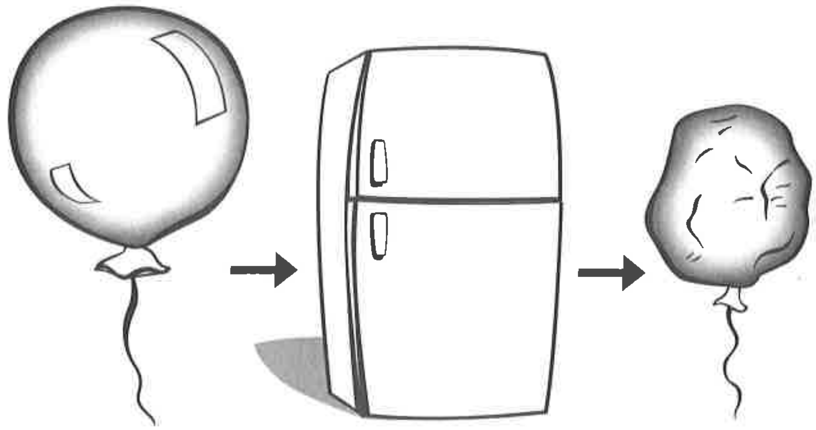
Hot and Cold Balloons



Moira filled a balloon with air. She tightly tied the balloon so no air could get in or out of the balloon. She kept the balloon in a warm room. An hour later she put the balloon in a cold freezer. When she took the balloon out 30 minutes later, it was still tied tightly shut. No air escaped from the balloon; however, the balloon had shrunk.

Moira wondered if the mass of the balloon (including the air inside it) also changed. Circle the answer that best matches your thinking.

A The mass of the warm balloon is less than the mass of the cold balloon.

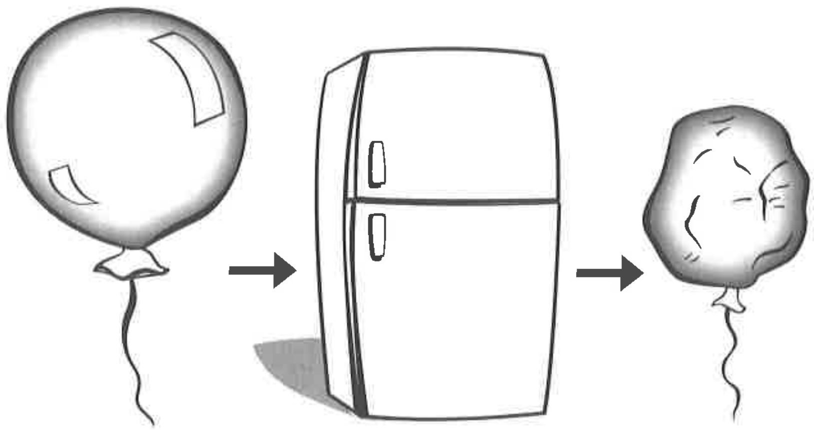
B The mass of the warm balloon is greater than the mass of the cold balloon.

C The mass of the warm balloon is the same as the mass of the cold balloon.

Describe your thinking. Provide an explanation for your answer.

Hot and Cold Balloons

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about conservation of matter. The probe is designed to reveal whether students recognize that the mass of a warm gas in a closed system is the same after it has been cooled, even though the volume it occupies has decreased.

Related Concepts

conservation of matter, gas, kinetic molecular theory, mass, properties of matter, weight

Explanation

The best response is C: The mass of the warm balloon is the same as the mass of the cold balloon. In the warm balloon, the gas molecules are free of each other and moving rapidly. They collide with each other and with the wall of the balloon exerting pressure, which gives the balloon its size (volume). As the balloon cools in the freezer, the air molecules transfer energy to the surrounding freezer. The molecules of air are still free of each other but they do not move as rapidly or as far apart and their collisions with the balloon wall are not as forceful. As a result, the volume of the balloon containing the cool air decreases. The conservation of matter principle explains why the masses are the same. Mass is the measure of the amount of matter in an object, material, or substance. Heat and cold only speed up or slow down the motion of molecules. Changing the temperature of the air inside a closed system does not change the mass because the number of molecules remains the same. The balloon is sealed so nothing can get in or out.

Curricular and Instructional Considerations

Elementary Students

At the elementary school level, students describe the properties of materials or objects and classify them as solids, liquids, or gases. Their experiences with solids and liquids are based on matter they can see. Gases are more difficult for them to understand, because they have not yet developed a particulate notion of matter. However, before proceeding to middle school, it is important for students at the elementary school level to understand that gases are matter and they have weight. At this age level, conservation of matter is taught using phenomena with pieces that are observable, such as parts of objects. The shrinking balloon phenomena used in this probe is appropriate at the observational level for elementary school students, but asking students to explain what happens in terms of the particles should wait until they are ready to use a particulate model.

Middle School Students

At the middle school level, students transition from focusing on the macroscopic properties of solids, liquids, and gases to explaining states of matter in terms of the position, arrangement, and motions of the atoms or molecules. Compared with elementary school grades, middle school students have more experiences investigating gases. At this level, they should understand the idea that gases are made of molecules that have mass (and weight). They develop the idea of a closed system and can use that idea to reason conservation of matter–related phenomena, although understanding conservation of matter in a gas context is more difficult.

High School Students

At the high school level, students deepen their understanding of gases by learning about the gas laws. They use Charles's law to explain what happens to the volume of a gas when the temperature changes. At this grade level, students are expected to be able to use the conservation of matter principle to explain a variety of changes within a closed system. However, they tend to hold on to their earlier ideas about the mass (and weight) of a gas if not confronted with their preconceptions.

Administering the Probe

Consider demonstrating this phenomenon with a balloon. If a freezer is not available, put the balloon outside in the cold, in a refrigerator, or in an ice chest. Make sure students understand that for the purpose of this probe, the balloon is sealed, although in reality some air can escape.

Related Ideas in *National Science Education Standards* (NRC 1996)

K–4 Properties of Objects and Materials

- Objects have many observable properties, including size, weight, shape, color, temperature, and the ability to react with other substances. Those properties can be measured using tools, such as rulers, balances, and thermometers.

- Materials can exist in different states, as a solid, liquid, or gas.

9–12 Structure and Properties of Matter

- Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids, the structure is nearly rigid; in liquids, molecules or atoms move around each other but do not move apart; and in gases, molecules or atoms move almost independently of each other and are mostly far apart.

9–12 Conservation of Energy and the Increase in Disorder

- Heat consists of random motion and the vibrations of atoms, molecules, and ions. The higher the temperature, the greater the atomic or molecular motion.

Related Ideas in *Benchmarks for Science Literacy* (AAAS 1993)

K–2 Structure of Matter

- Objects can be described in terms of the materials they are made of (clay, cloth, paper, etc.) and their physical properties (color, size, shape, weight, texture, flexibility, etc.).

3–5 Structure of Matter

- Heating and cooling cause changes in the properties of materials.
- No matter how parts of an object are assembled, the weight of the whole object is always the same as the sum of the parts.

3–5 The Earth

- Air is a substance that surrounds us, takes up space, and whose movement we feel as wind.

6–8 Structure of Matter

- Atoms and molecules are perpetually in motion. Increased temperature means greater average energy of motion, so most substances expand when heated. In solids, the atoms are closely locked in position and can only vibrate. In liquids, the atoms or molecules have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another, except during occasional collisions.
- ☆ No matter how substances within a closed system interact with one another or how they combine or break apart, the total mass of the system remains the same. The idea of atoms explains the conservation of matter: If the number of atoms stays the same, no matter how they are rearranged, then their total mass stays the same.

9–12 Structure of Matter

- An enormous variety of biological, chemical, and physical phenomena can be ex-

☆ Indicates a strong match between the ideas elicited by the probe and a national standard's learning goal.

plained by changes in the arrangement and motion of atoms and molecules.

Related Research

- Students may believe that matter does not include gases or that gases are weightless materials (AAAS 1993).
- Many researchers have noted that students do not initially seem to be aware that air and other gases are a type of "material" and thus have properties, such as weight or mass, like other materials (Driver et al. 1994).
- Research shows that some students have a difficult time conserving matter in a closed container when a gas is involved and the volume of the container changes. They confuse volume with quantity (Sere 1985). This can also be explained by the intuitive rule, "more A, more B" noted by Stavy and Tirosch (1995). Since the volume of the room temperature balloon is larger, students reason that the balloon has more matter, thus more mass.
- The idea that air or gas has mass is not obvious to children. Yet, when it is taught, it is a concept children can acquire easily and remember (Sere 1985).
- Some students believe a warmed gas weighs less than the same gas that is cooler (Driver et al. 1994).

Suggestions for Instruction and Assessment

- Have students carry out investigations to test their ideas. Use their findings to engage them in resolving the discrepancy between their prediction and ideas and their findings. However, be careful in humid climates that additional mass from condensation of water vapor in the air is not added to the balloon when it comes out of the freezer.
- Explicitly teach the concept of a closed and open system. Link conservation of matter to changes that happen in a closed system.
- Gases pose special difficulties for children because the gases they commonly experience, like air and helium, are invisible. It is suggested that this invisibility prevents students from developing a scientific conception of a gas. Explicit instruction is needed for children to understand the properties of a gas, including properties like mass and weight. This is in contrast to solids and liquids where students tend to learn about them intuitively (Kind 2004).
- Provide other opportunities to compare changes in volume of a gas with temperature, such as slipping a balloon over a flask and then heating it, observing the balloon as it expands. Ask students to explain what happens to the mass of the total system before and after heating.
- Encourage students to draw a "particle picture" of what is happening inside the balloon in both situations. Use their drawings to probe deeper into their understanding of the numbers and motion of the particles.
- Combine this probe with probes in Volume 1 (Keeley, Eberle, and Farrin 2005) to further examine students' ideas about conservation of matter during a physical change.

Related NSTA Science Store Publications and NSTA Journal Articles

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science: Research into children's ideas.* London and New York: RoutledgeFalmer.

Keeley, P. 2005. *Science curriculum topic study: Bridging the gap between standards and practice.* Thousand Oaks, CA: Corwin Press.

National Research Council (NRC). 1996. *National science education standards.* Washington, DC: National Academy Press.

Robertson, W. 2005. *Air, water, and weather: Stop Faking It! Finally Understanding Science So You Can Teach It.* Arlington, VA: NSTA Press.

Sadler, T., T. Eckart, J. Lewis, and K. Whitley. 2005. Tried and true: It's a gas! An exploration of the physical nature of gases. *Science Scope* (Nov./Dec.): 12–14.

Related Curriculum Topic Study Guides

(Keeley 2005)

"Behavior and Characteristics of Gases"

"Conservation of Matter"

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American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

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Keeley, P., F. Eberle, and L. Farrin. 2005. *Uncovering student ideas in science: 25 formative assessment probes.* Vol. 1. Arlington, VA: NSTA Press.

Kind, V. 2004. *Beyond appearances: Students' misconceptions about basic chemical ideas.* 2nd ed. Durham, England: Durham University School of Education. Also available online at *www.chemsoc.org/pdf/LearnNet/rsc/miscon.pdf.*

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Sere, M. 1985. The gaseous state. In *Children's ideas in science,* eds. R. Driver, E. Guesne, and A. Tiberghien, 105–123. Milton Keynes, UK: Open University Press.

Stavy, R., and D. Tirosch. 1995. *How students (mis) understand science and mathematics: Intuitive rules.* New York: Teachers College Press.