Grade 9–12
Physical Science
Item Specifications

Missouri
DEPARTMENT OF ELEMENTARY & SECONDARY
EDUCATION

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Introduction

In 2014 Missouri legislators passed House Bill 1490, mandating the development of the Missouri Learning Expectations. In April of 2016, these Missouri Learning Expectations were adopted by the State Board of Education. Groups of Missouri educators from across the state collaborated to create the documents necessary to support the implementation of these expectations.

One of the documents developed is the item specification document, which includes all Missouri grade level/course expectations arranged by domains/strands. It defines what could be measured on a variety of assessments. The document serves as the foundation of the assessment development process.

Although teachers may use this document to provide clarity to the expectations, these specifications are intended for summative, benchmark, and large-scale assessment purposes.

Components of the item specifications include:

Expectation Unwrapped breaks down a list of clearly delineated content and skills the students are expected to know and be able to do upon mastery of the Expectation.

Depth of Knowledge (DOK) Ceiling indicates the highest level of cognitive complexity that would typically be assessed on a large scale assessment. The DOK ceiling is not intended to limit the complexity one might reach in classroom instruction.

Item Format indicates the types of test questions used in large scale assessment. For each expectation, the item format specifies the type best suited for that particular expectation.

Content Limits/Assessment Boundaries are parameters that item writers should consider when developing a large scale assessment. For example, some expectations should not be assessed on a large scale assessment but are better suited for local assessment.

Sample stems are examples that address the specific elements of each expectation and address varying DOK levels. The sample stems provided in this document are in no way intended to limit the depth and breadth of possible item stems. The expectation should be assessed in a variety of ways.

Possible Evidence indicates observable methods in which a student can show understanding of the expectations.

Stimulus Materials defines types of stimulus materials that can be used in the item stems.

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Engineering, Technology, and Applications of Science</th><th>9-12.ETS1.A.1</th></tr>
<tr><td>Core Idea</td><td colspan="2">Engineering Design</td></tr>
<tr><td>Component</td><td colspan="2">Defining and Delimiting Engineering Problems</td></tr>
<tr><td>MLS</td><td colspan="2">Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.</td></tr>
<tr><td colspan="2" rowspan="2"><u>Expectation Unwrapped</u>

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Asking Questions and Defining Problems
● Analyze complex real-world problems by specifying criteria and constraints for successful solutions.

<u>DISCIPLINARY CORE IDEAS</u>
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.
● Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

<u>CROSSCUTTING CONCEPTS</u>
Influence of Science, Engineering, and Technology on Society and the Natural World
● New technologies can have deep impacts on society and the environment, including some that were not anticipated.
● Analysis of costs and benefits is a critical aspect of decisions about technology.</td><td><u>DOK Ceiling</u>
3</td></tr>
<tr><td><u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should not require students to differentiate between credible and non-credible sources.
● Tasks should focus on students drawing conclusions from graphs, tables, or text to support their conclusions.</td><td><u>Sample Stems</u></td></tr>
</table>

Possible Evidence	
• Students describe the challenge with a rationale for why it is a major global challenge. • Students describe qualitatively and quantitatively, the extent and depth of the problem and its major consequences to society and/or the natural world on both global and local scales if it remains unsolved. • Students document background research on the problem from two or more sources, including research journals. • In their analysis, students identify the physical system in which the problem is embedded, including the major elements and relationships in the system and boundaries so as to clarify what is and is not part of the problem. • In their analysis, students describe societal needs and wants that are relative to the problem (e.g., for controlling CO_2 emissions, societal needs include the need for cheap energy). • Students specify qualitative and quantitative criteria and limitations (constraints) for acceptable solutions to the problem.	
Stimulus Materials	
Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

Engineering, Technology, and Application of Science		9-12.ETS1.A.2
Core Idea	**Engineering Design**	
Component	**Defining and Delimiting Engineering Problems**	
MLS	Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.	

Expectation Unwrapped	**DOK Ceiling**
	3
SCIENCE AND ENGINEERING PRACTICES **Constructing Explanations and Designing Solutions** ● Design a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations. **DISCIPLINARY CORE IDEAS** **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. ● Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. **Organizing 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. **CROSSCUTTING CONCEPTS** **Stability and Change** ● Much of science deals with constructing explanations of how things change and how they remain stable.	**Item Format** Selected Response Constructed Response Technology Enhanced
Content Limits/Assessment Boundaries	**Sample Stems**
● Tasks should provide students with complex real-world problems that have more than one possible solution. ● Tasks should not require students to generate complex real world problems.	

Possible Evidence	
• Students restate the original complex problem into a set of two or more subproblems (possibilities include in writing or as a diagram or flow chart). • For each of the subproblems, students propose at least one solution that is based on student-generated data and/or scientific information from other sources. • Students describe how solutions to the subproblems are interconnected to solve all or part of the larger problem. • Students describe the criteria and limitations (constraints) for the selected subproblem. • Students describe the rationale for the sequence of how subproblems are to be solved and which criteria should be given highest priority if trade-offs must be made.	
Stimulus Materials	
Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

Engineering, Technology, and Application of Science		9-12.ETS1.B.1
Core Idea	**Engineering Design**	
Component	**Developing Possible Solutions**	
MLS	Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.	

Expectation Unwrapped

SCIENCE AND ENGINEERING PRACTICES

Constructing Explanations and Designing Solutions

- Evaluate a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations.

DISCIPLINARY CORE IDEAS

Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

CROSSCUTTING CONCEPTS

Influence of Science, Engineering, and Technology on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

DOK Ceiling

3

Item Format

Selected Response
Constructed Response
Technology Enhanced

Content Limits/Assessment Boundaries

- Tasks should require students to evaluate solutions based on at least two of the following: cost, safety, reliability, and aesthetics.
- Tasks should not require students to generate their own solutions.

Possible Evidence

- Provide an evidence-based decision of which solution is optimum, based on prioritized criteria, analysis of the strengths and weaknesses of each solution, and barriers to be overcome.
- In their evaluation, students describe which parts of the complex real-world problem may remain even if the proposed solution is implemented.

Stimulus Materials

Graphic organizers, diagrams, graphs, data tables, drawings

Sample Stems

Grades 9-12 PHYSICAL SCIENCE

Engineering, Technology, and Application of Science		9-12.ETS1.B.2
Core Idea	**Engineering Design**	
Component	**Developing Possible Solutions**	
MLS	Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.	

Expectation Unwrapped	**DOK Ceiling**
	3
SCIENCE AND ENGINEERING PRACTICES **Using Mathematics and Computational Thinking** ● Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. **DISCIPLINARY CORE IDEAS** **Developing Possible Solutions** ● Both physical models and computers can be used in various ways to aid in the engineering design process. ● Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical and in making a persuasive presentation to a client about how a given design will meet his or her needs. **CROSSCUTTING CONCEPTS** **Systems and System Models** ● Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.	**Item Format** Selected Response Constructed Response Technology Enhanced

Content Limits/Assessment Boundaries	**Sample Stems**
● Tasks should include real-world problems that are relevant to students. Adequate background information is needed for any problem not potentially relevant to students. ● Tasks should not require students to generate their own complex real-world problem.	

Possible Evidence	
● Students identify the complex real-world problem, with numerous criteria and limitations (constraints). ○ Identify the system that is being modeled by the computational simulation, including the boundaries and individual components of the systems. ○ Identify what variables can be changed by the user to evaluate the proposed solutions, trade-offs, or other decisions. ○ Identify the scientific principles and or relationships being used by the model. ● Students use the given computer simulation to model the proposed solutions by selecting logical and realistic inputs and using the model to simulate the effects of different solutions, trade-offs, or other decisions. ● Students analyze the simulated results as compared to the expected results. ● Students interpret the results of the simulation and predict the effects of the proposed solutions within and between systems relevant to the problem based on the interpretation. ● Students identify the possible negative consequences of solutions that outweigh their benefits. ● Students identify the simulation's limitations (constraints).	
Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS1.A.1</th></tr>
<tr><td>Core Idea
Component
MLS</td><td colspan="2">Matter and Its Interactions
Structure and Properties of Matter
Use the organization of the periodic table to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.</td></tr>
<tr><td colspan="2"><u>Expectation Unwrapped</u>

[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.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Developing and Using Models
● Use a model to predict the relationships between systems or between components of a system.

<u>DISCIPLINARY CORE IDEAS</u>
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.

<u>CROSSCUTTING CONCEPTS</u>
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.</td><td><u>DOK Ceiling</u>
3

<u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should only focus on main group elements.
● Tasks should avoid a quantitative understanding of ionization energy beyond relative trends.
● Tasks should avoid mathematical computations.</td><td><u>Sample Stems</u></td></tr>
</table>

Possible Evidence	

• From the given model, students identify and describe the components of the model that are relevant for their predictions, including
  ○ elements and their arrangement in the periodic table;
  ○ a positively-charged nucleus composed of both protons and neutrons, surrounded by negatively charged electrons;
  ○ electrons in the outermost energy level of atoms (i.e., valence electrons); and
  ○ the number of protons in each element.
• Students identify and describe the following relationships between components in the given model, including the following
  ○ The arrangement of the main groups of the periodic table reflects the patterns of outermost electrons.
  ○ Elements in the periodic table are arranged by the numbers of protons in atoms.
• 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.
• Students predict the following patterns of properties:
  ○ The number and types of bonds formed (i.e., ionic, covalent, metallic) by an element and between elements.
  ○ The number and charges in stable ions that form from atoms in a group of the periodic table.
  ○ 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.
  ○ The relative sizes of atoms both across a row and down a group in the periodic table.	

Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS1.A.2
Core Idea	**Matter and Its Interactions**	
Component	**Structure and Properties of Matter**	
MLS	Construct and revise an explanation for the products 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.	

Expectation Unwrapped	DOK Ceiling
[Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine or of oxygen and hydrogen. Students will use the periodic table to create an explanation of how main group elements react, by identifying reactants and products. Students should know that noble gases do not usually react.]	3
	Item Format Selected Response Constructed Response Technology Enhanced

SCIENCE AND ENGINEERING PRACTICES

Constructing Explanations and Designing Solutions

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

DISCIPLINARY CORE IDEAS

Structure and Properties of Matter

- 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.

Chemical Reactions

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

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.

Content Limits/Assessment Boundaries	Sample Stems
• Tasks should focus on synthesis, decomposition, combustion, and/or replacement reactions among main group elements. • Tasks should avoid the transition metals, actinides, and lanthanides. • Tasks should not require students to identify the type of reaction.	
Possible Evidence	
• Students construct an explanation of the outcome of the given reaction, including the following: ○ The idea that the total number of atoms of each element in the reactant and products is the same ○ The numbers and types of bonds (i.e., ionic, covalent) that each atom forms, as determined by the outermost (valence) electron states and the electronegativity ○ The outermost (valence) electron state of the atoms that make up both the reactants and the products of the reaction is based on their position in the periodic table ○ A discussion of how the patterns of attraction allow the prediction of the type of reaction that occurs (e.g., formation of ionic compounds, combustion of hydrocarbons) • Students identify and describe the evidence to construct the explanation, including the following: ○ Identification of the products and reactants, including their chemical formulas and the arrangement of their outermost (valence) electrons ○ Identification that the number and types of atoms are the same both before and after a reaction ○ Identification of the numbers and types of bonds (i.e., ionic, covalent) in both the reactants and the products ○ The patterns of reactivity (e.g., the high reactivity of alkali metals) at the macroscopic level as determined by using the periodic table ○ The outermost (valence) electron configuration and the relative electronegativity of the atoms that make up both the reactants and the products of the reaction based on their positions in the periodic table • Students describe their reasoning that connects the evidence, along with the assumption that theories and laws that describe their natural world operate today as they did in the past and will continue to do so in the future, to construct an explanation for how the patterns of outermost electrons and the electronegativity of elements can be used to predict the number and types of bonds each element forms. • In the explanation, students describe the causal relationship between the observable macroscopic patterns of reactivity of elements in the periodic table and the patterns of outermost electrons for each atom and its relative electronegativity.	

• Given new evidence or context, students construct a revised or expanded explanation about the outcome of a chemical reaction and justify the revision.
• Other possible evidence may include, but is not limited to the following:
  ○ The total number of atoms in reactant and products are the same
  ○ Type of bonds
  ○ Valence electrons
  ○ Patterns of reactivity	

<u>Stimulus Materials</u> Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS1.A.3</th></tr>
<tr><td>Core Idea</td><td colspan="2">Matter and Its Interactions</td></tr>
<tr><td>Component</td><td colspan="2">Structure and Properties of Matter</td></tr>
<tr><td>MLS</td><td colspan="2">Plan and conduct an investigation to gather evidence to compare physical and chemical properties of substances such as melting point, boiling point, vapor pressure, surface tension, and chemical reactivity to infer the relative strength of attractive forces between particles.</td></tr>
<tr><td colspan="2" rowspan="2"><u>Expectation Unwrapped</u>

[Clarification Statement: Emphasis is on understanding the relative strength of forces between particles. Examples of particles could include ions, atoms, molecules, and simple compounds (such as water).]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Planning and Carrying Out Investigations
● 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, quantity, and accuracy of data needed to produce reliable measurements; consider limitations on the precision of the data (e.g., number of trials, cost, risk, time); and refine the design accordingly.

<u>DISCIPLINARY CORE IDEAS</u>
Structure and Properties of Matter
● The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

<u>CROSSCUTTING CONCEPTS</u>
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.</td><td><u>DOK Ceiling</u>
3</td></tr>
<tr><td><u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should avoid mathematical computations.</td><td rowspan="2"><u>Sample Stems</u></td></tr>
<tr><td colspan="2"><u>Possible Evidence</u>

● Students describe the phenomenon under investigation, which includes the following: 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.</td></tr>
</table>

- 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.
- Students describe why the data on bulk properties would provide information about strength of the electrical forces between the particles of the chosen substances, including the following descriptions:
  - 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 farther apart).
  - 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.
  - The patterns of interactions between particles at the molecular scale are reflected in the patterns of behavior at the macroscopic scale. 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.
- In the investigation plan, students include the following:
  - A rationale for the choice of substances to compare and a description of the composition of those substances at the atomic molecular scale
  - A description of how the data will be collected, the number of trials, and the experimental setup and equipment required
- Students describe how the data will be collected, the number of trials, the experimental setup, and the equipment required.
- Students collect and record data—quantitative and/or qualitative—on the bulk properties of substances.
- Students evaluate their investigation, including the following:
  - Assessing the accuracy and precision of the data collected, as well as the limitations of the investigation
  - The ability of the data to provide the evidence required
- If necessary, students refine the plan to produce more accurate, precise, and useful data.
- Additional possible evidence may include, but is not limited to, melting point, boiling points, vapor pressure, surface tension, chemical reactivity, strength of attractive forces, malleability, ductility, density, conductivity, and flammability.

Stimulus Materials

Graphic organizers, diagrams, graphs, data tables, drawings

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS1.A.4
Core Idea	**Matter and Its Interactions**	
Component	**Structure and Properties of Matter**	
MLS	Apply the concepts of bonding and crystalline/molecular structure to explain the macroscopic properties of various categories of structural materials (i.e., metals, ionic [ceramics], and polymers).	

Expectation Unwrapped

[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. Students will be able to explain the properties of a substance based on its crystalline/molecular structure.]

SCIENCE AND ENGINEERING PRACTICES

Constructing Explanations and Designing Solutions

- Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

DISCIPLINARY CORE IDEAS

Structure and Properties of Matter

- In general, a substance will have certain macroscopic properties (i.e., conductivity, flexibility, shape) due to the types of bonds and arrangements between the atoms that make up the substance. Atoms that form ionic bonds typically have distinct characteristics (i.e., hard, soluble in water, high melting point, brittle, conductivity in solution) because of the lattice framework. Covalently bonded molecules have certain properties (i.e., low melting point, lower solubility, flexibility, ductility, malleability)

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.

DOK Ceiling

3

Item Format

Selected Response
Constructed Response
Technology Enhanced

Content Limits/Assessment Boundaries

- Tasks should avoid metallic bonds and complex polymers.

Sample Stems

Possible Evidence	

• Students construct an explanation of the impact of structural changes within a certain substance and the effects on the macroscopic properties (e.g., combining sodium metal and chlorine gas results in a substance with different macroscopic properties compared to the reactants).
• Students identify and describe evidence to construct the explanation, including evidence (e.g., from a data table, two opposing models) of a pattern that demonstrates the macroscopic properties for ionic and covalently bonded substances.
• Student will explain type of bond in a certain substance based on physical, chemical, and macroscopic properties.
  ○ Ionic bonds result in crystal lattice structures.
  ○ Covalent bonds result in molecules with varying macroscopic properties.	

Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS1.A.5
Core Idea	**Matter and Its Interactions**	
Component	**Structure and Properties of Matter**	
MLS	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.	

Expectation Unwrapped

[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. Students will organize reactants and products by bond energy.]

SCIENCE AND ENGINEERING PRACTICES

Developing and Using Models

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

DISCIPLINARY CORE IDEAS

Structure and Properties of Matter

- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.

Chemical Reactions

- Chemical processes, their rates, and whether energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

CROSSCUTTING CONCEPTS

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.

Content Limits/Assessment Boundaries

- Tasks should define the reactants and products.
- Tasks should provide students with the bond energies of products and reactants.

DOK Ceiling

3

Item Format

Selected Response
Constructed Response
Technology Enhanced

Possible Evidence	Sample Stems

• Students use evidence to develop a model in which they identify and describe the relevant components, including the following:
  ○ The chemical reaction, the system, and the surroundings under study
  ○ The bonds that are broken during the course of the reaction
  ○ The bonds that are formed during the course of the reaction
  ○ The energy transfer between the systems and their components or the system and surroundings
  ○ The transformation of potential energy from the chemical system interactions to kinetic energy in the surroundings (or vice versa) by molecular collisions
  ○ The relative potential energies of the reactants and the products.
• In the model, students include and describe the relationships between components, including the following:
  ○ The net change of energy within the system, resulting from bonds that are broken and formed during the reaction
  ○ The energy transfer between system and surroundings by molecular collisions
  ○ The total energy change of the chemical reaction system matched by an equal but opposite change of energy in the surroundings
  ○ The release or absorption of energy, depending on whether the relative potential energies of the reactants and products decrease or increase
• Students use the developed model to illustrate the following:
  ○ The energy change within the system is accounted for by the change in the bond energies of the reactants and products
  ○ Breaking bonds requires an input of energy from the system or surroundings, and forming bonds releases energy to the system and the surroundings
  ○ The energy transfer between systems and surroundings is the difference in energy between the bond energies of the reactants and the products
  ○ The overall energy of the system and surroundings is unchanged (conserved) during the reaction.
  ○ Energy transfer occurs during molecular collisions.
  ○ The relative total potential energies of the reactants and products can be accounted for by the changes in bond energy.	

Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS1.B.1
Core Idea	**Matter and Its Interactions**	
Component	**Chemical Reactions**	
MLS	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.	

Expectation Unwrapped	DOK Ceiling
	3
[Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules. Increasing the temperature increases the kinetic energy of particles. Increasing the number of reactants increases the number of collisions, which increases the reaction rate. Students will analyze data of reaction rates and explain how temperature or concentration affects the rate of reaction.] **SCIENCE AND ENGINEERING PRACTICES** **Constructing Explanations and Designing Solutions** ● Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. **DISCIPLINARY CORE IDEAS** **Chemical Reactions** ● Chemical processes, their rates, and whether energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. **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.	**Item Format** Selected Response Constructed Response Technology Enhanced

Content Limits/Assessment Boundaries	Sample Stems
● Tasks should focus on simple reactions with only two reactants. ● Tasks should provide students with all needed data. ● Tasks should not require students to complete any calculations.	

Possible Evidence

- Students construct an explanation that includes the idea that as the kinetic energy of colliding particles increases and the number of collisions increases, the reaction rate increases.
- Students identify and describe evidence to construct the explanation, including the following:
  - Evidence (e.g., from a data table) of a pattern that increases in concentration (e.g., a change in one concentration while the other concentration is held constant) increase the reaction rate, and vice versa
  - Evidence of a pattern that increases in temperature usually increase the reaction rate, and vice versa
- Students use and describe the following chain of reasoning that integrates evidence, facts, and scientific principles to construct the explanation:
  - Molecules that collide can break bonds and form new bonds, producing new molecules.
  - The probability of bonds breaking in the collision depends on the kinetic energy of the collision being sufficient to break the bond, since bond breaking requires energy.
  - Since temperature is a measure of average kinetic energy, a higher temperature means that molecular collisions will, on average, be more likely to break bonds and form new bonds.
  - At a fixed concentration, molecules that are moving faster also collide more frequently, so molecules with higher kinetic energy are likely to collide more often.
  - A high concentration means that there are more molecules in a given volume and thus more particle collisions per unit of time at the same temperature.

Stimulus Materials

Graphic organizers, diagrams, graphs, data tables, drawings

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS1.B.2
Core Idea	**Matter and Its Interactions**	
Component	**Chemical Reactions**	
MLS	Refine the design of a chemical system by specifying a change in conditions that would alter the amount of products at equilibrium.	

Expectation Unwrapped	DOK Ceiling / Item Format
[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. Students will change a variable and explain how that changes equilibrium.] **SCIENCE AND ENGINEERING PRACTICES** **Constructing Explanations and Designing Solutions** • Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations. **DISCIPLINARY CORE IDEAS** **Chemical Reactions** ● In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. **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. **CROSSCUTTING CONCEPTS** **Stability and Change** ● Much of science deals with constructing explanations of how things change and how they remain stable. Refer to Engineering, Technology, and Application of Science 9-12.ETS1.B1.	**DOK Ceiling** 3 **Item Format** Selected Response Constructed Response Technology Enhanced

<table>
<tr><td>

Content Limits/Assessment Boundaries

- Tasks should be limited to specifying the change in only one variable at a time. The changes are limited to pressure, concentration, volume, and temperature.
- Tasks should not require students to calculate equilibrium constants or concentrations.

</td><td rowspan="3">

Sample Stems

</td></tr>
<tr><td>

Possible Evidence

- Students identify and describe potential changes in a component of the given chemical reaction system that will increase the amounts of particular species at equilibrium. Students use evidence to describe the relative quantities of a product before and after changes to a given chemical reaction system (e.g., concentration increases, decreases, or stays the same), and will explicitly use Le Chatelier's principle, including the following:
  - How, at a molecular level, a stress involving a change to one component of an equilibrium system affects other components
  - That changing the concentration of one of the components of the equilibrium system will change the rate of the reaction (forward or backward) in which it is a reactant, until the forward and backward rates are again equal
  - A description of a system at equilibrium that includes the idea that both the forward and backward reactions are occurring at the same rate, resulting in a system that appears stable at the macroscopic level
- Students describe the prioritized criteria and constraints, and quantify each when appropriate. Examples of constraints to be considered are cost, energy required to produce a product, hazardous nature and chemical properties of reactants and products, and availability of resources.
- Students systematically evaluate the proposed refinements of the design of the given chemical system. The potential refinements are evaluated by comparing the redesign of the list of criteria (i.e., increased product) and constraints (e.g., energy required, availability of resources).
- Students refine the given designed system by making trade-offs that would optimize the designed system to increase the amount of product and describe the reasoning behind design decisions.

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Stimulus Materials

Graphic organizers, diagrams, graphs, data tables, drawings

</td></tr>
</table>

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS1.B.3</th></tr>
<tr><td>Core Idea</td><td colspan="2">Matter and Its Interactions</td></tr>
<tr><td>Component</td><td colspan="2">Chemical Reactions</td></tr>
<tr><td>MLS</td><td colspan="2">Use symbolic representations and mathematical calculations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.</td></tr>
<tr><td colspan="2"><u>Expectation Unwrapped</u>

[Clarification Statement: Emphasis is on conservation of matter and mass through balanced chemical equations, use of the mole concept and proportional relationships. Students will be able to demonstrate that the number of products equals the number of reactants.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Using Mathematics and Computational Thinking
● Use mathematical representations of phenomena to support claims.

<u>DISCIPLINARY CORE IDEAS</u>
Chemical Reactions
● The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

<u>CROSSCUTTING CONCEPTS</u>
Energy and Matter
● The total amount of energy and matter in closed systems is conserved.</td><td><u>DOK Ceiling</u>
3

<u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should avoid complex chemical reactions.</td><td><u>Sample Stems</u></td></tr>
</table>

Possible Evidence	

• Students identify and describe the relevant components in the mathematical representations:
  ○ Quantities of reactants and products of a chemical reaction in terms of atoms, moles, and mass
  ○ Molar mass of all components of the reaction
  ○ Use of balanced chemical equation
  ○ Identification of the claim that atoms, and therefore mass, are conserved during a chemical reaction.
  ○ Mathematical representations may include numerical calculations, graphs, or other pictorial depictions of quantitative information
• Students identify the claim to be supported.
• Students use the mole to convert between the atomic and macroscopic scale in the analysis.
• Given a chemical reaction, students use the mathematical representations to
  ○ predict the relative number of atoms in the reactants versus the products at the atomic molecular scale.
  ○ calculate the mass of any component of a reaction, given any other component.
• Students describe how the mathematical representations (e.g., stoichiometric calculations to show that the number of atoms or number of moles is unchanged after a chemical reaction where a specific mass of reactant is converted to product) support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
• Students describe how the mass of a substance can be used to determine the number of atoms, molecules, or ions using moles and mole relationships (e.g., macroscopic to atomic molecular scale conversion using the number of moles and Avogadro's number).	

Stimulus Materials	
Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS1.C.1</th></tr>
<tr><td>Core Idea</td><td colspan="2">Matter and Its Interactions</td></tr>
<tr><td>Component</td><td colspan="2">Nuclear Process</td></tr>
<tr><td>MLS</td><td colspan="2">Use symbolic representations 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.</td></tr>
<tr><td colspan="2" rowspan="2"><u>Expectation Unwrapped</u>

[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. Students can explain how the composition of the nucleus changes.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Developing and Using Models
● Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

<u>DISCIPLINARY CORE IDEAS</u>
Nuclear Processes
● Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.

<u>CROSSCUTTING CONCEPTS</u>
Energy and Matter
● In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.</td><td><u>DOK Ceiling</u>
3</td></tr>
<tr><td><u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should avoid quantitative calculations of energy released.</td><td><u>Sample Stems</u></td></tr>
</table>

Possible Evidence

- Students develop models in which they identify and describe the relevant components of the models, including
  - identification of an element by the number of protons.
  - the number of protons and neutrons in the nucleus before and after the decay.
  - the identity of the emitted particles (i.e., alpha, beta—both electrons and positrons, and gamma).
  - the scale of energy changes associated with nuclear processes, relative to the scale of energy changes associated with chemical processes.
- Students develop five distinct models to illustrate the relationships between components underlying the nuclear processes of 1) fission, 2) fusion, and 3) three distinct types of radioactive decay.
- Students include the following features, based on evidence, in all five models:
  - The total number of neutrons plus protons is the same both before and after the nuclear process, although the total number of protons and the total number of neutrons may be different before and after.
  - The scale of energy changes in a nuclear process is much larger (hundreds of thousands or even millions of times larger) than the scale of energy changes in a chemical process
- Students develop a fusion model that illustrates a process in which two nuclei merge to form a single, larger nucleus with a larger number of protons than were in either of the two original nuclei.
- Students develop a fission model that illustrates a process in which a nucleus splits into two or more fragments that each have a smaller number of protons than were in the original nucleus.
- In both the fission and fusion models, students illustrate that these processes may release energy and may require initial energy for the reaction to take place.
- Students develop radioactive decay models that illustrate the differences in type of energy (e.g., kinetic energy, electromagnetic radiation) and type of particle (e.g., alpha particle, beta particle) released during alpha, beta, and gamma radioactive decay, and any change from one element to another that can occur due to the process.
- Students develop radioactive decay models that describe that alpha particle emission is a type of fission reaction, and that beta emission and gamma emission are not.

Stimulus Materials

Graphic organizers, diagrams, graphs, data tables, drawings

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS2.A.1</th></tr>
<tr><td>Core Idea</td><td colspan="2">Motion and Stability: Forces and Interactions</td></tr>
<tr><td>Component</td><td colspan="2">Forces and Motion</td></tr>
<tr><td>MLS</td><td colspan="2">Analyze data to support and verify the concepts expressed by Newton’s 2nd law of motion, as it describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.</td></tr>
<tr><td colspan="2"><u>Expectation Unwrapped</u>

[Clarification Statement: Examples of data could include tables or graph of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force. Students can analyze diagrams with different variables to support relationship among mass, acceleration, and force.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
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.

<u>DISCIPLINARY CORE IDEAS</u>
Forces and Motion
● Newton’s second law accurately predicts changes in the motion of macroscopic objects.

<u>CROSSCUTTING CONCEPTS</u>
Cause and Effect
● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.</td><td><u>DOK Ceiling</u>
3

<u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

• Tasks should focus on one-dimensional motion and macroscopic objects moving and non-relativistic speeds
• Tasks should provide students with the formula: F = ma</td><td><u>Sample Stems</u></td></tr>
</table>

Possible Evidence	
● Students organize data that represent the net force on a macroscopic object, its mass (which is held constant), and its acceleration (e.g., via tables, graphs, charts, vector drawings). ● Students use tools, technologies, and/or models to analyze the data and identify relationships within the data sets, including the following: ○ A more massive object experiencing the same net force as a less massive object has a smaller acceleration, and a larger net force on a given object produces a correspondingly larger acceleration. ○ The result of gravitation is a constant acceleration on macroscopic objects as evidenced by the fact that the ratio of net force to mass remains constant. ● Students use the analyzed data as evidence to describe that the relationship between the observed quantities is accurately modeled across the range of data by the formula $a = F_{net}/m$ (e.g., double force yields double acceleration,). ● Students use the data as empirical evidence to distinguish between causal and correlational relationships linking force, mass, and acceleration. ● Students express the relationship $F_{net} = ma$ in terms of causality, namely that a net force on an object causes the object to accelerate.	
Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS2.A.2
Core Idea	**Motion and Stability: Forces and Interactions**	
Component	**Forces and Motion**	
MLS	Use mathematical representations to support and verify the concepts that the total momentum of a system of objects is conserved when there is no net force on the system.	

<u>Expectation Unwrapped</u>	**<u>DOK Ceiling</u>**
	3
[Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle. Students can mathematically demonstrate momentum before collision is equal to the momentum after collision in a closed system.] **<u>SCIENCE AND ENGINEERING PRACTICES</u>** **Using Mathematics and Computational Thinking** ● Use mathematical representations of phenomena to describe explanations. **<u>DISCIPLINARY CORE IDEAS</u>** **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. **<u>CROSSCUTTING CONCEPTS</u>** **Systems and System Models** ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.	**<u>Item Format</u>** Selected Response Constructed Response Technology Enhanced
<u>Content Limits/Assessment Boundaries</u>	**<u>Sample Stems</u>**
● Tasks should focus on a system of two macroscopic bodies moving in one dimension. ● Tasks should not require students to calculate the net force of a system.	

Possible Evidence	
• Students clearly define the system of the two interacting objects that is represented mathematically, including boundaries and initial conditions. • Students identify and describe the momentum of each object in the system as the product of its mass and its velocity, p = mv (p and v are restricted to one-dimensional vectors), using the mathematical representations. • Students identify the claim, indicating that the total momentum of a system of two interacting objects is constant if there is no net force on the system. • Students use the mathematical representations to model and describe the physical interaction of the two objects in terms of the change in the momentum of each object as a result of the interaction. • Students use the mathematical representations to model and describe the total momentum of the system by calculating the vector sum of momenta of the two objects in the system. • Students use the analysis of the motion of the objects before the interaction to identify a system with essentially no net force on it. • Based on the analysis of the total momentum of the system, students support the claim that the momentum of the system is the same before and after the interaction between the objects in the system, so that momentum of the system is constant. • Students identify that the analysis of the momentum of each object in the system indicates that any change in momentum of one object is balanced by a change in the momentum of the other object, so that the total momentum is constant.	
Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS2.A.3</th></tr>
<tr><td>Core Idea</td><td colspan="2">Motion and Stability: Forces and Interactions</td></tr>
<tr><td>Component</td><td colspan="2">Forces and Motion</td></tr>
<tr><td>MLS</td><td colspan="2">Apply scientific principles of motion and momentum to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.</td></tr>
<tr><td colspan="2" rowspan="2"><u>Expectation Unwrapped</u>

[Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute. Student can defend an argument using prior knowledge of relationship between force and momentum.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Constructing Explanations and Designing Solutions
● Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.

<u>DISCIPLINARY CORE IDEAS</u>
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.

<u>CROSSCUTTING CONCEPTS</u>
Cause and Effect
● Systems can be designed to cause a desired effect.</td><td><u>DOK Ceiling</u>
3</td></tr>
<tr><td><u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should focus on qualitative evaluations.
● Tasks should not require students to complete any mathematical calculations.</td><td><u>Sample Stems</u></td></tr>
</table>

Possible Evidence	
• Students design a device that minimizes the force on a macroscopic object during a collision. In the design, students ○ incorporate the concept 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 ($F\Delta t = m\Delta v$). ○ explicitly make use of the principle above so that the device has the desired effect of reducing the net force applied to the object by extending the time the force is applied to the object during the collision. • In the design plan, students describe the scientific rationale for their choice of materials and for the structure of the device. • Students describe and quantify (when appropriate) the criteria and constraints, along with the trade-offs implicit in these design solutions. Examples of constraints to be considered are cost, mass, the maximum force applied to the object, and requirements set by society for widely used collision-mitigation devices (e.g., seatbelts, football helmets). • Students systematically evaluate the proposed device design or design solution, including describing the rationales for the design and comparing the design to the list of criteria and constraints. • Students test and evaluate the device based on its ability to minimize the force on the test object during a collision. Students identify any unanticipated effects or design performance issues that the device exhibits. • Students use the test results to improve the device performance by extending the impact time, reducing the device mass, and/or considering cost-benefit analysis.	
Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS2.B.1
Core Idea	**Motion and Stability: Forces and Interactions**	
Component	**Types of Interaction**	
MLS	Use mathematical representations of Newton's law of gravitation to describe and predict the gravitational forces between objects.	

Expectation Unwrapped	**DOK Ceiling**
[Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational fields. Students can predict the gravitational force of an object based on a given ratio of mass to gravity.] **SCIENCE AND ENGINEERING PRACTICES** **Using Mathematics and Computational Thinking** ● Use mathematical representations of phenomena to describe explanations. **DISCIPLINARY CORE IDEAS** **Types of Interactions** ● Newton's law of universal gravitation provides the mathematical models to describe and predict the effects of gravitational forces between distant objects. ● Forces at a distance are explained by fields (i.e., gravitational, electric, magnetic) permeating space that can transfer energy through space. **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.	3 **Item Format** Selected Response Constructed Response Technology Enhanced
Content Limits/Assessment Boundaries	**Sample Stems**
● Tasks should be limited to a system with two objects. The mass and gravity of at least one of the objects is provided for students, and either the mass or gravity of the second object is provided for students. ● Tasks should provide students with the formula to calculate the force of gravity.	

Possible Evidence

- Students clearly define the system of the interacting objects that is mathematically represented.
- Using the given mathematical representations, students identify and describe the gravitational attraction between two objects as the product of their masses divided by the distance squared ($F_g = -G\,((m_1 m_2)/d^2)$), where a negative force is understood to be attractive.
- Students correctly use the given mathematical formulas to predict the gravitational force between objects or predict the electrostatic force between charged objects.
- Students describe that the mathematical representation of the gravitational field ($F_g = -G\,((m_1 m_2)/d^2)$), only predicts an attractive force because mass is always positive.
- Students use the given formulas for the forces as evidence to describe that the change in the energy of objects interacting through gravitational forces depends on the distance between the objects.

Stimulus Materials

Graphic organizers, diagrams, graphs, data tables, drawings

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS2.B.2</th></tr>
<tr><td rowspan="3">Core Idea
Component
MLS</td><td colspan="2">Motion and Stability: Forces and Interactions</td></tr>
<tr><td colspan="2">Types of Interaction</td></tr>
<tr><td colspan="2">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.</td></tr>
<tr><td colspan="2" rowspan="2"><u>Expectation Unwrapped</u>

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Planning and Carrying Out Investigations
● 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, quantity, 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.

<u>DISCIPLINARY CORE IDEAS</u>
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-PS2-4)
● Forces at a distance are explained by fields (gravitational, electric, 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.

Definitions of Energy
● “Electrical energy” may mean energy stored in a battery or energy transmitted by electric currents.

<u>CROSSCUTTING CONCEPTS</u>
Cause and Effect
● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.</td><td><u>DOK Ceiling</u>
3</td></tr>
<tr><td><u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should focus on designing and conducting investigations with given materials and tools. Students are not required to generate the materials and tools needed for the investigation.</td><td><u>Sample Stems</u></td></tr>
</table>

Possible Evidence	

• Students describe the phenomenon under investigation, which includes the following idea: that an electric current produces a magnetic field and that a changing magnetic field produces an electric current.
• Students develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data about 1) an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit and 2) an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit. Students describe why these effects seen must be causal and not correlational, citing specific cause-effect relationships.
• In the plan, students state whether the investigation will be conducted individually or collaboratively.
• Students measure and record electric currents and magnetic fields.
• Students evaluate their investigation, including
  ○ the accuracy and precision of the data collected, as well as limitations of the investigation.
  ○ the ability of the data to provide the evidence required.
• If necessary, students refine the investigation plan to produce more accurate, precise, and useful data such that the measurements or indicators of the presence of an electric current in the circuit and a magnetic field near the circuit can provide the required evidence.	

Stimulus Materials	
Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS3.A.1
Core Idea	**Energy**	
Component	**Definitions of Energy**	
MLS	Create a computational model to calculate the change in the energy of one component in a system when the changes in energy are known.	

Expectation Unwrapped

[Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.]

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.

DISCIPLINARY CORE IDEAS

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.

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, 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.
- The availability of energy limits what can occur in any system.

DOK Ceiling

3

Item Format

Selected Response
Constructed Response
Technology Enhanced

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CROSSCUTTING CONCEPTS

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.

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Content Limits/Assessment Boundaries

- Tasks should be limited to basic algebraic expressions or computations.
- Tasks should focus on thermal energy, kinetic energy, gravitational energy, magnetic energy, and electrical energy.
- Tasks should be limited to systems of two or three components.

Possible Evidence

- Students identify and describe the components to be computationally modeled, including the following:
  - The boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero)
  - The initial energies of the system's components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs—all expressed as a total amount of Joules in each component), including a quantification in an algebraic description to calculate the total initial energy of the system
  - The energy flows into or out of the system, including a quantification in an algebraic description with flow into the system defined as positive
  - The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system
- Students use the algebraic descriptions of the initial and final energy states of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy.
- Students use the 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.
- Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.
- Students identify and describe the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.

Stimulus Materials

Graphic organizers, diagrams, graphs, data tables, drawings

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Sample Stems

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</table>

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS3.A.2
Core Idea	**Energy**	
Component	**Definitions of Energy**	
MLS	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).	

Expectation Unwrapped	DOK Ceiling
	3
[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.] **SCIENCE AND ENGINEERING PRACTICES** **Developing and Using Models** ● Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. **DISCIPLINARY CORE IDEAS** **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 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. Refer to Engineering, Technology, and Application of Science 9-12.ETS1.B.2.	**Item Format** Selected Response Constructed Response Technology Enhanced

Content Limits/Assessment Boundaries	Sample Stems
• Tasks should provide students with all needed background information. Students are not required to generate their own phenomena. • Tasks should focus on how energy at the microscopic level is related to the macroscopic level.	

Possible Evidence
• Students develop models in which they identify and describe the relevant components, including the following:
  ○ All the components of the system and the surroundings, as well as energy flows between the system and the surroundings
  ○ Clear depictions of both a macroscopic and a molecular/atomic-level representation of the system
  ○ Depictions of the forms in which energy is manifested at two different scales:
    ▪ Macroscopic, such as motion, sound, light, thermal energy, potential energy, or energy in fields
    ▪ 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
• Students describe the relationships between components in their models, including the following:
  ○ 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).
  ○ Thermal energy includes both the kinetic and potential energies 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.
  ○ The total energy of the system and surroundings is conserved at a macroscopic and molecular/atomic level.
  ○ Chemical energy can be considered in terms of systems of nuclei and electrons in electrostatic fields (bonds).
  ○ As one form of energy increases, others must decrease by the same amount as energy is transferred among and between objects and fields.
• 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.
• 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.	

Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS3.A.3
Core Idea	**Energy**	
Component	**Definitions of Energy**	
MLS	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.	

<table>
<tr><td><u>Expectation Unwrapped</u>

[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.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Constructing Explanations and Designing Solutions
● Design, evaluate, and/or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations.

<u>DISCIPLINARY CORE IDEAS</u>
Definitions of Energy
● At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.

Energy in Chemical Processes
● Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

Defining and Delimiting an Engineering Problem
● Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.

<u>CROSSCUTTING CONCEPTS</u>
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.</td>
<td><u>DOK Ceiling</u>
3

<u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
</table>

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><td>

Content Limits/Assessment Boundaries

- Tasks should limit quantitative evaluations to total output for a given input.
- Tasks should provide students with all needed materials. Students are not required to generate their own materials or tools.

</td><td rowspan="3">

Sample Stems

</td></tr>
<tr><td>

Possible Evidence

- Students design a device that converts one form of energy into another form of energy.
- Students develop a plan for the device in which they
  - identify which scientific principles provide the basis for the energy conversion design;
  - identify the forms of energy that will be converted from one form to another in the designed system;
  - identify losses of energy by the design system to the surrounding environment;
  - describe the scientific rationale for choices of materials and structure of the device, including how student-generated evidence influenced the design; and
  - describe that this device is an example of how the application of scientific knowledge and engineering design can increase benefits for modern civilization while decreasing costs and risk.
- Students describe and quantify (when appropriate) prioritized criteria and constraints for the design of the device, along with the trade-offs implicit in these design solutions.
- Students build and test the device according to the plan.
- Students systematically and quantitatively evaluate the performance of the device against the criteria and constraints.
- Students use the results of the tests to improve the device performance by increasing the efficiency of energy conversion, keeping in mind the criteria and constraints, and noting any modifications in trade-offs.

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Stimulus Materials

Graphic organizers, diagrams, graphs, data tables, drawings

</td></tr>
</table>

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS3.B.1
Core Idea	**Energy**	
Component	**Conservation of Energy and Energy Transfer**	
MLS	Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperatures are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).	

Expectation Unwrapped	**DOK Ceiling**
	3
[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.]	**Item Format** Selected Response Constructed Response Technology Enhanced

SCIENCE AND ENGINEERING PRACTICES
Planning and Carrying Out Investigations
- 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, quantity, 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.

DISCIPLINARY CORE IDEAS
Conservation of Energy and Energy Transfer
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- 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).

Energy in Chemical Processes
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

CROSSCUTTING CONCEPTS
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.

Content Limits/Assessment Boundaries	Sample Stems
• Tasks should provide students with needed materials and tools. Students are not required to generate their own materials or tools.	
Possible Evidence	
• Students describe the purpose of the investigation, which includes the following idea: the transfer of thermal energy when two components of different temperatures are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). • Students develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data, including ○ the measurement of the reduction of temperature of the hot object and the increase in temperature of the cold object to show that the thermal energy lost by the hot object is equal to the thermal energy gained by the cold object and that the distribution of thermal energy is more uniform after the interaction of the hot and cold components. ○ the heat capacity of the components in the system (obtained from scientific literature). • In the investigation plan, students describe the following: ○ How a nearly closed system will be constructed, including the boundaries and initial conditions of the system ○ The data that will be collected, including masses of components and initial and final temperatures ○ The experimental procedure, including how the data will be collected, the number of trials, the experimental setup, and equipment required • Students collect and record data that can be used to calculate the change in thermal energy of each of the two components of the system. • Students evaluate their investigation, including ○ the accuracy and precision of the data collected, as well as the limitations of the investigation. ○ the ability of the data to provide the evidence required. • If necessary, students refine the plan to produce more accurate, precise, and useful data in that investigation. • If necessary, students refine the plan to produce more accurate, precise, and useful data that address the experimental question. • Students identify potential causes of the apparent loss of energy from a closed system (which should be zero in an ideal system) and adjust the design of the experiment accordingly.	

Stimulus Materials	
Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS3.C.1</th></tr>
<tr><td>Core Idea</td><td colspan="2">Energy</td></tr>
<tr><td>Component</td><td colspan="2">Relationship Between Energy and Forces</td></tr>
<tr><td>MLS</td><td colspan="2">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.</td></tr>
<tr><td colspan="2"><u>Expectation Unwrapped</u>

[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.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Developing and Using Models
● Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.

<u>DISCIPLINARY CORE IDEAS</u>
Relationship Between Energy and Forces
● When two objects interacting through a field change relative position, the energy stored in the field is changed.

<u>CROSSCUTTING CONCEPTS</u>
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.</td><td><u>DOK Ceiling</u>
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<u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should focus on systems containing two objects.</td><td><u>Sample Stems</u></td></tr>
</table>

Possible Evidence	

• 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:
  ○ The two objects in the system, including their initial positions and velocities (limited to one dimension).
  ○ The nature of the interaction (electric or magnetic) between the two objects.
  ○ The relative magnitude and the direction of the net force on each of the objects.
  ○ Representation of a field as a quantity that has a magnitude and direction at all points in space and which contains energy.
• 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.
• Students use the model to determine whether the energy stored in the field increased, decreased, or remained the same when the objects interacted.
• 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.
• 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.	

Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS4.A.1</th></tr>
<tr><td>Core Idea</td><td colspan="2">Waves and Their Applications in Technologies for Information Transfer</td></tr>
<tr><td>Component</td><td colspan="2">Wave Properties</td></tr>
<tr><td>MLS</td><td colspan="2">Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.</td></tr>
<tr><td colspan="2" rowspan="2"><u>Expectation Unwrapped</u>

[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 Earth.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Using Mathematics and Computational Thinking
● Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations.

<u>DISCIPLINARY CORE IDEAS</u>
Wave Properties
● The wavelength and frequency of a wave are related to one another by the speed at which the wave travels, which depends on the type of wave and the medium through which it is passing.

<u>CROSSCUTTING CONCEPTS</u>
Cause and Effect
● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.</td><td><u>DOK Ceiling</u>
3</td></tr>
<tr><td><u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should be limited to qualitative descriptions of algebraic relationships.
● Tasks should provide students with all needed formulas.</td><td><u>Sample Stems</u></td></tr>
</table>

Possible Evidence	

• Students identify and describe the relevant components in the mathematical representations:
  ○ Mathematical values for frequency, wavelength, and speed of waves traveling in various specified media
  ○ The relationships between frequency, wavelength, and speed of waves traveling in various specified media
• Students show that the product of the frequency and the wavelength of a particular type of wave in a given medium is constant and identify this relationship as the wave speed according to the mathematical relationship $v = f\lambda$.
• Students use the data to show that the wave speed for a particular type of wave changes as the medium through which the wave travels changes.
• Students predict the relative change in the wavelength of a wave when it moves from one medium to another (thus, different wave speeds), using the mathematical relationship $v = f\lambda$). Students express the relative change in terms of cause (different media) and affect (different wavelengths but same frequency).
• Using the mathematical relationship $v = f\lambda$, students assess claims about any of the three quantities when the other two quantities are known for waves travelling in various specified media.
• Students use the mathematical relationships to distinguish between cause and correlation with respect to the supported claims.	

Stimulus Materials	
Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS4.A.2</th></tr>
<tr><td>Core Idea</td><td colspan="2">Waves and Their Applications in Technologies for Information Transfer</td></tr>
<tr><td>Component</td><td colspan="2">Wave Properties</td></tr>
<tr><td>MLS</td><td colspan="2">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.</td></tr>
<tr><td colspan="2" rowspan="2"><u>Expectation Unwrapped</u>

[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.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Engaging in Argument from Evidence
● Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.

<u>DISCIPLINARY CORE IDEAS</u>
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.

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.

<u>CROSSCUTTING CONCEPTS</u>
Systems and System Models
● Models (e.g., physical, mathematical, computer) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.</td><td><u>DOK Ceiling</u>
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<tr><td><u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
</table>

Grades 9-12 PHYSICAL SCIENCE

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Content Limits/Assessment Boundaries

- Tasks should avoid using quantum theory.
- Tasks should provide students with all needed background information and evidence.

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Sample Stems

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Possible Evidence

- Students identify the given explanation that is to be supported by the claims, evidence, and reasoning to be evaluated, and that includes the following idea: 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.
- Students identify the given claims to be evaluated.
- Students identify the given evidence to be evaluated, including the following phenomena:
  - Interference behavior by electromagnetic radiation
  - The photoelectric effect
- Students identify the given reasoning to be evaluated.
- Students evaluate the given evidence for interference behavior of electromagnetic radiation to determine how it supports the argument that electromagnetic radiation can be described by a wave model.
- Students evaluate the phenomenon of the photoelectric effect to determine how it supports the argument that electromagnetic radiation can be described by a particle model.
- Students evaluate the given claims and reasoning for modeling electromagnetic radiation as both a wave and particle, considering the transfer of energy and information within and between systems, and why for some aspects the wave model is more useful and for other aspects the particle model is more useful to describe the transfer of energy and information.

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Stimulus Materials

Graphic organizers, diagrams, graphs, data tables, drawings

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</table>

Grades 9-12 PHYSICAL SCIENCE

Physical Sciences		9-12.PS4.B.1
Core Idea	**Waves and Their Applications in Technologies for Information Transfer**	
Component	**Electromagnetic Radiation**	
MLS	Communicate technical information about how electromagnetic radiation interacts with matter.	

Expectation Unwrapped	**DOK Ceiling**
[Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] **SCIENCE AND ENGINEERING PRACTICES** **Obtaining, Evaluating, and Communicating Information** ● Communicate 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). **DISCIPLINARY CORE IDEAS** **Energy in Chemical Processes** ● Solar cells are human-made devices that capture the Sun's energy and produce electrical energy. **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. **Electromagnetic Radiation** ● Photoelectric materials emit electrons when they absorb light of a high-enough frequency. **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. **CROSSCUTTING CONCEPTS** **Cause and Effect** ● Systems can be designed to cause a desired effect.	3 **Item Format** Selected Response Constructed Response Technology Enhanced

Grades 9-12 PHYSICAL SCIENCE

Content Limits/Assessment Boundaries	Sample Stems
• Tasks should include all needed background information. • Tasks are limited to qualitative information.	
Possible Evidence • Students use at least two different formats (e.g., oral, graphical, textual, mathematical) to communicate technical information and ideas, including fully describing at least two devices and the physical principles upon which the devices depend. One of the devices must depend on the photoelectric effect for its operation. Students cite the origin of the information as appropriate. • When describing how each device operates, students identify the wave behavior utilized by the device or the absorption of photons and production of electrons for devices that rely on the photoelectric effect and qualitatively describe how the basic physics principles were utilized in the design through research and development to produce this functionality (e.g., absorbing electromagnetic energy and converting it to thermal energy to heat an object; using the photoelectric effect to produce an electric current). • For each device, students discuss the real-world problem it solves or need it addresses and how civilization now depends on the device. • Students identify and communicate the cause and effect relationships that are used to produce the functionality of the device.	
Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	

Grades 9-12 PHYSICAL SCIENCE

<table>
<tr><th colspan="2">Physical Sciences</th><th>9-12.PS4.B.2</th></tr>
<tr><td>Core Idea
Component
MLS</td><td colspan="2">Waves and Their Applications in Technologies for Information Transfer
Electromagnetic Radiation
Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.</td></tr>
<tr><td colspan="2"><u>Expectation Unwrapped</u>

[Clarification Statement: Emphasis is on the idea that photons associated with 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.]

<u>SCIENCE AND ENGINEERING PRACTICES</u>
Obtaining, Evaluating, and Communicating Information
● Evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible.

<u>DISCIPLINARY CORE IDEAS</u>
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 (e.g., ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.

<u>CROSSCUTTING CONCEPTS</u>
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.

Refer to Engineering, Technology, and Application of Science 9-12.ETS1.A.1.</td><td><u>DOK Ceiling</u>
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<u>Item Format</u>
Selected Response
Constructed Response
Technology Enhanced</td></tr>
<tr><td colspan="2"><u>Content Limits/Assessment Boundaries</u>

● Tasks should include all needed published materials.
● Tasks should be limited to qualitative descriptions.</td><td><u>Sample Stems</u></td></tr>
</table>

Grades 9-12 PHYSICAL SCIENCE

Possible Evidence	
• Students obtain at least two claims proposed in published material (using at least two sources per claim) regarding the effect of electromagnetic radiation that is absorbed by matter. One of these claims deals with the effect of electromagnetic radiation on living tissue. • Students use reasoning about the data presented, including the energies of the photons involved (i.e., relative wavelengths) and the probability of ionization, to analyze the validity and reliability of each claim. • Students determine the validity and reliability of the sources of the claims. • Students describe the cause and effect reasoning in each claim, including the extrapolations to larger scales from cause and effect relationships of mechanisms at small scales (e.g., extrapolating from the effect of a particular wavelength of radiation on a single cell to the effect of that wavelength on the entire organism).	
Stimulus Materials Graphic organizers, diagrams, graphs, data tables, drawings	