

Keeping the Books on Energy: Where It Goes When Matter Changes

Learning target: I can use evidence from a passage to explain how energy crosses the boundary between a reaction and its surroundings, why it never simply appears, and how engineers use that flow in a device.

Reading with evidence

About 35 min

Individual

MS-PS1-6 · supports

reading

writing

Standards connections

MS-PS1-6 (supports): The passage explains the science behind devices that release or absorb thermal energy by chemical processes and ends with engineers judging a prototype by temperature and time. It is background reading for the design project rather than evidence toward the PE.

Purpose: build · **Time:** about 35 minutes · **Format:** individual

Answers with reasoning

Keeping the Books on Energy

[1] An accountant does not need to watch money change hands to know where it went. She draws a line around the business and records each time money crosses it. Chemists track energy the same way, drawing an imaginary boundary around the matter that is reacting, the reactants and the products they become, and calling that matter the system. Everything outside the boundary that can trade energy with it, such as the container, the air or a hand, is the surroundings. The boundary is a tool for thinking, not a real wall.

[2] The surroundings are where the evidence shows up. If the air next to a reaction grows warmer, or light and sound burst out of it, energy has crossed the boundary outward, and the change is exothermic. Open a pouch of iron powder to the air and the iron slowly combines with oxygen; over several hours the pouch warms a pair of gloves. A heater packet in some field rations is a louder example. It holds a powdered mixture of magnesium and iron; add water and the mixture reacts, releasing enough energy to heat a sealed food pouch to eating temperature in about ten to fifteen minutes, with no flame at all.

[3] If instead the surroundings grow cooler, energy has crossed the boundary inward, and the change is endothermic. Squeezing an instant cold pack bursts an inner bubble of water so that it reaches a solid such as ammonium chloride. As the solid dissolves, its particles, ammonium ions and chloride ions, separate and spread through the water, and separating them takes in more energy than is given out when water molecules attach to them. The solution chills, and energy then flows from your warmer hand into the colder pack. Nothing called cold ever moves into your hand; your hand is simply losing energy to the pack.

[4] Why does one change give energy out and another take it in? Think of bonds as attractions that must be paid for. Pulling bonded atoms apart always costs energy, and forming a new bond always pays energy back. When forming the new bonds pays back more than breaking the old ones cost, the extra

flows out to the surroundings and the reaction is exothermic. When breaking costs more than forming pays, the difference must come in from the surroundings, and the reaction is endothermic. This is why a match must be struck: the scrape pays to break the first bonds, and after that the reaction pays for itself and far more. Needing a push to start does not make a reaction endothermic. Only the net transfer, the overall balance once the whole reaction is counted, decides.

[5] Chemists write this balance into their equations. Energy is not made of atoms, so it never changes the atom count, but its position shows the direction of flow. For the iron pouch, energy belongs on the right, with the products: $4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3 + \text{energy}$. For the cold pack, energy belongs on the left, because it enters the system: $\text{NH}_4\text{Cl} + \text{energy} \rightarrow \text{NH}_4^+ + \text{Cl}^-$. Read this way, an equation shows at a glance whether a process warms or cools its surroundings.

[6] Engineers turn that direction into a device and judge it by numbers. Suppose a team designing a pocket warmer for a ski patrol decides it must reach at least 42 °C and stay above 38 °C for three hours, and builds a first prototype: 20 g of iron powder in a thin cloth pouch. In a room at 22 °C it climbs to 47 °C in half an hour, but it drops below 38 °C after only 90 minutes. The team changes one thing: a thicker pouch that lets air in more slowly. The second prototype peaks lower, at 44 °C, but holds above 38 °C for four hours. Slowing the reaction met the time criterion, because the same amount of iron releases the same total energy whether it does so quickly or slowly.

[7] Energy is never created inside a hand warmer or destroyed inside a cold pack. It is moved and stored in new arrangements of atoms, and a careful accountant can always find it. The books always balance.

Questions: cite the passage

1. According to paragraph 1, what is the system, what are the surroundings, and what does the passage say the boundary really is?

Answer: The system is the matter that is reacting, the reactants and the products they become. The surroundings are everything outside the boundary that can trade energy with the system, such as the container, nearby air, water in a cup or a hand. The boundary is 'a tool for thinking, not a real wall.'

Why: All three pieces are stated directly in paragraph 1.

Also acceptable: Accept 'imaginary line' for the boundary.

- System defined as reacting matter including products
- Surroundings defined as everything outside that exchanges energy
- Boundary described as imaginary or a thinking tool

2. Paragraph 2 names three kinds of evidence that energy has left a system. List them, then quote the words that describe the field-ration heater's energy release.

Answer: Warmer air (a temperature rise in the surroundings), light and sound. Quote: the mixture reacts, 'releasing enough energy to heat a sealed food pouch to eating temperature in about ten to fifteen minutes, with no flame at all.'

Why: Paragraph 2 lists warming, light and sound as evidence of outward flow; the quote must come from the ration-heater sentence.

Also acceptable: Accept a shorter quote such as 'releasing enough energy to heat a sealed food pouch.'

- Three kinds of evidence named
- A quotation from the ration-heater sentence

3. Using paragraph 3, describe what happens to the particles of ammonium chloride in a cold pack and explain why your hand feels cold. Which sentence in the paragraph rules out the idea that cold moves into your hand?

Answer: The solid's particles, ammonium ions and chloride ions, separate and spread through the water. Separating them takes in more energy than is given back when water molecules attach to them, so the solution chills; your hand is warmer than the pack, so energy flows out of your hand into the pack, and losing energy is what you feel as cold. The sentence that rules out cold moving: 'Nothing called cold ever moves into your hand; your hand is simply losing energy to the pack.'

Why: Students should name the ions, the energy balance and the direction of flow from hand to pack.

Also acceptable: Accept 'the particles break apart' for the ions if the direction of energy flow is correct.

- Ions separate and spread through the water
- Energy flows from hand into pack
- Quotes or closely paraphrases the 'nothing called cold' sentence

4. Paragraph 4 explains why a match needing to be struck does **not** make burning endothermic. Restate the explanation in your own words, then quote the sentence that gives the deciding rule.

Answer: Restated: the strike only pays a small amount of energy to break the first few bonds; once the reaction is running, forming new bonds pays back far more than that, so overall energy flows out. A reaction is labeled by its overall balance, not by whether it needed help to start. Quote: 'Only the net transfer, the overall balance once the whole reaction is counted, decides.'

Why: This is the correction to the 'needs heating means endothermic' rule. Full credit needs the small-start versus large-payback idea and the quoted deciding rule.

Also acceptable: Accept the quote 'Needing a push to start does not make a reaction endothermic' as the rule if the student also mentions net transfer in their own words.

- Small start-up input versus larger output
- States that the net or overall transfer decides
- Quotes the deciding sentence

5. Paragraph 5 puts energy on different sides of the two equations. Explain the rule for where it goes, and explain why writing the word energy does not change the number of atoms.

Answer: Energy is written with the products (on the right) when it leaves the system, as in the iron equation, and with the reactants (on the left) when it enters the system, as in the cold pack. The word energy is not made of atoms, so adding it to either side does not add or remove any atoms; the atom count on each side stays the same.

Why: Paragraph 5 states both the placement rule and the 'not made of atoms' point.

Also acceptable: Accept 'exothermic on the right, endothermic on the left' with the atom explanation.

- Right side for energy leaving, left side for energy entering
- Energy is not matter, so the atom count is unchanged

6. Using paragraph 6: by how many degrees did the first prototype rise above room temperature? By how many degrees did the second prototype's peak stay above the 38 °C threshold? Show both subtractions.

Answer: First prototype rise: $47\text{ }^{\circ}\text{C} - 22\text{ }^{\circ}\text{C} = 25\text{ }^{\circ}\text{C}$ above room temperature. Second prototype above threshold: $44\text{ }^{\circ}\text{C} - 38\text{ }^{\circ}\text{C} = 6\text{ }^{\circ}\text{C}$ above the 38 °C line.

Why: Both numbers come from paragraph 6; the point is reading values from text and subtracting correctly.

Also acceptable: Accept 25 degrees and 6 degrees without the unit symbol if the work is shown.

7. In paragraph 6, which criterion did the first prototype fail, what single change did the team make, and why did that change work? Cite the passage.

Answer: It failed the time criterion: it 'drops below 38 °C after only 90 minutes' instead of lasting three hours. The team changed one thing, 'a thicker pouch that lets air in more slowly.' It worked because slowing the oxygen supply slowed the reaction, spreading the same total energy over a longer time; the passage says 'the same amount of iron releases the same total energy whether it does so quickly or slowly.'

Why: Students must link the slower reaction to the longer time and recognize that total energy did not change.

Also acceptable: Accept 'the iron reacted more slowly so it lasted longer' with a citation.

- Names the time criterion as the failure
- Names the thicker pouch as the single change
- Explains the slower reaction spreading the same energy over more time

8. A classmate says, 'A hand warmer makes energy.' Using evidence from at least two different paragraphs, explain why the passage would disagree and what the hand warmer actually does with energy.

Answer: The passage would disagree. Paragraph 7 says energy 'is never created inside a hand warmer or destroyed inside a cold pack'; it is moved and stored. Paragraph 4 explains where the released energy comes from: forming the new bonds in iron oxide pays back more energy than breaking the old bonds cost, so the extra flows out to the surroundings. Paragraph 2 shows the result in the surroundings, the gloves warming. So the hand warmer does not make energy; it releases energy that was stored in the arrangement of atoms in the iron and oxygen, and transfers it to the surroundings.

Why: Full credit requires the conservation idea plus the bond-balance source of the energy, cited from two or more paragraphs, and must avoid 'energy stored in bonds is let out when bonds break.'

Also acceptable: A student who adds that the released energy is later stored in new arrangements of atoms or spreads into the surroundings (paragraph 7) is giving a strong answer. Do not accept 'the energy was in the bonds and breaking them let it out.'

- States energy is not created, citing paragraph 7
- Explains the source as the bond balance (forming pays more than breaking costs), citing paragraph 4
- Describes the transfer to the surroundings

Teacher notes

The passage is about 697 words. Factual claims are accurate: flameless ration heaters use a powdered magnesium-iron mixture activated by water; instant cold packs use ammonium chloride or ammonium nitrate (some use urea). The prototype numbers in paragraph 6 are an invented illustration and are labeled as such in the directions. The passage deliberately avoids 'energy stored in bonds' and describes bonds as attractions that cost energy to break and pay energy back when formed; if students use the 'stored in bonds' phrase in q8, correct it with the balloon warning from the chapter's misconception list. The cold-pack equation uses ions, not the textbook's incorrect ammonium hydroxide version.

Scaffold offered to students: Arrow margins

As you reread, draw a small arrow in the margin next to each example in the passage: an arrow pointing out of a circle for energy leaving a system, an arrow pointing in for energy entering. You should end up with arrows beside the iron pouch, the ration heater, the cold pack and the match. Questions 2, 3 and 8 can be answered by finding the right arrow and rereading the sentences around it.

Extension: Move the boundary

Paragraph 1 calls the boundary a tool for thinking, so you can place it wherever it helps. Redraw the cold-pack story with the boundary around the whole pack, water and all, and then with the boundary around your entire hand plus the pack. For each choice, say which matter is now the system, which direction energy crosses the new boundary (if it crosses at all), and whether the word endothermic still applies. Write three or four sentences explaining why, with the second boundary, the energy moving from hand to pack no longer crosses the boundary at all (only energy from the air and the rest of your body does), and why that is still consistent with the passage's last paragraph.