High School Conceptual Progressions Model Course 1 - Bundle 4
Energy and Bonds

This is the fourth bundle of the High School Conceptual Progressions Model Course 1. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 4 Question: This bundle is assembled to address the question of "How do substances combine or change(react) to make new substances?"

Summary

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

Connections between bundle DCIs

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 (PS1.B as in HS-PS1-4 and HS-PS1-5). These ideas connect to the concepts that with knowledge of the chemical properties of the elements involved and because atoms are conserved, chemical reactions can be used to described and predicted (PS1.B as in HS-PS1-7).

The ideas of energy and chemical processes (PS1.B as in HS-PS1-4 and HS-PS1-5) also connect to the concept that although energy cannot be destroyed, it can be converted to less useful forms such as to thermal energy in the surrounding environment (PS3.D as in HS-PS3-4) enabling energy to be transported from one place to another and transferred between systems. This concept of energy and systems connects to the idea that uncontrolled systems always evolve toward more stable states, in other words, toward more uniform energy distribution (PS3.B as in HS-PS3-4).

Concepts of energy and chemical processes (PS1.B as in HS-PS1-4 and HS-PS1-5) and energy and systems connect (PS3.B as in HS-PS3-4) to the concepts of the stability of molecules and adding energy to take molecules apart (PS1.A as in HS-PS1-4). These concepts about energy connect to the process of photosynthesis, which coverts light energy to stored chemical energy by converting carbon dioxide plus water into sugars and released oxygen (LS1.C as in HS-LS1-5).

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of developing a model (HS-PS1-4 and HS-LS1-5), planning and conducting an investigation (HS-PS3-4), using mathematical representations (HS-PS1-7), and applying scientific principles (HS-PS1-5). Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Patterns (HS-PS1-5), Systems and System Models (HS-PS3-4), Energy and Matter (HS-PS1-4, HS-PS1-7, and HS-LS1-5). Many other CCC elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations	HS-PS1-4. **Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.** [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.] HS-PS1-5. **Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.** [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.] 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.] HS-PS3-4. **Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).** [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.] HS-LS1-5. **Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.** [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [Assessment Boundary: Assessment does not include specific biochemical steps.]
Example Phenomena	Cookies bake when I put them into a hot oven. Hand warmers heat up after I open the package.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. Students could *ask questions that can be investigated with available resources* [about the idea that] ***chemical processes and whether or not energy is stored or released*** [depends on] ***the collisions of molecules and the rearrangements of atoms into new molecules***. HS-PS1-5 **Developing and Using Models** • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. Students could *evaluate merits and limitations of two different models* [for how] ***the rates of chemical processes can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules***. HS-PS1-4 and HS-PS1-5

Additional Practices Building to the PEs (Continued)	**Planning and Carrying Out Investigations** • Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts. Students could *conduct an investigation [*to provide evidence that] ***atoms are conserved*** [during a chemical reaction]**.** HS-PS1-7 **Analyzing and Interpreting Data** • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. Students could *compare and contrast various types of data sets to examine consistency of measurements and observations* [of] ***chemical processes, their rates, and whether or not energy is stored or released.*** HS-PS1-5 **Using Mathematical and Computational Thinking** • Apply techniques of algebra and functions to represent and solve scientific and engineering problems. Students could *apply techniques of algebra and functions* ***to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system.*** HS-PS3-4 **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 constraints, and tradeoff considerations. Students could *design and refine a solution to a real-world problem* [caused by the fact that] ***uncontrolled systems always evolve toward more stable states***. HS-PS3-4 **Engaging in Argument from Evidence** • Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. Students could *construct, an argument based on data and evidence* [for how] ***a stable molecule has less energy than the same set of atoms separated***. HS-PS1-4 **Obtaining, Evaluating, and Communicating Information** • Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler, but still accurate terms. Students could *read scientific literature to obtain information and summarize* [how] ***the process of photosynthesis converts light energy into stored chemical energy.*** HS-LS1-5

Additional Crosscutting Concepts Building to the PEs	**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. Students could describe how *models could be used to simulate* ***the effects of changing temperature or concentration of particles***. HS-PS1-4 and HS-PS1-5 **Energy and Matter** • Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. Students could develop a model to describe that *energy cannot be created or destroyed, but only moves between one place and another place, between objects and/or fields, or between systems* and [for how] ***chemical processes 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***. HS-PS1-4 and HS-PS1-5 **Stability and Change** • Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. Students could describe *quantifications of change and rates of change* of ***chemical processes*** *over very short or very long periods of time*. HS-PS1-5
Additional Connections to Nature of Science	**Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena (SEP):** • Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. Students could describe how *models, mechanisms, and explanations collectively have served as tools* [scientists have used to describe] ***chemical processes, their rates, and whether or not energy is stored or released***. HS-PS1-5 **Science is a Way of Knowing (CCC):** • Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. Students could describe how *empirical standards, logical arguments, and skeptical review* [are essential in supporting claims, such as] ***the claim that atoms are conserved***. HS-PS1-7

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
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Develop a model based on evidence to illustrate the relationships between systems or between components of a system.	**PS1.A: 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. **PS1.B: Chemical Reactions** • 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.	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Observable features of 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:	
		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.
2	Relationships		
	a	In the model, students include and describe* the relationships between components, including:	
		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

			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*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

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

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

Disciplinary Core Ideas

PS1.B: Chemical Reactions

- 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.

Crosscutting Concepts

Patterns

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

Observable features of the student performance by the end of the course:			
1	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:	
		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:	
		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.

		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
Using Mathematics and Computational Thinking Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical representations of phenomena to support claims.	**PS1.B: 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.	**Energy and Matter** • The total amount of energy and matter in closed systems is conserved. - ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** • 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:	
		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); and
		iv.	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	
		i.	Predict the relative number of atoms in the reactants versus the products at the atomic molecular scale; and
		ii.	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-PS3-4

Students who demonstrate understanding can:

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

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

Science and Engineering Practices

Planning and Carrying Out Investigations

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

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

Disciplinary Core Ideas

PS3.B: 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).

PS3.D: 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.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe* the purpose of the investigation, which includes the following idea, that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).	
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:	
		i.	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; and
		ii.	The heat capacity of the components in the system (obtained from scientific literature).
3	Planning for the investigation		
	a	In the investigation plan, students describe*:	
		i.	How a nearly closed system will be constructed, including the boundaries and initial

		conditions of the system;
		ii. The data that will be collected, including masses of components and initial and final temperatures; and
		iii. The experimental procedure, including how the data will be collected, the number of trials, the experimental set up, and equipment required.
4	Collecting the data	
	a	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.
5	Refining the design	
	a	Students evaluate their investigation, including:
		i. 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 that address the experimental question.
	c	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.

HS-LS1-5

Students who demonstrate understanding can:

HS-LS1-5. **Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.** [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [*Assessment Boundary: Assessment does not include specific biochemical steps.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Use a model based on evidence to illustrate the relationships between systems or between components of a system.	**LS1.C: Organization for Matter and Energy Flow in Organisms** • The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Observable features of 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 relevant for illustrating that photosynthesis transforms light energy into stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen, including:	
		i.	Energy in the form of light;
		ii.	Breaking of chemical bonds to absorb energy;
		iii.	Formation of chemical bonds to release energy; and
		iv.	Matter in the form of carbon dioxide, water, sugar, and oxygen.
2	Relationships		
	a	Students identify the following relationship between components of the given model: Sugar and oxygen are produced by carbon dioxide and water by the process of photosynthesis.	
3	Connections		
	c	Students use the given model to illustrate:	
		i.	The transfer of matter and flow of energy between the organism and its environment during photosynthesis; and
		ii.	Photosynthesis as resulting in the storage of energy in the difference between the energies of the chemical bonds of the inputs (carbon dioxide and water) and outputs (sugar and oxygen).