ASPECt
Assessing Students' Progress on the Energy Concept

Heating Water Bottles: AP50-4

High School – Thermal Energy

TASK OVERVIEW

In this task, students are shown that water in a plastic bottle suspended above a fire will boil without the bottle melting. They are asked several questions about the temperature and thermal energy of the bottle and to think about the transfer of energy between the fire, bottle, and water. Lastly, they are told that if the bottle is placed closer to the fire it will melt before the water boils and are asked to explain why the bottle melts in one case but doesn't in the other.

TARGETED DCIs, SEPs, AND CCCs

Disciplinary core ideas

- PS3.B-H.1 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.
- PS3.B-H.5 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.A-M.4 The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that

relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material.

- PS1.A-M.4 In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.

Science & engineering practices

- 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.
- SEP7-H.4 Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.

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.
- CC5-H.3: Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.
- CC7-H.2 Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.
- CC2-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-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.]

TASK PERFORMANCE EXPECTATION

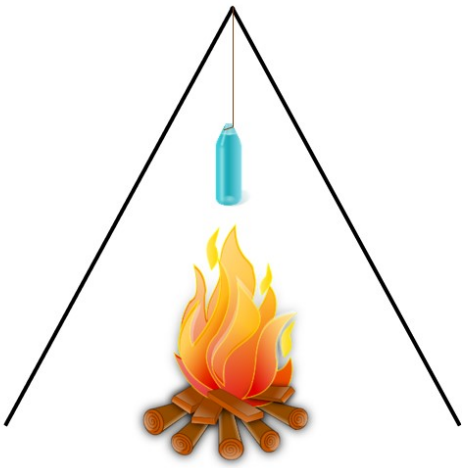
Describe the transfer of energy within a system and how the transfer of energy changes when one substance in the system changes state. *Explain why* an object melts in one case but not another using ideas about energy transfer and energy conservation.

LINK TO ONLINE VERSION

http://assess.bscs.org/i/test/597

Task

One way that campers boil water is to hang an open plastic bottle filled with water above a campfire and very slowly heat the bottle.



Eventually the water in the bottle begins to boil without melting the plastic that the bottle is made of. If the bottle remains above the campfire for too long, all the liquid water will boil away and become water vapor, and the bottle will start melting.

To make sense of their observations, the campers first think about the temperature and thermal energy of the plastic that makes up the bottle.

1. Given that the plastic bottle melts after the liquid water boils away, what can be said about the temperature of the plastic when the bottle is filled with liquid water compared to when it is filled with water vapor?

   A. The temperature of the plastic is higher when the bottle is filled with liquid water compared to when it is filled with water vapor.

   B. The temperature of the plastic is lower when the bottle is filled with liquid water compared to when it is filled with water vapor.

   C. The temperature of the plastic is the same whether the bottle is filled with liquid water or water vapor.

   D. More information is needed in order to say anything about the temperature of the plastic when the bottle is filled with liquid water or water vapor.

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2. What can be said about the amount of thermal energy the plastic has when the bottle is filled with liquid water compared to when it filled with water vapor?

   A. The plastic has more thermal energy when the bottle is filled with liquid water compared to when it is filled with water vapor.

   B. The plastic has less thermal energy when the bottle is filled with liquid water compared to when it is filled with water vapor.

   C. The plastic has the same amount of thermal energy when the bottle is filled with liquid water compared to when it is filled with water vapor.

   D. More information is need in order to say anything about the amount of thermal energy the plastic when the bottle is filled with liquid water or water vapor.

The campers also think about how energy is transferred between the fire, plastic of the bottle, and the water in the bottle. First, they consider the amount of energy transferred between the fire and the plastic.

3. Does the amount of energy being transferred from the fire to the plastic change after the liquid water becomes water vapor?

   A. Yes, the amount of energy being transferred from the fire to the plastic increases after the water becomes water vapor.

   B. Yes, the amount of energy being transferred from the fire to the plastic decreases after the water becomes water vapor.

C. No, the amount of energy being transferred from the fire to the plastic stays the same the whole time.

Next, they consider the amount of energy transferred between the plastic of the bottle and water inside the bottle.

4. Does the amount of energy being transferred from the plastic to the contents of the bottle change after the liquid water inside the bottle becomes water vapor?

   A. Yes, the amount of energy being transferred from the plastic to the contents of the bottle increases after the water becomes water vapor.

   B. Yes, the amount of energy being transferred from the plastic to the contents of the bottle decreases after the water becomes water vapor.

   C. No, the amount of energy being transferred from the plastic to the contents of the bottle stays the same the whole time.

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5. Use energy ideas to explain why the plastic melted after the liquid water boiled away and turned to water vapor but did not melt when the bottle was still filled with liquid water. Be sure to include reasoning based on the amounts of energy transferred to and away from the plastic.

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6. The campers put another plastic bottle filled with water over the fire but this time they put it closer to the fire. How will having the bottle closer to the fire affect the amount of energy being transferred from the fire to the plastic of the bottle?

   A. When the bottle is closer to the fire more energy will be transferred from the fire to the plastic than when it is farther from the fire.

   B. When the bottle is closer to the fire less energy will be transferred from the fire to the plastic than when it is farther from the fire.

   C. When the bottle is closer to the fire the same amount of energy will be transferred from the fire to the plastic than when it is farther from the fire.

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7. After placing the plastic bottle closer to the fire, the campers observe that the plastic of the bottle starts to melt before the liquid water becomes water vapor. Use energy ideas to explain why the plastic melted in this case but did not melt when the bottle was farther from the fire. Be sure to include reasoning based the amounts of energy transferred to and away from the plastic.

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

QUESTION 1

Given that the plastic bottle melts after liquid water becomes water vapor, what can be said about the temperature of the plastic when the bottle is filled with liquid water compared to when it filled with water vapor?

A. The temperature of the plastic must be higher when the bottle is filled with liquid water compared to when it is filled with water vapor.

B. The temperature of the plastic must be lower when the bottle is filled with liquid water compared to when it is filled with water vapor.

C. The temperature of the plastic must be the same whether the bottle is filled with liquid water or water vapor.

D. More information is needed in order to say anything about the temperature of the plastic when the bottle is filled with liquid water or water vapor.

LEARNING GOAL

Learning Performance

- Compare the temperature of the bottle before and after the water inside the bottle boiled away.

Targeted DCIs, SEP, and CCC

- PS1.A-M.6 The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	B. The temperature of the plastic must be lower when the bottle is filled with liquid water compared to when it is filled with water vapor.

QUESTION 2

What can be said about the amount of thermal energy the plastic has when the bottle is filled with liquid water compared to when it filled with water vapor?

A. The plastic has more thermal energy when the bottle is filled with liquid water compared to when it is filled with water vapor.

B. The plastic has less thermal energy when the bottle is filled with liquid water compared to when it is filled with water vapor.

C. The plastic has the same amount of thermal energy when the bottle is filled with liquid water compared to when it is filled with water vapor.

D. More information is need in order to say anything about the amount of thermal energy the plastic when the bottle is filled with liquid water or water vapor.

LEARNING GOAL

Learning Performance

- Compare the amount of thermal energy a bottle has before and after the water has boiled.

Targeted DCIs, SEP, and CCC

- PS3.A-M.4 The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a

system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	B. The plastic has less thermal energy when the bottle is filled with liquid water compared to when it is filled with water vapor.

QUESTION 3

Does the amount of energy being transferred from the fire to the plastic change after the liquid water becomes water vapor?

A. Yes, the amount of energy being transferred from the fire to the plastic increases after the water becomes water vapor.

B. Yes, the amount of energy being transferred from the fire to the plastic decreases after the water becomes water vapor.

C. No, the amount of energy being transferred from the fire to the plastic stays the same the whole time.

LEARNING GOAL

Learning Performance

- Compare the relative rates of energy transfer from the fire to the bottle before and after the water has boiled.

Targeted DCIs, SEP, and CCC

- PS3.A-H.4 These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a

combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

- PS3.B-H.1 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.
- 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	C. No, the amount of energy being transferred from the fire to the plastic stays the same the whole time.

QUESTION 4

Does the amount of energy being transferred from the plastic to the contents of the bottle change after the liquid water inside the bottle becomes water vapor?

A. Yes, the amount of energy being transferred from the plastic to the contents of the bottle increases after the water becomes water vapor.

B. Yes, the amount of energy being transferred from the plastic to the contents of the bottle decreases after the water becomes water vapor.

C. No, the amount of energy being transferred from the plastic to the contents of the bottle stays the same the whole time.

LEARNING GOAL

Learning Performance

- Compare the relative rates of energy transfer from the bottle to the water before and after the water has boiled.

Targeted DCIs, SEP, and CCC

- PS3.B-H.1 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.
- 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	B. Yes, the amount of energy being transferred from the bottle to the water decreases after the water becomes water vapor.

QUESTION 5

Use energy ideas to explain why the plastic melted after the liquid water boiled away and turned to water vapor but did not melt when the bottle was still filled with liquid water. Be sure to include reasoning based the amounts of energy transferred to and away from the plastic.

LEARNING GOAL

Learning Performance

- Construct an argument to support the description for how the transfer of energy among the fire, bottle, and water changes after the water boils away.

Targeted DCIs, SEP, and CCC

- PS3.A-H.4 These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.
- PS3.B-H.1 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.
- PS1.A-M.6 The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- PS3.A-M.4 The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material.
- PS3.C-M.1 When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.
- SEP7-H.4 Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence
- 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.
- CC2-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

The bottle melted after the liquid water turned to water vapor but did not melt when the bottle was filled with liquid water because there is less energy transferred from

the bottle to the water when the water is a gas than when the water is a liquid. This is because energy is transferred from the bottle to the water when the water molecules interact with the molecules that make up the bottle, and there are less interactions between the bottle and the water vapor than there are between the bottle and the liquid water. Because the amount of energy being transferred away from the bottle decreases, the bottle increases in energy after the liquid water turns to water vapor which causes it to melt.

Elements of a Correct Response

Categories	Elements
Student states or uses a general science idea	• The higher the temperature of an object is, the more energy it has (i.e., the hotter the bottle is the more energy it has or as the energy of the bottle increases, it melts). [*links temperature/melting and energy*] • The amount of energy transferred by light depends on the distance from the light source (i.e., if the distance between the fire and the bottle remains the same, the amount of energy transferred from the fire to the bottle remains the same). [*radiation*] • In a gas versus a liquid, molecules are farther apart and will have fewer interactions with their surrounds (i.e., The water vapor molecules will have fewer interactions with surface of the bottle than the liquid water molecules.) [*molecular spacing*] • When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object (i.e., the molecules that make up the plastic bottle transfer energy to the molecules of the water when they interact). [*links interactions and energy transfer*]
Student states or uses a general crosscutting concept	• The total change of energy in any system is equal to the total energy transferred into or out of the system (i.e., energy is flowing from the bottle to the water, so it doesn't melt). [*energy flows into or out of systems*] • Cause and effect relationships can be suggested by examining what is known about smaller scale mechanisms within the system (i.e., the bottle melts

	because there are less molecular-level interactions between the bottle and the water). [*cause and effect*]
Student uses reasoning based on valid science ideas or crosscutting concepts	• The amount of energy transferred from the bottle to the water decreases after the liquid water becomes a vapor because there are fewer water molecules in the bottle to which energy can be transferred. This increases the amount of energy the bottle has because while less energy is being transferred away from the bottle to the water, the amount of energy being transferred to the bottle from the fire doesn't change and causes the bottle to melt. [*Molecular level reasoning*] • The amount of energy transferred from the bottle to the water decreases when the water becomes vapor. This caused the amount of energy the bottle has to increase which caused the bottle to reach its melting point. [*substance level reasoning*]
Student does not use energy ideas but uses productive ideas about heat transfer	• When the water becomes vapor, less heat can be transferred from the bottle to the water causing the bottle to get hotter and melt. [*Heat transfer not energy*]

Sample Student Responses

Student response	Scoring description
"The plastic melted when it was not filled with water because it didn't have the extra layer of protection, when the water turned into water vapor the plastic had nothing left to protect it."	Score = 0 The response does not use energy ideas to explain the phenomenon.
"The energy being transferred to the plastic bottle also went to the water because the bottle was full with the water."	Score = 1 The response describes the flow of energy.

"Because when the water is still in the bottle there is more substance for the energy or heat to be dispersed throughout. When the water evaporates only the bottle is left for the same amount of energy."	Score = 2 The response uses reasoning with crosscutting concepts about the flow of energy to explain the phenomenon, but not science ideas.
"The amount of thermal energy being transferred into the plastic of the water bottle will remain constant as long as the bottle is still over the fire. However, when the bottle has water in it, much of the thermal energy transmitted on to the bottle will enter the water, allowing it to not melt. When there is no more water, there is less thermal energy being transferred out of the bottle, so it melts."	Score = 3 The response uses substance-level reasoning with science ideas about radiation and crosscutting concepts about the flow of energy.
"The plastic bottle was able to transfer the energy given to it to the water, heating it up. But after the water has turned into vapor, then the plastic doesn't give as much energy to the water, since it is now a gas and the molecules are further apart. So the plastic starts to melt because the fire is reaching a temperature the plastic cannot withstand."	Score = 3 The response uses molecular-level reasoning with science ideas about molecular spacing and crosscutting concepts about the flow of energy.

QUESTION 6

The campers put another plastic bottle filled with water over the fire but this time they put it closer to the fire. How will having the bottle closer to the fire affect the amount of energy being transferred from the fire to the plastic of the bottle?

A. When it is closer to the fire more energy will be transferred from the fire to the plastic than when it is farther from the fire.

B. When it is closer to the fire less energy will be transferred from the fire to the plastic than when it is farther from the fire.

C. When it is closer to the fire the same amount of energy will be transferred from the fire to the plastic than when it is farther from the fire.

LEARNING GOAL

Learning Performance

- Compare the amount of thermal energy a bottle has from the fire to the bottle before and after the water has boiled.

Targeted DCIs, SEP, and CCC

- PS3.A-H.4 These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	A. When it is closer to the fire more energy will be transferred from the fire to the bottle than when it is farther from the fire.

QUESTION 7

After placing the plastic bottle closer to the fire, the campers observe that the plastic of the bottle starts to melt before the liquid water becomes water vapor. Use energy ideas to explain why the plastic melted in this case but did not melt when the bottle was farther from the fire. Be sure to include reasoning based the amounts of energy transferred to and away from the plastic.

LEARNING GOAL

Learning Performance

- Explain why a water-filled bottle melts when it is heated more rapidly but doesn't melt when it is heated more slowly.

Targeted DCIs, SEP, and CCC

- PS3.A-M.5 Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- PS3.B-H.1 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.
- 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.
- CC2-M.2 Cause and effect relationships may be used to predict phenomena in natural or designed systems.

SCORING RUBRIC

Ideal Response

The bottle melted in this case but did not melt when the bottle was farther from the fire because there was more energy transferred to the bottle from the fire when the bottle was brought closer to the fire. The total amount of energy the bottle has is equal to the amount of energy transferred to it from the fire minus the amount of energy the bottle transfers to the water. When the bottle is closer to the fire the total amount of energy it has is larger than the amount it has when farther away from the fire, assuming the amount of water transferred away from the bottle to the water remains the same. This causes the bottle to melt.

Elements of a Correct Response

Categories	Elements
Student states or uses a general science idea	• The higher the temperature of an object is, the more energy it has (i.e., the temperature of the bottle increased, so it has more energy, or as the energy of the bottles increases it melts). [*links temperature/melting and energy*] • The amount of energy transferred by light depends on the distance from the light source (i.e., if the distance between the fire and the bottle decreases, the amount of energy transferred from the fire to the bottle increase). [*radiation*]
Student states or uses a cross-cutting concept	• The total change of energy in any system is equal to the total energy transferred into or out of the system (i.e., energy is flowing from the bottle to the water, so it doesn't melt). [*energy flows into or out of systems*]
Student uses reasoning based on valid science ideas or crosscutting concepts	• As the distance between the fire and the bottle decreases, the amount of energy transferred from the fire to the bottle increases. This causes the total amount of energy the bottle to increase, (assuming the amount of energy transferred away from the bottle stays the same). The increase in energy causes the bottle to melt.
Student does not use energy ideas but uses productive ideas about heat transfer	• The bottle melted before the liquid water becomes water vapor because heat from the fire is being transferred to the bottle faster than the bottle can transfer energy to the water.

Sample Student Responses

Student response	Scoring description
"Because the bottle is so close to the fire there is no longer that extra barrier."	Score = 0 The response does use energy ideas to explain the phenomenon.

"The energy from the fire gets stronger and stronger as you get closer, so if you get closer to the fire with water in the bottle the energy from the fire is too strong and makes the process faster."	Score = 1 The response includes the science idea that the amount of energy transferred increases as you get closer to the fire.
"Even with some of the thermal energy that is transmitted into the plastic of the bottle being transferred into the water, the increased proximity will make the bottle melt. This is because there is too much thermal energy at once, and the balance is disrupted."	Score = 2 The response includes the science idea that the amount of energy transferred increases as you get closer to the fire and crosscutting concepts about the flow of energy.
"When the bottle is closer to the fire more energy gets transferred to it because the energy can get to it quick since it is close so the bottle heats up faster and starts to melt before the water turns to vapor."	Score = 3 The response includes reasoning about science ideas and crosscutting concepts.

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