HIGH SCHOOL CHEMISTRY: THERMOCHEMISTRY

Standards Bundle:

Standards are listed within the bundle. Bundles are created with potential instructional use in mind, based upon the potential for related phenomena that can be used throughout a unit.

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. (SEP: 2; DCI: PS1.A, PS1.B; CCC: Energy/Matter) [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-PS3-4 Plan and carry out an investigation to provide evidence for the Second Law of Thermodynamics. (SEP: 3; DCI: PS3.B, PS3.D; CCC: Systems) *[Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]*

HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. (SEP: 5; DCI: PS3.A, PS3.B; CCC: Systems) [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] *[Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]*

HS-ESS2-4 Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. (SEP: 2; DCI: ESS2.A, ESS2.B, PS$.A; CCC: Energy/Matter) [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] *[Assessment Boundary: Assessment of the results of climate changes is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.]*

Content Overview

This section provides a generic overview of the content or disciplinary core ideas as an entry point to the standards.

A change in energy accompanies nearly every chemical reaction. The amount of energy required to break bonds in a chemical reaction is often not the same energy that is released when forming new bonds. This difference in energy is the basis for endothermic and exothermic reactions. Total bond energies of reactants and products can be compared, and the conservation of energy can be documented.

Heat energy moves in one direction only. When two different components (whether solid, liquid, or gas) are combined in a closed system, the heat energy will transfer from more heat energy to less and will eventually provide an even distribution of energy. Investigations can be conducted in order to track this transfer of heat energy. Using the equation Q=cmT students can calculate the heat energy within a system. Students can use this equation when adding two liquids together of different temperatures or a solid into a liquid, both of different temperatures.

Many factors affect the input of energy and output of energy on Earth. These are changes in Earth's orbit/orientation of its axis, changes in the sun's energy output, tectonic activity and configuration of continents, ocean circulation, atmospheric composition (including water vapor and carbon dioxide), atmospheric circulation, volcanic activity, glaciation, vegetation cover, and human activities. The factors that affect Earth's energy inputs and outputs operate on various time scales. In addition to the differences in time scales, these factors are also either causal or correlational. Lastly, the net effect of all the competing factors on Earth change the climate.

Phenomena

Phenomena can be used at varying levels of instruction. One could be used to anchor an entire unit, while another might be more supplemental for anchoring just a unit. Please remember that phenomena should allow students to engage in the SEP and use the CCC/DCI to understand and explain the phenomenon.

- A metal spoon in a pot on the stove gets too hot to handle long before a wooden spoon in the same pot gets hot.
- Your desk has been in the classroom all year and so is "room temperature" yet the metal legs of the desk feel different to your touch than the plastic desktop.
- I left my shoes in the car. When walking to the pool I noticed that the asphalt road, concrete sidewalk, and wet concrete poolside feel different on my feet.
- The type and amount of insulation in the roof of a home are not the same as the type and amount of insulation in the walls.
- Bridges and overpasses often have metal zipper-looking areas on both sides.
- Shaking a container of sand for five minutes or more causes the temperature of the sand to increase.
- Dry ice is used to make a smokey scene at concerts.
- Sidewalks have cracks between the slabs.

Storyline

This section aims to decode not only the DCI connections but also the SEP and CCC in a detailed account of how they possibly fit together in a progression for student learning, including both rationale and context for the bundle.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models ● Develop a model based on evidence to illustrate the relationships between systems or between components of a system. **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, 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. **Using Mathematics and Computational Thinking** ● Create a computational model or simulation of a phenomenon, designed device, process, or 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 to take the molecule apart. **PS1.B: 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. **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, and 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. **PS3.A: Definitions of Energy** ● Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is because a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. **PS3.B: 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	**Energy/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. **Systems** ● 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. **Technology** ● Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.

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

Models can be used to diagram energy in different forms. A model, such as a diagram, graph, or drawing, can be used to illustrate the storage of energy in chemical bonds and the transfer of energy between particles and their surroundings during a chemical reaction. This net change in energy depends on changes in the total bond energies of reactants and products. Thermal energy is conserved through a system.

Investigations can be planned and conducted to provide evidence that the transfer of thermal energy happens within a closed system, illustrating the second law of thermodynamics. During this process, the appropriate tools to collect, analyze, and evaluate data can be selected. Data can be used to support explanations for the phenomena. Investigations can be evaluated to ensure variables are being controlled. Knowledge about energy can be applied to a real-world problem or scenario. Students can take the role of engineers and apply design practices to increase benefits and decrease costs and risks impacting the world today utilizing scientific knowledge regarding energy. They may also design, build, and refine a device that converts one form of energy into another form. These changes of energy and matter in a system can be described in terms of energy that flows into, out of, and within the system. Energy cannot be created or destroyed, therefore the energy within the system must remain constant.

A computational model of the transfer of energy from within a system between two liquids at different temperatures or between a liquid and solid at two different temperatures may be created. Technology can be used to illustrate the transfer of energy. When describing the system, the boundaries and initial conditions of the system must be clearly defined.

A model can be used to describe how variations in the flow of energy into and out of Earth's systems result in climate changes. Geoscience data can be analyzed to explain changing feedback and responsive processes in Earth's systems. The role of system changes on regional climates and explaining climate changes can be described using evidence of energy transfer into and out of Earth's systems.

Formative Assessment

Formative assessment is crucial because all learners benefit from timely and focused feedback from others. It promotes self-reflection, self-explanation, and social learning. It can also make learning more relevant. Each of the questions below might be used throughout the formative assessment process. Specific prompts may focus on individual practices, core ideas, or crosscutting concepts, but, together, the components need to support inferences about students' three-dimensional science learning as described in a given bundle, standard or lesson-level performance expectation.

SEP Developing and Using Models

- Develop a model that illustrates that the release or absorption of bond energy from chemical reactions is a result of the changes in total bond energy.
- Using models of atoms, illustrate the transfer of energy between them and their surroundings during chemical reactions.
- Using a model of a chemical reaction identify the transfer of energy within the system and surroundings.

- Using a graph, identify and compare the total bond energy of the reactants and the products.
- Using models, identify the role of forcings (solar irradiance, greenhouse gases, air particles), climate feedback (clouds, precipitation, greening of forests, ice albedo), and tipping points (ocean circulation, ice loss, methane release) on the Earth's climate.

SEP Planning and Carrying Out Investigations
- Plan and carry out an investigation using technology 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).
- Plan and carry out an investigation to collect evidence for the transfer of energy in exothermic and endothermic reactions.
- Plan and carry out an investigation to collect evidence for the transfer of energy in a chemical reaction into different forms (light, heat).

SEP Using Mathematics and Computational Thinking
- Create a computational model to calculate the total energy available in a system that can be transferred.
- Use Q=cmT to solve for any unknown variable when the other variables are known.
- Create a computational model showing the energy transfer between two systems with differing amounts of heat energy.
- Explain the meaning of the equation Q=cmT as it applies to chemical systems.

CCC Energy and Matter
- In terms of bond energies, in what situation would a chemical reaction release energy?
- How do variations in the flow of energy into and out of Earth's systems result in climate changes?
- How do humans can affect climate change?
- How can forcings lead to climate change?
- How can climate feedback lead to climate change?
- How can tipping points lead to climate change?

CCC Systems
- Diagram a positive feedback system and explain its effects on climate change.
- Diagram a negative feedback system and explain its effects on climate change.

CCC Technology
- What kind of technology is currently utilized to detect feedback and responsive processes that can affect our climate?
- What role can technology play in our lives by utilizing energy flow on Earth?

Performance Outcomes

These are statements of how students use knowledge and are similar to the standards in how they blend DCI, SEP, and CCC, but at a smaller grain size. These are potential outcomes for instruction as it plays out in lessons and activities in the classroom. It is important to also think of these as smaller outcomes that build toward the larger goal of mastering the standards.

- **Use evidence to develop a model to** identify and describe the bonds that are broken during the reaction, the bonds that are formed during the reaction, *and the energy transfer between the systems and their components or the system and surroundings.*
- **Use evidence to develop a model to** identify and describe the net change of energy *within the system* is the result of bonds that are broken and formed during the reaction.
- **Use evidence to develop a model** to identify and describe the transformation of potential energy from the *chemical system interactions* to kinetic energy *in the surroundings (or vice versa)* by molecular collisions.
- **Use evidence to develop a model to** identify and describe the relative potential energies of the reactants and the products.
- **Use evidence to develop a model to** illustrate that the total energy change of the *chemical reaction system* is matched by an equal but opposite change of energy *in the surroundings.*
- **Use a model to** illustrate the energy change within the system is accounted for by the change in the bond energies of the reactants and products.
- **Use a model to** illustrate breaking bonds requires an input of energy *from the system or surroundings and* forming bonds releases energy *to the system and the surroundings.*
- **Use a model to** illustrate the energy transfer *between systems and surroundings* is the difference in energy between the bond energies of the reactants and the products.
- **Use a model to** illustrate the overall energy *of the system and surroundings* is unchanged (conserved) during the reaction.
- **Plan and carry out an investigation to** show that 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*.
- **Develop a model to** illustrate the energy changes that occur *in the system* when a hot object is placed into a cooler solution.
- **Plan and carry out an investigation that** compares the various specific heats of metals and documents the masses of components and initial and final temperatures, the experimental procedure, including how the data will be collected, the number of trials, the experimental set-up, and the equipment required.
- **From a model,** identify potential causes of the *apparent loss of energy from a closed system* and **adjust the design of the experiment accordingly.**
- **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.
- **Using a model,** identify and describe the relationships between components of the given model and identify at least one factor that affects the input of energy, at least one factor that affects the output of energy, and at least one factor that affects the storage and redistribution of energy.
- **From a given model,** organize the factors from the given model into three groups: those that affect the input, the output, and the storage and redistribution of energy. Factors to classify include changes in Earth's orbit and the orientation of its axis, changes in the sun's energy output, configuration of continents resulting from tectonic activity, ocean circulation, atmospheric composition (including amount of water vapor and CO_2), atmospheric circulation, volcanic activity, glaciation, changes in extent or type of vegetation cover, and human activities.
- **From a given model,** provide an account of the net effect of all the competing factors in changing the climate.