High School Physical Sciences

Students in high school continue to develop their understanding of the four core ideas in the physical sciences. These ideas include the most fundamental concepts from chemistry and physics, but are intended to leave room for expanded study in upper-level high school courses. The high school performance expectations in Physical Science build on the middle school ideas and skills and allow high school students to explain more in-depth phenomena central not only to the physical sciences, but to life and earth and space sciences as well. These performance expectations blend the core ideas with scientific and engineering practices and crosscutting concepts to support students in developing useable knowledge to explain ideas across the science disciplines. In the physical science performance expectations at the high school level, there is a focus on several scientific practices. These include developing and using models, planning and conducting investigations, analyzing and interpreting data, using mathematical and computational thinking, and constructing explanations; and to use these practices to demonstrate understanding of the core ideas. Students are also expected to demonstrate understanding of several engineering practices including design and evaluation.

The performance expectations in **PS1: Matter and its interactions** help students formulate an answer to the question, “How can one explain the structure, properties, and interactions of matter?” The PS1 Disciplinary Core Idea from the *NRC Framework* is broken down into three sub-ideas: the structure and properties of matter, chemical reactions, and nuclear processes. Students are expected to develop understanding of the substructure of atoms and to provide more mechanistic explanations of the properties of substances. Chemical reactions, including rates of reactions and energy changes, can be understood by students at this level in terms of the collisions of molecules and the rearrangements of atoms. Students are able to use the periodic table as a tool to explain and predict the properties of elements. Using this expanded knowledge of chemical reactions, students are able to explain important biological and geophysical phenomena. Phenomena involving nuclei are also important to understand, as they explain the formation and abundance of the elements, radioactivity, the release of energy from the sun and other stars, and the generation of nuclear power. Students are also able to apply an understanding of the process of optimization in engineering design to chemical reaction systems. The crosscutting concepts of patterns, energy and matter, and stability and change are called out as organizing concepts for these disciplinary core ideas. In the PS1 performance expectations, students are expected to demonstrate proficiency in developing and using models, planning and conducting investigations, using mathematical thinking, and constructing explanations and designing solutions; and to use these practices to demonstrate understanding of the core ideas.

The Performance Expectations associated with **PS2: Motion and Stability: Forces and Interactions** support students’ understanding of ideas related to why some objects will keep moving, why objects fall to the ground and why some materials are attracted to each other while others are not. Students should be able to answer the question, “How can one explain and predict interactions between objects and within systems of objects?” The disciplinary core idea expressed in the *Framework* for PS2 is broken down into the sub ideas of Forces and Motion and Types of Interactions. The performance expectations in PS2 focus on students building understanding of forces and interactions and Newton’s Second Law. Students also develop understanding that the total momentum of a system of objects is conserved when there is no net force on the system. Students are able to use Newton’s Law of Gravitation and Coulomb’s Law to describe and predict the gravitational and electrostatic forces between objects. Students are able to apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a
macroscopic object during a collision. The crosscutting concepts of patterns, cause and effect, systems and system models, and structure and function are called out as organizing concepts for these disciplinary core ideas. In the PS2 performance expectations, students are expected to demonstrate proficiency in planning and conducting investigations, analyzing data and using math to support claims, applying scientific ideas to solve design problems, and communicating scientific and technical information; and to use these practices to demonstrate understanding of the core ideas.

The Performance Expectations associated with **PS3: Energy** help students formulate an answer to the question, “How is energy transferred and conserved?” The Core Idea expressed in the Framework for PS3 is broken down into four sub-core ideas: Definitions of Energy, Conservation of Energy and Energy Transfer, the Relationship between Energy and Forces, and Energy in Chemical Process and Everyday Life. Energy is understood as quantitative property of a system that depends on the motion and interactions of matter and radiation within that system, and the total change of energy in any system is always equal to the total energy transferred into or out of the system. Students develop an understanding that energy at both the macroscopic and the atomic scale can be accounted for as either motions of particles or energy stored in fields. 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 system models; energy and matter; and the influence of science, engineering, and technology on society and the natural world are further developed in the performance expectations associated with PS3. In these performance expectations, students are expected to demonstrate proficiency in developing and using models, planning and carry out investigations, using computational thinking and designing solutions; and to use these practices to demonstrate understanding of the core ideas.

The Performance Expectations associated with **PS4: Waves and Their Applications in Technologies for Information Transfer** are critical to understand how many new technologies work. As such, this core idea helps students answer the question, “How are waves used to transfer energy and send and store information?” The disciplinary core idea in PS4 is broken down into Wave Properties, Electromagnetic Radiation, and Information Technologies and Instrumentation. Students are able to apply understanding of how wave properties and the interactions of electromagnetic radiation with matter can transfer information across long distances, store information, and investigate nature on many scales. Models of electromagnetic radiation as either a wave of changing electric and magnetic fields or as particles are developed and used. Students understand that combining waves of different frequencies can make a wide variety of patterns and thereby encode and transmit information. Students also demonstrate their understanding of engineering ideas by presenting information about how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. The crosscutting concepts of cause and effect; systems and system models; stability and change; interdependence of science, engineering, and technology; and the influence of engineering, technology, and science on society and the natural world are highlighted as organizing concepts for these disciplinary core ideas. In the PS3 performance expectations, students are expected to demonstrate proficiency in asking questions, using mathematical thinking, engaging in argument from evidence and obtaining, evaluating and communicating information; and to use these practices to demonstrate understanding of the core ideas.
HS-PS1 Matter and Its Interactions

Students who demonstrate understanding can:

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

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

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

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

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

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

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

HS-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.]

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

### HS-PS1 Matter and Its Interactions

|---------------------------------------------|----------|-----------|----------|----------|----------|----------|----------|----------|----------|----------|

| Common Core State Standards Connections:    | ELA/Literacy – | RST.11-12.1 | cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS1-3), (HS-PS1-5) |
|---------------------------------------------|---------------|-------------|-----------|----------|----------|----------|----------|----------|----------|----------|
|                                            |               | RST.9-10.7  | translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-PS1-1) |
|                                            |               | WHST.9-10.12 | write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS1-2), (HS-PS1-5) |
|                                            |               | WHST.9-12.5  | develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-PS1-2) |
|                                            |               | WHST.9-12.7  | conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS1-6) |
|                                            |               | WHST.11-12.8 | gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS1-3) |
|                                            |               | WHST.11-12.9 | draw evidence from informational texts to support analysis, reflection, and research. (HS-PS1-3) |
|                                            |               | SL.11-12.5   | make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (HS-PS1-4) |

| Mathematics –                             |               | MP.2        | reason abstractly and quantitatively. (HS-PS1-5), (HS-PS1-7) |
|                                            |               | MP.4        | Model with mathematics. (HS-PS1-4), (HS-PS1-8) |
|                                            |               | HSN-Q.A.1   | use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS1-2), (HS-PS1-3), (HS-PS1-4), (HS-PS1-5), (HS-PS1-7), (HS-PS1-8) |
|                                            |               | HSN-Q.A.2   | define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-4), (HS-PS1-7), (HS-PS1-8) |
|                                            |               | HSN-Q.A.3   | choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS1-2), (HS-PS1-3), (HS-PS1-4), (HS-PS1-5), (HS-PS1-7), (HS-PS1-8) |

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HS-PS2 Motion and Stability: Forces and Interactions

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS2-5)

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 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. (HS-PS2-1)

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponents and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena to describe explanations. (HS-PS2-2), (HS-PS2-4)

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

- Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects. (HS-PS2-3)

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate scientific and technical information (e.g., about

Disciplinary Core Ideas

PS2.A: Forces and Motion
- Newton’s second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1)
- Force is defined for a particular frame of reference; it is the mass times the velocity of the object. In any system, total momentum is always conserved. (HS-PS2-2)
- 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. (HS-PS2-2), (HS-PS2-3)

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. (HS-PS2-1)
- 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. (HS-PS2-4), (HS-PS2-5)
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (HS-PS2-6), (secondary to HS-PS2-1), (secondary to HS-PS2-3)

PS2.C: Definitions of Energy
- …and “electrical energy” may mean energy stored in a battery or energy transmitted by electric currents. (secondary to HS-PS2-2)

ETS1.A: Defining and Delimiting Engineering Problems
- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS2-3)

ETS1.C: Optimizing the Design Solution
- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS2-3)

Crosscutting Concepts

Patterns
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS2-4)

Cause and Effect
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-1), (HS-PS2-5)
- Systems can be designed to cause a desired effect. (HS-PS2-3)

Systems and System Models
- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. (HS-PS2-2)

Structure and Function
- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-PS2-6)

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HS-PS2  Motion and Stability: Forces and Interactions

the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-PS2-6)

**Connections to Nature of Science**

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- Theories and laws provide explanations in science. (HS-PS2-1), (HS-PS2-4)
- Laws are statements or descriptions of the relationships among observable phenomena. (HS-PS2-1), (HS-PS2-4)

**Connections to other DCIs in this grade-band:**  **HS-PS.A** (HS-PS2-4), **HS-PS.B** (HS-PS2-5), **HS-PS.C** (HS-PS2-1), **HS-PS.D** (HS-PS2-5), **HS.ESS.A** (HS-PS2-1), **HS.ESS.B** (HS-PS2-5), **HS.ESS.C** (HS-PS2-1), **HS.ESS.D** (HS-PS2-5), **HS.ESS.E** (HS-PS2-1), **HS.ESS.F** (HS-PS2-5), **HS.PS.A** (HS-PS2-1), **HS.PS.B** (HS-PS2-5), **HS.PS.C** (HS-PS2-1), **HS.PS.D** (HS-PS2-5), **HS.PS.E** (HS-PS2-1), **HS.PS.F** (HS-PS2-5), **HS.PS.G** (HS-PS2-1), **HS.PS.H** (HS-PS2-5)

**Common Core State Standards Connections:**

**ELA/Literacy –**

**RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS2-1), (HS-PS2-6)

**RST.11-12.2** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-PS2-1)

**WHST.9-12.2** Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. (HS-PS2-6)

**WHST.9-12.7** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS2-3), (HS-PS2-5)

**WHST.11-12.8** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS2-5)

**WHST.9-12.9** Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS2-1), (HS-PS2-5)

**Mathematics –**

**MP.2** Reason abstractly and quantitatively. (HS-PS2-1), (HS-PS2-2), (HS-PS2-4)

**MP.4** Model with mathematics. (HS-PS2-1), (HS-PS2-2), (HS-PS2-4)

**HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS2-1), (HS-PS2-2), (HS-PS2-4), (HS-PS2-5), (HS-PS2-6)

**HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling. (HS-PS2-1), (HS-PS2-2), (HS-PS2-4), (HS-PS2-5), (HS-PS2-6)

**HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS2-1), (HS-PS2-2), (HS-PS2-4), (HS-PS2-5), (HS-PS2-6)

**HSA-SSE.A.1** Interpret the structure of expressions that represent a quantity in terms of its context. (HS-PS2-1), (HS-PS2-4)

**HSA-SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (HS-PS2-1), (HS-PS2-4)

**HSA-CED.A.1** Create equations and inequalities in one variable and use them to solve problems. (HS-PS2-1), (HS-PS2-2)

**HSA-CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. (HS-PS2-1), (HS-PS2-2)

**HSA-CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. (HS-PS2-1), (HS-PS2-2)

**HSF-IF.C.7** Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. (HS-PS2-1)

**HSS-ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots). (HS-PS2-1)

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Students who demonstrate understanding can:

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

**HS-PS3-2.** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles or energy stored in fields. [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-PS3-3.** 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, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment is limited to quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]

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

**HS-PS3-5.** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other, including an explanation of how the change in energy of the objects is related to the change in energy of the field.] [Assessment Boundary: Assessment is limited to systems containing two objects.]

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**Science and Engineering Practices**

**Developing and Using Models**
Modeling in 9–12 builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

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

**Planning and Carrying Out Investigations**
Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of students, cost, risk, time), and refine the design accordingly. (HS-PS3-4)

**Using Mathematics and Computational Thinking**
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

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

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

- Design, evaluate, and/or refine a solution to a problem.

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**Disciplinary Core Ideas**

**PS3A: 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. There is a single quantity called energy due to the fact that a system’s total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HS-PS3-1, 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 either motions of particles or energy 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)

**PS3B: 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, HS-PS3-4)
- 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)
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4)

**PS3C: Relationship Between Energy and Forces**
- When two objects interact through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)

**PS3D: Energy in Chemical Processes**
- Although energy cannot be created, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3, HS-PS3-4)

**ETS1A: Defining and Delimiting Engineering Problems**
- Criteria and constraints also include satisfying any requirements.

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**Crosscutting Concepts**

**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. (HS-PS3-5)

**Systems and System Models**
- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-PS3-4)
- 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)

**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)

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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)

**Scientific Knowledge Assumes an Order and Consistency in Natural Systems**

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### HS-PS3  Energy

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<th>Connections to other DCIs in this grade-band:</th>
<th>Articulation to DCIs across grade-bands:</th>
<th>Common Core State Standards Connections:</th>
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</table>
| HS.PS1.A (HS-PS3-2); HS.PS1.B (HS-PS3-1), (HS-PS3-2); HS.PS2.B (HS-PS3-1), (HS-PS3-2); HS.PS2.C (HS-PS3-2); HS.PS2.D (HS-PS3-1); HS.ESS3.A (HS-PS3-2); MS.PS1.A (HS-PS3-2); MS.PS2.B (HS-PS3-2); MS.PS3.A (HS-PS3-1), (HS-PS3-2); MS.PS3.B (HS-PS3-1), (HS-PS3-2); MS.PS3.C (HS-PS3-2); MS.PS3.D (HS-PS3-1), (HS-PS3-2) | MS.PS1.A (HS-PS3-3); MS.PS2.B (HS-PS3-2), (HS-PS3-5); MS.PS3.A (HS-PS3-1), (HS-PS3-2), (HS-PS3-3); MS.PS3.B (HS-PS3-1), (HS-PS3-2), (HS-PS3-3); MS.PS3.C (HS-PS3-2), (HS-PS3-5); MS.ESS2.A (HS-PS3-1), (HS-PS3-3) | ELA/Literacy –

**RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS3-4)

**WHST.9-12.7** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS3-3), (HS-PS3-4), (HS-PS3-5)

**WHST.11-12.8** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS3-4), (HS-PS3-5)

**WHST.9-12.9** Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS3-4), (HS-PS3-5)

**SL.11-12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (HS-PS3-1), (HS-PS3-2), (HS-PS3-5)

**Mathematics –**

**MP.2** Reason abstractly and quantitatively. (HS-PS3-1), (HS-PS3-2), (HS-PS3-3), (HS-PS3-4), (HS-PS3-5)

**MP.4** Model with mathematics. (HS-PS3-1), (HS-PS3-2), (HS-PS3-3), (HS-PS3-4), (HS-PS3-5)

**HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS3-1), (HS-PS3-3)

**HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling. (HS-PS3-1), (HS-PS3-3)

**HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS3-1), (HS-PS3-3)

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*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.*

The section entitled "Disciplinary Core Ideas" is reproduced verbatim from A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas. Integrated and reprinted with permission from the National Academy of Sciences.
HS-PS4 Waves and Their Applications in Technologies for Information Transfer

Students who demonstrate understanding can:

**HS-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 data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]

**HS-PS4-2. Evaluate questions about the advantages and disadvantages of a digital transmission and storage of information.** [Clarification Statement: Examples of advantages could include that digital information is stable because it can be stored reliably in computer memory, transferred easily, and copied and shared rapidly. Disadvantages could include issues of easy deletion, security, and theft.]

**HS-PS4-3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.** [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.] [Assessment Boundary: Assessment does not include using quantum theory.]

**HS-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.** [Clarification Statement: Emphasis is on the idea that different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.] [Assessment Boundary: Assessment is limited to qualitative descriptions.]

**HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.** [Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] [Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.]

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

**Science and Engineering Practices**
- Asking Questions and Defining Problems
  - Engaging in Argument from Evidence
  - Obtaining, Evaluating, and Communicating Information
- Disciplinary Core Ideas
  - PS3.D: Energy in Chemical Processes
  - PS4.A: Wave Properties
  - PS4.B: Electromagnetic Radiation
  - PS4.C: Information Technologies and Instrumentation
- Crosscutting Concepts
  - Cause and Effect
  - Stability and Change
  - Connections to Engineering, Technology, and Applications of Science
- Interdependence of Science, Engineering, and Technology
  - Science and engineering complement each other in the cycle known as research and development (R&D).
- Influence of Engineering, Technology, and Science on Society and the Natural World

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# HS-PS4 Waves and Their Applications in Technologies for Information Transfer

**Common Core State Standards Connections:**

| ELA/Literacy – | MP.2 | Reason abstractly and quantitatively. (HS-PS4-1),(HS-PS4-3) |
| MP.4 | Model with mathematics. (HS-PS4-1) |
| RST.11-12.1 | Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS4-2),(HS-PS4-3),(HS-PS4-4) |
| RST.11-12.7 | Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-PS4-1),(HS-PS4-4) |
| RST.9-10.8 | Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. (HS-PS4-2),(HS-PS4-3),(HS-PS4-4) |
| RST.11-12.8 | Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-PS4-2),(HS-PS4-3),(HS-PS4-4) |
| WHST.9-12.2 | Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS4-5) |
| WHST.11-12.8 | Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS4-4) |

**Mathematics –**

| HS.A.CED.A.4 | Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. (HS-PS4-1),(HS-PS4-3) |
| HS.A.SSE.A.1 | Interpret expressions that represent a quantity in terms of its context. (HS-PS4-1),(HS-PS4-3) |
| HS.A.SSE.B.3 | Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (HS-PS4-1),(HS-PS4-3) |

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