ASPECt
Assessing Students' Progress on the Energy Concept

Natural Gas: AP47-4 (CR) & AP62-3 (MC)

High School - Energy and Chemical Reactions

TASK OVERVIEW

Students watch a video that shows a soap bubble filled with methane being popped by a lit candle and forming a large flame. The video shows a puzzling fact that such a small flame from the candle produced such a large flame from the bubble filled with methane. Students work through items that get them to think about the energy associated with the different configurations of atoms (reactant and product molecules and the separate atoms of those molecules). The students identify models that correctly represent the relative amounts of energy associated with the different atomic configurations and end with writing an explanation for why a little bit of energy was needed to start the reaction even though a lot of energy was released by the reaction. (Video from https://www.youtube.com/watch?v=j-jSJR_Yna0)

TARGETED DCIs, SEPs, AND CCCs

Disciplinary core ideas

- PS1.A-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 collisions of molecules and the

rearrangement of atoms into new molecules, with the consequent changes in the sum of all bond energy's in the set of molecules that are matched by changes in kinetic energy.

- PS2.B-H.3: Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.
- PS3.C-H.1: When two objects interacting through a field change relative position, the energy stored in the field is changed.

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.
- SEP2-H.4: Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.
- SEP6-H.4: Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion

Crosscutting concepts

- CCC5-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-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

Identify models that represent the relationship between the arrangement of atoms and the amount of energy in the chemical reaction system. *Apply scientific principles* about the energy of a stable molecule and separated atoms *to explain* the flow of energy into and out of a chemical reaction system.

Student difficulties and misconceptions that may affect students performance on the task

Students commonly think that energy is contained inside the bonds of molecules and, therefore, think that energy is released when bonds break. This may be due to a lack of understanding that there are attractive forces between atoms that must be overcome to separate the atoms. Students who think that energy is released when bonds break may think that forming bonds requires an input of energy.

LINK TO ONLINE VERSION

http://assess.bscs.org/i/test/604

Task

Natural gas is a fossil fuel that is found deep beneath the surface of the earth. It is made mostly of methane (CH_4). When natural gas is burned, methane reacts with oxygen (O_2) to form carbon dioxide (CO_2) and water (H_2O) as represented below.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

As methane reacts with oxygen, a flame is observed, and the temperature of the surroundings increases. The video below shows what happens when a soap bubble filled with methane gas reacts with oxygen in the air. The flame from a candle is used to start the reaction.

https://assess.bscs.org/items/media/uploads/image/ASPECt_3D/MethaneCombustion.mp4

Video from kosasihiskandarsjah on YouTube

A student notices that the flame from the methane-oxygen reaction is much bigger than the flame from the candle. The student wonders how such a small flame from the candle could produce such a large flame from the bubble filled with methane. The student knows that a flame is an indicator that energy is being released during the chemical reaction and that all chemical reactions involve breaking and forming bonds between atoms.

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1. To answer the question about why such a large flame was produced, the student starts to think about the energy changes that occur during the breaking and forming of bonds. Which of the following describes the energy changes associated with breaking and forming bonds during a chemical reaction?

   A. Energy is given off as bonds are broken, and energy is given off when bonds are formed.

   B. Energy is given off as bonds are broken, but energy is required to form bonds.

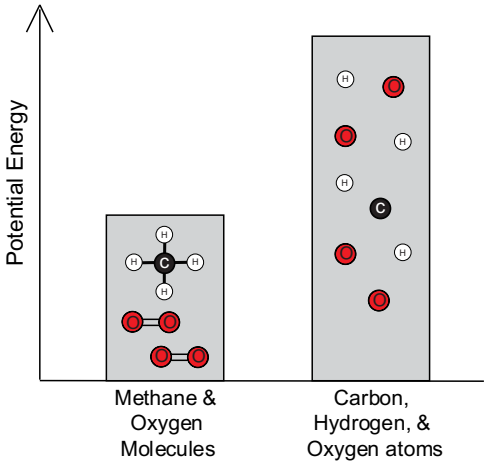
   C. Energy is required to break bonds, but energy is given off as bonds are formed.

   D. Energy is required to break bonds, and energy is required to form bonds.

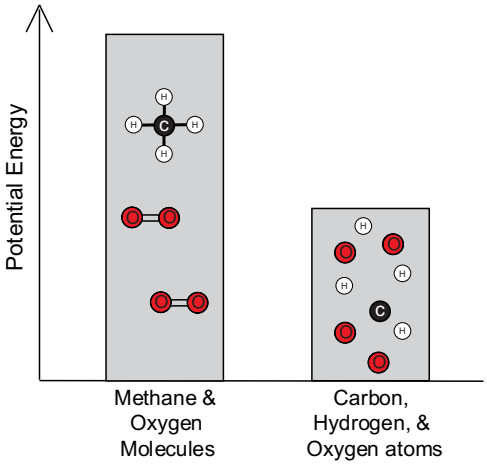
Next, he decides to draw models to help him think about the energy associated with the atoms and molecules in the chemical reaction system. He knows that to form the products, bonds between the atoms of the reactants need to break and new bonds need to form. So, he decides to model a hypothetical transition state where all the bonds are broken and the atoms are separated.

2. Which bar graph best represents the energy associated with the methane and oxygen molecules and with the separated carbon, hydrogen, and oxygen atoms?

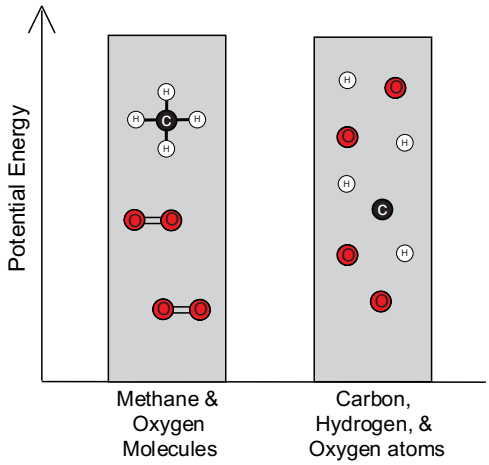
A.



B.



C.



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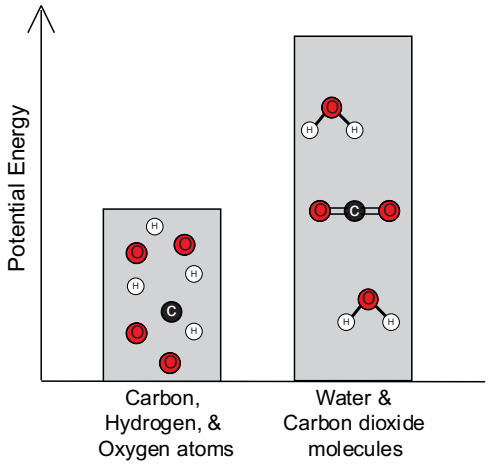
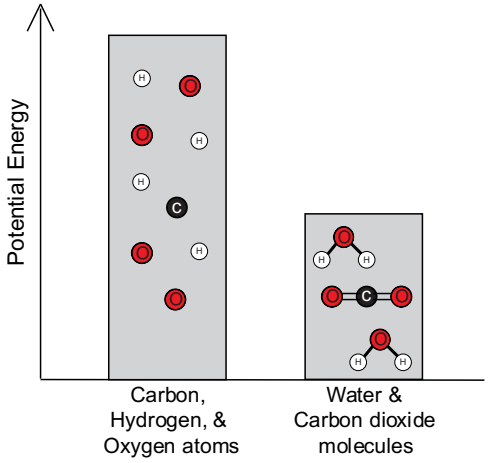
3. Which bar graph best represents the energy associated with the separated carbon, hydrogen, and oxygen atoms and with the water and carbon dioxide molecules?

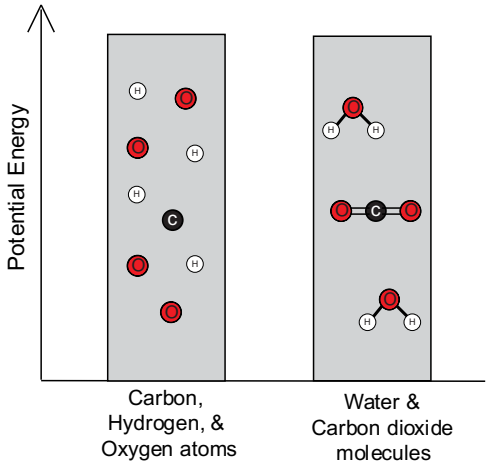
A.



B.



C.

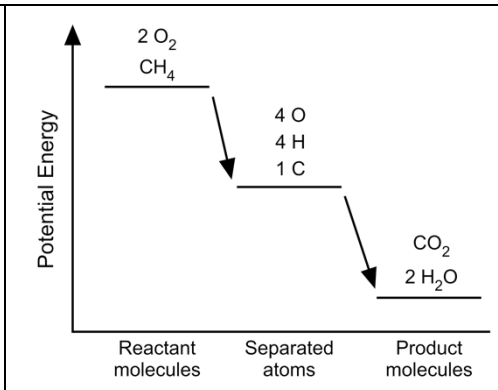


The student knows that there are attractive forces between the atoms that make up the molecules in the chemical reaction system.

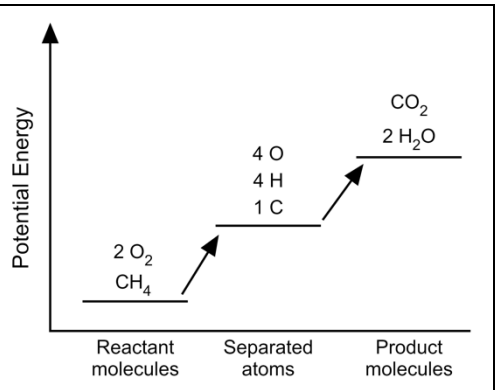
4. Using the idea that there are attractive forces between atoms, explain why the graphs you selected in Questions 2 and 3 best represent the energy associated with the different configurations of atoms. Be sure to link your explanation to the graphs you selected.

5. The student wants to use the graphs to make a simplified model that represents the energy changes that occur during the reaction. Which model represents the potential energy in the chemical reaction system for each configuration?

A



B



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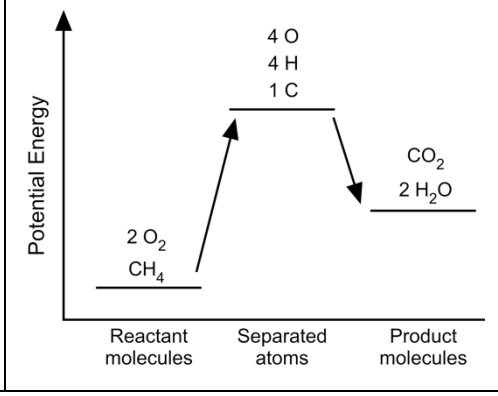

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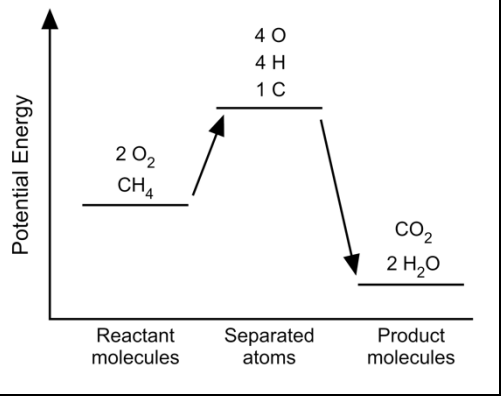
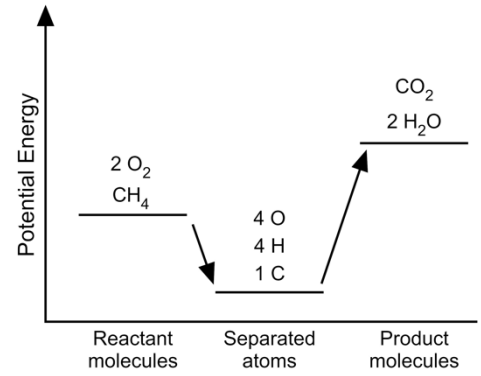
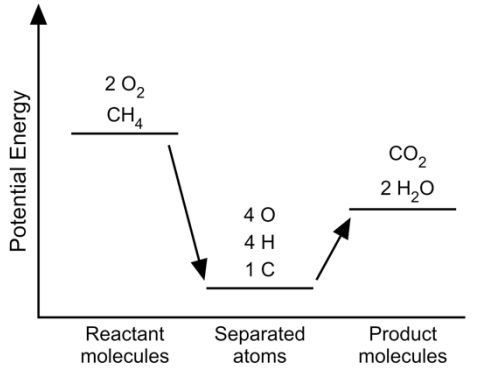


E		F	

----------Constructed-response Version of #6----------

6. Use ideas about energy and chemical reactions, the graphs you selected, and the student's observations to explain why a little bit of energy was needed to start the reaction even though a lot of energy was released by the reaction.

----------Multiple-choice Version of #6----------

6. Why was a little bit of energy from the candle needed to start the methane-oxygen reaction even though a lot of energy was released during the reaction?

   A. An input of energy was needed to start the reaction because bonds between the atoms of the product molecules need to be formed, and an initial input of energy is needed to form bonds.
   B. An input of energy was needed to start the reaction because bonds between the atoms of the reactant molecules must be broken for a reaction to occur, and an initial input of energy is required to break bonds.
   C. An input of energy was needed to start the reaction because energy is stored in the bonds between the atoms of the reactant molecules, and a small amount of energy is needed to trigger the release of that stored energy.
   D. An input of energy was needed to start the reaction because chemical reactions can only occur at high temperatures, and the flame from the candle heated the methane up to a temperature high enough for the reaction to occur.

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

QUESTION 1

To answer the question about why such a large flame was produced, the student starts to think about the energy changes that occur during the breaking and forming of bonds. Which of the following describes the energy changes associated with breaking and forming bonds during a chemical reaction?

A. Energy is given off as bonds are broken, and energy is given off when bonds are formed.

B. Energy is given off as bonds are broken, but energy is required to form bonds.

C. Energy is required to break bonds, but energy is given off as bonds are formed.

D. Energy is required to break bonds, and energy is required to form bonds.

LEARNING GOAL

Learning Performance

- Identify that energy is required to break bonds between atoms and energy is released when bonds form between atoms.

Targeted DCIs, SEP, and CCC

- PS1.A-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.

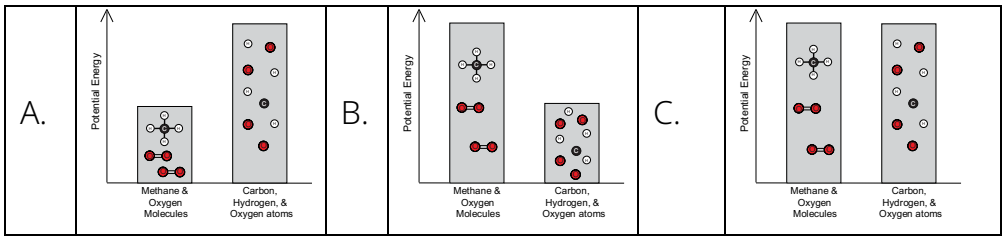
SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct prediction	C. Energy is required to break bonds, but energy is given off as bonds are formed.

QUESTION 2

Which bar graph best represents the energy associated with the methane and oxygen molecules and with the separated carbon, hydrogen, and oxygen atoms?



LEARNING GOAL

Learning Performance

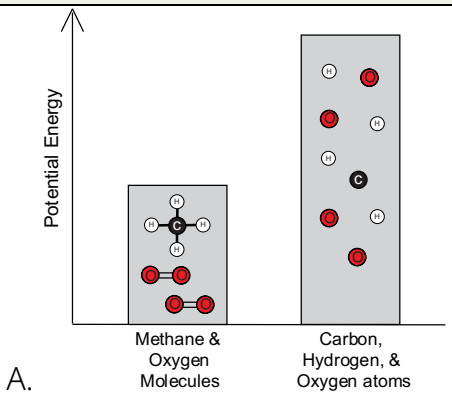
- Identify the bar graph that represents the relative amount of energy in the chemical reaction system before the reaction when only reactant molecules are present and during a hypothetical transition state when the atoms are separated.

Targeted DCIs, SEP, and CCC

- PS1.A-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.
- 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.

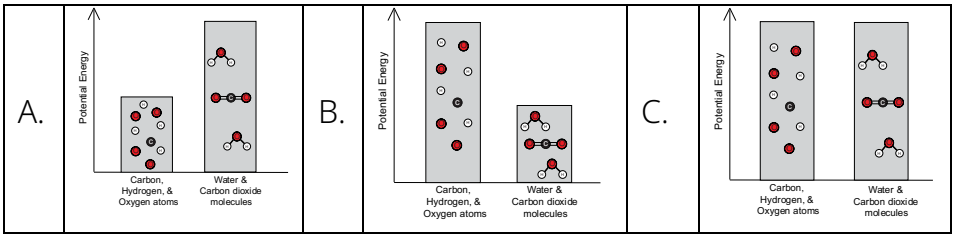
SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct model	

QUESTION 3

Which bar graph best represents the energy associated with the separated carbon, hydrogen, and oxygen atoms and with the water and carbon dioxide molecules?



LEARNING GOAL

Learning Performance

- Identify the bar graph that represents the relative amount of energy in the chemical reaction system during a hypothetical transition state when the atoms are separated and after the product molecules have formed.

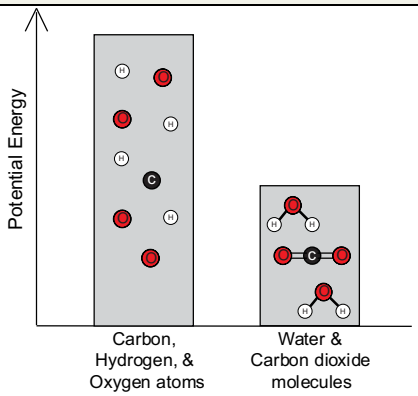
Targeted DCIs, SEP, and CCC

- PS1.A-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.

- 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 model	

QUESTION 4

Using the idea that there are attractive forces between atoms, explain why the graphs you selected in Questions 2 and 3 best represent the energy associated with the different configurations of atoms. Be sure to link your explanation to the graphs you selected.

LEARNING GOAL

Learning Performance

- Write an explanation for why the bar representing the energy associated with separated atoms is taller than the bar representing the reactant and product molecules formed using those atoms.

Targeted DCIs, SEP, and CCC

- PS1.A-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.
- PS2.B-H.3: Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.
- 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.
- 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 together, so the farther apart the atoms are the more potential energy the system has. This means that molecules to have less potential energy/are more stable than the same set of atoms separated. Therefore, the group of separated atoms should be represented as having more energy, that is a higher bar, than either the methane and oxygen molecules or the carbon dioxide and water molecules.

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. a water molecule has less energy than a set of two hydrogen atom and one oxygen atom). [Acceptable responses can include ideas such as the separated atoms have more energy (are less stable) than molecules.] [*energy of molecules vs. atoms*] • When two objects that are interacting through a field change relative position, the energy stored in the field is changed.

	(i.e. when the atoms get farther apart, there is more potential energy in the system). [*energy stored in fields*]
Student uses reasoning to link the general science idea to the graphs	• The bar representing the molecules should be shorter than the bar representing the separated atoms because attractive forces work to pull the atoms together which causes the potential energy of the system to change when the relative position of the atoms changes. OR • The bar representing the molecules should be shorter than the bar representing the separated atoms because attractive forces work to pull the atoms together which causes molecules to have less energy/be more stable than the same set of atoms when they are separated.

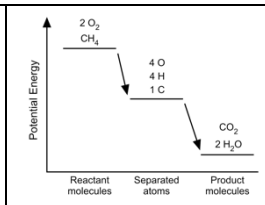
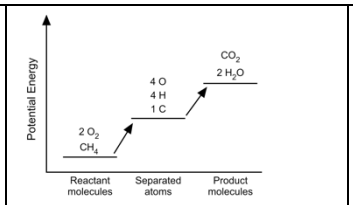
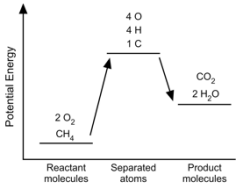
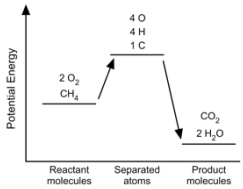
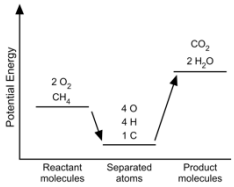
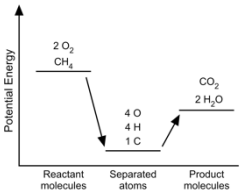
Sample Student Responses

Student response	Scoring description
"The graphs can't be equal on both bars. Energy is given off when bonds are broken."	Score = 0 The response does not include correct ideas about the energy associated with the different configurations of atoms. It includes the misconception that energy is released when bonds are broken.
"Since there are attractive forces between atoms, the individual atoms have a higher potential energy than the compounds."	Score = 1 The response is a statement of the science idea, but it does not use reasoning to link the science idea to the graphs.
"Because of the attractive forces between the atoms, the graphs that have the non-bonded atoms as having the most potential energy is correct. In both questions, the graphs that have the separate carbon,	Score = 2 The response includes both elements in the rubric.

hydrogen, and oxygen atoms have the most energy because they have not bonded to each other."	

QUESTION 5

The student wants to use the graphs to make a simplified model that represents the energy changes that occur during the reaction. Which model represents the potential energy in the chemical reaction system for each configuration?

A.		B.		C.	
D.		E.		F.	

LEARNING GOAL

Learning Performance

- Identify the graph that represents the relative amounts of energy in the system when the atoms are arranged into reactant and product molecules and when the atoms of those molecules are separated.

Targeted DCIs, SEP, and CCC

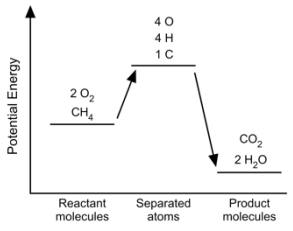
- PS1.A-H.4: A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.
- PS1.B-H.1: Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of collisions of molecules and the rearrangement of atoms into new molecules, with the consequent changes in

the sum of all bond energy's in the set of molecules that are matched by changes in kinetic energy.

- 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.
- SEP2-H.4:: Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct model	D. 

QUESTION 6

Use ideas about energy and chemical reactions, the graphs you selected, and the student's observations to explain why a little bit of energy was needed to start the reaction even though a lot of energy was released by the reaction.

LEARNING GOAL

Learning Performance

- Apply ideas about energy and chemical reactions to construct (or select) an explanation for why an energy-releasing chemical reaction would require an initial input of energy.

Targeted DCIs, SEP, and CCC

- PS1.A-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 collisions of molecules and the rearrangement of atoms into new molecules, with the consequent changes in the sum of all bond energy's in the set of molecules that are matched by changes in kinetic energy.
- SEP6-H.4: Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion
- CCC5-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

Energy-releasing chemical reactions always require an initial input of energy because in order for the reaction to occur, bonds between the atoms of the reactant molecules have to break. Breaking bonds requires an input of energy because there are attractive forces between atoms that make molecules more stable than separated atoms. When the atoms bond to form the product molecules, energy is released because the atoms are closer together. In the methane/oxygen reaction, the amount of energy released when new bonds formed was greater than the energy initially required to break the bonds. That's why the flame produced was so big. Even if the energy released is more than the input of energy, an initial input of energy is still required.

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., a water molecule has less energy than a set of two hydrogen atom and one oxygen atom). [Acceptable responses can include ideas such as the

	separated atoms have more energy (are less stable) than molecules.] [*energy of molecules vs. atoms*] • Energy is required to break bonds (i.e., an input of energy is required to break the bond between carbon and hydrogen atoms in the methane molecule). [*energy & bond breaking*]
Student uses reasoning to link observations and science ideas	• A little bit of energy was needed to start the reaction because the bonds between atoms of reactant molecules needed to break and breaking bonds requires an input of energy.
OR	
Student selects the correct explanation	B. An input of energy was needed to start the reaction because bonds between the atoms of the reactant molecules must be broken for a reaction to occur, and an initial input of energy is required to break bonds even though the net reaction releases energy.

Sample Student Responses

Student response	Scoring description
"there was more potential energy that was stored, so the reaction released that energy."	Score = 0 The response does not explain why an initial input of energy was needed.
"It is because when they break bonds it takes a lot of energy compared to start a bond/reaction."	Score = 1 The response includes the science idea about energy being required to break bonds.
"The reaction needs a little amount of energy because even the breaking of bonds requires energy."	Score = 2 The response links the energy needed to break bonds to the claim that the reaction needs an initial input of energy.

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