High School Modified Domains Model Course II - Physics
Bundle 1: Why don't we fall through the floor?

This is the first bundle of the High School Domains Model Course II - Physics. Each bundle has connections to the other bundles in the course, as shown in the [Course Flowchart](#).

Bundle 1 Question: This bundle is assembled to address the question "why don't we fall through the floor?"

Summary

The bundle organizes performance expectations with a focus on helping students understand how forces arise from the interactions between fields. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, but recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs

Every atom has a substructure consisting of a nucleus, which is made of positively-charged protons and neutral neutrons, surrounded by negatively-charged electrons (PS1.A as in HS-PS1-1). This concept connects to the idea that the structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms (PS1.A as in HS-PS1-3), as well as the idea that attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformation of matter, as well as the contact forces between material objects (PS2.B as in HS-PS2-6).

These ideas about how the interactions between charged particles at the atomic level relate to observations of matter also connect to the concepts about how forces and energy relate to the interaction of objects at a variety of scales. This includes the idea that forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space, including between two atoms (PS2.B as in HS-PS2-4). The idea that the presence of fields explains energy transfer and forces between distant objects connects to the idea that when two objects interacting through a field change relative position, the energy stored in the field is changed (PS3.B as in HS-PS3-5).

These concepts about relationships between forces, energy transfer, and observations of matter at multiple scales all connect to quantitative concepts about the nature and transfer of energy. These include the idea that energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system, and that the existence of a single quantity called 'energy' (as opposed to multiple independent kinds of energy) is because 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 (PS3.A as in HS-PS3-2). These concepts about the transfer and conservation of a single quantity 'energy' through various forms within systems are connected to the concepts of interactions of matter at the microscopic scale (e.g., particles, atoms), at which scale 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 their configuration, including cases in which the relative position energy can be thought of as stored in fields. This last concept includes radiation, a phenomenon in which energy stored in fields moves across space (PS3.A as in HS-PS3-2).

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of developing and using models (HS-PS1-1, HS-PS3-2, and HS-PS3-5), planning and carrying out investigations (HS-PS1-3), using mathematical thinking (HS-PS2-4), and communicating information (HS-PS2-6). Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Patterns (HS-PS1-3 and HS-PS2-4), Cause and Effect (HS-PS3-5), Energy and Matter (HS-PS3-2), and Structure and Function (HS-PS2-6). Many other crosscutting elements can be used in instruction. *All instruction should be three-dimensional.*	
Performance Expectations	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-PS1-3. **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-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 gravitational and electric fields.] [Assessment Boundary: Assessment is limited to systems with two objects.] HS-PS2-6. **Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*** [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.] HS-PS3-2. **Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).** [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.] 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.] [Assessment Boundary: Assessment is limited to systems containing two objects.]
Example Phenomena	When I use a compass close to a wire, the compass doesn't point to magnetic north. I can walk on a frozen lake but not on the same lake in the summer.

Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions to determine relationships, including quantitative relationships, between independent and dependent variables. Students could *ask questions to determine relationships between the* ***relative positions*** [of] ***two objects interacting through a field*** [and] ***the energy stored in the field.*** HS-PS3-5 **Developing and Using Models** • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. Students could *use* ***Coulomb's law*** [as] *a model to generate data to predict* ***the effects of electrostatic forces between distant objects***. HS-PS2-4 **Planning and Carrying Out Investigations** • Select appropriate tools to collect, record, analyze, and evaluate data. Students could *select appropriate tools to analyze data* [on the relationship between the] ***attraction and repulsion between electric charges at the atomic scale*** [and] ***the properties of matter***. HS-PS2-6 **Analyzing and Interpreting 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. Students could *analyze data using tools, technologies, and/or models in order to make valid and reliable science claims* [about how] ***when two objects interacting through a field change relative position, the energy stored in the field is changed***. HS-PS3-5 **Using Mathematical and Computational Thinking** • Apply techniques of algebra and functions to represent and solve scientific and engineering problems. Students could *apply techniques of algebra and functions to represent* [that] ***when two objects interacting through a field change relative position, the energy stored in the field is changed***. HS-PS3-5 **Constructing Explanations and Designing Solutions** • Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. Students could *make a qualitative claim regarding the relationships between* ***the structure of matter at the bulk scale*** [and the] ***electrical forces within and between atoms***. HS-PS1-3 **Engaging in Argument from Evidence** • Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. Students could *construct a written argument based on data and evidence* [for how] ***the structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms***. HS-PS1-3

Additional Practices Building to the PEs (Continued)	**Obtaining, Evaluating, and Communicating Information** • Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. Students could *evaluate the validity and reliability of multiple claims* [about how] ***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
Additional Crosscutting Concepts Building to the PEs	**Patterns** • Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. Students could construct an argument for [how the concept that] ***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*** [relates to the concept that] *explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced*. HS-PS2-6 **Energy and Matter** • The total amount of energy and matter in closed systems is conserved. Students could develop a model for how ***when two objects interacting through a field change relative position, the energy stored in the field is changed,*** [but] *the total amount of energy in closed system is conserved*. HS-PS3-5 **Structure and Function** • The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. Students could construct an argument for how *the functions and properties of natural and designed objects can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials,* [which] ***are determined by electrical forces within and between atoms***. HS-PS1-3
Additional Connections to Nature of Science	**Scientific Knowledge is Based on Empirical Evidence:** • Science knowledge is based on empirical evidence. Students could construct an argument [that our] *knowledge* [about how] ***forces at a distance are explained by fields permeating space that can transfer energy through space***, *is based on empirical evidence*. HS-PS2-4 **Science Addresses Questions About the Natural and Material World:** • Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. Students could evaluate design solutions [that make use of the scientific ideas about] ***field permeating space that can transfer energy***, [taking into account that] *many decisions rely on social and cultural contexts to resolve issues* [about the use of the design solution]. HS-PS2-4

HS-PS1-1

Students who demonstrate understanding can:

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

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Use a model to predict the relationships between systems or between components of a system.	**PS1.A: Structure and Properties of Matter** • Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.	**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.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	From the given model, students identify and describe* the components of the model that are relevant for their predictions, including:	
		i.	Elements and their arrangement in the periodic table;
		ii.	A positively-charged nucleus composed of both protons and neutrons, surrounded by negatively-charged electrons;
		iii.	Electrons in the outermost energy level of atoms (i.e., valence electrons); and
		iv.	The number of protons in each element.
2	Relationships		
	a	Students identify and describe* the following relationships between components in the given model, including:	
		i.	The arrangement of the main groups of the periodic table reflects the patterns of outermost electrons.
		ii.	Elements in the periodic table are arranged by the numbers of protons in atoms.
3	Connections		
	a	Students use the periodic table to predict the patterns of behavior of the elements based on the attraction and repulsion between electrically charged particles and the patterns of outermost electrons that determine the typical reactivity of an atom.	
	b	Students predict the following patterns of properties:	
		i.	The number and types of bonds formed (i.e. ionic, covalent, metallic) by an element and between elements;
		ii.	The number and charges in stable ions that form from atoms in a group of the periodic table;

		iii.	The trend in reactivity and electronegativity of atoms down a group, and across a row in the periodic table, based on attractions of outermost (valence) electrons to the nucleus; and
		iv.	The relative sizes of atoms both across a row and down a group in the periodic table.

HS-PS1-3

Students who demonstrate understanding can:

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

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.	**PS1.A: Structure and Properties of Matter** • The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.	**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.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe* the phenomenon under investigation, which includes the following idea: the relationship between the measurable properties (e.g., melting point, boiling point, vapor pressure, surface tension) of a substance and the strength of the electrical forces between the particles of the substance.	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data, including bulk properties of a substance (e.g., melting point and boiling point, volatility, surface tension) that would allow inferences to be made about the strength of electrical forces between particles.	
	b	Students describe* why the data about bulk properties would provide information about strength of the electrical forces between the particles of the chosen substances, including the following descriptions*:	
		i.	The spacing of the particles of the chosen substances can change as a result of the experimental procedure even if the identity of the particles does not change (e.g., when water is boiled the molecules are still present but further apart).
		ii.	Thermal (kinetic) energy has an effect on the ability of the electrical attraction between particles to keep the particles close together. Thus, as more energy is added to the system, the forces of attraction between the particles can no longer keep the particles close together.

		iii. The patterns of interactions between particles at the molecular scale are reflected in the patterns of behavior at the macroscopic scale.
		iv. Together, patterns observed at multiple scales can provide evidence of the causal relationships between the strength of the electrical forces between particles and the structure of substances at the bulk scale.
3	Planning for the investigation	
	a	In the investigation plan, students include:
		i. A rationale for the choice of substances to compare and a description* of the composition of those substances at the atomic molecular scale.
		ii. A description* of how the data will be collected, the number of trials, and the experimental set up and equipment required.
	b	Students describe* how the data will be collected, the number of trials, the experimental set up, and the equipment required.
4	Collecting the data	
	a	Students collect and record data — quantitative and/or qualitative — on the bulk properties of substances.
5	Refining the design	
	a	Students evaluate their investigation, including evaluation of:
		i. Assessing the accuracy and precision of the data collected, as well as the limitations of the investigation; and
		ii. The ability of the data to provide the evidence required.
	b	If necessary, students refine the plan to produce more accurate, precise, and useful data.

HS-PS2-4

Students who demonstrate understanding can:

HS-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 gravitational and electric fields.] [*Assessment Boundary: Assessment is limited to systems with two objects.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking

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

- Use mathematical representations of phenomena to describe explanations.

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Connections to Nature of Science

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

- Theories and laws provide explanations in science.
- Laws are statements or descriptions of the relationships among observable phenomena.

Disciplinary Core Ideas

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.

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.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students clearly define the system of the interacting objects that is mathematically represented.
	b	Using the given mathematical representations, students identify and describe* the gravitational attraction between two objects as the product of their masses divided by the separation distance squared $\left(F_g = -G\frac{m_1 m_2}{d^2}\right)$, where a negative force is understood to be attractive.
	c	Using the given mathematical representations, students identify and describe* the electrostatic force between two objects as the product of their individual charges divided by the separation distance squared $\left(F_e = k\frac{q_1 q_2}{d^2}\right)$, where a negative force is understood to be attractive.
2	Mathematical modeling	
	a	Students correctly use the given mathematical formulas to predict the gravitational force between objects or predict the electrostatic force between charged objects.
3	Analysis	
	a	Based on the given mathematical models, students describe* that the ratio between gravitational and electric forces between objects with a given charge and mass is a pattern that is independent of distance.

	b	Students describe* that the mathematical representation of the gravitational field $\left(F_g = -G\frac{m_1 m_2}{d^2}\right)$ only predicts an attractive force because mass is always positive.
	c	Students describe* that the mathematical representation of the electric field $\left(F_e = k\frac{q_1 q_2}{d^2}\right)$ predicts both attraction and repulsion because electric charge can be either positive or negative.
	d	Students use the given formulas for the forces as evidence to describe* that the change in the energy of objects interacting through electric or gravitational forces depends on the distance between the objects.

HS-PS2-6

Students who demonstrate understanding can:

HS-PS2-6. **Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*** [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [*Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information

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

- Communicate scientific and technical information (e.g., about the process of development and the design and performance of a proposed process or system) in multiple formats (including oral, graphical, textual and mathematical).

Disciplinary Core Ideas

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.

Crosscutting Concepts

Structure and Function

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

Observable features of the student performance by the end of the course:			
1	Communication style and format		
	a	Students use at least two different formats (including oral, graphical, textual and mathematical) to communicate scientific and technical information, including fully describing* the structure, properties, and design of the chosen material(s). Students cite the origin of the information as appropriate.	
2	Connecting the DCIs and the CCCs		
	a	Students identify and communicate the evidence for why molecular level structure is important in the functioning of designed materials, including:	
		i.	How the structure and properties of matter and the types of interactions of matter at the atomic scale determine the function of the chosen designed material(s); and
		ii.	How the material's properties make it suitable for use in its designed function.
	b	Students explicitly identify the molecular structure of the chosen designed material(s) (using a representation appropriate to the specific type of communication — e.g., geometric shapes for drugs and receptors, ball and stick models for long-chained molecules).	
	c	Students describe* the intended function of the chosen designed material(s).	
	d	Students describe* the relationship between the material's function and its macroscopic properties (e.g., material strength, conductivity, reactivity, state of matter, durability) and each of the following:	
		i.	Molecular level structure of the material;
		ii.	Intermolecular forces and polarity of molecules; and
		iii.	The ability of electrons to move relatively freely in metals.
	e	Students describe* the effects that attractive and repulsive electrical forces between molecules have on the arrangement (structure) of the chosen designed material(s) of molecules (e.g., solids, liquids, gases, network solid, polymers).	
	f	Students describe* that, for all materials, electrostatic forces on the atomic and molecular scale results in contact forces (e.g., friction, normal forces, stickiness) on the macroscopic scale.	

HS-PS3-2

Students who demonstrate understanding can:

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

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

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

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

Crosscutting Concepts

Energy and Matter

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

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop models in which they identify and describe* the relevant components, including:	
		i.	All the components of the system and the surroundings, as well as energy flows between the system and the surroundings;
		ii.	Clearly depicting both a macroscopic and a molecular/atomic-level representation of the system; and

		iii. Depicting the forms in which energy is manifested at two different scales:
		a) Macroscopic , such as motion, sound, light, thermal energy, potential energy or energy in fields; and
		b) Molecular/atomic, such as motions (kinetic energy) of particles (e.g., nuclei and electrons), the relative positions of particles in fields (potential energy), and energy in fields.
2	Relationships	
	a	Students describe* the relationships between components in their models, including:
		i. Changes in the relative position of objects in gravitational, magnetic or electrostatic fields can affect the energy of the fields (e.g., charged objects moving away from each other change the field energy).
		ii. Thermal energy includes both the kinetic and potential energy of particle vibrations in solids or molecules and the kinetic energy of freely moving particles (e.g., inert gas atoms, molecules) 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.
3	Connections	
	a	Students use their models to show that in closed systems the energy is conserved on both the macroscopic and molecular/atomic scales so that as one form of energy changes, the total system energy remains constant, 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 use their models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles/objects and energy associated with the relative positions of particles/objects on both the macroscopic and microscopic scales.

HS-PS3-5

Students who demonstrate understanding can:

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.] [*Assessment Boundary: Assessment is limited to systems containing two objects.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.	**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.	**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 the student performance by the end of the course:			
1	Components of the model		
	a	Students develop a model in which they identify and describe* the relevant components to illustrate the forces and changes in energy involved when two objects interact, including:	
		i.	The two objects in the system, including their initial positions and velocities (limited to one dimension).
		ii.	The nature of the interaction (electric or magnetic) between the two objects.
		iii.	The relative magnitude and the direction of the net force on each of the objects.
		iv.	Representation of a field as a quantity that has a magnitude and direction at all points in space and which contains energy.
2	Relationships		
	a	In the model, students 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 use the model to determine whether the energy stored in the field increased, decreased, or remained the same when the objects interacted.	
	b	Students use the model to support the claim that the change in the energy stored in the field (which is qualitatively determined to be either positive, negative, or zero) is consistent with the change in energy of the objects.	
	c	Using the model, students describe* the cause and effect relationships on a qualitative level between forces produced by electric or magnetic fields and the change of energy of the objects in the system.	