b. Students systematically and quantitatively evaluate the performance of the device against the criteria and constraints.
4. **Refining/optimizing the design solution**
    a. Students use the results of the tests to improve the device by increasing the efficiency of energy conversions, considering criteria and constraints, and noting any modifications in tradeoffs.

P-PS3-3 Academic Language

Question/Sentence Stems

- The flow of energy causes _______ to occur in the system as seen with _______ as evidence that it remains within the constraints.
- Within the design solution_______ happens to _______ when you change _______ because the energy is _______.
- The flow of energy between _______ and _______ drives the changes to the design solution as seen by _______ because _______.
- My/Our design solution shows the flow energy in _______ as seen by _______ because _______.
- In our design, energy is converted from _____ to _____, as _____ occurs.
- The design shows that _______ is the evidence that energy is being conserved in this system because _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- battery
- chemical energy
- conservative force
- cost
- effectiveness
- efficiency
- electric current
- electric field
- electrical energy
- electromagnet
- engine
- fuel cell
- generator
- heat work
- Law of Conservation of Energy
- magnetic field
- maintenance
- mechanical energy
- nonconservative force
- output energy
- power
- renewable energy
- Rube Goldberg Device
- safety
- solar cell
- solar oven
- source energy
- stability
- thermal energy
- thermal equilibrium
- thermodynamics
- watt (W)
- wind turbine

P-PS3-5. Develop and use a model to illustrate the forces between two objects and the changes in energy of the objects *due to their interaction* through electric or magnetic fields.

Clarification Statement: Examples of models could include drawings, diagrams, descriptions, or computer simulations.
State Assessment Boundary: Assessment is limited to systems containing two objects.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Developing and Using Models Modeling in 9-12 builds on K-8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components.	**PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed. Each force between the two interacting objects acts in the direction such that the motion in that direction would reduce the energy in the force field between the objects.	**Cause and Effect** 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.

Observable features of student performance by the end of the course:

1. **Components of the model**
   a. Students develop/use a model (conceptual, graphical, physical, etc.) and identify relevant components, including:
      i. two objects in the system, including initial positions and velocities (limited to: one dimension),
      ii. nature of the interaction (electric or magnetic) between the two objects,
      iii. relative magnitude and direction of the net force on each object, and
      iv. representation of a field as a quantity that has magnitude and direction at all points in space and which contains energy.
2. **Relationships**
   a. Students develop/use a model to identify and describe the relationships between components, including the change in the energy of the objects, given the initial and final positions and velocities of the objects.

3. **Connections**
    a. Students develop/use a model to determine whether the energy in the field increased, decreased, or remained the same when the object interacted.
    b. Students develop/use a model to support, refute, or revise a claim about the change in the energy stored in the field is consistent with the change in energy of the objects.
    c. Students develop/use a model to describe the cause-and-effect relationship between forces produced by electric or magnetic fields and the change of energy of the objects in the system.

P-PS3-5 Academic Language

Question/Sentence Stems

- By looking at patterns in the data, I/we determined that _______ caused _______.
- If _______ happens, I/we predict that _______ will occur.
- Even though I/we cannot see _______, it explains why _______ is happening.
- The fact that the data showed that _______ always happened [after/whenever] _______ occurred means that _______ causes _______ because _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- acceleration
- attraction
- circuit
- conservation of energy
- Coulomb’s law
- current
- electric current
- electric field
- electrical charge
- electrical energy
- electromagnet
- exert
- force
- force diagram
- heat radiation
- inertia
- kinetic energy
- kinetic energy
- Law of Conservation of Energy
- macroscopic scale
- magnet
- magnetic field
- magnetic force
- mechanical energy
- microscopic scale
- net force
- Newton’s Second Law
- potential energy
- repulsion
- store
- transfer
- velocity

PS4 – Waves and Their Applications in Technologies for Information Transfer

P-PS4-1. Use mathematical representations to support a claim regarding *relationships among* the frequency, wavelength, and speed of waves traveling in various media.

> ***Clarification Statement:*** Examples of different media that could be explored include electromagnetic radiation traveling in a vacuum or glass, sound waves traveling through air or water, or seismic waves traveling through Earth.
> ***State Assessment Boundary:*** Assessment is limited to algebraic relationships and describing relationships qualitatively.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 and 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 representations of phenomena or design solutions to describe and/or support claims and/or explanations.	**PS4.A: Wave Properties** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. The reflection, refraction, and transmission of waves at an interface between two media can be modeled on the bases of wave properties.	**Cause and Effect** Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of student performance by the end of the course:

1. **Representation**
    a. Students develop/use a mathematical and/or computational model to identify the relevant components, including:
        i. mathematical values for frequency, wavelength, and wave speed traveling in various media and
        ii. relationships between frequency, wavelength, and wave speed traveling in various media.

2. **Mathematical and/or computational modeling**
    a. Students develop/use a mathematical and/or computational model to show that frequency and wavelength of a particular type of wave in a particular medium is constant and identify this relationship as the wave speed ($v = f\lambda$).
    b. Students develop/use a mathematical and/or computational model to show that wave speed for a particular type of wave changes as the medium through which the wave travels changes.
    c. Students develop/use a mathematical and/or computational model to predict the relative change in wavelength of a wave when it moves from one medium to another ($v = f\lambda$).
3. **Analysis**
    a. Students develop/use a mathematical and/or computational model ($v = f\lambda$) to assess claims about any of these three quantities when the other two quantities are known for waves traveling through a particular medium.

P-PS4-1 Academic Language

Question/Sentence Stems

- By looking at patterns in the data, I/we determined that _______ caused _______.
- If _______ happens, I/we predict that _______ will occur.
- Even though I/we cannot see _______, it explains why _______ is happening.
- The fact that the data showed that _______ always happened [after/whenever] _______ occurred means that _______ causes _______ because _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- amplitude
- angle of incidence
- angle of reflection
- crest
- critical angle
- diffraction
- doppler effect
- electromagnetic radiation
- frequency
- index of refraction
- interface
- inverse relationship
- normal at the point of incidence
- properties of waves
- radiation
- red shift
- refraction
- resonance
- simple wave
- slue-shift
- Snell's law
- trough
- vacuum
- wave source
- wave speed ($v = f\lambda$)
- wavelength

P-PS4-2. Design, evaluate, and refine a solution *for improving* how digital devices store and transmit information.

Clarification Statement: Examples of design problems could include poor signal strength in rural areas with satellite radio or internet connections, lack of security on social media applications (reducing personal data theft), and low quality images (pixelated/fuzzy images, small size). Examples of evaluating the stability of the solution could include determining how successful the solution is at improving signal strength, preventing hacking, and improving image quality.

State Assessment Boundary: Assessment is limited to designed solutions with qualitative analysis of wave properties through drawings, diagrams, or computer simulations.

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 refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations.	**PS4.A: Wave Properties** Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this stable form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. Combining waves of different frequencies can make a wide variety of patterns and thereby encode and transmit information. **ETS1.B: Developing Possible Solutions** The aim of engineering is to design the best solution under clearly defined constraints and criteria, but there is often no one best solution. **ETS2.A: Interdependence of Science, Engineering, and Technology** Engineers continuously modify these technological systems by applying scientific knowledge. **ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World** Modern civilization depends on major technological systems, which can have deep impacts on society and the environment.	**Stability and Change** Systems can be designed for greater or lesser stability.

Observable features of student performance by the end of the course:

1. **Using scientific knowledge to generate design solutions**
    a. Students design a device to improve how digital devices store and transmit information.
    b. Students develop a plan for the device, including:
        i. which scientific principles provide the basis for the digital device,
        ii. rational for choices of materials and structures of the device, and
        iii. that this device is an example of how the application of scientific knowledge and engineering can increase benefits for modern civilization while decreasing costs and risks.
2. **Describing criteria and constraints, including quantification when appropriate**
    a. Students describe and quantify criteria of the device.
    b. Students describe the design constraints and tradeoffs, which may include:
        i. availability and cost of materials,
        ii. environmental impact,
        iii. human needs,
        iv. safety, and/or
        v. time (for example: construction, function, etc.).
3. **Evaluating potential solutions**
    a. Students build and test the device.
    b. Students systematically and quantitatively evaluate the performance of the device against the criteria and constraints.
4. **Refining/optimizing the design solution**
    a. Students use the results of the tests to improve the device, considering criteria and constraints, and noting any modifications in tradeoffs.

P-PS4-2 Academic Language

Question/Sentence Stems

- The system described in the scenario is (stable/unstable). The evidence to support my claim is _______.
- The factors that cause this system to be(stable/unstable) are _______.
- This system is affected in the long term by _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- accessibility
- adaptive technology
- amplitude
- analog
- binary
- bit
- byte
- capacity
- civilization
- computer
- crest
- data
- decode
- degradation
- digital
- discrete vs. continuous
- efficiency
- electromagnetic radiation
- electromagnetic waves
- emit
- encode
- frequency
- interdependence
- machine
- modulation
- optical data storage
- optimize
- performance
- pixel
- progress
- radio wave
- renewable energy
- security
- solution
- square waves
- storage capacity
- suitability
- trough
- USB
- vacuum
- wave pulse
- wavelength
- Wi-Fi device

P-PS4-3. Evaluate the claims, evidence, and reasoning about how electromagnetic radiation can be described either by a wave model or a particle model, *and in some situations one model is more useful than the other*.

Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.
State Assessment Boundary: Assessment does not include using quantum theory.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Engaging in Argument from Evidence Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.	**PS4.A: Wave Properties** Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. **PS4.B: Electromagnetic Radiation** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.	**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.

Observable features of student performance by the end of the course:

1. **Identifying the explanation and supporting evidence**
    a. Students identify an explanation about how electromagnetic radiation can be described either by a wave model or a particle model, and for some situations one model is more useful than the other and the relevant evidence including:
        i. interference behavior by electromagnetic radiation and
        ii. the photoelectric effect.

2. **Evaluating a critiquing**
    a. Students use evidence to assess the validity, reliability, strengths, and weaknesses of the explanation, including how:
        i. the interference behavior of electromagnetic radiation can be described by a wave model and
        ii. the photoelectric effect can support that electromagnetic radiation can be described by a particle model.
    b. Students evaluate the explanation and reasoning for modeling electromagnetic radiation as both a wave and particle, considering the transfer of energy and why for some instances the wave model is more useful and for other instances the particle model is more useful to describe the transfer of energy and information.

P-PS4-3 Academic Language

Question/Sentence Stems

- The key components of the system are _______ and they work together by _______.
- In the system, _______ and _______ are shown in the model.
- In the system, ______ is not shown in the model. This is not shown because _______.
- The key assumptions to the model of my system are _______ this affects the reliability of the model because _______.
- The (particle/wave) model was chosen to represent _______ because of _______.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- absorption
- amplitude
- brightness
- crest trough
- diffraction
- electromagnetic spectrum
- emission
- interference
- light
- mechanical wave
- medium
- particle property
- photoelectric effect
- photon
- photon energy
- quantum mechanics
- reflection
- refraction
- resonance
- speed of light
- transmission
- transverse wave
- visible light
- wave properties
- wave speed
- wavelength
- wave-particle duality

P-PS4-4. Evaluate the validity and reliability of claims in published materials *of the effects* that different frequencies of electromagnetic radiation have when absorbed by matter.

Clarification Statement: Examples of technology applications could include medical imaging devices, tanning beds, radiation cancer treatments, or potential health concerns related to digital signals. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.

State Assessment Boundary: Assessment is limited to qualitative descriptions.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9-12 builds on K-8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. Evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible.	**PS4.B: Electromagnetic Radiation** When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.	**Cause and Effect** 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.

Observable features of student performance by the end of the course:

1. **Obtaining information**
    a. Students research at least two claims proposed in published material (citing at least two sources per claim) about the impact of absorbed electromagnetic radiation on matter, including at least one claim that deals with living tissue.
2. **Evaluating information**
    a. Students use reasoning about the data presented to analyze the reliability and validity of the claim, including:
        i. photon energy (limited to relative wavelengths) and
        ii. ionization probability.

b. Students evaluate the information based on:
    i. the credibility, accuracy, and bias of each publication and the methods used to generate and collect the evidence; and
    ii. the cause-and-effect reasoning in each claim, including extrapolations to larger scales (for example: extrapolating from the effect of a particular wavelength of radiation on a single cell to the effect of that wavelength on the organism, etc.).

P-PS4-4 Academic Language

Question/Sentence Stems

- If _______ happens, I/we predict that ________ will occur.
- Even though I/we cannot see _______, it explains why _______ is happening.
- The evidence _______ presented in the scenario supports the claim that _______ causes _______.
- In order to conclude that _____ caused _____, the following evidence is needed ____.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- absorption
- brightness
- cells
- diffraction
- electric potential
- emission
- frequency
- gamma ray
- infrared radiation
- interference
- ionization
- ionize
- light scattering
- light transmission
- magnetic resonance imaging (MRI)
- medium
- microwave
- microwave radiation
- ohm
- organism
- phase
- photoelectric
- photoelectric effect
- photon
- photon energy
- radio wave
- refraction
- resonance
- semiconductor
- solar cell
- speed of light
- thermal imaging
- tissue
- transparent
- transverse wave
- ultraviolet
- ultraviolet radiation
- visible light
- vision
- wavelength
- X-ray

P-PS-4-5. Communicate technical information about how some technological devices *use the principles of wave behavior and wave interactions* with matter to transmit and capture information and energy.

> ***Clarification Statement:*** Examples could include solar cells capturing light and converting it to electricity, medical imaging, and communications technology.
> ***State Assessment Boundary:*** Assessments are limited to qualitative information. Assessments do not include band theory.

Science and Engineering Practices	Disciplinary Core Ideas	*Crosscutting Concepts*
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9-12 builds on K-8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. Communicate scientific 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).	**PS4.A: Wave Properties** Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. **PS4.B: Electromagnetic Radiation** Photoelectric materials emit electrons when they absorb light of a high-enough frequency. **PS4.C: Information Technologies and Instrumentation** Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. **ETS2.A: Interdependence of Science, Engineering, and Technology** Engineers continuously modify these technological systems by applying scientific knowledge. (*secondary*) **ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World** Modern civilization depends on major technological systems which can have deep impacts on society and the environment. (*secondary*)	**Cause and Effect** 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.

Observable features of student performance by the end of the course:

1. **Communication**
    a. Students use and cite at least two different formats (for example: oral, graphical, textual, mathematical, etc.) to communicate scientific information about at least two devices and the physical principles upon which the devices depend.
2. **Connections**
    a. Students identify and communicate information about the devices, including:
        i. how each device operates,
        ii. the wave behavior utilized by the device, and
        iii. qualitatively describe how basic physical principles were used through research and development to produce the functionality of the device (for example: absorbing electromagnetic energy and converting it to thermal energy to heat an object, etc.).
    b. Students discuss real-world problems or need each device addresses and how civilization depends on the device.
    c. Students identify and describe the cause-and-effect relationships that are used to produce the functionality of the device.

P-PS4-5 Academic Language

Question/Sentence Stems

- If _______ happens, I/we predict that ________ will occur.
- Even though I/we cannot see _______, it explains why _______ is happening.
- The evidence _______ presented in the scenario supports the claim that _______ causes _______.
- In order to conclude that _____ caused _____, the following evidence is needed ____.

Terminology to Support Student Discourse about Phenomena

*Teaching words or concepts in isolation or prior to experiences that give context (frontloading) deprives students of sense-making opportunities that lead to a greater depth of conceptual understanding.

- angle of incidence
- antenna
- constructive interference
- constructive wave
- demodulation
- destructive interference
- destructive wave
- diffraction
- dispersion
- electromagnetic spectrum
- frequency
- gamma ray
- infrared
- intensity
- interference
- light-emitting diode (LED)
- longitudinal wave
- mechanical wave
- medium
- microwaves
- navigation
- nodes
- oscillating electrons
- periodic motion
- photon
- photon energy
- prism
- radar
- radio
- rarefaction
- real image
- receiver
- reflection
- refraction
- resonance
- restoring
- sonar
- standing wave
- superposition
- transmitter
- transverse wave
- ultrasound
- ultraviolet (UV) ray
- velocity
- virtual image
- visible light
- wavelength
- weather monitoring
- Wi-Fi
- X-ray

References

Achieve. (2013). *Evidence Statements | Next Generation Science Standards*. https://www.nextgenscience.org/evidence-statements. Washington, DC.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.

Penuel, W. R. and Van Horne, K. (2018). *Prompts for Integrating Crosscutting Concepts into Assessment and Instruction*. https://stemteachingtools.org/assets/landscapes/STEM-Teaching-Tool-41-Cross-Cutting-Concepts-Promptsv2.pdf. Seattle, WA. University of Washington Institute for Science + Math Education.

South Carolina Department of Education. (2021). *South Carolina College- and Career-Ready Science Standards 2021*. https://ed.sc.gov/instruction/standards-learning/science/standards/south-carolina-college-and-career-ready-science-standards-2021-approved/. Columbia, SC.