

HS-PS1-1

Students who demonstrate understanding can:

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

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).</p> <ul style="list-style-type: none"> Use a model to predict the relationships between systems or between components of a system. 	<p>PS1.A: Structure and Properties of Matter</p> <ul style="list-style-type: none"> 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. 	<p>Patterns</p> <ul style="list-style-type: none"> Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

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

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

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

HS-PS1-2

Students who demonstrate understanding can:

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

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Constructing Explanations and Designing Solutions</p> <p>Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> 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. 	<p>PS1.A: Structure and Properties of Matter</p> <ul style="list-style-type: none"> 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. <p>PS1.B: Chemical Reactions</p> <ul style="list-style-type: none"> 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. 	<p>Patterns</p> <ul style="list-style-type: none"> Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

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

1	Articulating the explanation of phenomena								
	a Students construct an explanation of the outcome of the given reaction, including: <table border="1" style="width: 100%; border-collapse: collapse;"> <tbody> <tr> <td style="width: 20px;">i.</td> <td>The idea that the total number of atoms of each element in the reactant and products is the same;</td> </tr> <tr> <td>ii.</td> <td>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;</td> </tr> <tr> <td>iii.</td> <td>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; and</td> </tr> <tr> <td>iv.</td> <td>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).</td> </tr> </tbody> </table>	i.	The idea that the total number of atoms of each element in the reactant and products is the same;	ii.	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;	iii.	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; and	iv.	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).
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iv.	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).								
2	Evidence								
	a Students identify and describe* the evidence to construct the explanation, including: <table border="1" style="width: 100%; border-collapse: collapse;"> <tbody> <tr> <td style="width: 20px;">i.</td> <td>Identification of the products and reactants, including their chemical formulas and the arrangement of their outermost (valence) electrons;</td> </tr> <tr> <td>ii.</td> <td>Identification that the number and types of atoms are the same both before and after a reaction;</td> </tr> <tr> <td>iii.</td> <td>Identification of the numbers and types of bonds (i.e., ionic, covalent) in both the reactants and the products;</td> </tr> <tr> <td>iv.</td> <td>The patterns of reactivity (e.g., the high reactivity of alkali metals) at the macroscopic</td> </tr> </tbody> </table>	i.	Identification of the products and reactants, including their chemical formulas and the arrangement of their outermost (valence) electrons;	ii.	Identification that the number and types of atoms are the same both before and after a reaction;	iii.	Identification of the numbers and types of bonds (i.e., ionic, covalent) in both the reactants and the products;	iv.	The patterns of reactivity (e.g., the high reactivity of alkali metals) at the macroscopic
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iv.	The patterns of reactivity (e.g., the high reactivity of alkali metals) at the macroscopic								

		level as determined by using the periodic table; and
	v.	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 position in the periodic table.
3	Reasoning	
	a	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.
	b	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.
4	Revising the explanation	
	a	Given new evidence or context, students construct a revised or expanded explanation about the outcome of a chemical reaction and justify the revision.

HS-PS1-3

Students who demonstrate understanding can:

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

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Planning and Carrying Out Investigations Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.</p> <ul style="list-style-type: none"> Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. 	<p>PS1.A: Structure and Properties of Matter</p> <ul style="list-style-type: none"> The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. 	<p>Patterns</p> <ul style="list-style-type: none"> Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

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

1	Identifying the phenomenon to be investigated
	a Students describe* the phenomenon under investigation, which includes the following idea: the relationship between the measurable properties (e.g., melting point, boiling point, vapor pressure, surface tension) of a substance and the strength of the electrical forces between the particles of the substance.
2	Identifying the evidence to answer this question
	a Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data, including bulk properties of a substance (e.g., melting point and boiling point, volatility, surface tension) that would allow inferences to be made about the strength of electrical forces between particles.
	b Students describe* why the data about bulk properties would provide information about strength of the electrical forces between the particles of the chosen substances, including the following descriptions*:
	<ul style="list-style-type: none"> i. The spacing of the particles of the chosen substances can change as a result of the experimental procedure even if the identity of the particles does not change (e.g., when water is boiled the molecules are still present but further apart). ii. Thermal (kinetic) energy has an effect on the ability of the electrical attraction between particles to keep the particles close together. Thus, as more energy is added to the system, the forces of attraction between the particles can no longer keep the particles close together. iii. The patterns of interactions between particles at the molecular scale are reflected in the

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

HS-PS1-4

Students who demonstrate understanding can:

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

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.</p> <ul style="list-style-type: none"> Develop a model based on evidence to illustrate the relationships between systems or between components of a system. 	<p>PS1.A: Structure and Properties of Matter</p> <ul style="list-style-type: none"> 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. <p>PS1.B: Chemical Reactions</p> <ul style="list-style-type: none"> Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. 	<p>Energy and Matter</p> <ul style="list-style-type: none"> Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

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

1	Components of the model						
	a Students use evidence to develop a model in which they identify and describe* the relevant components, including: <table border="1" style="width: 100%; border-collapse: collapse;"> <tbody> <tr> <td style="padding-left: 20px;">i. The chemical reaction, the system, and the surroundings under study;</td> </tr> <tr> <td style="padding-left: 20px;">ii. The bonds that are broken during the course of the reaction;</td> </tr> <tr> <td style="padding-left: 20px;">iii. The bonds that are formed during the course of the reaction;</td> </tr> <tr> <td style="padding-left: 20px;">iv. The energy transfer between the systems and their components or the system and surroundings;</td> </tr> <tr> <td style="padding-left: 20px;">v. The transformation of potential energy from the chemical system interactions to kinetic energy in the surroundings (or vice versa) by molecular collisions; and</td> </tr> <tr> <td style="padding-left: 20px;">vi. The relative potential energies of the reactants and the products.</td> </tr> </tbody> </table>	i. The chemical reaction, the system, and the surroundings under study;	ii. The bonds that are broken during the course of the reaction;	iii. The bonds that are formed during the course of the reaction;	iv. The energy transfer between the systems and their components or the system and surroundings;	v. The transformation of potential energy from the chemical system interactions to kinetic energy in the surroundings (or vice versa) by molecular collisions; and	vi. The relative potential energies of the reactants and the products.
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vi. The relative potential energies of the reactants and the products.							
2	Relationships						
	a In the model, students include and describe* the relationships between components, including: <table border="1" style="width: 100%; border-collapse: collapse;"> <tbody> <tr> <td style="padding-left: 20px;">i. The net change of energy within the system is the result of bonds that are broken and formed during the reaction (Note: This does not include calculating the total bond energy changes.);</td> </tr> <tr> <td style="padding-left: 20px;">ii. The energy transfer between system and surroundings by molecular collisions;</td> </tr> <tr> <td style="padding-left: 20px;">iii. The total energy change of the chemical reaction system is matched by an equal but opposite change of energy in the surroundings (Note: This does not include calculating</td> </tr> </tbody> </table>	i. The net change of energy within the system is the result of bonds that are broken and formed during the reaction (Note: This does not include calculating the total bond energy changes.);	ii. The energy transfer between system and surroundings by molecular collisions;	iii. The total energy change of the chemical reaction system is matched by an equal but opposite change of energy in the surroundings (Note: This does not include calculating			
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iii. The total energy change of the chemical reaction system is matched by an equal but opposite change of energy in the surroundings (Note: This does not include calculating							

		the total bond energy changes.); and
	iv.	The release or absorption of energy depends on whether the relative potential energies of the reactants and products decrease or increase.
3	Connections	
	a	Students use the developed model to illustrate:
	i.	The energy change within the system is accounted for by the change in the bond energies of the reactants and products. (Note: This does not include calculating the total bond energy changes.)
	ii.	Breaking bonds requires an input of energy from the system or surroundings, and forming bonds releases energy to the system and the surroundings.
	iii.	The energy transfer between systems and surroundings is the difference in energy between the bond energies of the reactants and the products.
	iv.	The overall energy of the system and surroundings is unchanged (conserved) during the reaction.
	v.	Energy transfer occurs during molecular collisions.
	vi.	The relative total potential energies of the reactants and products can be accounted for by the changes in bond energy.

HS-PS1-5

Students who demonstrate understanding can:

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

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

<p style="text-align: center;">Science and Engineering Practices</p> <p>Constructing Explanations and Designing Solutions</p> <p>Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. 	<p style="text-align: center;">Disciplinary Core Ideas</p> <p>PS1.B: Chemical Reactions</p> <ul style="list-style-type: none"> Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. 	<p style="text-align: center;">Crosscutting Concepts</p> <p>Patterns</p> <ul style="list-style-type: none"> 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.
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Observable features of the student performance by the end of the course:

1	Articulating the explanation of phenomena										
	a 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.										
2	Evidence										
	a Students identify and describe* evidence to construct the explanation, including: <table border="1" style="margin-left: 20px;"> <tr> <td>i.</td> <td>Evidence (e.g., from a table of data) 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; and</td> </tr> <tr> <td>ii.</td> <td>Evidence of a pattern that increases in temperature usually increase the reaction rate, and vice versa.</td> </tr> </table>	i.	Evidence (e.g., from a table of data) 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; and	ii.	Evidence of a pattern that increases in temperature usually increase the reaction rate, and vice versa.						
i.	Evidence (e.g., from a table of data) 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; and										
ii.	Evidence of a pattern that increases in temperature usually increase the reaction rate, and vice versa.										
3	Reasoning										
	a Students use and describe* the following chain of reasoning that integrates evidence, facts, and scientific principles to construct the explanation: <table border="1" style="margin-left: 20px;"> <tr> <td>i.</td> <td>Molecules that collide can break bonds and form new bonds, producing new molecules.</td> </tr> <tr> <td>ii.</td> <td>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.</td> </tr> <tr> <td>iii.</td> <td>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.</td> </tr> <tr> <td>iv.</td> <td>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.</td> </tr> <tr> <td>v.</td> <td>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.</td> </tr> </table>	i.	Molecules that collide can break bonds and form new bonds, producing new molecules.	ii.	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.	iii.	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.	iv.	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.	v.	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.
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iv.	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.										
v.	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.										

HS-PS1-6

Students who demonstrate understanding can:

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

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Constructing Explanations and Designing Solutions</p> <p>Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none">Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	<p>PS1.B: Chemical Reactions</p> <ul style="list-style-type: none">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. <p>ETS1.C: Optimizing the Design Solution</p> <ul style="list-style-type: none">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. (<i>secondary</i>)	<p>Stability and Change</p> <ul style="list-style-type: none">Much of science deals with constructing explanations of how things change and how they remain stable.

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

1	Using scientific knowledge to generate the design solution
a	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: <ol style="list-style-type: none">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; andA 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.
2	Describing criteria and constraints, including quantification when appropriate
a	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.
3	Evaluating potential solutions
a	Students systematically evaluate the proposed refinements to the design of the given chemical

		system. The potential refinements are evaluated by comparing the redesign to the list of criteria (i.e., increased product) and constraints (e.g., energy required, availability of resources).
4	Refining and/or optimizing the design solution	
	a	Students refine the given designed system by making tradeoffs that would optimize the designed system to increase the amount of product, and describe* the reasoning behind design decisions.

HS-PS1-7

Students who demonstrate understanding can:

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

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Using Mathematics and Computational Thinking</p> <p>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.</p> <ul style="list-style-type: none">Use mathematical representations of phenomena to support claims.	<p>PS1.B: Chemical Reactions</p> <ul style="list-style-type: none">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.	<p>Energy and Matter</p> <ul style="list-style-type: none">The total amount of energy and matter in closed systems is conserved. <p>-----</p> <p>Connections to Nature of Science</p> <p>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</p> <ul style="list-style-type: none">Science assumes the universe is a vast single system in which basic laws are consistent.

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

1	Representation
a	Students identify and describe* the relevant components in the mathematical representations: <ul style="list-style-type: none">i. Quantities of reactants and products of a chemical reaction in terms of atoms, moles, and mass;ii. Molar mass of all components of the reaction;iii. Use of balanced chemical equation(s); andiv. Identification of the claim that atoms, and therefore mass, are conserved during a chemical reaction.
b	The mathematical representations may include numerical calculations, graphs, or other pictorial depictions of quantitative information.
c	Students identify the claim to be supported: that atoms, and therefore mass, are conserved during a chemical reaction.
2	Mathematical modeling
a	Students use the mole to convert between the atomic and macroscopic scale in the analysis.
b	Given a chemical reaction, students use the mathematical representations to <ul style="list-style-type: none">i. Predict the relative number of atoms in the reactants versus the products at the atomic molecular scale; andii. Calculate the mass of any component of a reaction, given any other component.
3	Analysis
a	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.
b	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).

HS-PS1-8

Students who demonstrate understanding can:

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

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.</p> <ul style="list-style-type: none"> Develop a model based on evidence to illustrate the relationships between systems or between components of a system. 	<p>PS1.C: Nuclear Processes</p> <ul style="list-style-type: none"> 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. 	<p>Energy and Matter</p> <ul style="list-style-type: none"> In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

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

1	Components of the model								
	a Students develop models in which they identify and describe* the relevant components of the models, including: <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20px;">i.</td> <td>Identification of an element by the number of protons;</td> </tr> <tr> <td>ii.</td> <td>The number of protons and neutrons in the nucleus before and after the decay;</td> </tr> <tr> <td>iii.</td> <td>The identity of the emitted particles (i.e., alpha, beta — both electrons and positrons, and gamma); and</td> </tr> <tr> <td>iv.</td> <td>The scale of energy changes associated with nuclear processes, relative to the scale of energy changes associated with chemical processes.</td> </tr> </table>	i.	Identification of an element by the number of protons;	ii.	The number of protons and neutrons in the nucleus before and after the decay;	iii.	The identity of the emitted particles (i.e., alpha, beta — both electrons and positrons, and gamma); and	iv.	The scale of energy changes associated with nuclear processes, relative to the scale of energy changes associated with chemical processes.
i.	Identification of an element by the number of protons;								
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iii.	The identity of the emitted particles (i.e., alpha, beta — both electrons and positrons, and gamma); and								
iv.	The scale of energy changes associated with nuclear processes, relative to the scale of energy changes associated with chemical processes.								
2	Relationships								
	a 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.								
	b Students include the following features, based on evidence, in all five models: <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20px;">i.</td> <td>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.</td> </tr> <tr> <td>ii.</td> <td>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.</td> </tr> </table>	i.	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.	ii.	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.				
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ii.	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.								
3	Connections								
	a 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.								
	b 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.								
	c 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.
d	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.
e	Students develop radioactive decay models that describe* that alpha particle emission is a type of fission reaction, and that beta and gamma emission are not.