Gold in the Ocean

Here's something to think about. The ocean is probably the most complex solution in the world. Just about everything you can think of is dissolved in there. One element in seawater is gold. The concentration of gold is about 0.00001 ppm. The question is how to get it out. You need something like a gold magnet.

If you did invent a gold magnet, could you get rich? Maybe. If you do the math, it looks like you could extract 200 g of gold (not quite half a pound) from every 180 billion liters of seawater. How much water is that? About the amount it takes to fill 75,000 Olympic-sized swimming pools.

Gold coins and gold bars

The gold in seawater is a little dilute. You probably want to focus on a more concentrated resource for a get-rich plan!

Review Questions

1. **What is the difference between a concentrated solution and a dilute solution?**
2. **Why does juice taste "weak" after the ice in it melts?**
3. **How can 50 mL of one salt solution have more mass than 50 mL of a second salt solution?**
4. **What is the maximum concentration of mercury allowed in drinking water in the United States?**

How Do Atoms Rearrange?

When you blow air through a straw into a cup of limewater, something happens. After a couple of breaths, the limewater is just noticeably hazy. After a couple more breaths, the limewater is definitely cloudy. After a dozen breaths, the cup of limewater is as white as milk.

What turns the limewater white? Plain air bubbled through limewater does not turn limewater white. Something in your breath does it. Carbon dioxide. It is the carbon dioxide in your breath that turns the limewater white.

That's not exactly right. Carbon dioxide isn't white, so it doesn't turn the limewater white. What happens is carbon dioxide mixes with something in the limewater to form a white substance. The white substance is not carbon dioxide or limewater. It is a new white substance.

What's happening is a **chemical reaction**. During a chemical reaction, starting substances change into new substances. Starting substances are called **reactants**. New substances are called **products**.

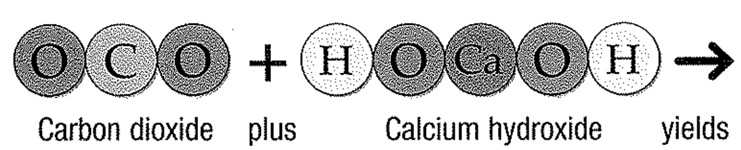
Figuring Out New Products

Carbon dioxide is one of the reactants. Limewater is the common name for a solution of calcium hydroxide and water. Calcium hydroxide is the other reactant. You can set up a **chemical equation** to help figure out what the white product might be. The **chemical formula** for carbon dioxide is CO_2. The formula for calcium hydroxide is $Ca(OH)_2$. The reactant side of the equation looks like this.

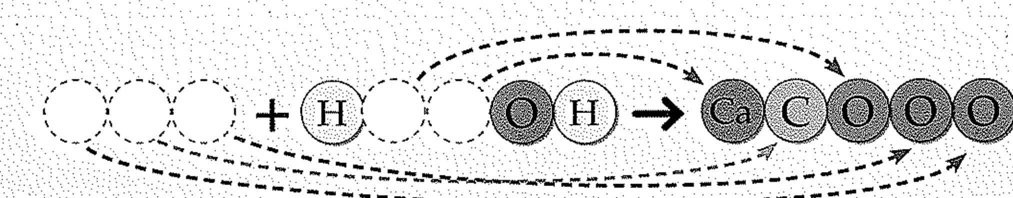
$$CO_2 + Ca(OH)_2 \rightarrow$$

This is how you read the equation: "One particle of carbon dioxide and one particle of calcium hydroxide react to yield..."

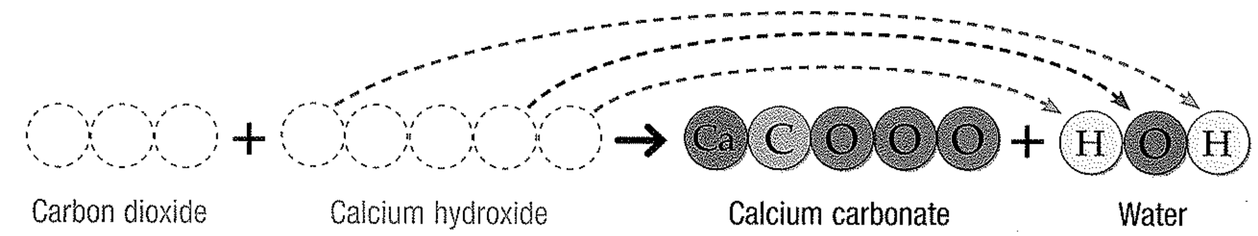
What could the products be? A set of **atom** tiles might help. Make representations of a carbon dioxide particle and a particle of calcium hydroxide. You can then move the atoms around to make products. An atom-tile representation of the equation looks like this.



The white substance that formed in the reaction did not dissolve in water. That's a clue. You need to see what insoluble substance you can make by rearranging the atoms in the reactants. Remember, calcium carbonate ($CaCO_3$) doesn't dissolve in water. The atoms needed to make a calcium carbonate particle are in the reactants. You can move those atoms to the product side of the equation.



What's left on the reactant side of the equation? Two hydrogen atoms and one oxygen atom. These combine to form a particle of water on the product side.



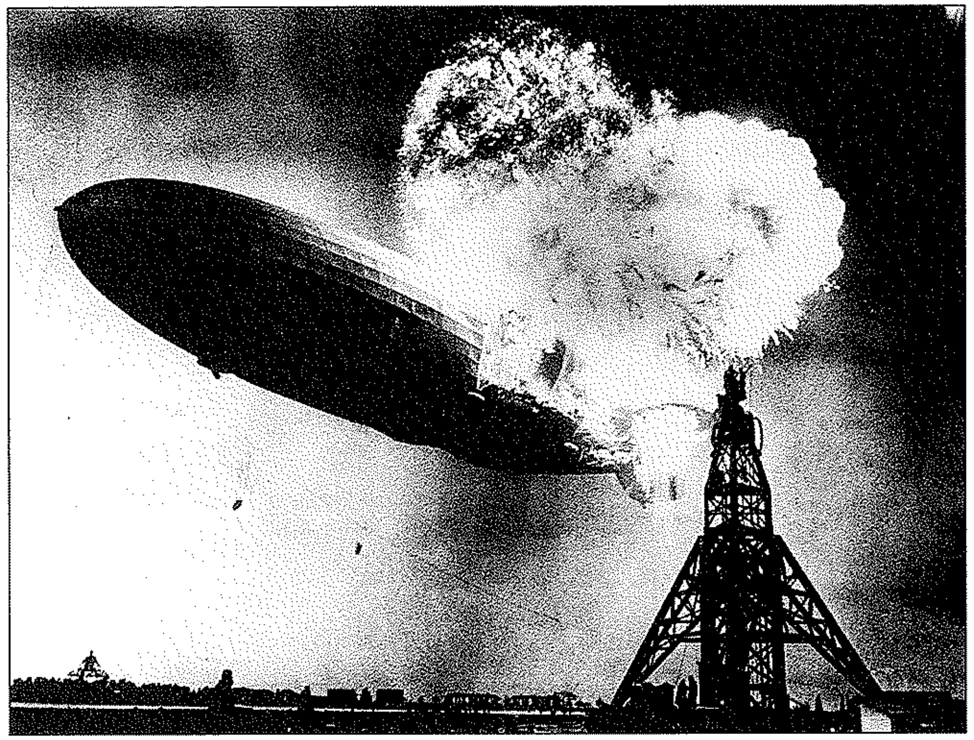
Notice that after the reaction has happened, the reactants are gone. They no longer exist. All the atoms that were in the reactants are now in the products. And the number of atoms on the product side is exactly the same as the number of atoms that started on the reactant side. During reactions, no atoms are destroyed or created. Matter is conserved. That means the number of atoms must be the same on both sides of the equation. This is a hard-and-fast rule.

Written with chemical formulas, the limewater equation looks like this. The down arrow by the formula for calcium carbonate means the substance appears as a **precipitate**.

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + H_2O$$

Other Reactions

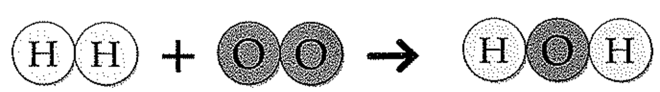
Did you ever see a blimp slowly sailing along overhead? It is an interesting vehicle. It stays aloft by being lighter than air. It actually floats in air in a way that is similar to a cork floating in water. To make the blimp lighter than air, it is filled with helium, element number 2. The blimp is a huge motorized helium balloon.



The hydrogen-filled *Hindenburg* burned completely in 37 seconds.

During the 1930s, lighter-than-air craft were developed for transportation. One of the largest such craft ever built was the *Hindenburg*, a 245-meter-long (800′) hydrogen-filled monster. On May 6, 1937, the largest structure ever to fly caught fire. In 37 seconds, the entire massive structure was destroyed.

The hydrogen burned. Burning is a reaction called combustion. The reactants were the hydrogen gas (H_2) in the *Hindenburg* and the oxygen (O_2) in the air. You can use atom tiles to see what products formed.



Water! When hydrogen burns, the single product is water. But look, something is wrong with the equation. There is one oxygen atom left over. How can this be fixed? The solution is to react *two* hydrogen particles with one oxygen particle to form two particles of water. Here is the balanced equation.

The field of modern chemistry grew out of experimental work with substances, called **alchemy**. One of the goals of the early alchemists was to turn common metals into gold. They never succeeded.

But changing one metal into another with a simple reaction is possible. If you have a solution of copper chloride ($CuCl_2$) and drop in a piece of aluminum foil (Al), a reaction takes place.

Aluminum metal and copper chloride react to form aluminum chloride and copper metal.

When the reaction is complete, the silvery aluminum is gone. In its place is a reddish brown precipitate of copper (Cu) metal and a solution of aluminum chloride ($AlCl_3$). Look at the reaction equation.

$$CuCl_2 + Al \rightarrow AlCl_3 + Cu$$

There is a problem. Do you see it? The chlorine atoms are not balanced, so it is not possible for one particle of each reactant to react. If you start with two $CuCl_2$ particles, then you have four chlorine atoms. That's too many. To balance the equation, you need to start with three $CuCl_2$ particles and two Al particles. The balanced equation looks like this.

$$3CuCl_2 + 2Al \rightarrow 2AlCl_3 + 3Cu$$

Reaction Summary

The particles of all substances are made of atoms. The kind, number, and arrangement of atoms determines the kind of substance.

New substances are created during chemical reactions.

During reactions, atoms rearrange. The atoms in the particles of the reactant substances rearrange to form the particles of the products.

Reactions can be described with equations. Substances in equations can be recorded with atom representations or chemical formulas.

Reaction equations must be balanced. The number of atoms of each kind must be equal on both sides of the equation. Balance is achieved by changing the number of particles reacting.

Matter is conserved. Particles of substances are created and destroyed during chemical reactions. Atoms are *not* created or destroyed during chemical reactions. Atoms rearrange to create new particles of substances.

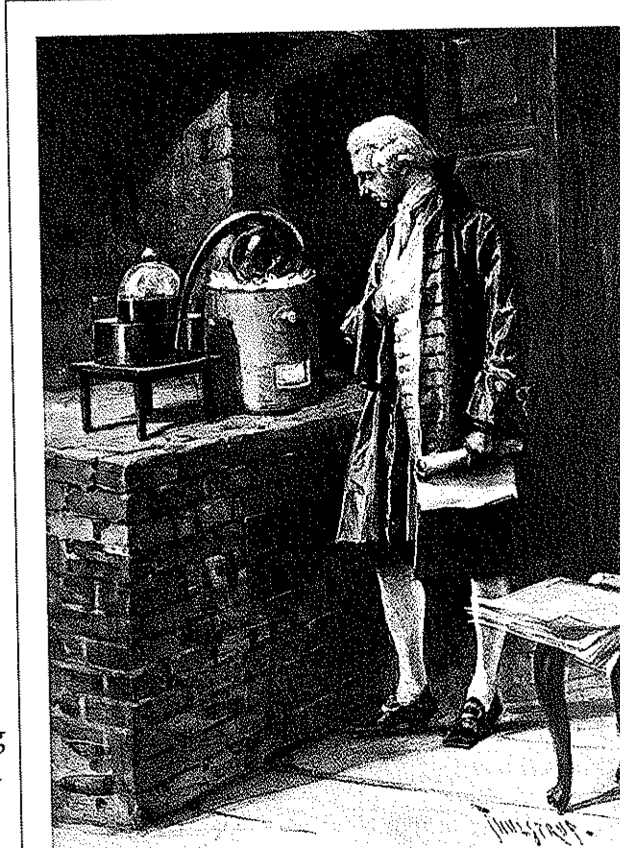
Review Questions

1. **What is destroyed and what is created during chemical reactions?**
2. **What are reactants and products? Write a reaction equation and label the reactants and products.**
3. **Write the equation for the reaction between hydrogen and oxygen. Use chemical formulas for the substances.**
4. **Methane (CH_4) is the main gas in natural gas. The products that form when methane burns are carbon dioxide and water. Write a balanced equation showing the combustion reaction when methane and oxygen react.**

Antoine-Laurent Lavoisier

The Father of Modern Chemistry

In 1794, during the French Revolution, a man was executed. This man was a famous chemist who helped revolutionize the study of chemistry. His experiments changed the way chemists understood fire. His work stressed the importance of careful measurement in experiments. He created a new language of chemistry and defended the idea that matter is not lost or gained during chemical reactions. Why was Antoine-Laurent Lavoisier's head cut off? Was it because of these ideas? Perhaps looking at his life and his work will help us understand.



Portrait of Lavoisier in his laboratory

Lavoisier (1743–1794) was born when King Louis XV ruled France. Because his family was wealthy, young Lavoisier was able to get an education. As a young man, he practiced law and owned a tax-collecting agency. Lavoisier was a prominent citizen in his community.

But it is Lavoisier's second life as a scientist for which he is remembered. Early in the morning and late at night, he studied mathematics, geology, physics, biology, and chemistry. His work in geology was so impressive that he was elected to the French Academy of Sciences when he was 25 years old.

Debunking Phlogiston

Lavoisier's interest in science turned more and more toward chemistry. One of many things he studied was combustion, the chemical reaction we usually call burning. During the 1600s and 1700s, chemists thought that all flammable substances contained an odorless, colorless substance called phlogiston. It was generally thought that when a substance burned, it gave up this phlogiston, and the material left behind weighed less than it did before.

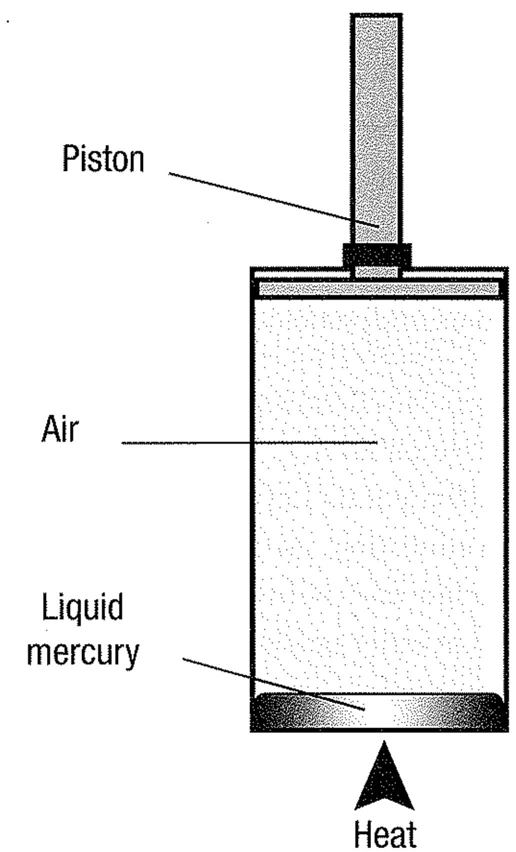
Lavoisier thought the theory of phlogiston was nonsense. He called it a "fatal error to chemistry." He set out to disprove the phlogiston theory.

In 1772, Lavoisier performed a series of experiments based on the work of another French chemist, Louis-Bernard Guyton de Morveau (1737–1816). He kept very detailed records, carefully measuring the weights of materials before and after he burned them. His results showed that substances such as sulfur and phosphorus actually gained weight when burned.

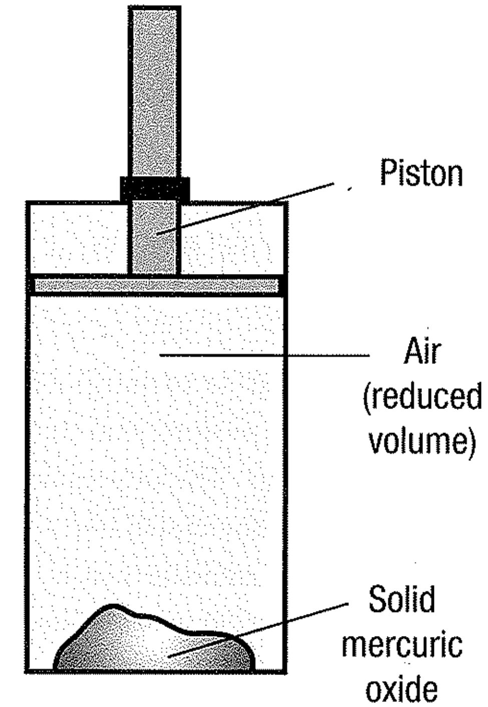
In 1774, Lavoisier met the English chemist Joseph Priestley (1733–1804). Priestley told him that he had discovered a "new kind of air" by burning mercuric oxide (HgO). Priestley tested animals in a closed container with this new air and found that they lived longer than animals in closed containers with regular air.

Intrigued, Lavoisier repeated Priestley's mercuric oxide experiments. But, unlike Priestley, he very systematically weighed and measured all parts of his experiments. He collected the gas given off and found that a candle thrust into the gas burned brighter than he could have imagined. Could Priestley's new air somehow be involved in the burning of other substances? Could it also explain why the substances he had burned before gained weight?

To find answers to his questions, Lavoisier devised a new piece of equipment. It was a kind of carefully crafted air-tight reaction chamber and oven. He put liquid mercury (Hg) into the reaction chamber, put the chamber in the oven, and heated it for 12 days.



Three interesting things happened. The mercury turned into a reddish solid substance. The volume of air in the container decreased from 50 to 42 cubic inches. And the new solid substance weighed more than the mercury!



Lavoisier concluded that the missing 8 cubic inches of air had combined with the shiny liquid mercury to produce the dull red mercuric oxide. The additional weight of the mercuric oxide was exactly equal to the weight of the "missing" 8 cubic inches of air.

He then heated the solid mercuric oxide to a higher temperature. It turned back into liquid mercury and gave off the exact amount of gas that had been lost before.

This change was proof to Lavoisier that combustion does not burn phlogiston out of a substance, but rather combines the substance with part of the air surrounding the substance. In 1785, he said that his ideas should replace the idea of phlogiston. Lavoisier later named this ingredient in air *oxygen*, a name that we still use.

Some important chemists, including Priestley, who first isolated oxygen and called it "new air," disagreed with Lavoisier's conclusion. They remained solid supporters of the phlogiston theory. But, in the end, the precisely measured results of Lavoisier's experiments convinced the new generation of chemists that oxygen explained combustion.

Other Major Contributions

What impressed Lavoisier's supporters more than anything else was his careful attention to quantitative detail. He spent a lot of his own money (he was wealthy) designing and building instruments, including balances as precise as those used today. With these instruments, he was able to establish the law of conservation of mass, which states that matter is neither gained nor lost during a chemical reaction.

Lavoisier was also quite the showman, making sure that his equipment was not only precise but flashy. One piece he developed, the gasometer, was used to measure volumes of gases. It stood about 6 feet tall, was made of gleaming brass, and was one of the most expensive pieces of chemistry apparatus anyone had ever seen. It cost more than $250,000 in today's dollars. Although its results were no better than anyone else's, its sheer expense and beauty made people begin to think of chemistry as serious science.

Chemistry, a serious science? Many people at that time still thought of chemistry as magic. But Lavoisier's Chemical Revolution was changing that. In addition to his experiments, he developed the system of chemical names that still exists today. This new vocabulary enabled chemists to communicate effectively and established chemistry as an independent, respected science.

To top it all off, he wrote what is now considered to be the first textbook of chemistry, *The Elements of Chemistry*, in 1789. In it, he introduced the idea of "elements," substances that could not be broken down into simpler substances. He included heat and light as substances, though they are now known to be energy.

Lavoisier was wrong about one major idea. When presented with the idea of atoms, tiny, unchangeable, defining units of an element, he dismissed them as impossible.

Death at Such a Young Age

Were these new ideas threatening to established scientific thought? Did Lavoisier deserve to lose his head for his ideas about chemistry? Actually, no. Science had been experiencing a revolution in thought called the Enlightenment. The intellectual world was ready to accept arguments based on experimentation and logical thought. Lavoisier and the chemists of the Chemical Revolution used those techniques. But it all came tumbling down for Lavoisier when the French Revolution broke out in 1789, the same year he published *The Elements of Chemistry*.

The French peasants had had enough of the monarchy and class system, and they rebelled against the king. The targets of their fury included anyone associated with the government. Lavoisier was a tax collector, and for that he was arrested, convicted of crimes against the people of France, and beheaded.

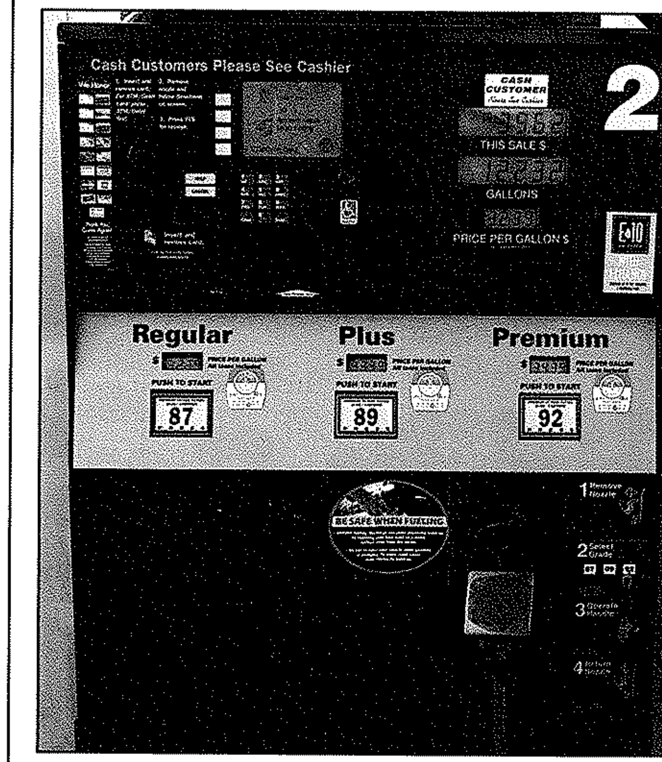
Review Questions

1. **Why did mercuric oxide in Lavoisier's reaction chamber weigh more than the mercury metal?**
2. **Why was there less air in Lavoisier's reaction chamber after he heated the mercury for 12 days?**
3. **What are some of the reasons Lavoisier is considered to be the father of modern chemistry?**

Organic Compounds

When a car pulls into a gas station, the driver is faced with a decision. Which grade of gas should I buy?

Regular is the lowest grade. If you check the pump, you may see that it is labeled 87 **octane**. More expensive grades have higher octane ratings, maybe as high as 92 or 93 octane. Motorists who choose economical cars reach for the regular. Those with high-performance cars must use the high-octane fuels.



A gas pump offers three grades of gasoline: 87 octane, 89 octane, and 92 octane.

What is octane? It is a substance. Its chemical formula is C_8H_{18}. Octane is the main ingredient in gasoline. Gasoline rated at 87 octane is 87% octane.

Under normal conditions octane is a liquid. If it is ignited with a match, it will react with oxygen in air and burn with a yellow flame. But if it is sprayed into a fine mist and ignited with a spark, it will explode. An explosion is a reaction that occurs extremely rapidly, and gives off a lot of energy in the forms of light and heat. That's what happens inside the cylinders of a car engine to make a car go.