Chapter 2: What's The Matter?

Introduction

Take a look around right now. What do you see? Nearly everything around you is made of matter. This book is made of matter, the ink that forms these words is made of matter. The eyes you are using to read these words are made of matter. Interestingly enough, though, you are observing all this matter with something that isn't composed of matter: light.

You see things because light reflects off them and enters your eyes. Specialized cells in your eyes detect that light, convert its energy into nerve impulses, which then get interpreted by your brain. Since light has no mass and doesn't take up any space, it isn't composed of matter. Everything you are seeing with that light, however, is composed of matter. In fact, there are even things you don't see that are composed of matter. You can't see the air you are breathing, but it is also composed of matter.

Obviously, then, there are a lot of different kinds of matter around you. One thing we have to do when we study matter is to group these different kinds matter into an organized system that will allow us to better understand it. In other words, we have to **classify** matter. That's the focal point of this chapter.

Mixtures and Pure Substances

One of the first things a chemist asks herself when she is studying a sample of matter is whether the sample is a **pure substance** or a **mixture**.

Pure substance – A substance whose properties are the same throughout

Mixture – A combination of two or more pure substances

Consider, for example, the table salt that is in a saltshaker. Ignoring any contaminants, such as dust that fell into the shaker while the salt was being added to it, the properties of the salt are the same everywhere. No matter how small the grain of salt or where it comes from in the salt shaker, the properties will always be the same. The salt in your saltshaker, then, is a pure substance.

Now suppose the saltshaker is getting low on salt, so you decide to refill it. Unfortunately, you mistakenly add pepper to it. What do you have now? You have a mixture of salt and pepper. If you used tweezers to pull one grain from the saltshaker, it might be a grain of salt. If so, it would have all the properties of salt. However, you might end up pulling out a grain of pepper instead, and it wouldn't have the properties of salt. It would have the properties of pepper.

One way you can make the distinction between mixtures and pure substances is to ask a question: can this sample of matter be separated into different substances by a simple, physical process? If so, you are dealing with a mixture. If not, you are dealing with a pure substance. Think, for example, about your saltshaker that has been contaminated with pepper. With tweezers and a magnifying glass, you could probably slowly (and tediously) separate the pepper from the salt. Fortunately, there is an easier way to do that. See how a chemist would separate the components of a slightly different mixture.

This shaker contains a mixture of salt and pepper.

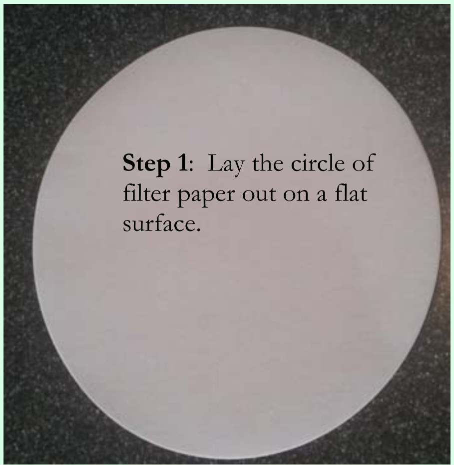
Experiment 2.1: Separating a Mixture of Salt and Chervil

Materials

- A $\frac{1}{8}$ measuring teaspoon
- A 100-mL beaker
- A 250-mL beaker
- An alcohol burner with stand
- A watch glass (the slightly curved circle of glass in your experiment kit)
- A funnel
- Filter paper
- Salt
- Chervil (This is a herb. Any leafy herb, such as chopped parsley, will work.)
- Safety goggles

Instructions

1. Add $\frac{1}{8}$ of a teaspoon of salt to the 100-mL beaker.
2. Add $\frac{1}{8}$ of a teaspoon of chervil to the same beaker.
3. Use the teaspoon to mix the salt and chervil together. You now have a mixture of salt and chervil. It looks like it would be tedious work to separate the salt from the chervil, doesn't it? It's easier than you might think.
4. Add water to the 100-mL beaker so it reaches the 50-mL mark on the beaker. Those marks aren't very precise, but they give you a rough idea of the volume.
5. Use the teaspoon to stir the water, salt and chervil. Stir for at least a full minute.



Step 1: Lay the circle of filter paper out on a flat surface.

Step 2: Fold the circle in half as shown here.

Step 3: Fold the circle in half again to make a cone.

Step 4: Wet the cone and push it into the funnel.

6. Observe what you have and write a description of it (or better yet, draw it) in your laboratory notebook.
7. Fold the filter paper as shown in the pictures on the left. Your goal is to make a cone out of the filter paper.
8. Wet the cone with water and put it in the top of the funnel so the sides of the cone stick to the sides of the funnel, as shown in the final picture in the sequence. That way, anything you pour into the funnel has to travel through the filter paper to exit.
9. Using one hand, hold the funnel over the 250-mL beaker.
10. Using the other hand, hold the 100-mL beaker that has the water, salt, and chervil in it.

11. Slowly and carefully pour the contents of the 100-mL beaker into the funnel. Be sure none of it spills outside the funnel, and do it slowly enough that the water level inside the funnel never gets higher than the top of the filter-paper cone. That way, all the contents of the 100-mL beaker must pass through the filter paper to drip into the 250-mL beaker.
12. Once you have poured all the contents of the 100-mL beaker into the funnel, continue to hold the funnel until all the liquid drains into the beaker.
13. Observe what you now have in the 250-mL beaker. Write a description of it (or better yet, draw it) in your laboratory notebook.
14. If there isn't alcohol in your burner already, add alcohol to it. Light the burner and put it under the stand so that the flame reaches (or at least comes near) the wire mesh on the stand.
15. Put the 250-mL beaker with the liquid in it on the stand.
16. Place the watch glass on the top of the beaker to make a "lid" for the beaker. The lid will not be airtight, of course, because of the spout in the beaker. That's good. You want the steam to escape.
17. Allow the water to heat up and boil. Continue to allow the water to boil until it has all boiled away.
18. While the water is heating, pull the filter paper out of the funnel and unfold it so it is a flat circle again. Draw or describe what you see on the filter paper.
19. It will take a while for all the water to boil away. As long as you can keep a careful eye on the boiling solution, feel free to do some other work while you are waiting.
20. When the water has boiled away, blow out the alcohol flame.
21. Draw or describe what you see in the beaker.
22. Clean up your mess, except for the beaker. Leave it on the stand to cool. Once it is cool, rinse all the salt out of it.

What did you see in your experiment? When you mixed the water, salt, and chervil, you should have seen a clear solution with bits of chervil in it. The chervil was not distributed evenly throughout the beaker, though, was it? It tended to clump in certain places. The salt wasn't visible, however, because it dissolved in the water.

When you poured the solution into the funnel, the chervil was unable to travel through the filter paper, so it stayed in the funnel. The water (and the salt dissolved in it) were able to travel through, though, so you ended up with a clear liquid in the 250-mL beaker. Because the clear liquid looked the same throughout, you might be tempted to think it was a pure substance. However, it wasn't. In fact, it was a mixture of salt and water. You showed that by boiling off the water. What was left after you did that? Only the salt. Since you could separate the salt from the water with a simple, physical process, you clearly had a mixture of salt and water, even though it appeared to be a pure substance.

Sometimes, then, a mixture can be deceptive. It can look like something that's pure, but it's not. Think, for example, of a steel rod. The steel rod looks like it is made of only one substance, but in fact, it is a mixture of two substances: iron and carbon. If care is taken, the iron and carbon can be separated from one another by a physical process. That means it's a mixture.

Comprehension Check

1. Classify the following as a mixture or a pure substance:

a. A bowl of cereal and milk
b. An ice cube
c. A drink made by dissolving a powder in water
d. A sample of oxygen

Homogeneous and Heterogeneous Mixtures

We will be discussing pure substances again soon. For right now, however, I want to concentrate on mixtures. Think back to your experiment. When you mixed the water, salt, and chervil, you clearly had a mixture. When you poured that mixture into the funnel, a mixture of salt and water dripped out of the funnel and into the 250-mL beaker. However, that mixture was fundamentally different from the mixture of water, salt, and chervil that you originally had. What was the difference?

The chervil was no longer in the mixture, so that's one difference. However, there was another difference as well: While the mixture of salt dissolved in water looked the same no matter where it was in the beaker, the solution of water, salt, and chervil did not. The chervil clumped together in some parts of the beaker, and in other parts of the beaker, there was no chervil at all. This is an important difference. When a mixture is the same no matter where you look at it (like the saltwater in the 250-mL beaker), we call it a **homogeneous mixture**. When a mixture is different depending on where you sample it, we call it a **heterogeneous mixture**.

Homogeneous mixture – A mixture whose composition is the same throughout the sample

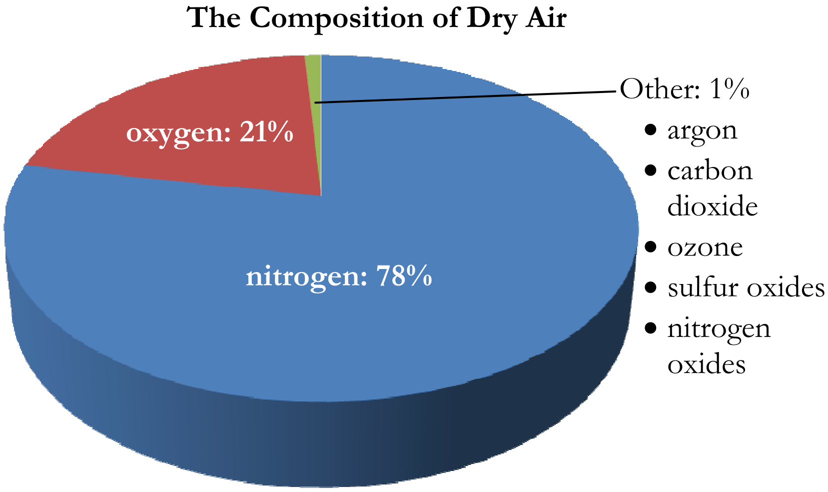
Heterogeneous mixture – A mixture whose composition is different in different parts of the sample

These terms should make sense. After all, the prefix "homo" means "the same," while the prefix "hetero" means "different."

The glass on the left contains milk bought in a store, which is a homogeneous mixture. The Italian salad dressing on the right is a heterogeneous mixture.

Heterogeneous mixtures are easy to identify as mixtures. For example, Italian salad dressing is a heterogeneous mixture, since you might get more spices if you sample one part of the bottle than if you sample another part. That's why people tend to shake the bottle before pouring. The milk you buy in a store is a homogeneous mixture. It has many different substances in it (water, sugars, fats, and proteins), but the relative amounts of each are the same regardless of where it is in the sample. In fact, that's why it's called "homogenized milk." If you take milk directly from the cow, the cream will rise to the top, making a heterogeneous mixture. Milk that you buy at the store has gone through a process that evens the composition out, making it a homogeneous mixture. Because it's a homogeneous mixture, however, it is easy to mistake for a pure substance. Nevertheless, it is a mixture, because you can separate the fats, water, sugar, and proteins with a simple, physical process.

Another homogeneous mixture that is easy to confuse with a pure substance is the air that you are currently breathing. You can't even see the air, but it's there. You probably already know it is a mixture of several different gases. If you get about 80 km off the ground (or higher), the mixture of gases becomes heterogeneous, but at altitudes where people are breathing, the mixture of gases we call air is always the same. If we ignore humidity (water vapor in the air), the air you breathe is the mixture shown on the right.



At the altitudes where people breathe, air is a homogeneous mixture, because the percentages of gases shown here remain the same.

This homogeneous mixture we call air is worth studying, because it is simply the ideal mixture for us to breathe. The reason we breathe, of course, is to get the oxygen that is in the air (you will learn why we need oxygen later on in this course). We don't use the other gases that are in the mixture, but we are very fortunate that they are there. If the air we breathe were pure oxygen, we would suffer all sorts of health problems, including blindness! In addition, for reasons you will learn later, the higher the percentage of oxygen in the air, the larger the chance of natural forest fires occurring. Indeed, experiments indicate that if the percentage of oxygen in the air were just 31% instead of 21%, there would be *seven times as many forest fires as there are now*. The percentage of oxygen in the air is the ideal level for us to get what we need and stay safe.

Now, of course, if you can't breathe pure oxygen, there needs to be something else in the air. We are fortunate that nitrogen makes up most of the rest of air. That's because nitrogen doesn't interact with our bodies. We breathe it in, and we breathe it right back out. Most gases that exist at standard temperatures are toxic to us in large enough quantities. However, nitrogen doesn't affect us in any way, so it is the ideal gas to fill up most of the rest of the air.

But that's not all! The levels of the gases in the remaining 1% are important as well. For example, carbon dioxide is a **greenhouse gas**. That means it tends to absorb the energy contained in a specific kind of light (called "infrared light"). This keeps the planet warm. If there were no carbon dioxide in the air, the earth would be too cold to support life. Too much carbon dioxide in the air would lead to the planet being too warm to support life. Fortunately, we currently have the ideal level of carbon dioxide to provide a warm, but not too warm, planet.

Ozone is also an important gas for our survival. As you will learn later, it absorbs a specific kind of light that can harm us (called "ultraviolet light"). If it weren't for the ozone in the air, we would all be fried by the sun! Interestingly enough, however, the ozone on planet earth is not very concentrated where we are breathing. Instead, it becomes more concentrated in high altitudes, where the air is no longer homogeneous. This is also fortunate for us, because high ozone levels are toxic to people. So we need ozone to survive, but it isn't good for us to breathe it. We are very fortunate, then, that the earth's ozone is concentrated where we are not breathing it!

If you believe this world was formed by a natural process, it would be hard to understand how it got the ideal mixture of gases to support life. However, for those who understand that the earth was fashioned by God, it is easy to understand why the mixture of gases we call air is so ideal for us. After all, God made the earth for people, so of course He would give us the right kind of air to breathe. The ideal mixture of gases we call air is one of the many testimonies of God's handiwork.

Now before we leave this section, I have to point out that even at the altitudes where people are breathing, air is not a *perfectly* homogeneous mixture of gases. If you go into a large city, you will find that the percentages of sulfur oxides, ozone, and nitrogen oxides in the air are a bit higher than they are outside the city, because they are found in the pollutants produced by automobiles and industry. Nevertheless, for most purposes, you can consider air to be a homogeneous mixture at altitudes where people are breathing.

Comprehension Check

2. Classify the following mixtures as heterogeneous or homogeneous:

    a. A bowl of cereal and milk
    b. A clump of dirt pulled from a lawn
    c. A drink made by dissolving a powder in water
    d. A clear sample of sea water

Mass Conservation: It's Not Just a Good Idea, It's the Law!

I want to move on to discussing pure substances, but in order for you to understand what you need to know about them, you need to learn a very important law of chemistry. It is called the **Law of Mass Conservation**, or sometimes just the **conservation of mass**.

Law of Mass Conservation – In any chemical or physical process, the total mass of everything involved must remain the same

An 18th-century French natural philosopher (that's what they called scientists back then) named **Antoine** (an' twahn) **Laurent** (law' rent) **de Lavoisier** (la vwah zee' ay) is generally given credit for formulating this law, but other 18th-century natural philosophers also expressed similar ideas. The law was such an important breakthrough in our understanding of matter that some science historians consider Lavoisier to be the father of modern chemistry. Most science historians give that honor to Robert Boyle, however, as he came earlier than Lavoisier and wrote a book (*The Sceptical Chymist*) that was the first to propose chemistry as a scientific endeavor rather than just a way to make useful substances.

Before you learn why this law is so important to our study of chemistry, perform the following experiment to become better acquainted with it.

Experiment 2.2: The Conservation of Mass

Materials

- Milk
- Vinegar
- A watch glass
- A 250-mL beaker
- A 100-mL beaker
- A mass scale

Instructions

1. Add milk to the 250-mL beaker until it reaches the very first line on the beaker.
2. Add vinegar to the 100-mL beaker until it reaches the second line on the beaker.
3. Turn on the mass scale and use the tare button to zero it.
4. Put the 250-mL beaker on the scale.
5. Put the watch glass on top of the 250-mL beaker so it rests there comfortably.
6. Put the 100-mL beaker on top of the watch glass so it rests there comfortably. Your setup should now look like the picture on the right.
7. Read the total mass of the beakers, watch glass, vinegar, and milk. Record it.
8. Carefully lift the 100-mL beaker off the watch glass with one hand.
9. Carefully lift the watch glass off the 250-mL beaker with the other hand.
10. Pour the vinegar in the 100-mL beaker into the 250-mL beaker so the milk and vinegar mix.
11. Put the watch glass on top of the 250-mL beaker, like it was before.
12. Put the 100-mL beaker back on the watch glass, like it was before.
13. Once again, read the mass and record it.
14. Remove both the 100-mL beaker and the watch glass.
15. Examine the contents of the 250-mL beaker. Describe (or draw) what you see.
16. Clean up your mess.

What happened in the experiment? You might not have noticed it when you first added the vinegar to the milk, but after you examined the beaker's contents, you should have seen that there was a white solid mixed in with the liquid. That solid was made up of clumps of a protein called "casein." The vinegar caused those clumps to form by making the milk too acidic. When casein clumps out of milk like that, we often say that the milk has "curdled."

Generally, we think of solids as much heavier than liquids. As a result, you might be tempted to say that the curdled milk and vinegar mixture got heavier than the milk and vinegar were before they were mixed. However, what did your mass readings indicate? The mass shouldn't have changed. It's possible that the mass changed by 0.1 grams or so, because remember, there is uncertainty in the last significant figure, even in a digital readout. From a scientific point of view, measurements that differ slightly in the last significant figure are the same. So, despite the fact that a solid formed from two liquids, the mass was the same both before and after the solid formed. That's the conservation of mass. Even though the appearance of the system changed significantly, the total mass didn't change at all.

This is important in chemistry because there are times when you can't see some of the substances involved in a chemical process. Think, for example, about a fire burning in a fireplace. What happens to the wood? It slowly changes into ashes, and the ashes take up significantly less volume than the wood did before it started burning. If you measured the mass of the ashes and compared that to the mass of the wood before it was burned, you would find that the ashes have a *lot less* mass than the wood.

What does that tell you? Since the conservation of mass tells us that the total mass in a chemical process can't change, it tells you that the wood must have turned into something besides just ash, and whatever it turned into is very hard to see. Well, it turns out that when wood is burned, two gases (water vapor and carbon dioxide) are produced. Those gases rise into the air and move away from the wood, and you can't see them. The conservation of mass tells you that even though you couldn't see them, the gases must have been produced.

In fact, the burning of wood is even trickier than that. Supposed you burned a bunch of wood and carefully collected all the ash, water vapor, and carbon dioxide produced in the burning. How would the mass of the ash, water vapor, and carbon dioxide compare to the mass of the wood before it burns? You might be tempted to say that the two masses would be the same, *but they wouldn't be*. In fact, the total mass of the ash, water vapor, and carbon dioxide would be *more* than the mass of the wood before it burned.


The conservation of mass helps us to determine that in the process of burning, oxygen and wood are consumed, producing ash, carbon dioxide gas, and water vapor.

What does that tell you? Well, once again, the total mass of whatever is involved in the process has to be conserved. If there is more mass in the ash, carbon dioxide, and water, then *something else must have been involved in the* process of burning. Once again, that something is a gas (oxygen), which you cannot see. In the burning process, then, oxygen and wood are consumed, making ash, water vapor, and carbon dioxide. If it weren't for the conservation of mass, it would be hard (if not impossible) to understand the process of burning, since we can't see the oxygen that is being added to the wood or the water vapor and carbon dioxide that are being made! When I start discussing pure substances in the next section, you will see how important this kind of reasoning is.

Comprehension Check

3. Believe it or not, you can burn metals. Magnesium metal, for example, burns with a bright, white flame. As it burns, it turns into a white powder. The mass of the white powder produced is greater than the mass of the magnesium burned. What does that tell you about the process of burning magnesium?

Elements and Compounds

Now that you know about the conservation of mass, you can learn about how we classify pure substances. When a substance is pure, it is either an **element** or a **compound**.

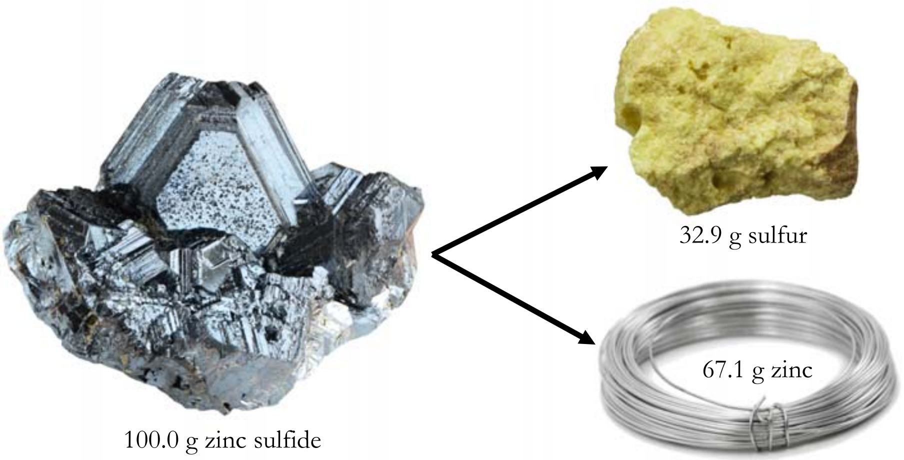
Element – A substance that cannot be chemically broken down into simpler substances

Compound – A pure substance that is composed of two or more elements

What do these definitions mean? Well, think for a moment about a flashlight. If you open up one, you will find that it has different parts. There are batteries, a tube that holds the batteries, a switch that turns it on an off, and a light bulb that emits the light. None of these parts makes light on its own. Instead, in order for the flashlight to make light, all the parts have to be there working together. By taking apart the flashlight, you have broken it down into simpler components. You can think of those components as the "elements" of the flashlight and the flashlight as a "compound" made up of those elements. Without all its "elements" in the proper place, the "compound" called the flashlight wouldn't work.

The pure substances that chemists call compounds are like the flashlight. Using the right kind of chemical processes, you can break these compounds down into simpler pure substances. When you get to the point where you can't break a substance down into simpler substances, then you know you have an element. Consider, for example, a chemical known as zinc sulfide, which is found naturally in many different parts of the world. Once it is mined, chemical processes are used to turn it into zinc metal, which is very useful in several different ways. In this process, a yellow powder known as sulfur is also produced.

If you start with 100.0 grams of zinc sulfide, you can make 67.1 grams of zinc from it. When you do that, you will also produce 32.9 grams of sulfur. This should tell you something. Zinc sulfide is made up of zinc and sulfur and nothing else. After all, mass conservation tells us that the total mass of everything involved has to stay the same. Since the mass of zinc and sulfur add up to the mass of the original sample, there can't be anything else that makes up zinc sulfide.



A 100.0-gram sample of zinc sulfide (left) can be chemically processed to make 67.1 grams of zinc (bottom right) and 32.9 grams of sulfur (top right).

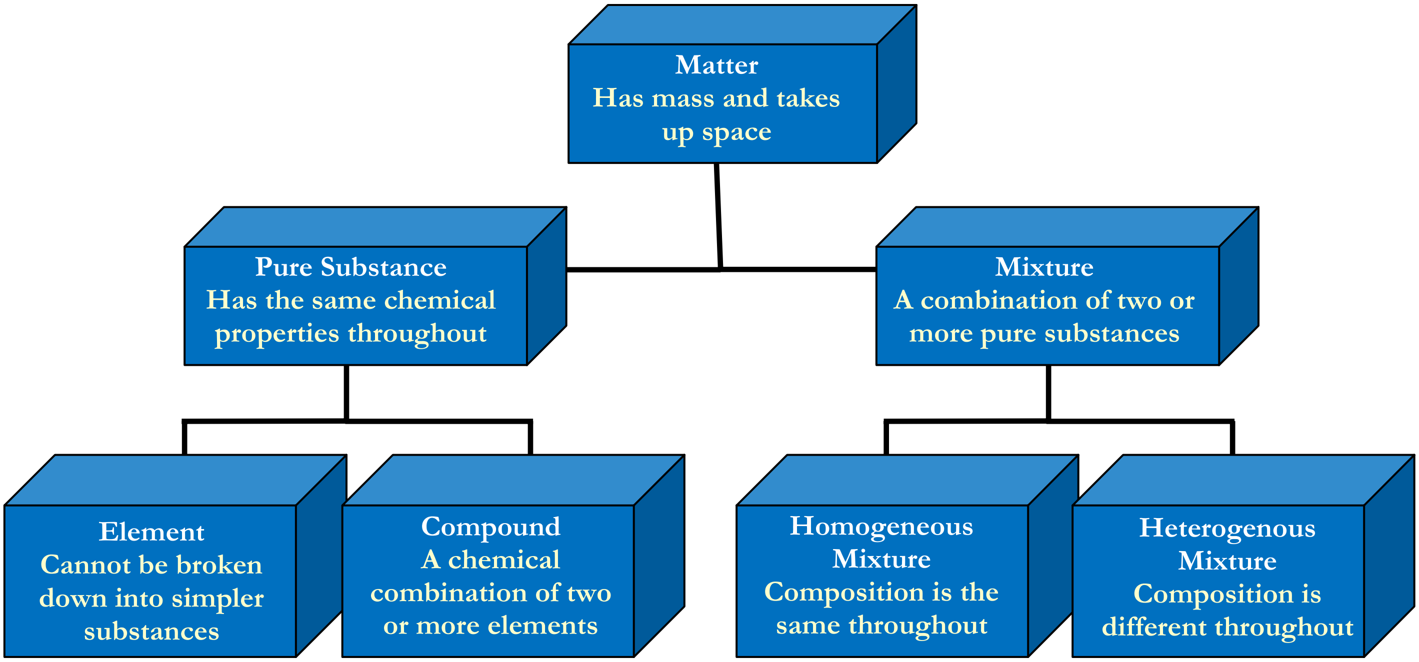
Now please understand that zinc sulfide isn't a *mixture* of zinc and sulfur. If that were the case, parts of it would have the properties of sulfur, and parts of it would have the properties of zinc. However, zinc sulfide has its own properties, which are quite different from those of zinc and sulfur. For example, zinc is hard but **malleable** (mal' ee uh bul), which means it can be bent and shaped without breaking easily. Zinc sulfide, however, is **brittle**, which means it is hard but can break when you try to bend or shape it. Sulfur, on the other hand, is a soft powder.

So zinc sulfide is made up of zinc and sulfur, but it is not a mixture of zinc and sulfur. Instead, it is a compound made when zinc and sulfur come together and form a chemical relationship. When that happens, zinc and sulfur lose their individual properties and combine to make a completely new substance with completely new properties.

What about zinc and sulfur? What are they? Well, no matter what kind of chemical process you try on either one of them, you can't break them down into simpler substances. In other words, if you start with 100.0 grams of sulfur, there is nothing you can do to make two different substances, each with masses that add up to 100.0 grams. You can do lots of chemistry with sulfur, but it always involves *adding* something to the sulfur so that the mass increases. What does that mean? It means sulfur is an element. The same is true for zinc, so zinc is also an element.

In the end, then, zinc sulfide is a compound that is made up of two elements: zinc and sulfur. When those two elements come together to form the compound, they lose their individual properties and make a pure substance that has totally new properties. This is the way chemists look at a pure substance. It is either an element or a compound.

If you think about what you have learned so far, we can put all the matter we see around us into one of four categories: heterogeneous mixture, homogeneous mixture, element, or compound. The chart below illustrates this.



Iron is an example of an element.

The rust on this metal is a compound made from the elements oxygen, hydrogen, and iron.

The fruit punch in this glass is a homogeneous mixture.

The fruit smoothie in this glass is a heterogeneous mixture.

Comprehension Check

4. A 50.0-gram sample of baking soda can be chemically converted into 13.7 grams of sodium, 0.6 grams of hydrogen, 9.5 grams of oxygen, and carbon dioxide. No other chemical is involved.

a. How much carbon dioxide is made in this process?
b. The sodium, hydrogen, and oxygen cannot be made into simpler substances, but the carbon dioxide can be made into two simpler substances. Identify each of the chemicals involved (baking soda, sodium, hydrogen, oxygen, and carbon dioxide) as compounds or elements.

5. Laughing gas is often used as an anesthetic by dentists. It is a pure substance made up of two elements: nitrogen and oxygen. The air you are breathing is mostly a mixture of nitrogen and oxygen. Why can't air be used as an anesthetic? After all, it contains the same elements as laughing gas.

The Law of Definite Proportions

About ten years after Lavoisier had described the law of mass conservation, another French scientist named **Joseph Louis** (loo wee') **Proust** (proost) discovered a law that also advanced our understanding of chemistry. To see the importance of that law, perform the following experiment.

Experiment 2.3: Oh What a Difference Some Oxygen Makes

Materials

- Water
- Hydrogen peroxide (sold in drugstores for disinfecting wounds)
- Active dry yeast (sold in supermarkets for baking)
- A 100-mL beaker
- A 50-mL graduated cylinder
- A ¼ measuring teaspoon
- Matches or a lighter
- Toothpicks (You need only one, but you might want a spare in case you run into some difficulties.)
- A sink
- Safety goggles

Instructions

1. Use your water faucet to get warm (not hot) water running from the tap.
2. Add warm water to the 100-mL beaker until it reaches the 30-mL mark. It doesn't have to be exact.
3. Add ¼ teaspoon of yeast to the water and use the measuring spoon to stir. Write down in your notebook what happens. (It's not very exciting.)
4. Add hydrogen peroxide to the graduated cylinder until you get 20 mL of hydrogen peroxide. Once again it doesn't have to be exact – just close.
5. Stand the graduated cylinder in the sink, as the next step results in a bit of a mess.
6. Pour the yeast/water mixture that is in the 100-mL beaker into the graduated cylinder.
7. Watch what happens, but don't write anything down yet. You should see foam rise up and then spill out of the graduated cylinder. At first, the bubbles in the foam will be small, but as the reaction continues, the bubbles will get bigger.
8. Once the foam has slowed down and the bubbles are big enough to easily see each individual bubble, hold the toothpick with one end between your thumb and forefinger and the other end pointing away from your hand.
9. With your other hand, light the match or lighter and use it to light the end of the toothpick that is farthest from your hand.
10. Allow the toothpick to burn until about one-third of it has burnt away. **Don't let the flame get too close to your fingers, however!** Your goal is to have a nice, visible red ember.
11. Blow the toothpick out so there is no flame. There still should be a red ember, however.
12. Slowly lower the toothpick into the bubbles at the top of the flame. It needs to be slow enough that the ember pops the bubbles but not so quickly that the ember gets wet. If you do it properly, a flame should appear again. If it doesn't work the first time, try again.
13. Now that you are done, describe or draw in your notebook what you saw when you poured the yeast/water mixture into the graduated cylinder and what happened when you put the toothpick with a red ember into the bubbles.
14. Clean up your mess.

What's the point of the experiment? Well, you know water is a pure substance. The water that comes out of your tap isn't really pure, but for the purposes of this experiment, we can treat it as if it is. This pure substance is a compound formed from the elements hydrogen and oxygen. When you added yeast to the water, nothing exciting happened. It formed a heterogeneous mixture of yeast and water, but that's it. When you added that mixture to hydrogen peroxide, however, something quite different happened – a foam formed that rose and spilled out of the graduated cylinder.

Well, guess what hydrogen peroxide is? It's a compound as well. Guess what elements it's made of? Hydrogen and oxygen. Now think about that for a moment. Water is a compound made from only two elements – hydrogen and oxygen. Hydrogen peroxide is also made from only two elements – hydrogen and oxygen. Nevertheless, they react quite differently to yeast. Water doesn't do anything but mix with yeast, and it does that very poorly. Hydrogen peroxide, on the other hand, forms a foam when exposed to yeast.

What's in that foam? Oxygen. That's why the red ember flared back into a flame when you put it in the bubbles. Oxygen is needed for fire, and the more oxygen you have, the better something burns. The toothpick was burning very slowly when it had just the red ember. By exposing it to the oxygen in the bubbles, however, you were able to get it to burn more quickly, eventually forming a flame.

So, water and hydrogen peroxide are both made of only hydrogen and oxygen, but they obviously have very different properties, so they are obviously different compounds. Does that strike you as odd? It should. How can the same two elements form two completely different compounds – one that doesn't react to yeast, and the other that produces oxygen when mixed with yeast? The answer lies in what Proust discovered – the Law of Definite Proportions:

Law of Definite Proportions – A given compound will always have the same proportion of elements by mass

In other words, the elements that come together to form a compound are very important, but that's not the end of the story. When they form a compound, the *proportion* in which they come together is also important.

In the case of water, for example, 1 gram of hydrogen comes together with 8 grams of oxygen to make 9 grams of water. Of course, you can scale this up any way you want. For example, you can double it so that 2 grams of hydrogen react with 16 grams of oxygen to make 18 grams of water. However, if you want to make water, the elements must be reacted in a 1:8 proportion – 1 gram of hydrogen for every 8 grams of oxygen.

In the case of hydrogen peroxide, you are still dealing with only hydrogen and oxygen, but *the proportion is different.* In hydrogen peroxide, 1 gram of hydrogen reacts with 16 grams of oxygen to make 17 grams of hydrogen peroxide. Since the proportion of the two elements is different (1:16 instead of 1:8), the compound that the two elements make is different. This is an important concept, so let's do a couple of problems using it.

Example 2.1

A chemist uses 32.0 grams of carbon and 32.0 grams of oxygen to make 44.0 grams of a gas, along with some leftover carbon. If she wants to make 110.0 grams of the same gas and have no leftovers at all, how much carbon and oxygen should she use?

To solve this problem, we have to use both the Law of Mass Conservation and the Law of Definite Proportions. First, we have to figure out how many grams of each element were used. There was no leftover oxygen, so all 32.0 grams of it were used. However, there was some leftover carbon, so not all of it was used. How much was not used? Mass conservation gives us the answer. After all, the chemist started with a certain amount of mass, so she must end with that same amount of mass. She started with:

$$\text{Starting mass} = 32.0\text{ g} + 32.0\text{ g} = 64.0\text{ g}$$

She ended up with 44.0 grams of the gas, so the rest of the mass must be the mass of leftover carbon:

$$\text{Mass of the leftover carbon} = 64.0\text{ g} - 44.0\text{ g} = 20.0\text{ g}$$

The chemist started with 32.0 grams of carbon, but 20.0 grams were left over. The amount of carbon actually used, then, was:

$$\text{Mass of carbon used} = 32.0\text{ g} - 20.0\text{ g} = 12.0\text{ g}$$

Now we know the real "recipe" for making the gas. You start with 12.0 grams of carbon and 32.0 grams of oxygen, and you will get 44.0 grams of the gas.

How do we determine what amounts to use to make 110.0 grams of the gas? It's just like using a recipe. If you have a recipe for a cake that feeds 8 people, and you want to make a cake that feeds 16 people, what do you do? You double all the ingredients. After all, 16 divided by 8 is 2, which tells us we need 2× as much cake. To make 2× as much cake, you need 2× as much of each ingredient.

We can do the same thing here now that we know the recipe. If we divide 110.0 grams by 44.0 grams, we will know what we have to multiply our ingredients by to get the right result.

$$\text{Multiplication factor} = \frac{110.0\ \cancel{\text{g}}}{44.0\ \cancel{\text{g}}} = 2.50$$

Note that since we are dividing grams by grams, the multiplication factor has no units. Also, while 110.0 has four significant figures, 44.0 has only three, so the multiplication factor can have only three. Now that we have the multiplication factor, we just multiply our recipe (12.0 g of carbon + 32.0 g of oxygen) to get the answer.

$$\text{Mass of carbon} = 12.0\text{ g} \times 2.50 = 30.0\text{ g}$$

$$\text{Mass of oxygen} = 32.0\text{ g} \times 2.50 = 80.0\text{ g}$$

To make 110.0 grams of the gas, then, the chemist must react <u>30.0 grams of carbon with 80.0 grams of oxygen</u>.

The same chemist does a different experiment where she reacts 18.0 grams of carbon with 30.0 grams of oxygen to make 42.0 grams of a gas and some leftover oxygen. Is this the same gas she made before?

She reacted the same elements together, so if they combined in the same proportion, they made the same gas. If they combined in a different proportion, they made a different gas. To determine the proportion, we have to determine what masses actually combined. There was no leftover carbon, so all 18.0 grams of carbon reacted. However, the total mass was:

$$\text{Total mass} = 18.0\text{ g} + 30.0\text{g} = 48.0\text{ g}$$

Since the gas made up only 42.0 grams, the mass of leftover oxygen must be:

$$\text{Mass of leftover oxygen} = 48.0\text{ g} – 42.0\text{ g} = 6.0\text{ g}$$

That means the mass of oxygen actually used was:

$$\text{Mass of oxygen used} = 30.0\text{ g} – 6.0\text{ g} = 24.0\text{ g}$$

So the actual recipe for this gas is 18.0 grams of carbon plus 24.0 grams of oxygen make 42.0 grams of the gas. Is this the same as the previous recipe? The best way to find out is to divide the two elements. That will give us the proportion. It doesn't matter which element I divide by the other, as long as I am consistent with each gas, so I will divide carbon by oxygen. For this gas, I get:

$$\text{Ratio of carbon to oxygen for this gas} = \frac{18.0\ \cancel{\text{g}}}{24.0\ \cancel{\text{g}}} = 0.750$$

The gas in the previous problem was made using 12.0 grams of carbon and 32.0 grams of oxygen. Thus, the ratio is:

$$\text{Ratio of carbon to oxygen for the first gas} = \frac{12.0\ \cancel{\text{g}}}{32.0\ \cancel{\text{g}}} = 0.375$$

We could have also used the final numbers we determined for the first gas (30.0 grams of carbon and 80.0 grams of oxygen), because the proportion would have been the same. Notice, however, that the ratio of carbon to oxygen for this gas is quite a bit higher than the ratio of carbon to oxygen for the previous gas. The Law of Definite proportions tells us that <u>the two gases are not the same</u>. It turns out that the previous gas was carbon dioxide, a gas we exhale. The gas made in this problem is carbon monoxide, which is toxic to people, even in relatively small amounts. It has the same elements as carbon dioxide, but because they combine in a different proportion, the gas has different properties.

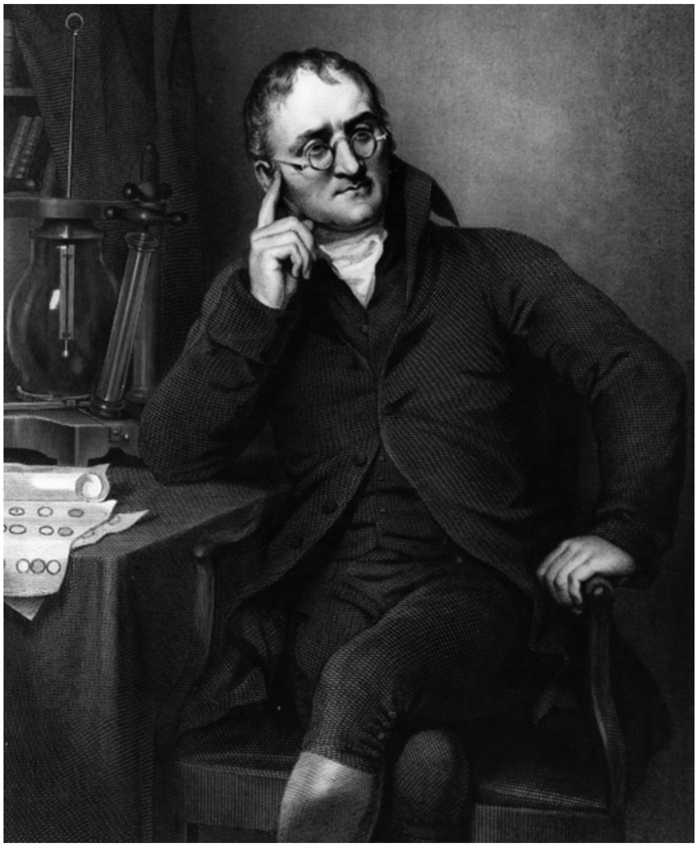
Comprehension Check

6. A chemist reacts 10.00 grams of copper and 3.21 grams of sulfur to make 9.56 grams of a blue powder. He also has some leftover copper. How much of each element should he react to make 100.4 grams of the blue powder with no leftovers?

7. A chemist reacts 50.0 grams of sulfur and with 50.0 grams of oxygen to make 83.4 grams of a gas, along with some leftover sulfur. In a different experiment, he reacts 20.0 grams of sulfur with 30.0 grams of oxygen to make 49.9 grams of a gas, along with some leftover oxygen. Are the two gases he made the same?

Dalton's Atomic Theory

In the very early 1800s, an English natural philosopher named John Dalton was studying a great many things, including how elements combined to form compounds. Dalton was a Quaker, and his deeply-held religious views affected everything he did, including his science. If you aren't familiar with Quakers, they are a group of Christians that started with a theologian named George Fox back in the mid-1600s. They are formally called the "Religious Society of Friends," and their churches are often simply called, "Friends Church." In Dalton's day, they were known for their emphasis on a personal relationship with God through Jesus Christ, plain dress, modest lifestyles, refusal to fight in wars, and opposition to drinking alcohol.


This engraving of John Dalton was made by William Henry Worthington and is based on a painting by Joseph Allen.

While studying chemical reactions, Dalton became intrigued by the laws of mass conservation and definite proportions. He wanted to do more than just use them. He wanted to understand why they worked. In an attempt to do that, he formulated what is now known as **Dalton's Atomic Theory**. In this theory, he proposed that all the substances in nature are composed of tiny particles called **atoms**, and if chemists really wanted to understand the nature of a substance, they had to understand the atoms which composed it.

Now, the concept of atoms wasn't new. Indeed, it was discussed by a Greek philosopher named Democritus about 400 years before Christ. Dalton's atomic theory was different, however, because it actually explained many observations, including the laws of mass conservation and definite proportions. It also was able to do something else, which you will learn about soon. The theory consists of four propositions:

Dalton's Atomic Theory

1. All matter is made up of atoms, which are indestructible and indivisible.
2. All atoms of a given element are identical in all their properties.
3. Compounds are formed by a combination of two or more different kinds of atoms.
4. A chemical reaction is a rearrangement of the atoms that exist in the substances which are reacting.

Today, scientists understand that while Dalton's atomic theory has some flaws, its essential ideas are mostly correct. As a result, it formed the basis of our current atomic theory. Because of this, Dalton is often referred to as the father of modern atomic theory.

You will learn what's wrong with Dalton's theory in a little while. For right now, let's just look at its propositions and understand how they explain what had already been observed about matter and its changes by this point in history. Consider, for example, the first proposition. If all matter is made of atoms and those atoms are indestructible, what does that tell us about mass? If you can't destroy atoms, you can't destroy mass. Of course, that's part of the Law of Mass Conservation. If the total mass in a chemical or physical process can't change, then mass can't be destroyed.

The second proposition says that if you look at all the atoms in an element, they are the same. When you include part of the first proposition, this explains why elements can't be broken down into simpler substances. The first proposition says that atoms are not only indestructible, they are also indivisible. That means they can't be broken down in any way. So, once you get to the point where you have atoms that are all identical, there is no way to break the element down into simpler substances. Since you can't break atoms down, you can't do anything to make an element simpler.

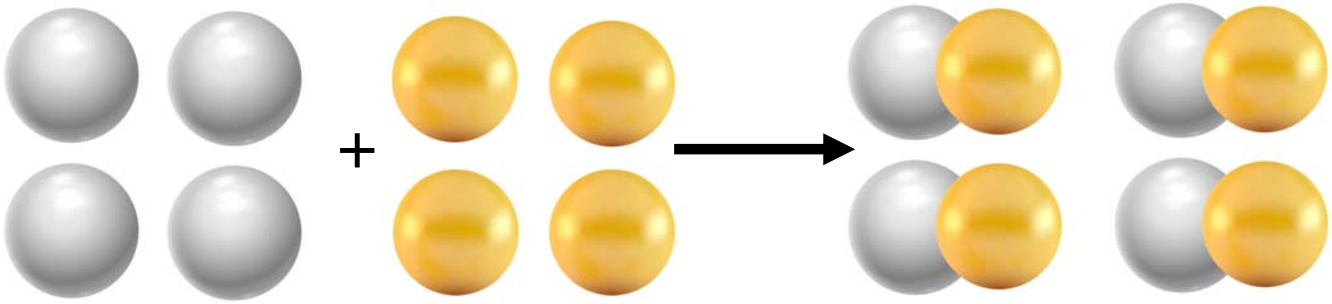
The third proposition gives us the distinction between compounds and elements. While the atoms that make up an element are all the same, the atoms that make up compounds are different. The zinc sulfide we discussed earlier, for example, is made from a combination of zinc atoms and sulfur atoms. Today, we call these combinations **molecules** (mol ih kyoolz').

<u>Molecule</u> – A combination of two or more atoms joined together

This, of course, explains why a compound can be broken down into two simpler substances. If you can separate the atoms in a molecule of zinc sulfide, the result will be zinc (a collection of identical zinc atoms) and sulfur (a collection of identical sulfur atoms).

The fourth proposition tells us what a chemical reaction is. It is a process by which atoms are rearranged. If I react zinc atoms with sulfur atoms, they join together to make zinc sulfide. That's a rearrangement of atoms. This completely explains the conservation of mass. Since all chemical reactions are just rearranging atoms, the total mass before and after the chemical reaction has to be the same, because the total number of atoms before and after have to be the same. After all, when you are just rearranging things, you aren't creating or destroying them; you are just shuffling them around. Since a reaction just shuffles atoms around, it can't change the total mass that is involved.

Given these four propositions, the illustration below shows how Dalton's Atomic Theory would explain a chemical reaction in which zinc and sulfur form zinc sulfide:



A sample of zinc, which is a collection of identical zinc atoms.

A sample of sulfur, which is a collection of identical sulfur atoms.

A sample of zinc sulfide, which is a collection of zinc atoms and sulfur atoms that are held together in a compound.

While the illustration gives an oversimplified view of this process, it is essentially correct. When zinc and sulfur react, their identical atoms are being rearranged so that they associate with one another and become a compound.

Now, of course, it is very nice when a theory can explain things that have already been observed. However, a scientific theory should be able to do more than that. It should also be able to make predictions about things that haven't been observed. After all, if a theory really is an accurate description of reality, you should be able to use that theory to predict how things will work out. So, of Dalton's Atomic Theory really is an accurate (or mostly accurate) description of chemicals, it should be able to predict things about chemical reactions. This is exactly what Dalton was able to do with his theory. You will learn about that in the next section.

Comprehension Check

8. Which of the following are not consistent with Dalton's Atomic Theory?

   a. Atoms cannot be created or destroyed in a chemical reaction.
   b. Compounds are composed of identical atoms.
   c. Chemical reactions change the atoms that are involved.
   d. When two compounds react, the atoms change how they are associated with one another.

The Law of Multiple Proportions

Once Dalton formulated his theory, he realized that he could use it to predict something about what happens when different compounds are formed by the same two elements. Since he thought that elements were made up of identical atoms that are indivisible, he realized that compounds must have whole numbers of atoms. A compound can't be made from half of an atom of one element and one-third of an atom of another element. When elements join to form compounds, they must do it in increments of one atom at a time. This limits the way elements can combine to make different compounds.

Based on this limitation, Dalton developed a prediction which we now call **The Law of Multiple Proportions**.

Law of Multiple Proportions – When two elements combine to form different compounds, a fixed amount of one element will combine with the other element so that ratio of the masses of the other element is a small whole number.

Now this law sounds awfully hard, but it's actually easy to understand with an example. Consider the gases in Example 2.1. For one gas, the recipe was 12.0 grams of carbon react with 32.0 grams of oxygen to make carbon dioxide, the gas that we exhale. Now suppose I take 12.0 grams of carbon and see how many grams of oxygen react with it to form the other gas, carbon monoxide, the gas that is toxic to us in even relatively small doses. I would find that to make carbon monoxide, I would need to react 12.0 grams of carbon with 16.0 grams of oxygen.

Look what I did. I *fixed* the amount of carbon. So, as the definition says, I used a fixed amount of one element (12.0 grams of carbon). To make carbon dioxide, I would have to react 32.0 grams of oxygen with the carbon. However, to make carbon monoxide, I would have to react 16.0 grams of oxygen. What is the ratio of those two masses of oxygen? It's 32÷16, which is 2. So when I fix the amount of carbon, the ratio of the masses of oxygen that react with it to form the two different gases is a small whole number.

Why does the Law of Multiple Proportions work? Well, let's look a bit more closely at the two gases we are discussing. Carbon monoxide is made when one carbon atom is linked to one oxygen atom. Carbon dioxide is made when one carbon atom is linked to two oxygen atoms. So, carbon dioxide has twice as many oxygen atoms as carbon monoxide. That means the mass of oxygen in carbon dioxide is twice as much as the mass of oxygen in carbon monoxide. That's why the ratio is 2!

The Law of Multiple Proportions itself is not as important as where it came from. Remember, Dalton was able to use his atomic theory to *predict* it. That's what makes it important. When a theory can correctly predict something that has never been investigated before, there is a good reason to believe that the theory is correct. In fact, that's one of the main ways scientists today determine which theories are likely to be correct. They use theories to make predictions, and then they test those predictions to see if they are accurate. If the predictions are accurate, there is good reason to believe that the theory is correct.

This is, in fact, one reason I am a creation scientist today. Scientific theories built on the concept of creation have made a lot of successful predictions over the years. For example, evolutionary scientists have taught for more than 40 years that the majority of the DNA in your body is useless junk that was leftover from the evolutionary process. Creationists, however, have long predicted that further genetics research would show that the vast majority of human DNA is not junk. Instead, it is used in the body. In 2012, a huge research initiative called ENCODE made the discovery that a minimum of 80% of the DNA in your body is used at some point in your life. In other words, the creationist prediction was found to be correct, while the evolutionary notion was found to be wrong. This is just one of many creationist predictions that have been successful over the years. You can find more confirmed creationist predictions at the course website discussed in the introduction to this book.

Comprehension Check

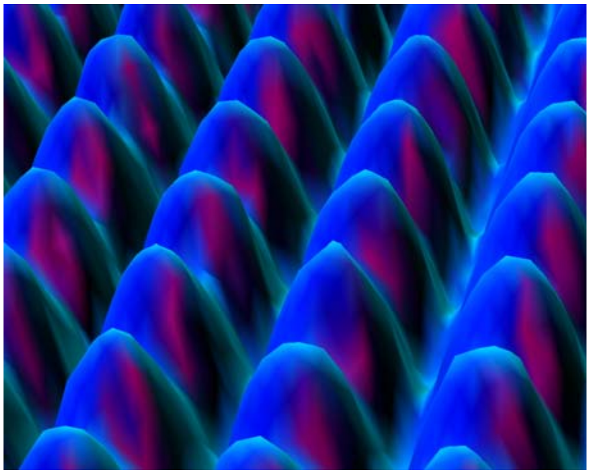
9. If a chemist reacts 6.4 g of copper with 1.6 grams of oxygen, cupric oxide is made. It is composed of one copper atom and one oxygen atom. However, copper and oxygen can also combine to make cuprous oxide, which is made of two copper atoms and one oxygen atom. Suppose you react 1.6 grams of oxygen with copper to make cuprous oxide. How many grams of copper would you have to use? (HINT: Think about the number of copper atoms in each molecule.)

What's Wrong with Dalton's Theory: Part One

As I told you, Dalton's Atomic Theory forms the basis of modern atomic theory, but there are several things wrong with it, so I need to tell you about them. Let's start with the first proposition. Dalton believed that atoms are both indestructible and indivisible. Both of those ideas are wrong. We now know that atoms are made up of three smaller particles, called **protons** (proh' tahns), **neutrons** (new' trahns), and **electrons** (ih lek' trahns). Marvelously enough, protons and neutrons seem to be made up of even smaller particles, called quarks, but that's way beyond the scope of this course.

How do we know that atoms are made of these three smaller particles? We can't see them. In fact, we can't even really see atoms, because they are simply too small. In order to see individual atoms, light must reflect off them and then enter our eyes. However, individual atoms are so small that light cannot reflect off them. It can reflect off large groups of atoms, which is why we can see all the things around us. However, it simply can't reflect off individual atoms. As a result, we cannot see them.

Even though we can't see atoms, we can "look" at them in an indirect way. It turns out that if you pass a small, electrically-charged probe across the surface of a metal, the way electricity flows between the metal and the probe depends on how close the two are. As a result, you can make a "map" of the metal's surface. If you do that, you end up getting a map that looks like the illustration on the right. Now please understand that this *is not* a picture of atoms. Pictures require light, and light cannot be used to see atoms. Instead, this is an image based on the results of an equation. There is a lot of evidence that the equation is correct, so it is very reasonable to interpret this as an image of atoms. It's just not a picture, because there is no known way to get a picture of atoms.



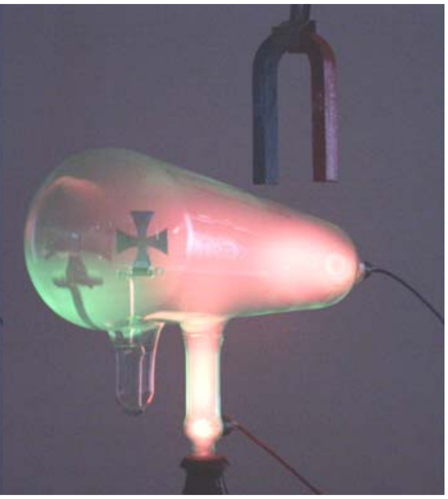
This is an image of a metal's surface at very high magnification. The bumps are interpreted to be atoms.

If an image like you see above is the best we can do when "looking" at atoms, it's clear that we can't "see" electrons, protons, and neutrons. How do we know they are real and are actually components of atoms? Once again, there are indirect ways of "seeing" these **subatomic** (sub' uh tom' ik – smaller than an atom) particles. Back in the 1870s, for example, William Crookes (krooks) and others experimented with special tubes, which are now called **Crookes tubes**. These tubes are filled with a small amount of gas, and when they are hooked up to a source of electricity, like a battery, the gas and glass both glow.

What causes the glow? At first, Crookes didn't really know. However, he made a special tube that had an obstacle inside. When the tube was connected to an electrical source, something very interesting happened:

Crookes tube before the electricity is turned on.

Crookes tube after the electricity is turned on.



Crookes tube and magnet after the electricity is turned on.

The first thing to notice from these pictures is that when the electricity is turned on, the tube begins to glow in two different colors. The pinkish color comes from the gas, while the greenish color comes from the glass. The second thing to notice is that the cross-shaped piece of metal inside the tube casts a shadow on the glass. What does that tell you? It told Crookes that the piece of metal is stopping whatever is causing the glow. That means the glow must be caused by things that are shooting from the back of the tube and traveling to the other end of the tube.

Look back at the previous page so you can see the rightmost picture. Do you see that the cross's shadow is lower and a bit distorted? That's from the magnet that you see at the back of the tube. This also told Crookes something: whatever is being made in the tube is electrically charged. In fact, based on the orientation of the magnet and the fact that the shadow of the cross-shaped object went down, it can be determined that whatever is produced in the tube is negatively charged. This is important, because the gas inside the tube is electrically neutral. This means that something must have been pulled from the atoms of gas in order to produce these negative charges.

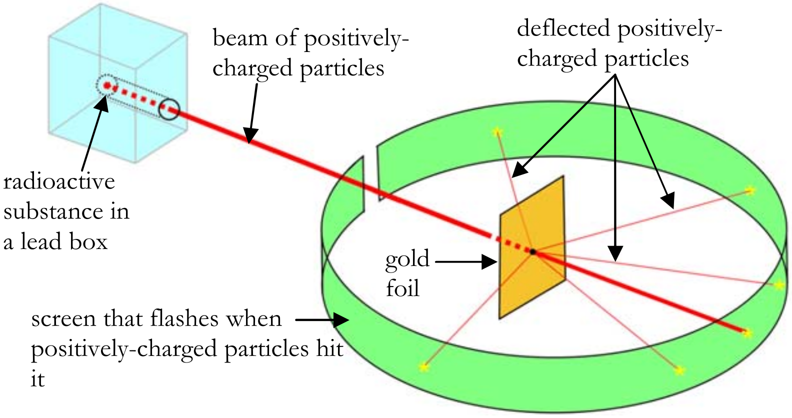
This illustrates the plum pudding model of the atom, with the bread representing the positive charge, and the raisins representing the electrons.

We now understand that the particles produced in the Crookes tubes are electrons, and they come from the atoms of the gas. Thus, contrary to what Dalton thought, atoms are divisible. They can be divided into negative charges (which we now call electrons) and positive charges (which we now call protons). For quite some time, scientists thought those were the only particles that made up atoms. As a result, they developed a **model** of how they are arranged in an atom. It was called the **plum pudding model**, because it had the positive charges distributed throughout the atom, like pudding. The electrons were small particles embedded in the pudding, like "plums."

Before I move on and tell you how scientists found out that the plum pudding model isn't accurate, I want to explain why it is called a model. As you know, we can't see atoms, much less protons and electrons. In order to think about what they might look like, then, we have to make a model. In everyday language, a model is usually a small-scale representation of something larger, such as a model car or a model airplane. In science, a model is a representation of some physical entity or physical process. So, chemists make models of atoms in an attempt to visualize what they look like.

While the plum pudding model was consistent with what chemists knew about atoms in the latter parts of the 19th century, English physicist Ernest Rutherford directed an experiment in 1909 that showed it couldn't be correct. The experiment, illustrated below, started with a radioactive substance that was known to emit positively-charged particles. The substance was put in a lead box that had a single hole through which the particles could escape. This produced a "beam" of positively-charged particles that traveled in the direction the hole was pointed.

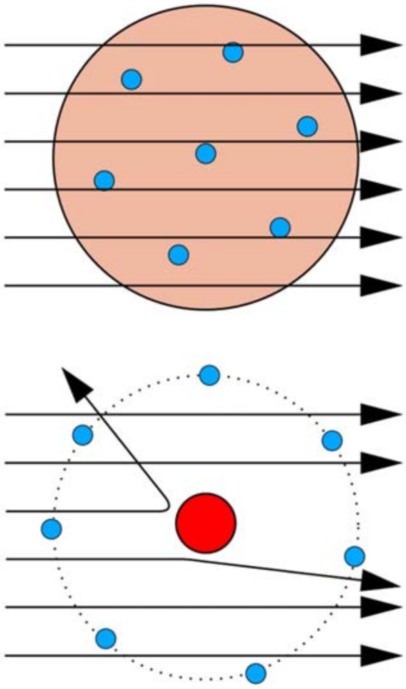
The particles were aimed at a thin foil made of gold, and that foil was surrounded by a screen made out of material that would light up when it was hit by the particles produced by the radioactive substance. So, the experiment forced positively-charged particles to hit a gold foil, and the screen would indicate where those particles went after they hit the foil. If the plum pudding model of the atom were correct, the positively-charged particles should travel straight through the foil. After all, the positive charges would be repelled by the positive "pudding" in the atom, but they would be attracted by the negative "plums." On average, they would experience no net push or pull, so they should travel pretty much straight through the foil.



This is a simplified illustration of Rutherford's famous experiment.

Rutherford and his assistants (Hans Geiger and Ernest Marsden) saw that most of the positively-charged particles did just that. However, they were shocked to find that some of the particles were deflected by the foil at various angles, some of which were near 180 degrees! This made no sense if the plum pudding model were correct. Rutherford (who was known to sing "Onward Christian Soldiers" while doing his experiments) remarked, "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." [Edward Neville da Costa Andrade, *Rutherford and the Nature of the Atom*, (Peter Smith Pub Inc, 1964), p. 111]

Rutherford realized that a new model of the atom had to be made, and it had to be consistent with the surprising results of his experiment. In the end, he decided that the only way to do that was to assume that the positive charges in the atom were concentrated at one place in the atom. He decided it was probably the center. If that were the case, then, most of the positively-charged particles in his experiment would move straight through the atoms of gold in the foil. However, the particles whose paths were close to that concentration of charge would feel a strong repulsion, and they would be deflected. The closer their paths were to the positive charge, the more they would be deflected, as shown in the illustration on the right.



In the plum pudding model (top), the positively-charged particles would pass straight through the gold atoms in the foil. In Rutherford's model (bottom), most of them would still do that, but those whose paths put them close to (or on a collision course with) the positive nucleus of the atom would be deflected, as he saw in his experiment.

Rutherford's model is often referred to as the **planetary model** of the atom, because it has the same structure as our solar system. Just as the planets orbit the sun in the solar system, the electrons orbit the protons in Rutherford's model of the atom. We now call the concentration of positive charge at the center of the atom the **nucleus**.

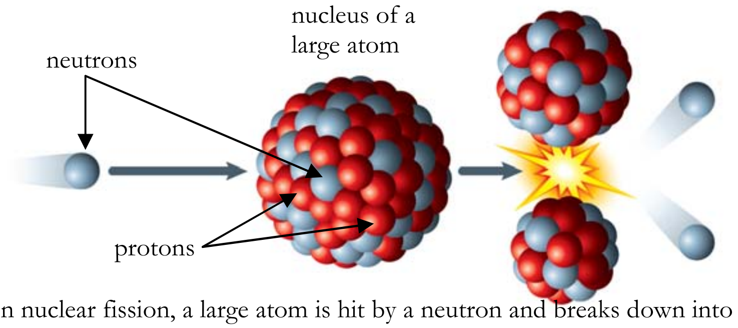
But it turns out there are more than just protons in the nucleus of most atoms. There are also uncharged particles called neutrons. Those took longer to discover, because it is much easier to see the effects of charged particles than the effects of neutral ones. Nevertheless, one of Rutherford's students, James Chadwick, was able to design a clever experiment to detect their existence. As a result, we now know that atoms are made up of positively-charged protons and uncharged neutrons, which are squeezed into the center of the atom, which is called the nucleus. The negatively-charged electrons orbit that positively-charged nucleus. The negative charges of the electrons perfectly cancel the positive charges of the proton, so that in the end, an atom has no net charge.

Comprehension Check

10. A gold atom has 79 protons in its nucleus. An atom of carbon has only 12 protons in its nucleus. Suppose Rutherford did his experiment with a carbon foil instead of a gold foil. Would he see more deflected particles, fewer deflected particles, or the same number of deflected particles?

What's Wrong with Dalton's Theory: Part Two

The fact that the atom is made up of three subatomic particles tells us that Dalton's idea of indivisible atoms is wrong. However, he was right about atoms being indestructible, right? Not really. Atoms can, indeed, be destroyed. For example, in a nuclear power plant, large atoms are hit with neutrons, and they fall apart into two smaller atoms and a few extra neutrons. What's really incredible about this process, which we call **nuclear fission**, is that the mass of the final products is *lower* than the mass of the initial atom and the neutron. That's because some of the mass gets converted into energy, which the nuclear power plant can then use to produce electricity.



In nuclear fission, a large atom is hit by a neutron and breaks down into two smaller atoms and a few extra neutrons. Mass is lost in the process, being converted to energy. (Only the nucleus of each atom is shown.)

Now wait a minute. If the total mass of the two smaller atoms and the extra neutrons that are made is less than the mass of the initial neutron and large nucleus, doesn't that mean the Law of Mass Conservation is wrong? Technically, yes. However, nuclear fission and processes like that do not occur in chemistry. It takes much more energy to destroy an atom than what exists in even the warmest chemical reactions. So as long as we restrict ourselves to *chemical* processes, the Law of Mass Conservation is still a useful law.

So, we now know that Dalton was wrong on two points. First, he thought atoms were indivisible, and we now know that's wrong. Second, he also thought atoms were indestructible, but we now know that's wrong. Surely that's all, right? If Dalton's Atomic Theory forms the basis of modern atomic theory, surely it's right about everything else.

Actually, there's one more thing he was wrong about, and it's the fault of the neutron. As you will learn in the next chapter, the chemistry of an atom depends on its electrons. Since atoms always have the same number of protons and electrons, you could also say that the number of protons in an atom determines its chemistry. As a result, all atoms that have the same number of protons have the same chemistry. However, the neutrons in an atom don't affect its chemistry. They affect other things, like the atom's mass.

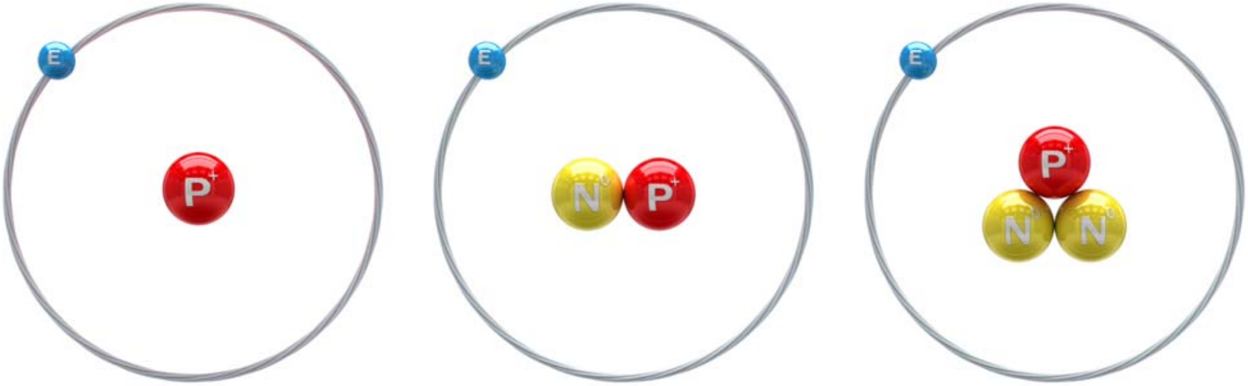
This causes a problem when it comes to discussing elements. Dalton thought that an element is a collection of atoms that are identical in all their properties. In terms of chemistry, that's true. Every atom in an element has the same chemistry as every other atom. However, they don't have the same mass. As a result, they aren't identical in *all* their properties.

Consider, for example, the simplest element that exists: hydrogen. It's a gas at room temperature, and it's so light that a balloon filled with hydrogen will float in air. The gas is also explosive. If you ignite it, hydrogen violently reacts with oxygen to make water and a lot of energy in the form of light, heat, and sound. Have you heard of the famous airship known as the

This photo shows the Hindenburg crashing after its hydrogen was accidentally ignited.

Hindenburg? It was filled with hydrogen so that it would be less dense than air and would therefore float in the air. Unfortunately, that hydrogen was accidentally ignited, resulting in an explosion that destroyed the ship, killing 35 of the 97 people on board.

Most atoms of hydrogen are made up of just one proton and one electron. However, about 0.01% of the atoms in a sample of hydrogen are made up of one proton, one neutron, and one electron. In addition, a very, very small percentage of hydrogen is made up of one proton, two neutrons, and one electron.



All three of these atoms are hydrogen atoms. They behave identically in any chemical reaction, because they all have one proton and one electron. However, they have different masses, because the first one on the left has no neutrons, the one in the middle has one neutron, and the one on the right has two neutrons.

Because each different form of hydrogen has a different number of neutrons, they each have a different mass. Hydrogen atoms with no neutrons are lighter than hydrogen atoms with one neutron. In the same way, hydrogen atoms with one neutron are lighter than those with two neutrons. We call these different forms of hydrogen **isotopes**.

<u>Isotopes</u> – Two or more atoms of the same element that have different numbers of neutrons

Because all naturally-occurring elements have isotopes, we know Dalton was wrong about what an element looks like on the atomic scale. An element isn't a collection of atoms that are identical in every way. Instead, an element is a collection of atoms that all have the same number of protons. This is something you need to remember:

An element is a collection of atoms that all have the same number of protons.

As far as we know, those are all the errors in Dalton's Atomic Theory. Of course, as chemists learn more about atoms, it's possible we'll find more things wrong with it, but for now, those are the problems of which we are aware. So, allow me to edit Dalton's Atomic Theory so that it is correct according to our current knowledge of chemistry.

Dalton's Atomic Theory (edited)

1. All matter is made up of atoms. ~~which are indestructible and indivisible.~~
2. All atoms of a given element are identical in ~~all~~ their *chemical* properties.
3. Compounds are formed by a combination of two or more different kinds of atoms.
4. A chemical reaction is a rearrangement of the atoms that exist in the substances which are reacting.

Now please don't think Dalton was a bad scientist because his atomic theory was flawed. All great scientists of the past produced theories that were flawed to one degree or another. What about the great scientists doing research today? Most likely, future scientists will find flaws in their work as well. This is the nature of science. It is constantly changing because we are constantly learning more about the world around us. Hopefully, each generation's theories are a bit better than the previous generation's theories, but science will never be perfect, because it is built on experiments. Those experiments and the way we interpret them can be flawed, so as a result, science will always be flawed to one extent or another.

Does that mean science is worthless, since it will always be flawed to a certain extent? Of course not! Consider what the Bible says in Romans 3:23: "for all have sinned and fall short of the glory of God." In other words, all people are flawed. That doesn't make us worthless! On the contrary, God considered us of so much worth that He sent his only Son to die for us so that our sins would be washed away. In a similar way, science is not worthless because it is flawed. It has given us a lot of knowledge and allowed us to make a lot of useful things like life-saving medicines, airplanes, and computers.

Despite the value of science, you have to understand that it is flawed. As a result, you shouldn't build your life around it. Instead, you should build your life around something that isn't flawed. That's why a good scientist understands that the Bible is the best place to start when it comes to making sense of the world around you. Since the Bible is without flaw, it is a better starting point than science. Science can help us make sense of the world around us, but since it is flawed, it shouldn't be our ultimate authority when it comes to how we live our life or understand the world around us.

Comprehension Check

11. Consider the following four atoms. Which pair could be called isotopes?

    a. An atom made from six protons, six electrons, and six neutrons
    b. An atom made from eight protons, eight electrons, and nine neutrons
    c. An atom made from ten protons, ten electrons, and nine neutrons
    d. An atom made from eight protons, eight electrons, and eight neutrons

As I have told you before, Dalton's Atomic Theory formed the basis of our current theory of the atom. What is the current theory? That's the subject of the next chapter. For now, complete the review to make sure you understand everything presented in this chapter. Once again, if you need more review, check the course website. Once you feel confident about the material, take the test so you can then move on to our current understanding of atomic structure.

Solutions to the "Comprehension Check" Questions

1. a. You can pick the cereal out of the milk, so this is a mixture
b. An ice cube is just frozen water, and you already learned that water is a pure substance.
c. Just like the saltwater you made in the experiment, you could boil off the water and be left with the powder, so this is a mixture.
d. Oxygen is a single chemical, so a sample of oxygen is a pure substance.
(Don't worry too much if you had problems with this question. The more you study this module, the easier it will be for you to classify pure substances and mixtures.)

2. a. Some parts of the bowl will have more milk, others will have clumps of cereal. That makes this a heterogeneous mixture.
b. Some parts of the dirt will have sticks, stones, grass, etc., in them, while other parts will not. Thus, this is a heterogeneous mixture.
c. Once dissolved, the powder is spread out evenly, so this is a homogeneous mixture.
d. If the sample is clear, it is a solution of water and several different dissolved salts. The dissolved salts are spread evenly through the mixture, so this is a homogeneous mixture.

3. It tells you that something besides magnesium is involved in the burning process. After all, the total mass of what is involved cannot change. If the mass of the powder is greater than the mass of the magnesium, something else must be involved. It turns out that oxygen gas is added to the magnesium while it burns, producing the white powder known as magnesium oxide.

4. a. Since there are no other chemicals involved, mass conservation says that the masses of everything produced must add up to the mass of the original sample. With the masses given so far, we have 13.7 g + 0.6 g + 9.5 g = 23.8 g. The total must add up to 50.0, however, because that's what we started with. Thus, the rest of the mass must be in carbon dioxide. That means 50.0 – 23.8 = 26.2 g of carbon dioxide is made.

b. Since they cannot be broken down into simpler substances, the sodium, hydrogen, and oxygen are elements. The baking soda was broken down into simpler substances, and the question says the same is true of carbon dioxide. Thus, baking soda and carbon dioxide are compounds.

5. Laughing gas is a *compound* made from nitrogen and oxygen, while air is just a mixture of nitrogen and oxygen. In a compound, the elements come together to make a substance with completely different properties. The substances in a mixture, on the other hand, retain their own properties. Since air is just a mixture of nitrogen and oxygen, those elements retain their own properties, which are quite different from the properties of laughing gas.

6. Since copper was leftover, we have to determine how much was actually used:

$$\text{Total mass} = 10.00\text{ g} + 3.21\text{ g} = 13.21\text{ g}$$

$$\text{Mass of copper leftover} = 13.21\text{ g} - 9.56\text{ g} = 3.65\text{ g}$$

$$\text{Mass of copper actually used} = 10.00\text{ g} - 3.65\text{ g} = 6.35\text{ g}$$

The actual recipe, then, is 3.21 grams of sulfur + 6.35 grams of copper make 9.56 g of the blue powder. To make 100.4 grams, we just determine the number we have to multiply everything by:

$$\text{Multiplication factor} = \frac{100.4\ \cancel{\text{g}}}{9.56\ \cancel{\text{g}}} = 10.5$$

We can now use that number to multiply the recipe:

$$\text{Mass of sulfur} = 3.21\ \text{g} \times 10.5 = 33.7\ \text{g}$$

$$\text{Mass of copper} = 6.35\ \text{g} \times 10.5 = 66.7\ \text{g}$$

To make 100.4 g of the powder, the chemist must react <u>33.7 grams of sulfur and 66.7 grams of copper</u>.

7. To determine if they are the same gas, we have to determine the proportion of the elements. To do that, we have to figure out what is leftover so we know the real recipe. For the first gas:

$$\text{Total mass} = 50.0\ \text{g} + 50.0\ \text{g} = 100.0\ \text{g}$$

$$\text{Mass of sulfur leftover} = 100.0\ \text{g} - 83.4\ \text{g} = 16.6\ \text{g}$$

$$\text{Mass of sulfur actually used} = 50.0\ \text{g} - 16.6\ \text{g} = 33.4\ \text{g}$$

The recipe, then, is 50.0 grams of oxygen and 33.4 grams of sulfur. That means the ration of oxygen to sulfur is:

$$\text{Ratio of oxygen to sulfur for this gas} = \frac{50.0\ \cancel{\text{g}}}{33.4\ \cancel{\text{g}}} = 1.50$$

The actual answer, 1.49700…, must be rounded to three significant figures, because both of the masses have three significant figures. That means dropping the “7,” which rounds the number to 1.50. For the other gas, we have to do the same thing:

$$\text{Total mass} = 20.0\ \text{g} + 30.0\ \text{g} = 50.0\ \text{g}$$

$$\text{Mass of oxygen leftover} = 50.0\ \text{g} - 49.9\ \text{g} = 0.1\ \text{g}$$

Note that since we are subtracting, we must report our answer to the same precision as the least precise number in the problem. Both masses have their last significant figure in the tenths place, so the answer must have its last significant figure in the tenths place.

$$\text{Mass of oxygen actually used} = 30.0\ \text{g} - 0.1\ \text{g} = 29.9\ \text{g}$$

So, the recipe is 29.9 grams of oxygen to 20.0 grams of sulfur. To compare the gases, I calculate the same ratio that I did for the other gas, which was oxygen to sulfur:

$$\text{Ratio of oxygen to sulfur for this gas} = \frac{29.9\ \cancel{\text{g}}}{20.0\ \cancel{\text{g}}} = 1.50$$

This is the same ratio, so the elements are added in the same proportion. That means <u>the two gases are the same</u>.

8. Statements (b) and (c) are not consistent with Dalton's Atomic Theory. Statement (a) just restates that atoms are indestructible. Statement (b) would be correct for elements, but not compounds. Statement (c) is wrong because atoms don't change in a chemical reaction. They only get rearranged. Statement (d) is correct, because changing how they associate with one another means they are being rearranged.

9. You would need 12.8 grams. The difference between cuprous oxide and cupric oxide is the number of copper atoms. Cupric oxide has one copper atom, while cuprous oxide has two. Thus, there are twice as many copper atoms in cuprous oxide. That means the mass of copper is twice as much. When reacted with a fixed amount of oxygen (1.6 grams in each case), twice as much mass is needed to make cuprous oxide.

10. He would see fewer deflected particles. With fewer protons, the nucleus is smaller. That means there will be fewer positively-charged particles passing close to it. Also, with fewer protons, the total positive charge of the nucleus is lower. That means a carbon nucleus cannot exert nearly as much force on a positively-charged particle.

11. Atoms (b) and (d) are isotopes. Remember isotopes have to belong to the same element and have different numbers of neutrons. Elements are composed of all atoms that have the same number of protons. In the list provided, only two atoms have the same number of protons: (b) and (d). That means they are both from the same element. Since they belong to the same element and have different numbers of neutrons, they are isotopes.

Review

1. Define the following terms:

    a. Pure substance
    b. Mixture
    c. Homogeneous mixture
    d. Heterogeneous mixture
    e. Law of Mass Conservation
    f. Element
    g. Compound
    h. Law of Definite Proportions
    i. Molecule
    j. Law of Multiple Proportions
    k. Isotopes

2. Classify the following as an element, compound, heterogeneous mixture, or homogeneous mixture.

    a. A bowl of fruit covered with yogurt
    b. A sample of helium gas, which cannot be broken down into simpler substances
    c. A sample of sugar thoroughly dissolved in water
    d. A sample of sodium bicarbonate (baking soda), which can be broken down into hydrogen, carbon, oxygen, and sodium.
    e. Several grams of magnesium, which is one of the two simplest substances produced when magnesium oxide breaks down.
    f. The magnesium oxide from which the magnesium discussed above was produced.
    g. A strawberry
    h. A cup of tea with no leaves in it.

3. A student does a chemical reaction with two chemicals. The total mass of the two chemicals is 45.0 grams. When she is done, she finds that the mass of all the chemicals she has collected is now only 34.5 grams. Has she collected all the products of the reaction? How do you know?

4. In the situation discussed in problem #3, what is the mass of the chemical or chemicals the student didn't collect?

5. Water is a compound that can be broken down into hydrogen gas and oxygen gas. However, a mixture of hydrogen gas and oxygen gas looks and behaves nothing like water. Why?

6. A 75.0-gram sample of a white powder is chemically broken down into 29.86 grams of copper, 15.06 grams of sulfur, and an unknown amount of oxygen gas.

    a. How much oxygen gas was made?
    b. Suppose you want to make 11.2 grams of the white powder with no leftovers. How much copper, sulfur, and oxygen would you have to use?

7. A chemist makes 86.94 grams of a black powder by reacting 54.94 grams of manganese with 32.00 grams of oxygen. If a student breaks down 144.9 grams of that powder, what mass of manganese and what mass of oxygen will be made?

8. In an experiment, a chemist reacts 7.85 grams of manganese with 2.29 grams of oxygen to make 10.14 grams of a powder. Is it the same as the powder made in problem #7?

9. In another experiment, a chemist reacts 10.0 grams of manganese with 5.8 grams of oxygen to make 25.8 grams of a powder. Is this the same as the powder made in problem #7?

10. Write down the original propositions for Dalton's Atomic Theory.

11. Note anything wrong with the propositions you wrote for #10.

12. A chemist makes two different compounds from the same two elements: tin and chlorine. He reacts 50.0 grams of tin with 29.87 grams of chlorine. There are no leftovers from either element. He then reacts 50.0 grams of tin with 59.74 grams of chlorine. Once again, there are no leftovers. If the first compound has two atoms of chlorine in the molecule, how many atoms of chlorine are in a molecule of the second compound?

13. A chemist is making two different compounds from the same two elements: nitrogen and oxygen. To make the first gas, she reacts 10.0 grams of nitrogen and 11.42 grams of oxygen to make 21.42 grams of the first gas. Suppose she starts with 10.0 grams of nitrogen again but wants to make a completely different gas with no leftover oxygen. Should she use 20.50 grams of oxygen, 22.84 grams of oxygen, or 35.12 grams of oxygen?

14. What three particles make up most atoms?

15. Give the sign of the electrical charge on each of the particles listed in #14.

16. Describe the plum pudding model of the atom and indicate what experiment demonstrated it wasn't correct.

17. Describe the planetary model of the atom and indicate who proposed it.

18. Of the three particles that make up most atoms, there is one particle that doesn't appear in some hydrogen atoms. Which is it?

19. Which two of the following atoms would be isotopes?

    a. An atom made of 13 protons, 14 neutrons, and 13 electrons
    b. An atom made of 14 protons, 14 neutrons, and 14 electrons
    c. An atom made of 13 protons, 12 neutrons, and 13 electrons
    d. An atom made of 15 protons, 16 neutrons, and 15 electrons

20. Which of the two isotopes you found in #19 would be the heaviest?

21. When you burn a fuel, what besides the fuel gets used up?

22. What particles do you find in the nucleus of an atom?

A rainbow forms because light coming from the sun is composed of many different wavelengths, some of which correspond to specific colors. You will learn about this in Chapter 3.