LESSON

1 Toxic Reactions

Chemical Equations

Think About It

Matter in the world around you undergoes many changes. Some of these changes have very little impact on living things on the planet. Other changes may be vital and necessary for life. Still other changes may threaten the health and well-being of plant and animal life. Chemists use chemical equations to keep track of all types of changes in matter, including those that are beneficial and those that are unsafe.

How do chemists keep track of changes in matter?

To answer this question, you will explore

1. Chemical Equations
2. Toxic Substances and Their Effects

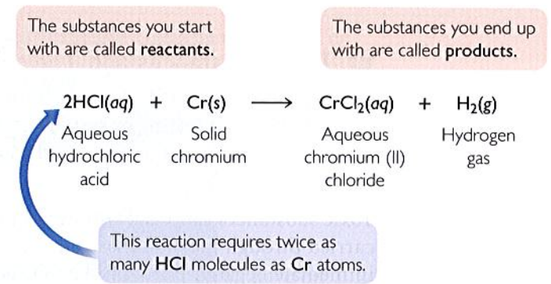
Exploring the Topic

1 Chemical Equations

A chemical equation is a chemical "sentence" that describes change, using numbers, symbols, and chemical formulas. Chemical equations describe what happens when a single substance is changed, or when two or more substances are combined and a change occurs. Once you understand how to decode chemical equations, you will be able to use them to predict what you might observe when substances are mixed.

Interpreting a Chemical Equation

In some reactions that take place in your body, the element chromium is safe and even necessary. In other reactions it is toxic. Consider what happens if you ingest chromium metal and it reacts with the hydrochloric acid in your stomach. A chemical equation can help you decode this reaction.



Chemical equation: $2HCl(aq) + Cr(s) \longrightarrow CrCl_2(aq) + H_2(g)$

Interpretation: Hydrochloric acid reacts with solid chromium to produce a solution of chromium (II) chloride and bubbles of hydrogen gas.

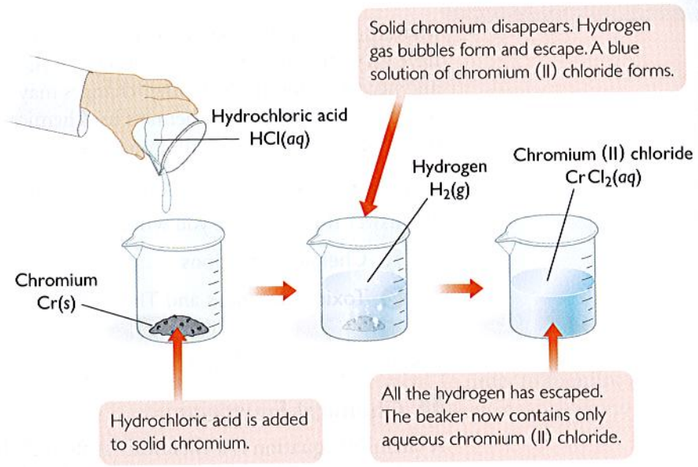
ENVIRONMENTAL CONNECTION

In larger amounts, some chromium compounds cause cancer. Since the 1980s, Erin Brockovich has brought several successful lawsuits in California to stop unsafe levels of chromium compounds in drinking water. A legal clerk at the time of her first legal case, she is now a consultant and speaker.

A chemical equation can help you anticipate what you will observe when the reactants are combined. Examine the same equation, but focus on what you expect to observe.

$$2HCl(aq) + Cr(s) \longrightarrow CrCl_2(aq) + H_2(g)$$

According to the equation, when hydrochloric acid and chromium react, the solid chromium will disappear. You would expect to see the formation of a new aqueous solution as well as some evidence that a gas was produced.



Sometimes, the changes that take place when substances are mixed are not visible to the eye. For example, death from poisoning occurs within minutes of swallowing a solution of sodium cyanide, NaCN. One successful treatment for this type of poisoning is injection of an antidote, or a remedy that counteracts the poison. The antidote for sodium cyanide is a solution containing sodium thiosulfate, $Na_2S_2O_3$. If the reaction between sodium cyanide and sodium thiosulfate were observed in a beaker, you would not be able to tell that a reaction had occurred because both reactants and both products are clear, colorless liquids.

BIG IDEA Chemical equations keep track of changes in matter.

EXERCISES

Reading Questions

1. What is the difference between a reactant and a product?
2. Are chemicals and chemical reactions important for life? Why or why not?
3. Describe in your own words what a toxic substance is.

Reason and Apply

4. Both bleach and ammonia are used for cleaning. However, it is very dangerous to mix bleach with ammonia because they react to produce sodium hydroxide and the toxic gas chloramine.

$$NaOCl(aq) + NH_3(aq) \longrightarrow NaOH(aq) + NH_2Cl(g)$$

   a. Write an interpretation of the chemical equation.

   b. What do you expect to observe?

5. Poisoning with mercury chloride can be reversed by chelation therapy. The chelating agent called EDTA, $C_{10}H_{16}N_2O_4$, is injected into the bloodstream. EDTA forms a water-soluble compound with mercury ions, allowing removal from the body through the kidneys.

$$HgCl_2(s) + C_{10}H_{16}N_2O_4(aq) \longrightarrow HgC_{10}H_{12}N_2O_4(aq) + 4HCl(aq)$$

   a. Write an interpretation of the chemical equation.

   b. What do you expect to observe?

6. Describe at least three types of effects that a toxic substance can have on the body.

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#4 on page 356
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#4 on page 360

Solution

The mass of the products on the right side must equal the mass of the reactants on the left side. So, the mass of the carbon dioxide produced is 22 grams.

2 Conservation of Mass

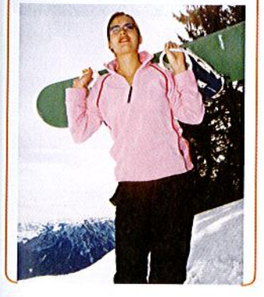
The fact that the mass of the reactants is equal to the mass of the products follows the law of conservation of mass. Mass is conserved during chemical and physical changes because no atoms are created or destroyed.

Getting Rid of Garbage

People generate a lot of waste: cups, cans, bottles, candy wrappers, paper, and diapers. Most of this waste just keeps piling up in landfills. Some of the waste is quite toxic. In the United States alone, about 132 million tons of garbage are put into landfills each year. Will it be there forever?

ENVIRONMENTAL CONNECTION

Compounds are sometimes recycled in surprising ways. For example, PETE plastic bottles can be recycled to make t-shirts, suits and fleece!



Atoms are not created or destroyed; they are simply rearranged to form new substances. Therefore, everything on the planet is made up of a limited number of atoms. Even your body does not have the same atoms in it that it did several years ago. You are continually generating new cells of every kind and getting rid of the old ones.

The law of conservation of mass is important in considering waste disposal. You cannot get rid of the atoms in the waste that you throw away. Smelly, toxic garbage accumulates in large quantities in waste disposal sites. A small portion of it may biodegrade—that is, get broken down into harmless products by microorganisms—but the process can take decades. The waste will be there unless scientists find ways to convert more of our waste into useful products. Given this fact, it makes sense to reuse and recycle as much as possible.

Lesson Summary

How does mass change during a chemical or physical change?

When chemical and physical changes take place, the atoms in substances rearrange. A rearrangement may be a physical change, such as the mixing of two substances, or a chemical change, the formation of new compounds. However, the atoms involved in these rearrangements cannot be created or destroyed. A chemical equation tracks the atoms involved in chemical and physical changes. All of the atoms are accounted for, so the mass of the products is identical to the mass of the reactants. This is known as the law of conservation of mass.

EXERCISES

Reading Questions

1. Explain the law of conservation of mass.
2. Explain how the law of conservation of mass applies to garbage.

Reason and Apply

3. Below is a chemical equation along with a verbal description of the reaction.

   Verbal description: Gaseous sulfur trioxide is added to liquid water to produce aqueous sulfuric acid.

   Chemical equation: $SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$

   a. Was matter lost or gained during this reaction? Explain how you could prove this by taking measurements.

   b. The left side of the equation shows one atom of S, two atoms of H, and four atoms of O. How many atoms of each element are on the right side of the equation? How does this provide evidence for the law of conservation of mass?

4. When an ice cube melts, which of these quantities will change?

   A. The number of atoms it contains

   B. Its mass

   C. Its volume

   D. All of the above

   E. None of the above

5. Explain what happens to the number of atoms, the mass, and the weight of the water in a glass when it evaporates.
6. Write a paragraph to convince a friend that mass is conserved when chemical and physical changes take place. Give evidence.
7. What would you have to do to prove that matter is conserved when a piece of paper is burned?

ENVIRONMENTAL CONNECTION

Bacteria can break down organic waste such as food scraps and dead leaves. But if garbage is piled deep in a landfill, the bacteria can't access the air and water they need to break things down. Some trash companies collect food scraps and garden waste separately, so they can be composted.

LESSON 5

Atom Inventory

Balancing Chemical Equations

Think About It

The law of conservation of mass states that mass is not lost or gained in a chemical reaction. When you write a chemical equation to describe change, it is important that the equation follow this law. So any equation describing a chemical change must account for every atom involved.

How do you balance atoms in a chemical equation?

To answer this question, you will explore

1. Balancing Chemical Equations
2. Coefficients Are Counting Units

INDUSTRY CONNECTION

Ammonia can be made by first converting methane into another carbon compound and hydrogen gas. Then an iron compound is used as a catalyst to react hydrogen with nitrogen. Ammonia produced through this process is used to fertilize approximately one-third of the agricultural crops in the world.

Exploring the Topic

1 Balancing Chemical Equations

Imagine you're in business to make ammonia, NH_3, for farmers to fertilize their crops. It would be helpful to know how much nitrogen, $N_2(g)$, and hydrogen, $H_2(g)$, to combine so that nothing is wasted. How do you make sure you have the correct amount of nitrogen and hydrogen so that you have enough of each with no extra?

A chemical equation represents the exact ratio in which reactants combine to form products. A chemical equation that accounts for all the atoms involved and shows them combining in the correct ratio is called a *balanced* chemical equation. Learning how to balance chemical equations is a necessary part of working with chemical reactions.

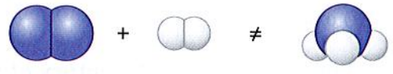
Formation of Ammonia

The unbalanced equation below describes how nitrogen gas and hydrogen gas react to make ammonia gas.

To balance this equation, first take an inventory of the atoms on each side.

Reactants Product

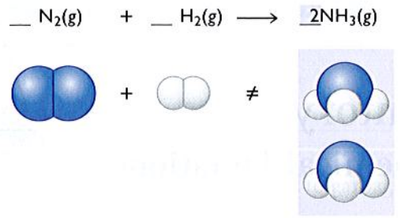
$\_\ N_2(g) + \_\ H_2(g) \longrightarrow \_\ NH_3(g)$



Inventory of Atoms

Reactants	Products	
2 N	1 N	Unbalanced
2 H	3 H	Unbalanced

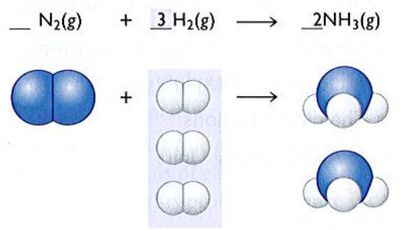
Next, balance the atoms on each side by adding units of N_2, H_2, or NH_3. The product side needs one more N atom. The only way to accomplish this is to add a whole ammonia molecule, NH_3, to the product side.



Inventory of Atoms

Reactants	Products	
2 N	2 N	Balanced
2 H	6 H	Unbalanced

Take a new inventory. The N atoms are now balanced. Now the reactant side needs four more H atoms. The only way to accomplish this is to add two more molecules of H_2 to the reactant side.



Inventory of Atoms

Reactants	Products	
2 N	2 N	Balanced
6 H	6 H	

The equation is now balanced. The balanced equation shows that mass is conserved. There are the same numbers of N and H atoms on each side of the arrow.

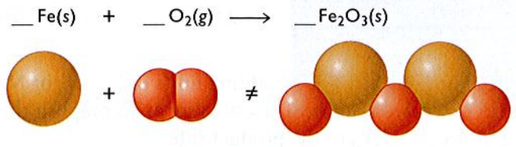
In the balanced equation above, the 3 in front of the H_2 and the 2 in front of the NH_3 are called **coefficients.** Coefficients indicate how many units of each substance take part in the reaction. If there is no number in front of a chemical formula in an equation, the coefficient is understood to be a 1.

Important to Know To balance a chemical equation, you can change only the coefficients, or the numbers in front of each chemical formula. You cannot change the chemical formulas. ◀

Formation of Rust

Iron reacts with oxygen in the air to form iron (III) oxide, or rust. Iron (III) oxide is *not* a molecule. It is a highly organized collection of Fe and O atoms that are bonded to each other ionically. It is an ionic solid. There are a huge number of atoms in any piece of iron (III) oxide. But each piece will have two Fe atoms for every three O atoms. So Fe_2O_3 is the **formula unit** of iron oxide.

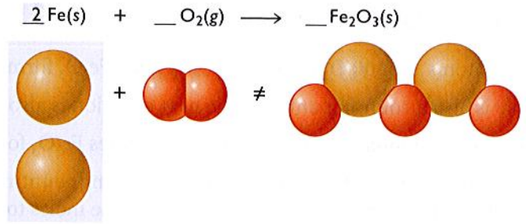
The unbalanced equation below describes how iron reacts with the oxygen in the air to form iron (III) oxide.



Inventory of Atoms

Reactants	Products	
1 Fe	2 Fe	Unbalanced
2 O	3 O	Unbalanced

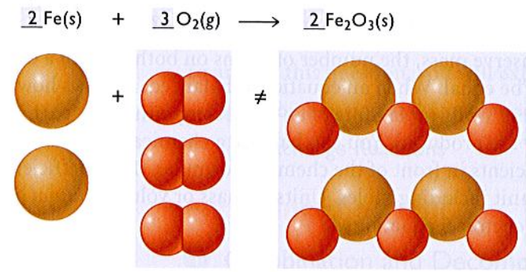
Balance the atoms on each side by adding molecules of O_2, atoms of Fe, or formula units of Fe_2O_3. If you add an Fe atom to the reactant side, the Fe atoms are balanced. However, the O atoms are still not equal.



Inventory of Atoms

Reactants	Products	
2 Fe	2 Fe	
2 O	3 O	Unbalanced

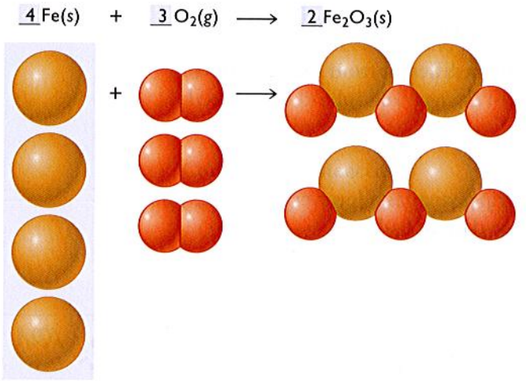
If you add two O_2 molecules to the reactant side and one Fe_2O_3 formula unit to the product side, the oxygen atoms are balanced.



Inventory of Atoms

Reactants	Products	
2 Fe	4 Fe	Unbalanced
6 O	6 O	

But now the iron atoms are unbalanced again. Add two more iron atoms on the reactant side, increasing the total to four. The balanced chemical reaction is shown here.



Inventory of Atoms

Reactants	Products	
4 Fe	4 Fe	Balanced
6 O	6 O	

It took a few steps, but the equation is finally balanced. Four iron atoms combine with three oxygen molecules to form two formula units of iron oxide.

2 Coefficients Are Counting Units

Once you have a balanced equation, multiplying all the coefficients by any counting unit will also give a balanced equation. You can multiply the coefficients by a dozen, or a thousand, or a million.

Original balanced equation → **4** Fe atoms + **3** O_2 molecules ⟶ **2** Fe_2O_3 formula units

× 2 → **8** Fe atoms + **6** O_2 molecules ⟶ **4** Fe_2O_3 formula units

× 12 → **4 dozen** Fe atoms + **3 dozen** O_2 molecules ⟶ **2 dozen** Fe_2O_3 formula units

× 1000 → **4000** Fe atoms + **3000** O_2 molecules ⟶ **2000** Fe_2O_3 formula units

Recall that a mole is also a counting unit. So, the next equation is also balanced.

× 602,000,000,000,000,000,000,000 → **4 moles** Fe atoms + **3 moles** O_2 molecules ⟶ **2 moles** Fe_2O_3 formula units

The coefficients in chemical equations can be multiples of any counting unit. The one used most often by chemists is the mole. We can use moles to count the number of atoms, molecules, or formula units involved in a reaction.

Key Terms

coefficient
formula unit

Lesson Summary

How do you balance atoms in a chemical equation?

In order to conserve mass, the number of atoms on both sides of a chemical equation must be equal. When an equation is balanced, it shows how many molecules, atoms, or formula units of an ionic compound take part in a reaction and how many are produced. You can balance a chemical equation by working with the coefficients in front of the chemical formulas. The coefficients can be any counting unit including moles. Units of mass or volume *cannot* be used as coefficients in chemical equations.

EXERCISES

Reading Questions

1. Why do chemical equations need to be balanced?
2. How are the coefficients in chemical equations different from the subscripts in chemical formulas?

Reason and Apply

3. Your recipe for banana bread calls for two ripe bananas. However, you have six ripe bananas that you want to use before they go bad.
   a. How can you make banana bread with all six bananas?
   b. How is this related to balancing a chemical equation?
4. Copy and balance these chemical equations.
   a. $K(s) + I_2(s) \longrightarrow KI(s)$
   b. $Mg(s) + Br_2(l) \longrightarrow MgBr_2(s)$
   c. $KBr(aq) + AgNO_3(aq) \longrightarrow KNO_3(aq) + AgBr(s)$
   d. $KClO_3(s) \longrightarrow KCl(s) + O_2(g)$
   e. $C_2H_6(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(l)$
   f. $Al(s) + O_2(g) \longrightarrow Al_2O_3(s)$
   g. $P_4(s) + H_2(g) \longrightarrow PH_3(g)$