Changes in Matter

When you put liquid water in a freezer, it changes to solid water, or ice. When you pour brownie batter into a pan and bake it, the liquid batter changes to a solid. In both cases, a liquid changes to a solid. Are these changes the same?

Physical Changes
Recall that matter can undergo two types of changes—chemical or physical. A physical change does not produce new substances. The substances that exist before and after the change are the same, although they might have different physical properties. This is what happens when liquid water changes to ice. Its physical properties change from a liquid to a solid. But the water, H₂O, does not change into a different substance. Water molecules are always made up of two hydrogen atoms bonded to one oxygen atom, regardless of whether the water is solid, liquid, or gas.

Chemical Changes
Recall that during a chemical change, one or more substances change into new substances. The starting substances and the substances produced have different physical and chemical properties.

Key Concepts
- What are some signs that a chemical reaction might have occurred?
- What happens to atoms during a chemical reaction?
- What happens to the total mass in a chemical reaction?
Physical and Chemical Properties
During baking, brownie batter changes physically from a liquid to a solid. But a chemical change also occurs. Many substances in the batter change to new substances in the baked brownies. As a result, baked brownies have physical and chemical properties that are different from those of brownie batter.

Chemical Reaction
A chemical change also is called a chemical reaction. These terms mean the same thing. A chemical reaction is a process in which atoms of one or more substances rearrange to form one or more new substances.

Signs of a Chemical Reaction
How can you tell if a chemical reaction has taken place? You have read that the substances before and after a reaction have different properties. One way to detect a chemical reaction is to look for changes in properties. Changes in color, state of matter, and odor are signs that a chemical reaction might have occurred. Another sign of a chemical reaction is a change in energy. If substances get warmer or cooler or if they give off light or sound, a reaction probably has occurred. The table below describes some signs of a chemical reaction.

However, these signs are not proof of a chemical change. For example, bubbles appear when water boils. But bubbles also appear when baking soda and vinegar react and form carbon dioxide gas. How can you be sure that a chemical reaction has taken place? The only way to know is to study the chemical properties of the substances before and after the change. If they have different chemical properties, then the substances have undergone a chemical reaction.
What happens in a chemical reaction?
In a chemical reaction, one or more substances react and form one or more new substances. How do these new substances form?

Atoms Rearrange and Form New Substances
Recall that there are two types of substances—elements and compounds. Substances have a fixed arrangement of atoms. For example, a single drop of water has trillions of oxygen and hydrogen atoms. However, all of these atoms are arranged in the same way—two atoms of hydrogen are bonded to one atom of oxygen. If this arrangement changes, the substance is no longer water. Instead, a different substance forms with different physical and chemical properties. This is the kind of change that happens during a chemical reaction. Atoms of elements or compounds rearrange and form different elements or compounds.

Bonds Break and Bonds Form
Atoms rearrange when chemical bonds between atoms break and other chemical bonds form. All substances, including solids, are made of particles that move constantly. As particles move, they collide. If the particles collide with enough energy, the bonds between atoms can break. The atoms separate and rearrange, and new bonds can form.

The figure below shows the reaction that forms hydrogen and oxygen from water. Adding electric energy to water molecules can cause this reaction. The added energy causes bonds between the hydrogen and oxygen atoms to break. Then new bonds can form between pairs of hydrogen atoms and between pairs of oxygen atoms. The reaction creates no new atoms. Instead, it rearranges the existing atoms.

**Visual Check**
6. Explain how you can tell that this reaction created no new atoms?

**Key Concept Check**
5. Describe what happens to atoms during a chemical reaction?
Chemical Equations

In your science laboratory, you usually describe a chemical reaction in the form of a chemical equation. A chemical equation is a description of a reaction using element symbols and chemical formulas. Element symbols represent elements. Chemical formulas represent compounds.

Element Symbols

Element symbols appear in the periodic table. The symbol for carbon is C. Copper is Cu. Each element can exist as just one atom. Some elements exist in nature as diatomic molecules—two atoms bonded together. A diatomic element’s formula includes the element’s symbol and the subscript 2. Subscripts describe the number of atoms of an element in a compound. Oxygen (O₂) and hydrogen (H₂) are diatomic molecules. Element symbols are shown below.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Formula</th>
<th># of Atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>C</td>
<td>C: 1</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>Cu: 1</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Co</td>
<td>Co: 1</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
<td>O: 2</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>H: 2</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl₂</td>
<td>Cl: 2</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>C: 1, O: 2</td>
</tr>
<tr>
<td>Water</td>
<td>H₂O</td>
<td>H: 2, O: 1</td>
</tr>
<tr>
<td>Hydrogen peroxide</td>
<td>H₂O₂</td>
<td>H: 2, O: 2</td>
</tr>
<tr>
<td>Glucose</td>
<td>C₆H₁₂O₆</td>
<td>C: 6, H: 12, O: 6</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>NaCl</td>
<td>Na: 1, Cl: 1</td>
</tr>
<tr>
<td>Magnesium hydroxide</td>
<td>Mg(OH)₂</td>
<td>Mg: 1, O: 2, H: 2</td>
</tr>
</tbody>
</table>

Interpreting Tables

8. Describe the number of atoms in each element in the following: C, Co, CO, CO₂.

Chemical Formulas

When atoms of two or more elements bond, they form a compound. Recall that a chemical formula uses elements’ symbols and subscripts to describe the number of atoms in a compound. If an element’s symbol does not have a subscript, the compound contains only one atom of that element. For example, carbon dioxide (CO₂) is made up of one carbon atom and two oxygen atoms. Two formulas might be similar, but each represents a different substance. The table above shows some chemical formulas. Notice the parentheses in magnesium hydroxide. This means the subscript applies to both elements within the parentheses.
Writing Chemical Equations

A chemical equation includes the substances that react and the substances that form in a chemical reaction. The starting substances in a chemical reaction are reactants. The substances produced by the chemical reaction are products. The figure below shows how to write a chemical equation. Chemical formulas describe the reactants and the products. Write the reactants to the left of the arrow. Write the products to the right of the arrow. Separate two or more reactants or products with a plus sign. The structure for an equation is:

reactant + reactant → product + product

Be sure to use correct chemical formulas for the reactants and the products. For example, suppose a chemical reaction produces carbon dioxide and water. The product carbon dioxide is CO₂, not CO. CO is the formula for carbon monoxide, which is not the same compound as CO₂. Water is H₂O, not H₂O₂, the formula for hydrogen peroxide.

Conservation of Mass

Antoine Lavoisier (AN twan·luh VWAH see ay) (1743–1794), a French chemist, discovered something interesting about chemical reactions. In a series of experiments, Lavoisier measured the masses of substances before and after a chemical reaction inside a closed container. He found that the total mass of the reactants always equaled the total mass of the products. Lavoisier’s results led to the law of conservation of mass. The law of conservation of mass states that the total mass of the reactants before a chemical reaction is the same as the total mass of the products after the chemical reaction.

Visual Check

9. Identify Highlight the symbol that separates the reactants from the products in a chemical equation.

Key Concept Check

10. Explain What happens to the total mass of the reactants in a chemical reaction?
Atoms are conserved.
The discovery of atoms helped explain Lavoisier’s observations. Mass is conserved in a reaction because atoms are conserved. During a chemical reaction, bonds break and new bonds form. However, a reaction does not destroy atoms, and it does not form new atoms. All atoms at the start of a chemical reaction are present at the end of the reaction.

Suppose you attach a balloon with baking soda inside to a flask of vinegar. You place the flask on a scale and record the mass. Then you mix the two substances. They react, and the balloon fills with gas. You find that the products after the reaction have the same mass as the reactants. Mass is conserved. The atoms also are conserved, as shown in the equation below.

\[
\text{Mass is equal.} \\
\text{baking soda} + \text{vinegar} \rightarrow \text{sodium acetate} + \text{water} + \text{carbon dioxide}
\]

\[
\text{Atoms are equal.} \\
\text{NaHCO}_3 + \text{H}_2\text{O}_2 \rightarrow \text{NaC}_2\text{H}_3\text{O}_2 + \text{H}_2\text{O} + \text{CO}_2
\]

Conservation of Mass

Is an equation balanced?
Because atoms are conserved, the number of atoms of each element must be the same, or balanced, on each side of the arrow. The equation in the figure below shows the reaction between carbon and oxygen that produces carbon dioxide. The formula for oxygen is O\(_2\) because it is a diatomic molecule. The formula for carbon dioxide is CO\(_2\). There is one carbon atom on the left of the arrow and one on the right. Carbon is balanced. Two oxygen atoms are on each side of the arrow. Oxygen also is balanced. The atoms of all elements are balanced. So, the equation is balanced.

**Visual Check**
13. Explain Were the atoms conserved in this equation? How do you know?

**Reading Check**
12. Recognize How do you know that a chemical equation is balanced?

**Interpreting Tables**
11. Identify How many atoms of hydrogen are on each side of the equation in the table?
You might think a balanced equation happens automatically when you write the symbols and formulas for reactants and products. However, this usually is not the case.

For example, the reaction between hydrogen ($H_2$) and oxygen ($O_2$) that forms water ($H_2O$) is shown in the figure above. Count the number of hydrogen atoms on each side of the arrow. There are two hydrogen atoms in the product and two in the reactants. They are balanced.

Now count the number of oxygen atoms on each side of the arrow. Did you notice that there are two oxygen atoms in the reactants and only one in the product? Because they are not equal, this equation is not balanced. To accurately represent this reaction, you need to balance the equation.

**Balancing Chemical Equations**

Balancing a chemical equation is the process of counting the atoms in the reactants and the products and then adding coefficients to balance the atoms. A coefficient is a number placed in front of an element symbol or chemical formula in an equation. A coefficient tells the number of units of a substance in the reaction. For example, the coefficient 2 added to $H_2O$ is written as $2H_2O$. This means that two molecules of water take part in the reaction.

If one molecule of water contains two hydrogen atoms and one oxygen atom, how many H and O atoms are in two molecules of water ($2H_2O$)? Multiply each by 2.

- $2 \times 2$ H atoms = 4 H atoms
- $2 \times 1$ O atom = 2 O atoms

When no coefficient is present, only one unit of that substance takes part in the reaction.
The table above shows the steps of balancing a chemical equation. Notice that adding the coefficient 2 in front of $\text{H}_2\text{O}$ in the equation balances the oxygen atoms but unbalances the hydrogen atoms. Adding the coefficient 2 in front of the reactant $\text{H}_2$ brings the hydrogen atoms back into balance.
Mini Glossary

- **chemical equation**: a description of a reaction using element symbols and chemical formulas
- **chemical reaction**: a process in which atoms of one or more substances rearrange to form one or more new substances
- **coefficient**: a number placed in front of an element symbol or chemical formula in an equation
- **law of conservation of mass**: states that the total mass of the reactants before a chemical reaction is the same as the total mass of the products after the chemical reaction
- **product**: a substance produced by a chemical reaction
- **reactant**: a starting substance in a chemical reaction

1. Review the terms and their definitions in the Mini Glossary. Write a sentence that describes how a chemical equation and a chemical reaction are related.

2. Count the number of atoms of each element on both sides of the chemical equation below. Then determine whether the equation is balanced or unbalanced.

   \[
   \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}
   \]

   \[
   \begin{array}{c}
   \text{C} = \underline{\phantom{0}} \\
   \text{H} = \underline{\phantom{0}} \\
   \text{O} = \underline{\phantom{0}}
   \end{array}
   \]

   balanced or unbalanced? __________________

3. When water boils, bubbles form. Is this a chemical change or a physical change? Explain your answer.