Lessons 1-15: Science Before Christ, Part 1

Lesson 1: When Did Science Begin?

Note to the parent/teacher: This lesson needs a day that is sunny enough so that things cast an easy-to-see shadow. I wouldn't start the course until you have such a day.

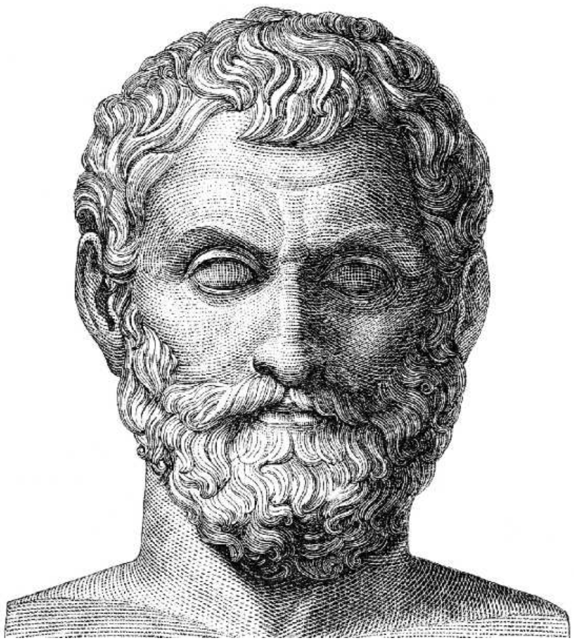
Let's suppose you meet someone new. What's one of the first things you want to know about this person? You probably want to know her name, right? What's the next thing you want to know? If you are anything like me, you want to learn how old the person is. Now it's impolite to ask an adult how old she is, but it's okay for one young person to ask that of another young person. In order to get to know your new friend, then, you probably ask how old she is. Well, in this course, I want you to get to know my favorite subject: science. That's the subject's name, but how old is it? It turns out that's kind of a hard question to answer, but I will give it a try.

If you study history, you will find very, very old accounts of people treating others for diseases and injuries. More than 2,500 years before Christ was born, there are written accounts of Egyptian doctors who would try to cure a person's illness or injury. We call these doctors **ancient** because they lived a long, long time ago. These ancient doctors would have long lists of plants that would be used to cure specific diseases or at least help the person deal with the pain caused by an injury. For example, it was common for ancient people to eat something contaminated with **tapeworm** eggs. Often, those eggs would hatch inside a person's body, and the worms would grow there. Obviously, this wasn't a good thing, and ancient Egyptian doctors used to give those people roots from the pomegranate tree. It turns out that those roots contain chemicals that help the body get rid of tapeworms, so the treatment often cured the patient.

This is a picture of the front end of a tapeworm, showing its head. These worms can hatch and live inside people and animals.

Would you call that science? Some people would. However, most scientists would not. Today's doctors use science, but ancient doctors really didn't. They used **trial and error**. In other words, they would give medicine to a person (perhaps because of something they observed or heard from someone), and if the medicine didn't help, they would try something else. The hope was that eventually, they would find a medicine that would work (like the pomegranate roots), and then they would write that down so that the next time a person had the same illness, they would start with that medicine. That's not really science, however. That's just trying all sorts of things, hoping something will work.

Many scientists would say that real science started much later, only about 600 years before Christ was born. Even though there were people (especially the Egyptians) who had pretty good medicine and some impressive inventions (like paper), they didn't try to understand *why* the medicines worked or *why* the things they did produced paper. Instead, they just tried things out, and if those things produced something worthwhile, they repeated them. Otherwise, they forgot about them. About 625 years before Jesus Christ was born, however, a man named **Thales** (thay' leez) was born. As as adult, he tried to figure out *why* certain things happened. That's when many scientists think that science began.


This is a drawing of a sculpture of Thales

Since Thales was born around 625 years before Jesus, we say that was born around 625 BC (before Christ). Historians often abbreviate the word "around" with a "c," because in Latin, the word "circa" means "around." So historians would say he was born c. 625 BC. Where did he live? He lived in an ancient Greek city called Miletus (my lee' tus), so he was often called Thales of Miletus. Even though he lived there, he didn't stay there all his life. In fact, he traveled to Egypt to learn from the Egyptians. What did he learn? He learned a lot about math. The ancient Egyptians were known around the world for their excellent math skills, and Thales wanted to learn all he could from them. He obviously learned a lot, because he started making some improvements on Egyptian math.

Now wait a minute. You are supposed to be learning about science. Why are you learning about a guy who went to Egypt to learn math? Because Thales was a **philosopher** (fuh lah' suh fur), which is a person who thinks and tries to figure things out. Back then, lots of philosophers studied math, because it helped them figure things out. To see what I mean, do the following experiment, which will teach you how to figure out the height of a tree without measuring the tree itself.

Measuring Tall Things

What you will need:

- A nice, sunny day
- A ruler
- A measuring tape or another ruler
- An adult to help you
- A tree or tall pole that casts an easy-to-see shadow
- A piece of paper and pencil to write some things down

Note: An example of how to use the numbers from this experiment is given in the "Helps and Hints" book, under the "Older Students" section. The parent/teacher should feel free to help the student with the math.

What you should do:

1. Stand the ruler straight up on the ground as near to the tree as possible but so that it is still in the sun and casts an easy-to-see shadow.
2. Have an adult help you use the measuring tape or other ruler to measure how long the ruler's shadow is.
3. Write that number down.
4. Write down the length of the ruler that is casting the shadow.

5. Stand as close to the tree as possible so that you cast an easy-to-see shadow, and have the adult measure the length of your shadow from the center of your feet to the very end of your shadow.
6. Write that number down.
7. Have the adult measure your height.
8. Write that number down.
9. Have the adult help you measure the length of the tree's shadow, from the center of the tree's trunk to the end of its shadow.
10. Write that number down.
11. Go inside, and put the rulers away.

Believe it or not, you have all the information you need to figure out how high the tree is. All you have to do is use a little math. In other words, you have to use math to help you figure something out, just like an ancient philosopher!

First, take the length of the ruler (you wrote it down in step 4) and divide it by the length of the ruler's shadow (you wrote that down in step 3). We will call that number the **factor**. Now take the length of your shadow (you wrote that down in step 6) and multiply it by the factor. Compare what you got to your own height (you wrote that down in step 8). The numbers should be almost the same, because when you multiply the length of a shadow by the factor, you get the height of the thing making the shadow. Now multiply the length of the tree's shadow by the factor. That's the height of the tree! Why does this work? You'll find out in the next lesson.

LESSON REVIEW

Youngest students: Answer these questions:

1. What is the name of the philosopher who started trying to figure out *why* things happened?

2. Why did this philosopher travel to Egypt?

Older students: Remember the notebook I told you about in the introduction to the course? It is time to get it out and do some work. On the first page of your journal, write "Thales" at the top. Then, explain who Thales was and why he went to Egypt.

Oldest students: Do what the older students are doing. In addition, I want you to record the experiment you just did. To do that, start by writing out all of the measurements you made. We call them **data**. You need to label your data so that you know what they are. So for the number you wrote down in step 3, write "Length of the ruler's shadow:" and write the number after the colon. Do that with all the lengths you measured. Next, write down how you got the factor. Do that by writing "Factor =" and then, after the "=" sign, write the length of the ruler, a "÷" sign, and then the length of the ruler's shadow. On the next line, write "Factor =" and then the actual number you got when you divided the two. Next, write "My height =" and then write the length of your shadow, the "×" sign, and then the factor. On the next line, write "My height =" followed by the number you got. Then write how close it was to your actual height. Finally, write "Height of the tree =" followed by the length of the tree's shadow, the "×" sign, and the factor. On the next line, write "Height of the tree =" followed by the number you got. This is how scientists record the data from their experiments as well as the results from their experiments. (The *Helps and Hints* book has an example of how to do this.)

Lesson 2: Math and Science

In the previous lesson, you did an experiment where you measured the height of a tree by measuring the length of its shadow. Why did this work? Well, as you probably already know, the length of an object's shadow depends on how tall the object is and where the sun is in the sky. The higher it is in the sky, the shorter the shadow, and the lower it is in the sky, the longer the shadow. The sun's position affects objects in a given area the same way, however, so if one object casts a shadow that is half of its height, all objects in that area will cast a shadow that is half of their height.

In your experiment, you took something of known height (a ruler standing up straight) and measured the length of its shadow. When you divided the length of the ruler by the length of the shadow, you got a factor. That factor told you how much you needed to multiply the length of a shadow by in order to get the height of the object. So when you measured your shadow's length and then multiplied it by the factor, you ended up getting something that was very close to your measured height. In the same way, then, when you measured the length of the tree's shadow by the factor, you got something that would be very close to the measured height of the tree.

The whole reason this works is because the length of an object's shadow is determined by two things: the height of the object and the position of the sun in the sky. Since the position of the sun in the sky affects the shadows of objects in a given area the same way, if we know the height of one object, we can measure its shadow and learn how the position of the sun in the sky affects all other objects in that area. Then we can determine the height of any object just by measuring its shadow.

This is what Thales was able to do with the math he learned in Egypt. Specifically, he used it to measure the height of the pyramids in Egypt. Have you seen pictures of the pyramids? The one shown here is a good example. These impressive structures were built by the ancient Egyptians, and they are incredibly tall. The one in the picture, for example, is 136 meters (448 feet) tall. You can get a good idea of how tall it is by looking at the people I have pointed out. They look tiny compared to the pyramid, because the pyramid is so huge. The ancient Egyptians were interested in knowing how tall the pyramids were, but they had no way of measuring them. Thales used essentially the same method you used in your experiment to measure the height of the pyramids.

This is a pyramid in Egypt. Notice how small the people in the lower left of the picture look. That tells you the pyramid is *really* tall.

Do you see why Thales wanted to learn as much math as possible? Math is incredibly useful, and it helps you figure out a lot of things. In science, you have to figure out a lot of things, so math is an important part of science. In fact, for a long time, math was not even considered separate from science. In ancient times, science was known as "natural philosophy," because it was involved in figuring out how nature works. Math was a part of natural philosophy. So in ancient times, and for quite some time after that, math and science were really thought of as the same thing. It is only fairly recently that people started considering them different subjects!

Because math and science were considered the same thing back then, Thales's math education was part of his science education, and he ended up using it to figure out lots of things. For example, he used math to figure out how far ships were from shore, and he was able to predict that a total eclipse of the sun would occur in 585 BC. (If you didn't learn this already, a total eclipse of the sun happens when the moon gets directly in between the earth and the sun. This keeps the sun's light from hitting a large section of the earth, making that region dark even in the middle of the day.) Obviously, being able to predict when such an event would happen is an impressive thing, and Thales was able to do that with a combination of what we would call math and science. In his day, however, it was all called natural philosophy.

One thing that's important to remember is that scientists aren't always right. Even when they are wrong, however, their thinking can sometimes lead to an idea that is right. Thales was wrong about a lot of things, but sometimes, even his wrong thinking was on the right track. For example, Thales thought that water was the most basic form of creation. According to him, everything was made of water and, eventually, it would turn back into water. We know that this idea isn't correct, but it does contain some bits of truth. In a sense, water is in a lot of things, and if you do it right, you can make a lot of things change so that water is made. Try this experiment to see what I mean.

Making Water

What you will need:
- A small glass, like a juice glass
- A candle that either supports itself or is in a candle holder
- Matches or a lighter
- A kitchen countertop
- An adult to help you

What you should do:
1. Put the candle on a kitchen counter far from anything that can burn.
2. Have an adult use a match or lighter to light the candle.
3. Hold the glass in the air upside down over the candle, as shown in the picture on the right. Don't lower the glass too far, or the candle flame will go out.
4. As you are holding the glass over the candle, watch the glass carefully. You should notice something happening in less than a minute.
5. Pull the glass more than an arm's length away from the candle, but keep looking at it. Once again, you should notice something happening in less than a minute.
6. Repeat steps 4 and 5 to see the effect one more time.
7. Blow out the candle, put everything away, and clean up any mess you might have made.

What did you see in the experiment? You should have noticed that after just a few seconds, the glass started fogging up. However, once you pulled the glass far from the flame, the fog inside slowly went away. When you put the glass back over the flame, it fogged up again.

What explains the experiment's results? The fog you saw on the glass was actually *water*. You have probably already learned that water can exist as a gas (called "water vapor"), a solid (called "ice"), or a liquid (usually just called "water"). Well, the candle flame actually produced water vapor. However, as the water vapor moved away from the flame and hit the glass, it cooled enough to become little drops of liquid, and those drops fogged up the glass.

Why did the flame produce water? Because when you burn the wax in a candle, the chemicals in the wax interact with oxygen in the air. As a part of this interaction, the chemicals in the wax change into completely different chemicals, and one of those chemicals is water. So the *makings* of water can actually be found in wax and air! If you treat wax and air in a specific way (burn them), they can produce water.

Like burning the candle in your experiment, burning wood produces water vapor, because the wood and the oxygen in the air contain the makings of water.

In a sense, then, Thales was on the right track when he thought that things were made of water. That's not really true, but in some things (like candle wax and air), the *makings* of water can be found. If you treat these things in a specific way, they will produce water. At the same time, however, there are some things that don't contain the makings of water at all. No matter what you do to them, they can never be used to produce water.

As you learn more and more about science and its history, you will find that it is very common for even the greatest of scientists to be wrong about many, many things. Thus, no matter how great the scientist, you should not just trust his or her opinions. You should examine the evidence yourself, since even the greatest of scientists can be wrong. That's one reason I want you to do so many experiments in this course. I want you to get used to the idea of looking at the evidence yourself!

LESSON REVIEW

Youngest students: Answer these questions:

1. In the experiment for Lesson 1, you measure the height of a tree by measuring the length of its shadow. What did Thales measure in the same way?

2. What is one of the chemicals made when wax is burned?

Older students: Make a drawing of the experiment you did. Underneath the drawing, write what you saw happening to the glass and why it happened.

Oldest students: Do what the older students are doing. Also, do a bit of research and find out what other chemical (besides water) is made when wax is burned. Indicate why you didn't see it in the experiment.

Lesson 8: Some Correct Ideas about Atoms

As I already mentioned, Democritus had some incorrect ideas when it came to atoms. However, he had some correct ideas as well. One of the most important correct ideas he had about atoms is that atoms are always in motion. Today we understand that while some things are made up of atoms (a bar of iron is made up of atoms), most things are made up of molecules. If we modify Democritus's idea to say that atoms and molecules are always in motion, we come up with something that modern scientists still think is true.

Now you might have already learned that atoms and molecules are in constant motion, but it might be a bit hard for you to believe. After all, this page that you are reading is made up of molecules, and the page is not moving. If the molecules that make up the page are moving, wouldn't we see the page moving? If nothing else, wouldn't we *feel* that motion when we touch the paper? Well, let's do a quick experiment which allows you to see that even in something that is not moving, the molecules which make it up are moving like crazy.

The Motion of Water Molecules

What you will need:

- Two small glasses, like juice glasses (At least one of them should be able to withstand boiling-hot water.)
- Water
- Something to heat the water (A microwave will do, as will a stove and a pot.)
- A hotpad
- Pepper
- A blank sheet of white paper

What you should do:

1. Fill one of the glasses ¾ of the way with water that is room temperature or cooler.
2. Fill the other glass ¾ of the way with water that is near boiling. You can do this by putting water in the glass and then heating it in the microwave oven until you see it boiling, or you can heat water to boiling in a pot on the stove and then pour it into the glass.
3. Using the hotpad to handle the glass with hot water in it, put the glasses right next to each other on a counter or tabletop. If you are using a table, put the glasses on coasters.
4. Put the white sheet of paper behind the glasses.
5. Position yourself so that your eyes are level with the center of the glasses and observe the water. You should be seeing the white paper in the background. Is the water moving? Depending on how you held and moved the glasses, there might be some motion in the water, but that motion should quickly die out. In the end, you should see nothing moving in the glasses.
6. Shake pepper on the surface of the water in both glasses. You want to completely cover the surface of the water in each glass with a lot of pepper, so don't be stingy!
7. Put the white sheet of paper behind the glasses again.
8. Position yourself so that your eyes are level with the center of the glasses and observe the water now.
9. If there is no pepper falling down into the water from the surface, gently tap the glasses. You should see pepper slowly falling down from the surface of the room-temperature water to the bottom of the glass. However, what happens in the glass that holds hot water should be quite different. What do you see happening there?

10. Continue your observations for a while, gently tapping the glasses from time to time to encourage pepper to fall from the surface of the water.
11. Clean up your mess and put everything away.

What did you see in your experiment? Hopefully, you saw that while the pepper fell gently down to the bottom of the glass that contained room-temperature water, the pepper didn't do that in the glass with hot water. Instead, the pepper started to fall, but it *got pushed back up to the surface*! Why did that happen?

As you probably already know, something sinks because it weighs more than an equal volume of water. Since most of the pepper weighs more than a pepper-sized sample of water, the pepper starts to sink. However, in order to sink, what must it do? It must push the water molecules out of the way so that it can fall down into the water. That's why it has to be heavier than an equal volume of water. If it isn't heavier than an equal volume of water, it can't push the water molecules out of the way and fall between them. In the glass that contained room-temperature water, then, the pepper successfully pushed water molecules out of the way and fell between them, sinking to the bottom of the glass.

In the hot water, the pepper *started* to do that. You saw pepper falling from the surface, but rather quickly, the pepper started *moving up to the surface again*! What pushed the pepper up to the surface of the water? The motion of the water molecules did! Even though the water looked like it wasn't moving, the water molecules were moving like crazy. Water molecules near the surface of the glass were cooling down, and that made them sink. Hotter water molecules were rising from the bottom of the glass, and those rising, hot water molecules collided with the pepper, pushing the pepper back up to the surface. So even though it didn't look like the hot water was moving, its molecules were!

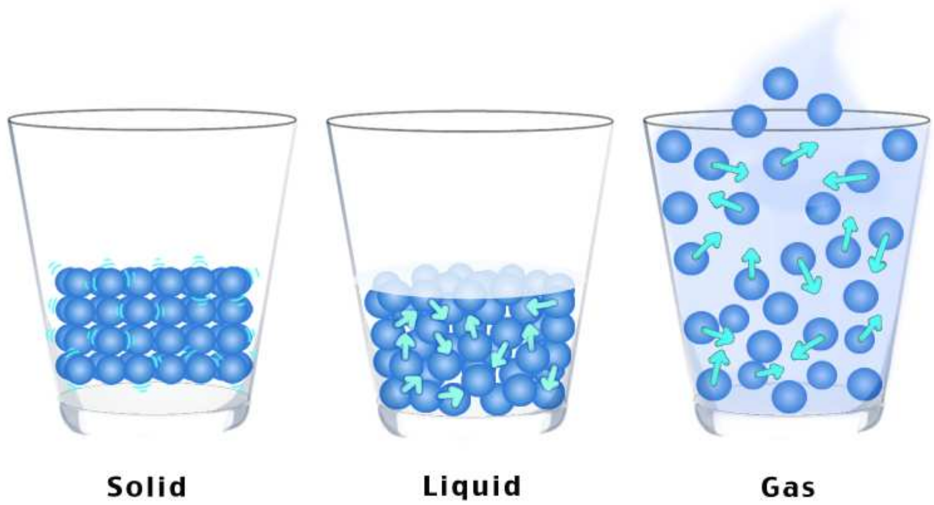
But wait a minute. If water molecules are always in motion, why didn't the water molecules in the room-temperature water push the pepper back up to the surface? Because the water molecules in the room-temperature water were moving *randomly*. Some of the molecules were moving one way, and some were moving the other. As a result, some water molecules pushed the pepper up, but other water molecules pushed it down. Others pushed it to the right, and still others pushed it to the left. Since water molecules were pushing in all directions, they didn't have any overall effect on the pepper, and it just sank. In the hot water, the hot water molecules were moving up, and that forced the pepper up as well.

But wait another minute. In the hot water, there were cooler molecules falling down. Why didn't they push the pepper down, allowing it to sink? Because ***the hot water molecules had more energy than the cooler water molecules***. This is the most important lesson from the experiment. When something is hot, the molecules or atoms that make it up move with a lot more energy. When something is cold, the molecules move around with less energy. Because hot molecules move more quickly than cold molecules, the molecules that were rising to the surface in the glass of hot water hit the pepper harder than the water molecules that were sinking to the bottom of the glass. As a result, the pepper was pushed back to the surface and could not sink very easily.

Now even though Democritus did give us the idea that atoms are in constant motion, he didn't know that the hotter the molecules were, the faster they moved. That's something scientists figured out much later. Nevertheless, in order for them to have figured this out, they needed the idea that atoms were in constant motion, and Democritus (or his teacher, Leucippus – we aren't sure which) gave us this initial idea, which leads to our current understanding of how temperature affects the motion of molecules and atoms.

What's the practical significance of all this? Well, you have probably already learned that matter comes in three basic phases: solid, liquid, and gas. Water, for example, can be solid (what we call ice), liquid (what we usually call water), and gas (what we call water vapor). What's the difference between water in these three phases? The only significant difference is how much the water molecules move. When water is a solid, the water molecules are held in a specific arrangement and do nothing but vibrate back and forth (like someone shivering). If you add enough energy in the form of heat, however, the temperature rises, and the ice melts. It melts because the water molecules move around with enough energy to break apart from their specific arrangement. That turns the solid (ice) into a liquid (water). If you keep heating the water, the molecules move faster and faster until they move so quickly that they can escape the confines of the container that the water is being heated in. At that point, they become a gas (water vapor).

So the thing that really separates solids, liquids, and gases is how much their molecules or atoms are moving. In solids, there is some motion, but it is mostly just a little bit of vibration. In liquids, there is more motion, but the molecules or atoms still stay relatively close to one another. In a gas, the molecules or atoms are moving so quickly that they fly far apart from one another. This is why it is so important to understand that molecules and atoms are in constant motion. This motion is really what determines the phase of the object. Democritus didn't know that, of course, but his idea of atoms being in constant motion helped others figure it out.



When something is solid (left), its molecules or atoms are in a specific arrangement and only vibrate. When it is a liquid (middle), its molecules or atoms are no longer in a specific arrangement and move around a bit. When it is a gas (right), its molecules or atoms are far from one another and move around a lot.

LESSON REVIEW

Youngest students: Answer these questions:

1. Which have more energy: the molecules in hot water or the molecules in cold water?

2. Which has the most motion in its molecules: a liquid, a solid, or a gas?

Older students: Draw a picture like the one above to illustrate the difference between solids, liquids, and gases. Write an explanation of the picture in your own words.

Oldest students: Do what the older students are doing. In addition, explain why increasing the temperature of something can change it from solid to liquid to gas.

Lesson 10: More about Atoms and Ions

In the previous lesson, you learned that atoms are made of protons, neutrons, and electrons. The protons have positive electrical charge, while the electrons have negative electrical charge. Neutrons have no electrical charge. An atom has equal numbers of protons and electrons. A carbon atom, for example, has six protons and six electrons. That means it has equal numbers of positive and negative charges, which means that they all cancel each other out. So an atom has no electrical charge. However, if an electron is removed, there are more protons than electrons, and you now have a positive ion. If an extra electron is added, there are more electrons than protons, and you now have a negative ion.

I want you to see how this ends up working out in the real world. To do that, you will need to start the following experiment. Once you have it started, continue with the lesson, and we will see how the experiment turns out at the end.

Copper and Iron

What you will need:

- About 30 pennies (the duller and uglier, the better)
- A nail (It should not be a stainless steel or a galvanized nail.)
- White vinegar
- Salt
- A small glass, like a juice glass
- A ½-cup measuring cup
- A measuring teaspoon

What you should do:

1. Use the measuring cup to add ½ cup of vinegar to the small glass.
2. Use the measuring teaspoon to add 1 teaspoon of salt to the vinegar in the small glass.
3. Stir the vinegar and salt so that most (if not all) of the salt dissolves.
4. Put all 30 pennies in the vinegar/salt solution.
5. Stand the nail in the vinegar/salt solution so that part of the nail is in the solution and part stays above the solution. You should be able to lean it against the inside of the glass, and with all the pennies in the solution already, it should stay standing without you holding it the whole time.
6. Watch the pennies and the nail for a while. What do you see happening?
7. Let the experiment sit while you continue doing the lesson.

Now what does this experiment have to do with atoms and ions? Well, pennies are made of a bunch of **copper** atoms. Copper atoms have 29 protons and 29 electrons. Remember, an atom has to have equal numbers of protons and electrons. Otherwise, it would have electrical charge and would therefore be an ion. Most copper atoms in a penny have 34 neutrons, but some have 36 neutrons. This brings up a new, important point. If you change the number of protons in an atom, you change the kind of atom it is, but if you change the number of neutrons, you don't change the kind of atom it is. Copper atoms have 29 protons, but nickel atoms have 28 protons. Zinc atoms have 30 protons. So in the end, the number of protons really determines what kind of atom you have. If the number of neutrons varies, however, the kind of atom actually stays the same. As a result, even though some copper atoms have 34 neutrons in them, other copper atoms can have a different number of neutrons in them.

When you get a new penny, it is nice and shiny, because copper is nice and shiny. However, as the penny sits out in air, the copper atoms slowly combine with the oxygen atoms in the air, making a molecule called copper oxide. This molecule is not shiny at all, so over time, a nice, shiny penny will get dull, because the copper atoms on the surface of the penny slowly combine with oxygen in the air to make molecules of copper oxide.


The shiny parts of these pennies are from the copper atoms that make up the pennies. The dull parts are from copper oxide, which forms on the surface of pennies over time.

When you put the pennies in the vinegar, the vinegar started reacting with the copper oxide, releasing copper ions. Ions love to dissolve into water, so as the copper oxide turned into copper ions, the ions dissolved into the water, making a solution of copper ions.

You should have known that something was going on in the experiment, because you should have seen bubbles forming on the pennies. Bubbles mean there is a gas, so there was something going on that made a gas. Actually, several things were going on, but for the purpose of this lesson, just understand that copper ions were being formed. Those ions were positive, which means they had more protons than electrons. They dissolved into the vinegar and salt solution. In the process, the copper oxide was removed from the pennies.

Did you see bubbles forming on the nail? You should have. What does that tell you? It tells you that a gas was being formed on the nail as well. But nails aren't made out of copper. They are made out of iron. Iron atoms have 26 protons and 26 electrons. That's only three fewer protons and electrons than copper, but the atoms are completely different. They don't have the same color as copper, and as you will see in a bit, they most certainly don't behave like copper atoms. Most of the iron atoms in a nail have 28 neutrons, but some have 30, some have 31, and some have 32. Since a nail is made (mostly) of iron, and since iron atoms are different from copper atoms, you can probably guess that whatever happened to the nail in the experiment is different from what happened to the pennies, even though both had bubbles forming on them.

Take the pennies and nails out of the solution now. Look at them. The pennies should be shinier than they were before. That's because the copper oxide has been at least partly removed, revealing the shiny copper underneath. If you wash them off, let them soak in more vinegar and salt, wash them again, etc., you will eventually have really nice, shiny pennies. That's because eventually, all the copper oxide will be gone, leaving nothing but shiny copper atoms.

Now pull the nail out of the solution and look at it. Do you see a difference between the part of the nail that was above the solution and the part of the nail that was in the solution? If not, put the pennies back in the solution and let the nail soak for a few more minutes and check again. Eventually, you should see that the part of the nail that was soaking in the solution is colored like a penny, while the rest of the nail looks just like a nail. Why? Remember that there were copper ions in the solution. They came from the pennies. Well, the iron atoms in the nail love to give away their electrons. They saw that the copper ions in the solution were short on electrons, so they "kindly" gave some electrons to them.

Since the copper ions gained electrons, they ended up having the same number of electrons as protons again. That made them have no overall charge, which means they became atoms again. Those atoms came to rest on the surface of the nail, because that's where they got their new electrons. As a result, the nail started being covered in copper. However, think about what happened to the iron atoms. They gave their electrons to the copper ions floating in the solution. What happened then? The iron atoms became positively charged iron ions, because they gave away some of their electrons. As a result, the iron ions dissolved in the solution. So what really happened was that the iron atoms in the nail were being *replaced* by copper atoms. The iron atoms turned into ions and dissolved in the solution. At the same time, the copper ions turned into atoms, becoming solid copper right there on the nail.

In the experiment, then, you saw the effect of taking electrons away from copper. When you take electrons away from a copper atom, you make a positive copper ion. Ions love to dissolve in water, so the copper ions dissolved into the solution. Remember, however, that atoms and ions are in constant motion. So those copper ions eventually made their way over to the nail. The iron atoms in the nail "happily" gave up their electrons so that the copper ions could have them. As a result, the copper ions turned back into copper atoms. Since the iron atoms gave away their electrons, however, the iron atoms turned into iron ions, which ended up dissolving in the solution.

The lesson you need to draw from the experiment is that under the right conditions, atoms can exchange electrons. One atom can give away one or more of its electrons, making it a positive ion. Another atom might take those electrons. This is, in fact, how the salt you use on your food is formed. Sodium atoms each give one of their electrons to a chlorine atom. As a result, the sodium atom becomes a positive ion, and the chlorine atom becomes a negative ion, which is called the chloride ion. This makes sodium chloride, which is the scientific name for table salt.

LESSON REVIEW

Youngest students: Answer these questions:

1. What kind of atoms do you find in a penny?

2. If an atom loses an electron, does it become a positive ion or a negative ion?

Older students: Explain in your notebook what happened in your experiment. Explain why the pennies got shiny, and explain why the part of the nail that soaked in the solution looked like copper. Be sure to use the word "ion" in your explanation.

Oldest students: Do what the older students are doing. In addition, suppose you have negative ions in a solution of water. Write what you would need to do to make them come out of the solution as atoms.

NOTE TO THE TEACHER: The next lesson contains an experiment (on page 32) that needs to sit for two or more days. It would be best if you had the students start the experiment now so that its results will be ready when you read the lesson. You don't need to read the first part of the lesson. Just do the experiment down to the point where you are supposed to let it sit. However, if you need to be completely done with science for today, just realize that you need to plan your next few days so that you start the experiment at least two days before the lesson.

Lesson 13: Hippocrates and Bile, Part 1

If you read the introduction, you know that this is a "challenge lesson." You don't need to do it, but it is available for those who want to learn more about the fluids Hippocrates studied.

In this lesson, you are going to start to learn about bile and what it really does in your body. You need to start the experiment first, however, so it can sit for a while. Then you can do other things and return to science when it is finished.

Digestion

What you will need:

- Four small glasses, like juice glasses
- Jell-O or some other form of gelatin
- Vinegar
- A pineapple (It *cannot* be canned. It needs to be an actual pineapple.)
- A knife to cut the pineapple
- A spoon

What you should do:

1. If it hasn't already been made, make the Jell-O according to the instructions. It needs to be completely gelled and ready to eat before you can do the rest of the experiment.
2. Fill two of the glasses a third of the way full of vinegar.
3. Have an adult cut the pineapple into chunks that you can squeeze.
4. Squeeze the pineapple chunks so that the juice goes into the other two glasses. Pulp and seeds can go in as well; you aren't going to drink it. Squeeze the pineapple chunks until you have the other two glasses a third of the way full of pineapple juice.
5. Use the spoon to pull out a spoonful of Jell-O, and then put it into one of the glasses that contains vinegar. Try to keep it in one glob, but if it splits into a couple of globs, that's no big deal.
6. Do the same thing again, but this time put the spoonful of Jell-O into a glass that has pineapple juice in it. The glob should be about the same size as the one you used in step 5.
7. Use the spoon to pull out a spoonful of Jell-O, about the same size as the other two you got. This time, use your fingers to break the Jell-O into several smaller globs, and put those globs into the remaining glass of vinegar.
8. Do the same thing again, but this time put all the smaller globs into the remaining glass of pineapple juice. You should now have four glasses. One contains pineapple juice and a single glob of Jell-O. One contains pineapple juice and several small globs of Jell-O. One contains vinegar and a single glob of Jell-O. The last one contains vinegar and several globs of Jell-O.
9. Let the four glasses sit for about five hours. Every hour or so, come back and look at each glass to see if anything is happening. Also, when you are done looking, gently swirl each glass to mix the contents.

Now that you've let the experiment sit for about five hours, you are ready to start learning about **bile** and what it does for your body. First, you need to know that bile is a real fluid in your body. It is often yellow, but sometimes it is green. It is also called **gall**, and even though no one wants to taste it, every now and again you are forced to, because it is what comes up when you vomit on an empty stomach. When you are forced to taste it that way, it tastes incredibly bitter.

Notice that I said bile is yellow or green. I never said it was black. Hippocrates, however, thought there were two kinds of bile in the body: yellow bile and black bile. It turns out that bile is never black, so what Hippocrates thought was black bile was not bile at all. What was it? Most likely, it was dried blood. You see, Hippocrates determined the fluids in the body by observation. He knew blood existed in the body because he saw people bleeding. He knew yellow bile was in the body because when someone vomits on an empty stomach, you can see the yellow bile. Well, people who are really sick can vomit up dried blood as well, which is usually black. So even though we aren't sure, most people who study the history of medicine think that Hippocrates mistook dried blood for a second form of bile. So even though bile is a fluid in the body, it doesn't come in two forms. It only comes in one form, and it is typically greenish-yellow in color.

In order for your body to get energy from the food you eat, you must digest the food.

What does bile do? To learn about that, you first need to learn a bit about **digestion**. You probably already know that you eat food in order to get energy. There is chemical energy stored in the food, and your body converts that chemical energy into another form of energy that it can use to run, work, and do all the things it needs to do to keep you alive. Well, the first step in turning your food into energy is to digest it. When your body digests food, it breaks the food down. It doesn't just tear the food into tiny pieces, although that is a part of the digestion process. Instead, it breaks the food down into its individual molecules.

The digestion process is very interesting, and you will learn more about how it happens in your body later on. For right now, you just need to know the basics. To learn that, it is time to think about the results of your experiment. What happened? Most likely the Jell-O in the pineapple juice slowly "disappeared," and the color of the pineapple juice changed, becoming more like the color of the Jell-O. However, very little (if any) of the Jell-O in the vinegar was gone. What explains these results?

Jell-O starts out as a liquid solution. You dissolve the Jell-O mix into hot water, and then you let the water cool. As the water cools, the Jell-O sets and becomes a wobbly solid. This actually happens because the molecules of gelatin in the solution start to join together, making larger molecules. Those larger molecules eventually intertwine until they form the wobbly solid. To turn Jell-O back into a liquid, then, you need to break those molecules apart.

It turns out that pineapple juice contains a specific chemical called an **enzyme** (en' zime). That chemical attacks the molecules in gelatin and breaks them apart. This turns the gelatin back into a liquid. Vinegar doesn't have that enzyme. So even though the Jell-O sat for a long, long time in the vinegar, the vinegar wasn't able to break the molecules apart, so the Jell-O stayed in its wobbly solid form. Since the pineapple juice contained the right enzyme, it was able to break down the Jell-O molecules, turning it back into a liquid.

That's what digestion is all about. Your food has a lot of big molecules in it, but for your body to use the energy that is stored in those molecules, they need to be broken down. Your body makes all sorts of chemicals (including many enzymes) that break the food down into simple molecules that can then be sent throughout your body and used for many things, including making energy. Do you know what carries these molecules around your body? Your blood, of course! The molecules travel in the circulatory system so they can go anywhere they are needed in the body.

Now you might ask why I had you get a pineapple for the experiment. Why didn't I just have you get a can or jar of pineapple juice? It turns out that the enzyme needed to digest Jell-O is very sensitive to temperature, and when juices are canned or jarred, they are typically heated in order to kill bacteria that might have gotten in them. This makes them safer, but it destroys the enzyme that is needed to digest Jell-O. For the experiment to work, then, you need pineapple juice that hasn't been heated up, and usually, you can only get that from a pineapple.

So the vinegar wasn't able to digest the Jell-O, but the pineapple juice was. Did you notice, however, that the Jell-O you had broken into smaller globs got digested faster than the Jell-O that was in one large glob? That's because in order to attack the molecules in the Jell-O, the pineapple juice had to actually touch the Jell-O. It could only do that on the surface of the glob. Where there was only one big glob, only a certain amount of pineapple juice could touch the Jell-O. However, when you broke it up into smaller globs, there was a lot more access to the Jell-O, so more pineapple juice could touch it.

This should tell you something. Since your body also digests things by mixing them with a bunch of chemicals that have to touch the food to digest it, small chunks of food digest faster and better than large chunks of food. That's why you should always chew your food thoroughly before swallowing it. Fairly large chunks of food can fit down your throat, but they don't digest very easily. They tend to sit in your stomach for a long time. The smaller the chunks of food, the easier they are to digest.

Now remember, the reason I taught you about digestion is so that you can learn what bile does in your body. Obviously then, bile has something to do with digestion. You will learn exactly what it has to do with digestion in the next lesson.

LESSON REVIEW

Youngest students: Answer these questions:

1. When you eat food, what must happen to it before your body can use it?

2. Which digests faster, large chunks of food or small chunks of food?

Older students: In your notebook, write down a definition of digestion, and explain why your body digests food. Also, explain why small chunks of food digest faster than large chunks of food.

Oldest students: Do what the older students are doing. In addition, write down the following question and your answer to it: "If you heated up the pineapple juice before you put the Jell-O into it, would the experiment have turned out the same? Why or why not?" Check your answer and correct it if you were wrong.