ASPECt
Assessing Students' Progress on the Energy Concept

Aluminum Bottles: AP44-6

Middle School – Thermal Energy

TASK OVERVIEW

Students are given a scenario where they are asked to decide on the best design for a bottle to keep samples of bacteria warm as they are transferred from one lab to another. They are asked to design and describe an experiment to collect data to determine which bottle design minimizes the amount of thermal energy that is transferred from the bottle's contents to the surroundings. Students are then asked to explain the temperature changes of the liquid inside the bottle and the air outside the bottle using ideas about thermal energy transfer between the molecules of the bottle's contents to the molecules outside the bottle. Lastly, students are told which bottle keeps its contents the warmest and asked to explain why that specific bottle design reduces the amount of thermal energy the most.

TARGETED DCIs, SEPs, AND CCCs

Disciplinary core ideas

- 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-M.2: The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- PS3.B-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones
- 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.
- PS3.A-M.1: Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.

Science & engineering practices

- SEP3-M.1: Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.
- SEP3-M.2: Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.
- SEP6-M.4: Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events.

Crosscutting concepts

- CC5-M.4: The transfer of energy can be tracked as energy flows through a designed or natural system.

Related Performance Expectations

- MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.* [*Clarification Statement*: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [*Assessment Boundary*: Assessment does not include calculating the total amount of thermal energy transferred.]
- MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. [*Clarification Statement*: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature

change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [*Assessment Boundary*: Assessment does not include calculating the total amount of thermal energy transferred.]

TASK PERFORMANCE EXPECTATION

Design an experiment to collect data on which design of a water bottle minimizes the amount of thermal energy that is transferred from the bottle's contents to the surroundings. *Explain* temperature changes using the relationships between temperature, the motion of molecules, and energy transfer. *Explain why* a specific bottle design minimizes the thermal energy transferred from the molecules inside the bottle to the molecules outside the bottle.

LINK TO ONLINE VERSION

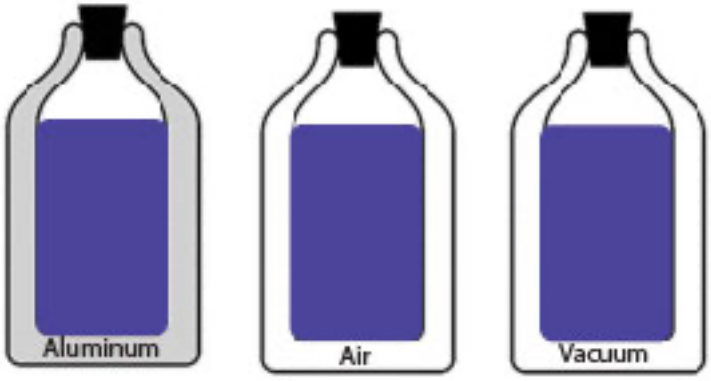
http://assess.bscs.org/i/test/596

Task

Aluminum bottles are used every day to keep hot liquids from getting cold and to keep cold liquids from getting warm. Below is a photo of an aluminum bottle that contains hot coffee and a photo of an aluminum bottle that contains liquid nitrogen, a very cold liquid used by scientists.

Photo of coffee from Pixabay and photo of liquid nitrogen by Cory Doctorow on Flickr

Aluminum bottles can be designed in different ways. Some aluminum bottles have walls made of solid aluminum, and some have walls that are hollow. Bottles that have hollow walls have the space between the walls filled with air or have had all the air removed. When all the air is removed so that there is no matter in the space, it is called a vacuum.



A biologist wants to move some bacteria in her lab to another lab. She doesn't want the bacteria to get cold while she moves them. She decides to put them and the warm liquid in which they live into an aluminum bottle.

She is interested in testing the three different bottles to see which one does the best job of minimizing the transfer of thermal energy from the warm liquid inside the bottle to the cooler air outside the bottle.

---

1. First, the biologist thinks about how she could measure the transfer of thermal energy from a liquid inside the bottle to the air outside the bottle. She puts warm water in one bottle and leaves the bottle in a refrigerator for five minutes. Which of the following would the biologists have to measure to calculate the change in energy of the water inside the bottle? Choose all that apply.

   A. The mass of the water

   B. The temperature of the water before it was put in the refrigerator

   C. The temperature of the water after it was left in refrigerator for five minutes

---

2. Next, she decides to design a controlled experiment that could help her figure out which of the three bottles would reduce the transfer of thermal energy the most. She has the following materials for her experiment:
   - One of each of the three different aluminum bottles
   - A refrigerator

- A scale
- A measuring cup
- Water
- A thermometer

Write a step-by-step procedure outlining a controlled experiment to determine which bottle reduces the transfer of thermal energy the most. Your procedure should include:

- Specific steps to follow
- What measurements should be made
- When measurements should be made

---

3. If you did your experiment and collected data, how could you use that data to figure out which bottle reduced the transfer of thermal energy the most?

---

4. How did you make sure that your experiment was a fair comparison of the different bottles?

---

5. Now the biologist starts to think about why the water inside the bottles cools down and the air around the bottles warms up. She knows that the main difference between the bottles is the number and type of molecules between the walls. So, she wants to focus her explanation on the movement of the molecules.

   Write a molecular-level explanation for why the water inside the bottles cools down and the air around the bottles warms up. Explain these temperature changes using what you know about the relationships between temperature, the motion of molecules, and energy transfer.

---

6. After doing the experiment, the biologist finds that the bottle with the vacuum keeps water warmer than the solid aluminum bottle or the hollow bottle filled with air.

   Why does the bottle with the vacuum keep the water inside the bottle warmer than the other bottles? Remember that the vacuum means that there are no molecules of air in the space between the walls of the bottle.

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

QUESTION 1

First, the biologist thinks about how she could measure the transfer of thermal energy from a liquid inside the bottle. She puts warm water in one bottle and leaves the bottle in a refrigerator for five minutes. Which of the following would the biologists have to measure to calculate the change in energy of the water inside the bottle? Choose all that apply.

A. The mass of the water

B. The temperature of the water before it was put in the refrigerator

C. The temperature of the water after it was left in refrigerator for five minutes

---

LEARNING GOAL

Learning Performance

- Identify that the mass of the liquid and the change in temperature need to be measured in order to calculate the change in thermal energy.

Targeted DCIs, SEP, and CCC

- PS3.B-M.2: The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- 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.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct answer choices	A. The mass of the liquid. B. The temperature of the liquid before it was put in the refrigerator. C. The temperature of the liquid after it was left in refrigerator for five minutes

---

QUESTION 2

Next, she decides to design a controlled experiment that could help her figure out which of the three bottles would reduce the transfer of thermal energy the most. She has the following materials for her experiment:

- One of each of the three different aluminum bottles
- A refrigerator
- A scale
- A measuring cup
- Water
- A thermometer

Write a step-by-step procedure outlining a controlled experiment to determine which bottle reduces the transfer of thermal energy the most. Your procedure should include:

- Specific steps to follow
- What measurements should be made
- When measurements should be made

LEARNING GOAL

Learning Performance

- Describe and design a controlled experiment to determine which container minimizes the transfer of thermal energy from its contents.

Targeted DCIs, SEP, and CCC

- PS3.B-M.2: The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. (Note: Student may use ideas from this DCI to decide what variables need to be controlled in their experiment.)
- PS3.B-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- SEP3-M.1: Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.

SCORING RUBRIC

Ideal Response

Put the same mass and temperature water in each bottle. Put the bottles in an environment colder than the water inside the bottles, for example a refrigerator. Measure the temperature of the water in each bottle over time.

- Step 1: Put the same mass and temperature water in each bottle. One example would be 100 grams of water at 100 °C in each bottle.
- Step 2: Put the bottles in an environment colder than the liquid inside the bottles. For example, if the water is 100 °C putting the bottles in a freezer at 0 °C would work.
- Step 3: Measure the temperature of the liquids in each bottle using a thermometer every 5 minutes.

Elements of a Correct Response

Categories	Elements
Student describes the independent variable	• The type of bottle used: hollow with air, hollow with vacuum, and solid aluminum.
Student describes controls	• The same starting temperature of water or measures the initial temperature. AND • The same amount/mass of water AND • Placing the bottles inside the refrigerator, whose temperature is constant, or explicitly refers to the environment should be the same for all the bottles. Note: Students who only describe an investigation with one bottle cannot get points for the controls.
Student describes what measurements will be recorded	• Measure the water temperature AND • Make at least two measurements at different time points

Sample Student Responses

Student response	Scoring description
"First, pour water into the cups and put them into the refrigerator for the same amount of time. Then, after that time is up, measure the amount of water and write results down."	Score = 0 The response does not describe the independent variable, all the controls, or the measurements that should be made.
"I would measure the mass of the water, the temperature of the water before and after."	Score = 1 The response includes the correct measurements to be made but did not describe all the controls or independent variable.

“For each bottle she should check the temperature of the liquid and the surrounding air first when she puts it in the fridge and then later after some time to see how the temperature changed."	Score = 2 The response describes the correct independent variable and measurements to be made but does not control for the mass of the liquid.
“1: put equal amounts of water in all of the aluminum bottles. 2: use the thermometer and measure the original temperature of the 3 aluminum bottles. 3: put all of the bottles inside of the fridge 4: decide a time for how long the bottles will be in the fridge 5: after designated time is over, take the bottles out of the fridge 6: measure the new temperature of the bottles 7: decisde which was the best bottle to transfer the bacteria”	Score = 3 The response describes a controlled experiment.

QUESTION 3

If you did your experiment and collected data, how could you use that data to figure out which bottle reduced the transfer of thermal energy the most?

LEARNING GOAL

Learning Performance

- Explain why data obtained in an experiment meet the goal of the experiment.

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-M.2: The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- SEP3-M.2: Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.
- CC5-M.4: The transfer of energy can be tracked as energy flows through a designed or natural system.

SCORING RUBRIC

Ideal Response

The temperature measurements will allow the biologist to look at the how much the temperature changes over time. Because temperature change is an indicator of how much thermal energy is transferred to or from the object, the water that has the smallest decrease in temperature transferred the smallest amount of energy to the air outside the bottle. Therefore, the bottle containing the water with the smallest change in temperature is the one that reduced the transfer of thermal energy the most.

Elements of a Correct Response

Categories	Elements
Student either states or uses a general science idea	• A change in the temperature of an object is a measure of the amount of thermal energy transferred to or away from the object (i.e. the change in water temperature indicates that the amount of energy the water has changed). [links change in temperature with energy transfer] Note: Students can get this point for saying that they would look at the changes in temperature. They don't have to explicitly say energy transfer as it is implied by the question.

Student uses reasoning to link the measurements to science ideas	• The bottle containing the liquid with the smallest temperature change is the bottle that reduced the transfer of thermal energy the most. Note: The reasoning contains the science idea so students who are awarded the reasoning point also get the science idea point.

Sample Student Responses

Student response	Scoring description
"by writing it down on a piece of paper and making multiple expiriments"	Score = 0 The response describes a procedure and not how the data could be used to figure out which bottle reduces the transfer of thermal energy.
"I would use my experiment to see if the bottle transferred thermal energy by checking the temperature of the liquid and the bottle."	Score = 1 The response uses the science idea linking temperature with energy, but it does not use reasoning to link the measurements to the science idea.
"whichever bottle had the closest temperature to it's original temperature was the bottle that reduced the transfer of thermal energy the most."	Score = 2 The response includes both elements.

QUESTION 4

How did you make sure that your investigation was a fair comparison of the different bottles?

LEARNING GOAL

Learning Performance

- Evaluate an experimental procedure to make sure the experiment is a fair comparison

Targeted DCIs, SEP, and CCC

- PS3.B-M.2: The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- SEP3-M.1: Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.

SCORING RUBRIC

Ideal Response

I kept the relevant variables, like the mass of water in the bottles, constant. The only variable that changed was the bottle design.

Elements of a Correct Response

Categories	Elements
Student explains how their experimental procedure is a fair comparison by discussing control of variables	• Control relevant variables such as the mass of water, the environment the bottles are in, or the starting temperature of the water. Note: Students may receive a point for saying the general principle or by providing an example of a variable that needs to be controlled.

Sample Student Responses

Student response	Scoring description
"Check temperature before and after."	Score = 0 The response describes the dependent variable, i.e., change in temperature, but not experimental controls.
"I eliminated any extra variables by making them controlled variables. This includes the starting temperature of the water, the amount of water, and the time spent in the refrigerator."	Score = 1 The response describes a fair comparison by discussing the need to control variables.

QUESTION 5

Now the biologist starts to think about why the water inside the bottles cools down and the air around the bottles warms up. She knows that the main difference between the bottles is the number and type of molecules between the walls. So, she wants to focus her explanation on the movement of the molecules.

Write a molecular-level explanation for why the water inside the bottles cools down and the air around the bottles warms up. Explain these temperature changes using what you know about the relationships between temperature, the motion of molecules, and energy transfer.

LEARNING GOAL

Learning Performance

- Explain why the temperatures of the liquid inside the bottle and the air outside the bottle change using ideas about relationships between temperature, the motion of molecules, and energy transfer.

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.A-M.1 Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- 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.
- SEP6-M.4 Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events
- CC5-M.4 The transfer of energy can be tracked as energy flows through a designed or natural system.

SCORING RUBRIC

Ideal Response

The water inside the bottles cools down and the air around the bottles warms up because energy is transferred from the liquid inside the bottle to the air outside the bottle. The molecules that make up the warm liquid inside the bottle collide with the molecules that make up the bottle. This collision transfers energy from the liquid to the bottle causing the molecules that make up the bottle to move faster. The same process happens between the bottle and the cool air outside the bottle such that energy from the warm liquid is gradually transferred to the air outside the bottle by the collision of molecules. The transfer of energy by collisions causes the molecules of the liquid inside the bottle to slow down and the molecules of air outside the bottle to speed up, which means the temperature of the liquid will decrease and the temperature of the air will increase.

Elements of a Correct Response

Categories	Elements
Student makes a claim that answers the question	• The liquid inside the bottle cools down and the air around the bottle warms up because energy is transferred (from the liquid in the bottle to the air outside the bottle).
Student either states or uses a general science idea	• The warmer a substance is the faster the molecules making up that substance are moving (i.e., when the molecules of the liquid inside the bottle slow down, the liquid decreases in temperature). [*links molecular speed and temperature*] • When objects interact/collide they transfer energy, causing a change in their motion (i.e., when the molecules of the warm liquid collide with the molecules of the bottle, energy is transferred.). [*links collisions and energy transfer*] • The faster an object moves the more energy it has (i.e., when the molecules of the air speed up, they have more energy). [*links speed and energy*]

Student uses reasoning that links general science ideas to the claim	• Energy is transferred from the molecules of the warm liquid inside the bottle to the molecules of the cooler air outside of the bottle through a series of collisions. The collisions cause the faster moving molecules of the warm liquid to lose energy and move slower, which means the temperature of the liquid will decrease. The collisions cause the slower moving molecules of the cool air to gain energy and move faster, which means the temperature of the air will increase.
Student does not provide a molecular-level explanation but does include productive ideas about the transfer of thermal energy	• Energy is spontaneously transferred out of hotter regions into colder regions (i.e., energy will be transferred from the warmer liquid to the cooler air). [*conduction*] • Heat is transferred from hotter regions to colder regions (i.e., heat will be transferred from the warmer liquid to the cooler air). [*heat transfer*]

Sample Student Responses

Student response	Scoring description
"The temperature of the liquid cools down and the outside warms up because of thermal energy."	Score = 0 The response does not include a molecular-level explanation for the changes in energy.
"The motion of molecules is related to temperature because the hotter the faster the molecules are moving and the colder the slower. That is all I know…"	Score = 1 The response states a science idea but does not apply it to answer the question.
"This temperature change with the bottle is due to energy transfer. The warm water inside of the air bottle transfers the energy into the surrounding air molecules. The air molecules begin to move due to the heat of the water, causing the water to cool while the air will warm."	Score = 2 The response includes a claim and science idea, but it doesn't describe molecular-level collisions between the liquid and the bottle or the bottle and the air.

"When two mediums are near each other of vastly different temperature, naturally they transfer energy until they are the same temperature. All of the warm molecules inside the water bottle are moving around very fast while the air molecules outside are moving slowly. The water is bouncing and moving around a bunch with a lot of motion in its molecules, while the cold air has very little movement. The energy transfers the way it does because a fast moving water molecule is more likely to hit other molecules and transfer some of it's energy. These fast moving molecules keep moving and hitting their medium which then transfers all the way to the outside of the bottle, and this effectively slows down the molecules inside the bottle while speeding up the molecules outside the bottle, resulting in an observable temperature change"	Score = 3 The response includes all the elements in the rubric.

QUESTION 6

After conducting the experiment, the biologist finds that the bottle with the vacuum keeps liquids warmer than the solid aluminum bottle or the hollow bottle filled with air.

Why does the bottle with the vacuum keep the water inside the bottle warmer than the other bottles? Remember that the vacuum means that there are no molecules of air in the space between the walls of the bottle.

LEARNING GOAL

Learning Performance

- Explain why a vacuum between two objects minimizes the transfer of thermal energy between the objects.

Targeted DCIs, SEP, and CCC

- 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.
- SEP6-M.4 Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events
- CC5-M.4 The transfer of energy can be tracked as energy flows through a designed or natural system.

SCORING RUBRIC

Ideal Response

The hollow bottle with the vacuum did the best job at reducing the transfer of thermal energy because the hollow section of the bottle contains fewer atoms/molecules. Having fewer atoms/molecules means there are fewer collisions and fewer opportunities for energy to be transferred between the warm liquid inside the bottle and cool air outside the bottle.

Elements of a Correct Response

Categories	Elements
Student makes a claim that answers the question	• The hollow bottle with the vacuum did the best job at keeping the liquid warm because the hollow section of the bottle contains fewer atoms/molecules (or no air).
Student either states or uses a general science idea	• When objects interact/collide they transfer energy (i.e., the molecules that make up the warmer liquid transfer energy to the molecules that make up the bottle when they collide). [*links collisions and transfer of energy*]
Student uses reasoning that links general science ideas to the claim	• If there are no atoms/molecules inside the walls of the bottle, energy cannot be transferred via collisions, and the temperature of the liquid inside the bottle will remain the same.

Sample Student Responses

Student response	Scoring description
"All the molecules all stay together and which is why it is hotter then all the other bottles."	Score = 0 The response does not describe the correct reason why the bottle with a vacuum keeps the water warmer.
"The vacuum bottle kept the water the same temperature because of the space in between of the walls."	Score = 1 The response makes the correct claim but doesn't reason with science ideas to support the claim.
"A vacuum would keep the water inside the bottle warmer because there are no molecules to transfer the energy to. In the vacuum, molecules cannot transfer energy because there are no molecules."	Score = 2 The response reasons that energy cannot be transferred if there are no molecules but does not include the idea that energy is transferred by collisions.
"If there are no molecules in the space between the walls of the bottle, it would make it more difficult for the molecules in the water to interact with those outside of the water. As a result, there would be little to no energy transfer and the water would stay warmer."	Score = 3 The response includes all the elements in the rubric.

The research reported here was supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305A180512 to BSCS Science Learning. The opinions expressed are those of the authors and do not represent views of the Institute or the U.S. Department of Education.