ACTIVITY 3

Messing With Mass

Activity Summary

Students conduct an inquiry into the meaning of *m* in $E=mc^2$ by exploring how objects of mass interact during a chemical reaction in a plastic bag, and by measuring mass before and after chemicals are mixed together.

Materials for teacher demonstration

- 250 ml beaker with 100 g citric acid
- 250 ml beaker with 100 g baking soda

Materials for each team

- copy of the "Messing With Mass" student handout
- 1/4 tsp citric acid
- 1/4 tsp baking soda
- quart freezer bag
- plastic bowl (large enough to contain an expanded freezer bag)
- film container, filled with 20 ml water
- lab balance accurate to a tenth of a gram
- goggles

Background

Without the insights of scientists before him, Albert Einstein would not have had the foundation from which to make his brilliant leap of understanding about the equivalence of mass and energy. Two of the people responsible for providing a critical understanding about mass were Antoine-Laurent Lavoisier and his wife, Marie Anne. By day, Lavoisier was a tax collector. But his true passion was chemistry. A meticulous experimenter, Lavoisier was the first to demonstrate that matter is conserved in a chemical reaction. In the late 1700s, Lavoisier showed that when water was turned to steam, nothing was lost—the water was just transformed. His wife provided detailed drawings of his experiments and translations of other scientists' work.

In this activity, students examine the components of a chemical reaction and make measurements to confirm the conservation of mass in a closed system (quart freezer bag). Students will gain an understanding of the meaning of mass in a reaction. They will learn how objects of mass can interact and change and that mass is always conserved in a chemical reaction.

LEARNING OBJECTIVES

Students will be able to:

- explain what the *m* in $E=mc^2$ represents.
- relate that mass in a chemical reaction is always conserved.
- convey that atoms rearrange themselves in chemical reactions to form different molecules and compounds.

KEY TERMS

chemical reaction: A process in which one or more substances are changed into other substances.

conservation of mass: A law stating that the products of a chemical reaction always have the same total mass as that of the reactants.

endothermic: Chemical reactions that take in heat from their surroundings.

exothermic: Chemical reactions that give off heat to their surroundings.

mass: The amount of matter an object contains.

products: Substances resulting from a chemical reaction.

reactants: Substances that take part in a chemical reaction.

weight: The force of gravity acting on matter.

The reaction in this activity is between two fairly harmless chemicals—citric acid ($H_3C_6H_5O_7$) and baking soda ($NaHCO_3$), both white powders. The reaction can only occur in the presence of water. The reaction produces a gas (CO_2) and the compound sodium citrate ($Na_3C_6H_5O_7$). The balanced reaction looks like this:

$$H_3C_6H_5O_7 + 3NaHCO_3 \Rightarrow Na_3C_6H_5O_7 + 3H_2O + 3CO_2$$

The reaction is *endothermic* so students will feel the plastic bag get colder when the three ingredients are mixed. To further verify for students that a chemical reaction is taking place, you may want to add an acid-base indicator, such as phenol red, to reveal that a change (in pH) has occurred after the reaction has taken place.

Procedure

1. Obtain the necessary chemicals from your chemistry lab, a science supply house, or stores in your area. Baking soda is sold in grocery stores and citric acid, which is used in canning and winemaking, is sold in some drug stores.
2. Begin by pointing out the *m* in $E=mc^2$ and asking what this letter stands for. Students may say, "How much something weighs." Pick up an object such as a stapler and ask how much the stapler would weigh independent of a gravitational field. The answer is "nothing" because weight is just a name for the force of gravitational attraction that exists between two objects, in this case Earth and the stapler. The fact that weight is simply a force of attraction, not a unit of mass, can be a difficult concept for some students. Try to help students understand that mass is the amount of "stuff," or atoms, an object contains. Mass is defined by units like grams and kilograms.
3. To help students start thinking about mass, conduct a demonstration about how mass interacts. Have one 250 milliliter beaker filled with 100 grams of citric acid and another filled with 100 grams of baking soda. Hold the two cups out in front of you and tell students the cups contain two different chemicals of equal mass. Ask students to predict what will happen if the two of them are mixed together. After students answer, mix the substances. *(Nothing will happen.)* Ask students why nothing occurred. What evidence did they have that led them to their conclusion? *(No noise, no smoke, no visual chemical changes seen, etc.)*
4. Now that students understand that not all mass reacts, have them conduct their activity in which a chemical reaction does occur. Organize students into teams and give each team a copy of the student handout and other materials.

STANDARDS CONNECTION

The "Messing With Mass" activity aligns with the following National Science Education Standards (see books.nap.edu/html/nses).

GRADES 5–8
Science Standard
Physical Science
- Properties and changes of properties in matter
- Transfer of energy

GRADES 9–12
Science Standard
Physical Science
- Chemical reactions

5 Review safety rules with students:
   - Wear goggles.
   - Do not allow the chemicals to touch bare skin. (If students accidentally touch a substance, tell them to wash their hands immediately. These chemicals are about as dangerous as lemon juice, but precautions should be followed.)
   - When chemicals are mixed in the plastic bag, make sure the opening of the bag is well sealed and pointed away from students.
   - Students may feel the bag while the reaction is proceeding, but they should not squeeze it.

6 Circulate around the room as student teams do the experiment. Help anyone having trouble using the balance.

7 When students are finished making their observations, collect the bags in a bucket or container. Give students time to answer the questions on their student handout. Then have a discussion about the nature of a chemical reaction. Why was there a reaction in the student activity but not one in the teacher demonstration? *(The water in the student activity served as a solvent that allowed the two solids to react.)* How was mass conserved in this reaction? *(Although a chemical change occurred—two dry, white granular solids when mixed with water became a gas and a dissolved solid in a water medium—mass was conserved as evidenced by the almost identical masses before and after the reaction.)* Brainstorm with students some possible reasons for any mass differences they saw. *(Small weight differences, on order of 0.1 to 0.3 percent, may be seen; see Activity Answer on page 18 for more information.)*

8 As an extension, turn the investigation into a quantitative one and have students measure the temperature of the reaction as the reaction proceeds (a thermometer should be placed on a desk, the bag set down on the bulb end of the thermometer, and the temperature read every minute or so). Then, have students change the quantities of one of the chemicals and take more temperature data. Plot both sets of data on a single set of axes. Ask students interpret their results.

ACTIVITY ANSWER

It is important to stress that mass is always conserved in a chemical reaction in a closed system. (An extremely small amount of mass—on order of a few parts per trillion—is lost or gained when light and/or heat is absorbed or released in a reaction. But for all practical purposes this is too small to measure.)

The reaction in a quart bag is a good example of a closed system. However, any measurement contains a degree of uncertainity. There may be a slight difference in mass due to loss of gas or errors of measurement. (Sample test results showed a 0.1 percent to 0.3 percent weight difference.) In an experiment in an open system, such as weighing a piece of wood, burning it, and weighing the ashes afterwards, it would appear that mass is not conserved. But in fact it is. It is just that the escape of invisible gases, both carbon dioxide and water, prevent the measurement of the mass of all of the products.

The word *mass* is used deliberately in the student activity instead of the more commonly used *weight*. If necessary, reinforce the difference between the two terms when students use their balances to weigh their bags.

Student Handout Questions

1 When a reaction gives off heat, it is called *exothermic*. When a reaction absorbs heat, it is called *endothermic*. Is the reaction you observed endothermic or exothermic? The reaction is endothermic. Students should feel the bag getting colder as the reaction proceeds. Exothermic reactions are much more familiar to students (striking a match, burning a candle) than endothermic ones. Students may need help in understanding that the chemicals in the bag cool because heat is being used in the reaction to turn the reactants into products.

2 How did the mass of the reactants compare to the mass of the products? Use this formula to calculate any percent difference in the mass between the two:

absolute value of the difference between the two masses divided by mass before reaction x 100 = percent difference

Students should arrive at the conclusion that the mass of the products is extremely close to the mass of the reactants.

3 What might have caused any difference in mass that you found? There may be a small difference in mass due to loss of gas from the plastic bag or errors in measurement. Accept reasonable answers.

4 What evidence would you give to show that a chemical reaction did indeed occur? There are two signs that a chemical reaction occurred: a change in temperature and the formation of a gas.

LINKS AND BOOKS

Links

NOVA—Einstein's Big Idea
www.pbs.org/nova/einstein
Hear top physicists explain $E=mc^2$, discover the legacy of the equation, see how much energy matter contains, learn how today's physicists are working with the equation, read quotes from Einstein, and more on this companion Web site.

Periodic Table of the Elements
periodic.lanl.gov
Provides a periodic table and information about each element.

Welcome to Chembalancer!
www.dun.org/sulan/chembalancer
Includes a game focused on correctly balancing chemical equations.

Books

40 Low-Waste, Low-Risk Chemistry Experiments
by David Dougan.
Walch Publishing, 1997.
Includes introductory labs on measurement, density, temperature, relative mass, and more.

Physics: The Human Adventure: From Copernicus to Einstein and Beyond
by Gerald James Holton and Stephen G. Brush.
Rutgers University Press, 2001.
Introduces concepts and theories in physical science and features a chapter on the conservation of mass.

The Visual Dictionary of Chemistry
by Jack Challoner.
DK Publishing, 1996.
Provides photographs of chemical experiments, illustrations of molecules and chemical reactions, and information about the periodic table of elements.

Messing With Mass

What is mass, and how can masses react with each other? Is mass gained or lost during a chemical reaction? These are the questions you will consider during this activity.

You will be investigating the reaction of two common chemicals—citric acid and baking soda. In a chemical reaction, the substances that are mixed together are called reactants, and the substances resulting from the reaction are called products. You will be asked to describe (to the best of your ability) what is occurring inside the bag where the reaction is happening. Use all your senses **(except taste!)** to make your observations.

Procedure

1. Describe the two chemicals involved in the chemical reaction (citric acid and baking soda) on a separate sheet of paper. You may smell the chemicals but *DO NOT taste them.*
2. Add 1/4 teaspoon of citric acid to a 1-quart plastic bag.
3. Add 1/4 teaspoon of baking soda to the bag.
4. Place the open container of water inside the bag. Be careful not to spill the water inside the bag. Place the bag in the bowl, then center the bowl on the balance. Record the total mass of the bag and its contents to the nearest tenth of a gram: _____ g
5. *Carefully* take the bag out of the bowl (without spilling the water) and seal it well. Mix the contents of the bag together. Then hold the bag in your hands without squeezing or manipulating it in any way.
6. On a separate sheet of paper, write down as many observations of the chemical reaction as you can.
7. Place the closed bag in the bowl on the balance and find its mass again after the reaction has occurred. Record the mass to the nearest tenth of a gram: _____ g

Questions

Write your answers on a separate sheet of paper.

1. When a reaction gives off heat, it is called *exothermic.* When a reaction absorbs heat, it is called *endothermic.* Is the reaction you observed endothermic or exothermic?
2. How did the mass of the reactants compare to the mass of the products? Use this formula to calculate any percent difference in the mass between the two:

   absolute value of the difference between the two masses divided by mass before reaction x 100 = percent difference
3. What might have caused any difference in mass that you found?
4. What evidence would you give to show that a chemical reaction did indeed occur?