ASPECT
Assessing Students' Progress on the Energy Concept

Hummingbird Food: AP33-6

High school – Energy and Chemical Reactions

TASK OVERVIEW

Students learn about a family that wants to attract more hummingbirds to their backyard. They read about how the family makes a solution of sucrose and water to feed the hummingbirds. They are tasked with modeling and explaining the energy changes that occur when the hummingbirds use the sucrose to get energy. The students are asked to select the correct diagram that represents the energy changes and are then asked to use the diagram to write their own explanations for why the energy changes occur.

TARGETED DCIs, SEPs, AND CCCs

Disciplinary core ideas

- PS1. B-H.4: 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-H.1: 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.

- PS3.C-H.1: When two objects interacting through a field change relative position, the energy stored in the field is changed.
- LS1.C-H.4: As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.

Science & engineering practices

- SEP2-H.1: 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.
- SEP6-H.3: Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Crosscutting concepts

- CC5-H.2: 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.
- CCC2-H.2: Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

Related Performance Expectations

- HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy. [*Clarification Statement*: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [*Assessment Boundary*: Assessment should not include identification of the steps or specific processes involved in cellular respiration.]
- 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.]

TASK PERFORMANCE EXPECTATION

Select a model that illustrates the energy changes during cellular respiration. *Using the model, explain how* energy flows into and out of the chemical reaction system.

LINK TO ONLINE VERSION

http://assess.bscs.org/i/test/603

Task

A family decides to put a hummingbird feeder in their backyard to attract more hummingbirds. Hummingbirds, like many animals, can get energy by eating sugars such as common table sugar known as sucrose. So, they fill the hummingbird feeder with a mixture of sucrose and water.

Hummingbird and feeder by Dorian Wallender on flickr (CC BY-SA 2.0)

Sucrose molecules inside the hummingbird will react with oxygen molecules that the hummingbird breathes in to form carbon dioxide molecules and water molecules. Your task is to explain the energy changes that occur when a hummingbird uses sucrose to get energy. First, think about the potential energy difference between the

reactant molecules (sucrose and oxygen) and the product molecules (carbon dioxide and water).

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1. In order for the hummingbird to get energy from this chemical reaction, how must the potential energy of the reactant molecules (sucrose and oxygen) compare to the potential energy of the product molecules (carbon dioxide and water)?

A. The reactant molecules must have more potential energy than the product molecules.

B. The reactant molecules must have less potential energy than the product molecules.

Next, you will make a diagram to illustrate the energy changes that take place during the chemical reaction. Below are several different diagrams. The bars in the diagrams represent the potential energy associated with the chemical reaction system at three times:

1) The initial state before oxygen and sucrose molecules have reacted,
2) A hypothetical intermediate state* where all the atoms are separated, and
3) The final state after carbon dioxide and water molecules have formed

(*During the reaction, atoms are separating and coming together to form new molecules. There is never a time when they are all completely separated at the same time. It is shown that way here to simplify the diagrams.)

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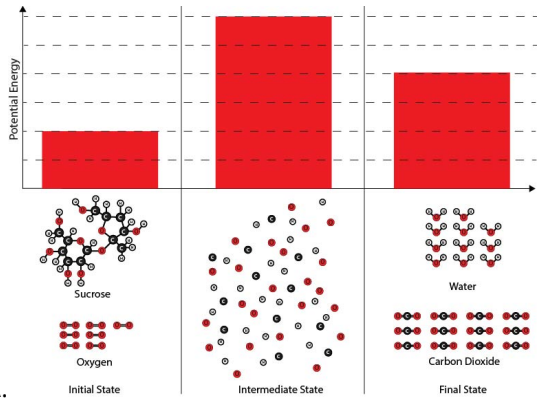
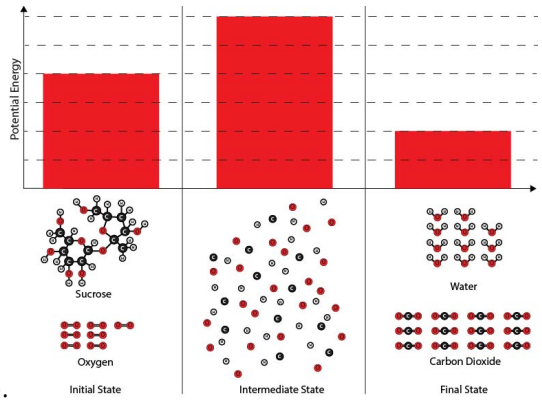
2. Which of the diagrams best shows the potential energy changes of the chemical reaction system during the reaction between sucrose and oxygen molecules?

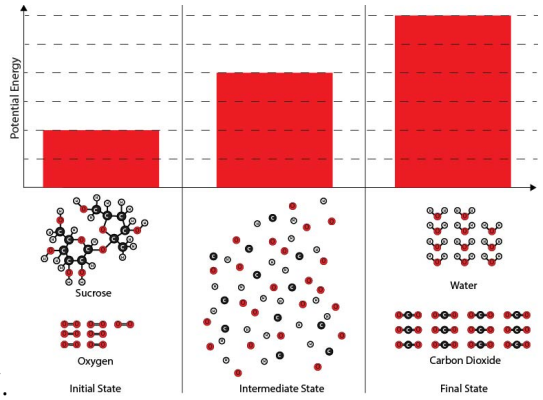
A.



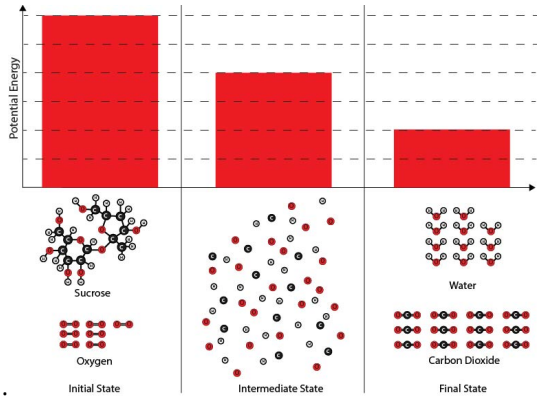
B.



C.



D.



Now, use your diagram to help explain the energy changes that occur during the chemical reaction between sucrose and oxygen.

3. How does the amount of energy in the chemical reaction system change when going from the initial state to the intermediate state? In your explanation, be sure to write about energy inputs or outputs to the chemical reaction system.

4. How does the amount of energy in the chemical reaction system change when going from the intermediate state to the final state? In your explanation, be sure to write about energy inputs or outputs to the chemical reaction system.

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5. Given that there are attractive forces between atoms that make up the molecules involved in the chemical reaction, explain why the energy of the chemical reaction system changes when the arrangement of atoms changes (for example, when going from molecules in the initial state to separated atoms in the intermediate state and going from the intermediate state to different molecules in the final state).

Alignment to Targeted DCIs, SEPs, and CCCs and Scoring Rubrics

QUESTION 1

In order for the hummingbird to get energy from this chemical reaction, how must the potential energy of the reactant molecules (sucrose and oxygen) compare to the potential energy of the product molecules (carbon dioxide and water)?

A. The reactant molecules have more potential energy than the product molecules.
B. The reactant molecules have less potential energy than the product molecules.

LEARNING GOAL

Learning Performance

- Identify the energy difference between the reactant molecules and product molecules of the chemical reaction between sucrose and oxygen.

Targeted DCIs, SEP, and CCCs

- LS1.C-H.4: As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.
- CC5-H.2: 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.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	A. The reactant molecules have more potential energy than the product molecules.

QUESTION 2

Which of the diagrams best show the potential energy changes of the chemical reaction system during the reaction between sucrose and oxygen molecules?

LEARNING GOAL

Learning Performance

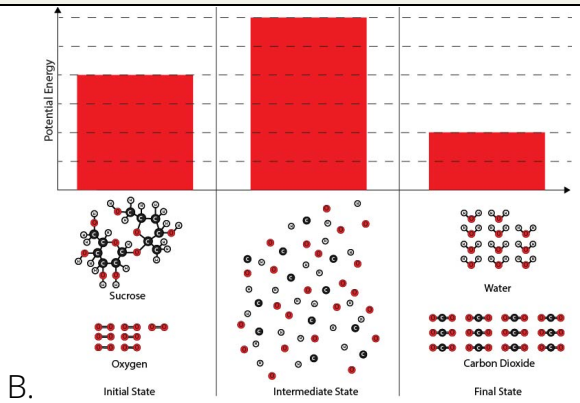
- Identify the model that correctly represents the energy differences between the initial state, intermediate state, and final state of the chemical reaction between sucrose and oxygen.

Targeted DCIs, SEP, and CCCs

- PS1.B-H.4: 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-H.1: 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.
- PS3.C-H.1: When two objects interacting through a field change relative position, the energy stored in the field is changed.
- SEP2-H.1: 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.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	 B.

QUESTION 3

How does the amount of energy in the chemical reaction system change when going from the initial state to the intermediate state? In your explanation, be sure to write about energy inputs or outputs to the chemical reaction system.

LEARNING GOAL

Learning Performance

- Write an explanation for the energy changes that occur when bonds break between the atoms of the reactants to form an intermediate state of separated atoms.

Targeted DCIs, SEP, and CCCs

- PS1.B-H.4: 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.
- SEP6-H.3: Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

- CC5-H.2: 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.

SCORING RUBRIC

Ideal Response

The amount of energy in the system increases when going from the initial state to the intermediate state because an energy input is needed to break the bonds and separate the atoms.

Elements of a Correct Response

Categories	Elements
Student makes a claim	• The amount of energy in the system will increase.
Student states or uses general science ideas	• A molecule has less energy (is more stable) than the same set of atoms separated (i.e., water and carbon dioxide molecules are more stable than separate carbon, hydrogen, and oxygen atoms). [*energy of molecules vs. atoms*] • Energy is required to break bonds between atoms (i.e., breaking the carbon/carbon bonds in sucrose requires energy). [*energy and bond breaking*]
Student uses crosscutting concepts the flow of energy	• There is an initial input of energy into the system when going from the initial state to the intermediate state.

Sample Student Responses

Student response	Scoring description
"The energy in the chemical reaction system changes when going from initial state to intermediate state when the sucrose and oxygen combine to bring it to the state of intermediate. "	Score = 0 This response does not indicate whether the amount of energy in the system increases or decreases, only that it changes.

"In the initial state, the energy is still pretty low. Once it gets to the intermediate state, the energy rises."	Score = 1 This response only indicates that the energy increases from the initial state to the intermediate state, not that there was an energy input to separate the atoms.
"It increases because the atoms have separated"	Score = 2 This response includes a claim that the energy increases and the idea that separated atoms have more energy than molecules.
"Energy increases since some energy input is required to break apart the molecules increasing the end energy output"	Score = 3 This response includes all the elements of the rubric.

QUESTION 4

How does the amount of energy in the chemical reaction system change when going from the intermediate state to the final state? In your explanation, be sure to write about energy inputs or outputs to the chemical reaction system.

LEARNING GOAL

Learning Performance

- Learning performance: Write an explanation for the energy changes that occur when bonds form between the atoms of the products.

Targeted DCIs, SEP, and CCCs

- PS1.B-H.4: 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.

- SEP6-H.3: Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
- CC5-H.2: 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.

SCORING RUBRIC

Ideal Response

The amount of energy in the system decreases when going from the intermediate state to the final state because there was an output of energy from the system when new bonds were formed.

Elements of a Correct Response

Categories	Elements
Student makes a claim	• The amount of energy in the system will decrease.
Student states or uses general science ideas	• A molecule has less energy (is more stable) than the same set of atoms separated (i.e., water and carbon dioxide molecules are more stable than separate carbon, hydrogen, and oxygen atoms). [*energy of molecules vs. atoms*] • Energy is released when bonds between atoms form (i.e., energy is released when hydrogen and oxygen atoms bond to form water molecules). [*energy and bond making*]
Student uses crosscutting concepts the flow of energy	• There is an output of energy from the system when going from the intermediate state to the final state.

Sample Student Responses

Student response	Scoring description
"Some energy is required to bond the molecules back together, increasing the energy output."	Score = 0 This response includes the misconception that energy is required to make bonds.
"The energy decreases between the intermediate state and the final state."	Score = 1 This response only indicates that the energy decreases from the intermediate state to the final state, not the idea that energy is released when bonds are formed.
"When it goes from the intermediate to final state, there is less in the final state because energy becomes an output and the energy amount decreases over time."	Score = 2 This response includes a claim that the energy decreases and the crosscutting concept that changes in energy can be described in terms of energy outputs.
"It decreases because in the intermediate state all the atoms are separate and when it goes into the final stage they all form new molecules and there is an output of energy"	Score = 3 This response includes all the elements of the rubric.

QUESTION 5

Given that there are attractive forces between atoms that make up the molecules involved in the chemical reaction, explain why the energy of the chemical reaction system changes when the arrangement of atoms changes (for example, when going from molecules in the initial state to separated atoms in the intermediate state and going from the intermediate state to different molecules in the final state).

LEARNING GOAL

Learning Performance

- Write an explanation for why the energy of a chemical reaction system changes when atoms rearrange using ideas about attractive forces between atoms.

Targeted DCIs, SEP, and CCCs

- PS1.B-H.4: 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-H.1: 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.
- PS3.C-H.1: When two objects interacting through a field change relative position, the energy stored in the field is changed.
- SEP6-H.3: Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
- CCC2-H.2: Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

SCORING RUBRIC

Ideal Response

Separating the atoms that make up a molecule requires increasing the distance between them. The attractive forces work to pull the atoms closer so the farther apart the atoms are the more potential energy the system has. This means that molecules have less energy/are more stable than the same set of atoms separated. Therefore, the amount of energy in a chemical reaction system depends on how the atoms are arranged.

Elements of a Correct Response

Categories	Elements
Student either states or uses a general science idea	• A molecule has less energy (is more stable) than the same set of atoms separated (i.e., water and carbon dioxide molecules are more stable than separate carbon, hydrogen, and oxygen atoms). [*energy of molecules vs. atoms*] • When two objects interacting through a force field change relative position, the energy stored in the field is changed (i.e., when the atoms get farther apart, there is more energy in the system). [*links energy and arrangement of atoms*]
Student uses reasoning to link science ideas to the claim	• The amount of energy in a chemical reaction system depends on how the atoms are arranged because the attractive forces pull the atoms together, which causes the potential energy of the system to be greater when the atoms are farther apart and less when the atoms are closer together. OR • The amount of energy in a chemical reaction system depends on how the atoms are arranged because the attractive forces work to pull the atoms together which causes molecules to have less energy/be more stable than the same set of atoms separated.

Sample Student Responses

Student response	Scoring description
"The energy of the chemical reaction system changes when the arrangement of atoms changes because the bonds hold energy and as the bonds are broken, they release energy thus showing why the intermediate state has more energy."	Score = 0 This response includes the misconception that energy is something contained in bonds.

"The atoms need more energy to break apart than when coming together."	Score = 1 This response implies the science idea that energy is needed to separate atoms in molecules.
"The energy of the chemical reactions change when the atoms change because if they are far apart, they will gain more potential energy whereas if they are more compact, they have less potential energy."	Score = 2 This response includes both science ideas about potential energy and reasoning.

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