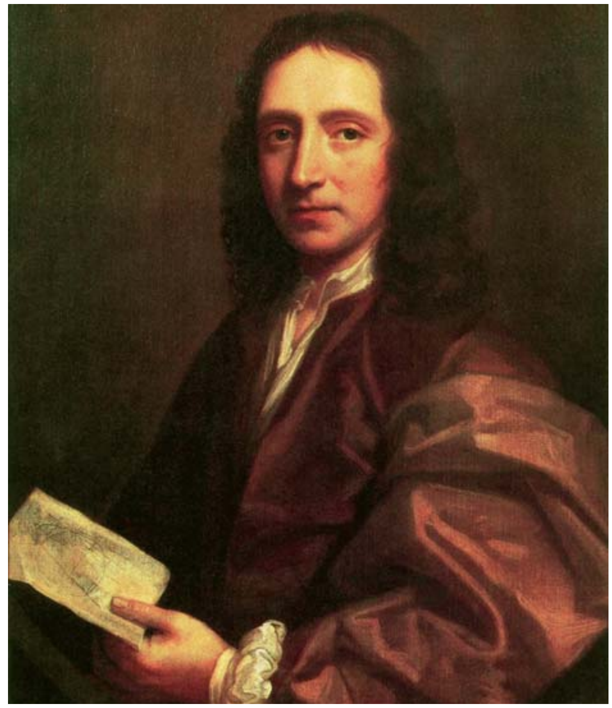
Lessons 1-15: Science in the Early 18th Century

Lesson 1: Edmond Halley (1656 – 1742)

The 17th century was a time of great progress in the way natural philosophers understood the heavens. With the help of Kepler's Laws, Newton had produced his theory of gravity, which explained why the planets in the solar system orbit the sun. There was still a lot left to explain, but Newton had provided an incredibly important insight into how the solar system works. Towards the end of that century, a young natural philosopher by the name of **Edmond Halley** (hal' ee) visited Newton to discuss some details regarding the way the planets orbit the sun. While he didn't contribute a lot to our understanding of the planets, this young natural philosopher did help us figure out something else about what is seen in the heavens.



This portrait of Edmond Halley was painted by Scottish artist Thomas Murray.

Halley was the son of a very successful English soap merchant who was also named Edmond. Because his father was wealthy, he had the best education money could buy. At an early age, he became interested in astronomy, and his father purchased some very expensive equipment to help him observe the heavens. This allowed him to make some keen observations of Mars as the moon passed between it and the earth. He published those observations in a scientific paper at the ripe old age of 20!

This is a picture of comet Hale-Bopp, which appeared in the night sky in the late 1990s. It was visible to the naked eye for 18 months.

He continued to observe the heavens as much as he could. He even travelled to St. Helena, an island off the Atlantic coast of southern Africa. The stars seen in the sky of the Southern Hemisphere are quite different from those seen in Northern Hemisphere, and at this time in history, most of the scientific observations of the heavens had taken place in the Northern Hemisphere. As a result, Halley's work at St. Helena greatly expanded natural philosophers' knowledge of the stars in the night sky.

While this work was important, it wasn't what made Halley famous. Instead, it was his study of something he observed while he was on vacation. In 1680, he had been touring Europe with a friend of his when he observed a **comet**. As you might already know, a comet appears as a light in the night sky. It looks a bit like a star but has a bright "tail." Often, you can see two tails coming from a comet, as shown in the picture on the right.

Unlike a planet, a comet is only visible for a little while (usually months or weeks), and then it is no longer visible. Why? Natural philosophers at the time weren't sure. Tycho Brahe had demonstrated that comets were farther from the earth than the moon, and he had also shown that the direction in which their tails point depends on where they are relative to the sun. This also points to the reason that comets appear only temporarily in the night sky. Perform the following experiment to see what I mean.

Sublimation

What you will need:
- A mothball
- A jar
- A small plate that is bigger than the jar's opening (It can't be made of paper or plastic.)
- A pot for boiling
- Water
- A stove, preferably one with an exhaust fan
- Ice
- An adult to help you

NOTE: Step 10 should be done outside, because there will be a strong mothball smell, and mothball flakes will scatter in the air.

What you should do:
1. Put enough water in the pot so that when the jar is placed in the pot, about half of the jar will be under water.
2. Have an adult help you heat the water until it is boiling. Turn the stove's exhaust fan on if you have one. This experiment will produce a mothball smell.
3. With the help of the adult, adjust the heat of the burner so the water stops boiling but stays hot.
4. Put a few ice cubes on the plate.
5. Put a mothball in the jar.
6. Put the plate on the jar so it covers the jar and still has ice on it.
7. Put the jar with its plate cover in the pot so it is in the hot water. **Be careful. The water is hot!**
8. Wait 10 minutes. If the water stops steaming, increase the heat a bit. If it starts boiling, decrease the heat. Your goal is to keep the water hot but not boiling. Also, if the ice on the plate completely melts, add some more to keep the plate cold.
9. Carry the pot outside (with the covered jar still in it), and set it down on something that won't be ruined by a hot pot.
10. Remove the plate from the jar when it is outside. Look at the bottom of the plate where it covered the opening of the jar. Look at the mothball in the jar. What do you see?
11. Clean up your mess and put everything away.

What did you see in your experiment? If all went well, you should have seen that the mothball was *a lot* smaller, and there was a flaky, white solid on the bottom of the plate. However, you shouldn't have seen any white liquid. You probably saw some water inside the jar, because some vapor got into the jar. However, there shouldn't be anything that looks like a melted mothball. That's because the mothball went through a process known as **sublimation** (sub' luh may' shun), where a solid turns directly into a gas. As you probably already know, all substances have three phases: solid, liquid, and gas. Usually, when you heat a solid, it first melts, turning into a liquid. Then, if you heat the liquid, it boils, turning into a gas. Under certain conditions, however, a solid can skip the liquid phase and go straight from being a solid to being a gas. That's what happened in your experiment. The mothball went from solid to gas, and when the gas hit the cold plate, it turned back into a solid.

That's also what happens in comets. When they get near the sun, some of the solids that make up the comet go through sublimation, turning into a gas. That gas then reflects the light from the sun, making the comet bright and visible. This is why comets can only be seen in the night sky for a short time. They only become bright enough to be seen when they are close enough to the sun for some of their solids to go through sublimation.

Halley didn't know any of that. When he saw the comet on vacation, he just knew that it wouldn't be visible for very long. When he got to Paris, he quickly tracked down Giovanni Cassini, the famous astronomer who explained zodiacal light and discovered that Saturn has more than one ring around it. Together, they tracked the comet's movements in the sky in order to try to figure out how it was moving. Newton's Laws suggested that comets should orbit the sun, much like the planets. However, no one had ever really confirmed that. Even Newton's writing on the subject of comets was vague.

This picture of Halley's Comet was taken in 1986 by the European Southern Observatory (ESO).

While Halley didn't figure out anything definitive during the time he worked with Cassini, their work helped him when he started studying another comet that appeared in 1682. Comparing his observations of this new comet with historical records, he determined something incredible. He realized that two comets which had been observed in 1531 and 1607 seemed to follow the same path. This made him think that comets orbit the sun like the planets do, but they only become visible at certain times in their orbit. He reasoned that the comets seen in 1531 and 1607 were the same comet he was tracking in 1682.

Halley used Newton's Laws to calculate what the comet's orbit around the sun would have to be if all three sightings were of the same comet orbiting the sun and becoming visible only in certain parts of its orbit. Based on his calculations, he said that if he was right, the comet should reappear in the night sky in 1758. Unfortunately, Halley died before then, but sure enough, the comet was spotted again on December 25, 1758, and is now called Halley's Comet in his honor. Its most recent appearance in the night sky was in 1986, and its next appearance will be in 2061, because it takes between 75 and 76 years to make one orbit around the sun.

LESSON REVIEW

Youngest students: Answer these questions:

1. What do we call it when a solid turns into a gas without first becoming a liquid?

2. What do comets have to get close to in order for us to see them?

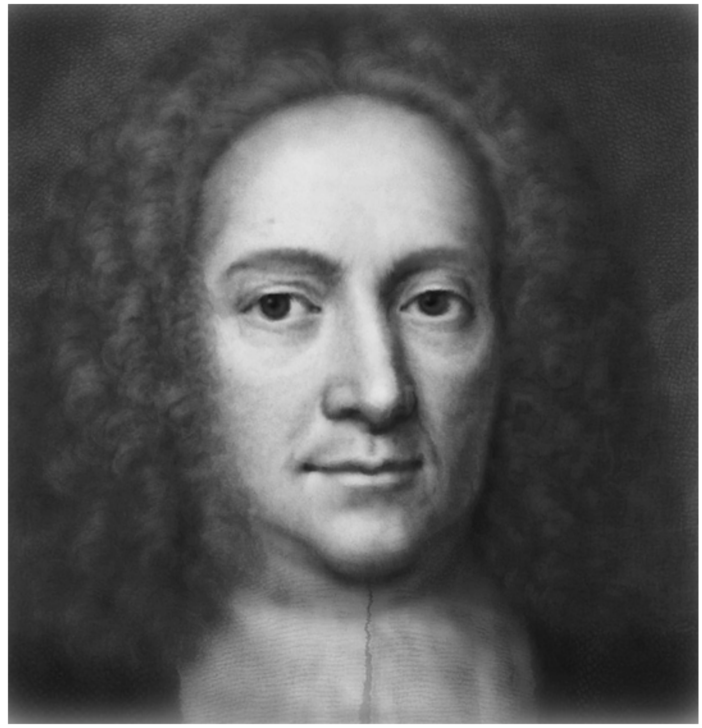
Older students: It is time to get out your journal and do some work. Explain in your own words what sublimation is and how it relates to comets.

Oldest students: Do what the older students are doing. In addition, explain how Halley figured out when the comet he observed in 1682 would reappear in the night sky.

NOTE: The experiment on page 28 must sit for a several days. You should start it either today or tomorrow. It won't take too much time.

Lesson 3: Daniel Gabriel Fahrenheit (1686 – 1736)

A few years before Edmond Halley determined that the stars are not fixed on a sphere in the heavens, **Daniel Gabriel Fahrenheit** (fair' uhn height') was learning how to be a merchant's bookkeeper. He was born in Poland, but his parents had died from eating poisonous mushrooms when he was 15. The government arranged for him to work for a merchant, who took him to Amsterdam, where thermometers were being sold as a novelty item.



There is no known portrait or statue of Daniel Gabriel Fahrenheit. However, scientists at Gdańsk University made this possible likeness of him using historical data and portraits of his relatives.

You might have learned about thermometers before. Back in the late 1500s, Galileo invented a way to measure temperature using water in glass container that had a long, thin neck. Over the years, many people improved on the device. However, there were no standards. As a result, every thermometer was different. Fahrenheit was fascinated by these thermometers, so he actually ran away from the merchant for whom he was working and started making his own thermometers.

In case you have forgotten, a thermometer works because things tend to expand when they are heated and contract when they are cooled. Usually, a thermometer is a closed tube with a liquid inside. The warmer it is, the more the liquid expands, so the higher it rises in the tube. The cooler it is, the more the liquid contracts, so the lower it goes in the tube. As Fahrenheit experimented with different ways of making thermometers, he determined something very important. Perform the following experiment to help you understand what he learned.

Expanding Examples

What you will need:
- A bar of Ivory soap (Other brands will work, but not nearly as well.)
- A potato
- A marshmallow (not the tiny ones that you put in hot cocoa)
- A microwave oven (It is best to use one you can see inside while the food is cooking.)
- A microwave-safe plate
- A serrated knife
- An adult to help you

What you should do:
1. Have an adult help you use the knife to cut off a section of the bar of soap that is about the same size as the marshmallow. It doesn't need to be exactly the same size – just make it close.
2. Do the same with the potato. It is best if you cut out a section that has no skin on it.

3. Put the marshmallow, the piece of soap, and the piece of potato on the plate.
4. Put the plate in the microwave oven.
5. Close the door and cook the contents of the plate on high for 30 seconds. If nothing dramatic happens, add 30 seconds and do it again.
6. Notice the difference between how the three things were affected.
7. If you want to have some fun, scrape everything off the plate and into the trash, and then repeat the experiment with the rest of the bar of soap. You will probably want to heat it for about a minute.
8. Clean up your mess.

What did you see in the experiment? You should have seen that the section of potato hardly changed size at all. However, the marshmallow should have expanded significantly, but the section of the bar of soap should have expanded even more. Why? Well, remember that things do tend to expand when they get hot, and the microwave was making everything hotter. However, the marshmallow and soap expanded so much because they have a lot of air in them. Gases such as air expand much more noticeably than solids, such as a potato, so as the air in the marshmallow and soap expanded, it pushed its way out, making those things expand dramatically.


The silvery liquid pouring out of the tube in this picture is mercury.

The main point, then, is that different substances expand differently when they are heated. To make a really good thermometer, then, Fahrenheit had to use the right liquid inside his thermometer. He finally settled on mercury. It is a silvery liquid at room temperature, and it expands very evenly as it is heated. As a result, when he used mercury in his thermometers, he was able to get a very consistent reading time after time.

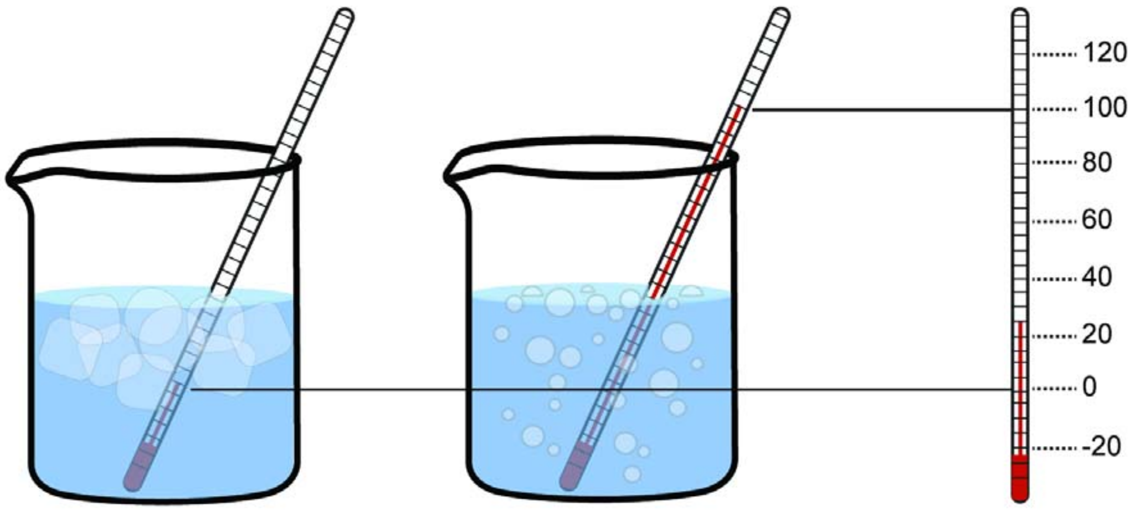
But making a consistent thermometer was only the first step. He also had to determine a **scale** for his thermometer to read. After all, the height of liquid in an enclosed tube tells you how warm or cold it is, but in order to report the temperature as a number, you have to define what the height means. A thermometer has lines on it, and you read the temperature by seeing what line the mercury is nearest. However, those lines are drawn on the thermometer. How does someone know what lines to draw where?

Fahrenheit decided that since his mercury thermometer gave very consistent readings, he could use specific things to define temperature. He decided that the temperature at which water froze should be called 32. So he put his thermometer in a mixture of ice and water and marked the height of the mercury as 32.

He then put the thermometer under his arm to measure his body temperature. The mercury rose in the thermometer, and where it ended up he marked as 96 (3x32). He then made lines that divided the distance between the zero mark and the 96 mark into equal segments, and that allowed him to turn the height of mercury in any thermometer into a number that represented temperature.

Over time, we have changed Fahrenheit's definition a bit, so while the temperature at which water freezes is still called 32 degrees, the temperature of boiling water is called 212 degrees. On that scale, normal body temperature is now 98.6 degrees. Despite this minor adjustment, we still call this the Fahrenheit temperature scale, in honor of the man who invented it.

Now, since anyone can define a temperature scale, there are others besides the one made by Fahrenheit. Scientists typically use the Celsius temperature scale, which is illustrated below. In that scale, water freezes at 0 degrees and boils at 100 degrees. Using those definitions, normal body temperature is 37 degrees. Regardless of the scale that is used, the key is that the scale allows you to take a physical measurement (like the height of mercury in a tube) and turn it into a number that represents something else (like how warm it is).



In the Celsius temperature scale, water freezes at 0 °C and boils at 100 °C. So to make a Celsius thermometer, you put your thermometer in a mixture of water and ice, and label that reading as 0. You then put it in boiling water, and label that reading as 100. If you make equal marks between those two readings, you now have a thermometer that reads in Celsius.

LESSON REVIEW

Youngest students: Answer these questions:

1. What liquid gave Fahrenheit the best results in his thermometer?

2. Fill in the blank: Soap expands dramatically in the microwave because it has a lot of ___ in it.

Older students: Explain why Fahrenheit used mercury in his thermometers. In addition, draw a picture like the one above and use it to explain how the Fahrenheit temperature scale is currently defined. Please realize that your numbers will be different from the ones in the picture above, because that one is illustrating the Celsius temperature scale.

Oldest students: Do what the older students are doing. In addition, suppose you had a thermometer marked off in Fahrenheit's *original* scale. If the mercury was halfway in between the mark made in freezing water and the mark made at normal body temperature, what would the temperature be? Check your answer and correct it if it is wrong.

Lesson 6: Pierre-Louis Moreau de Maupertuis (1698 – 1759)


This is a portrait of Pierre-Louis Moreau de Maupertuis.

Pierre- (pee air') **Louis** (loo' ee) **Moreau** (maw roh') **de Maupertuis** (moh per twee') was born into a merchant family that had enough money to pay for a private tutor. He loved studying mathematics, but he actually started his career as an officer in the French cavalry. He studied mathematics as a hobby, which ended up allowing him to meet some natural philosophers. The more he talked with such men, the more intrigued he became. After only five years in the cavalry, he devoted himself completely to the study of mathematics and how it applies to the natural world.

During this time, there was a big disagreement about the shape of the earth. No one thought it was flat. Philosophers knew the earth was round several hundred years before Christ, and a Greek philosopher, Eratosthenes, determined the distance around the earth in 200 B.C. However, even though everyone understood it was round, they also suspected it was not *perfectly* round. They just couldn't agree on the earth's precise shape.

Those who followed the teachings of René Descartes (who had died about 80 years before this) thought the earth was shaped like an egg, with its two poles stretched out and its middle thinner than a perfect sphere. Sir Isaac Newton (who had died only about 10 years before this) argued instead that the earth would be flattened at its poles, and its middle would be fatter than a perfect sphere. Both of these natural philosophers had their followers, so there was an intense debate on the issue.

The French government, under King Louis XV, decided it would settle the debate. Two expeditions were sent out – one to the northernmost part of Sweden, and one to Peru near the equator. Maupertuis was in charge of the entire experiment and went with the northern expedition. Both groups did some careful measurements, and when they returned, they compared notes. Based on their results, Sir Isaac Newton was right. The earth was fatter in its middle and flattened at its poles.

Because Maupertuis was in charge of the entire affair, he wrote a book about the results. It was an incredible accomplishment, of course, but it went to his head a bit. He had the portrait above made of himself once the conclusions of the expeditions had been reached. Do you see how Maupertuis has his hand on the globe? It's as if he is pushing down on it, forcing it into the proper shape of being fat in the middle and flatter at the poles. This portrait was meant to show everyone that he was the man who was responsible for "flattening the world."

Now you might wonder why the earth is shaped that way. Perform the experiment on the next page to find out.

The Shape of the Earth

What you will need:

- A sheet of paper
- Scissors
- Cellophane tape
- A pushpin
- A pencil

What you should do:

1. Have an adult help you use the scissors to cut two strips of paper that are each about a centimeter (slightly less than half an inch) wide and as long as the paper.
2. Make a loop out of one strip and use the tape to fasten the two ends of the strip together. Now you have a circle made out of one strip of paper.
3. Repeat step 2 for the other strip.
4. Put one of the loops inside the other one but pointing in the opposite direction so that you have the outlines of a sphere (like what's on top of the pencil in the photo on the right).
5. Use the tape to fasten the loops together.
6. Have an adult help you use the pushpin to attach the two loops of paper to the pencil's eraser. In the end, you should have a device that looks something like the picture on the right.
7. Hold the pencil so it is between your two palms, and look at the four strips of paper that make the outline of a sphere.
8. While you are watching the sphere, move one palm forward and the other palm backward so the pencil spins quickly. Note the shape of the "sphere" when the pencil is spinning.
9. Repeat step 8, but this time, slow the motion a bit so the pencil doesn't spin quite as quickly.
10. Play with this for a while to determine the relationship between the shape of the "sphere" and the speed at which the pencil spins.
11. Clean up your mess.

What did you see in the experiment? As the pencil spun, the "sphere" spun as well. However, the faster the "sphere" spun, the fatter it became in the middle and the flatter it became on the top and bottom. The same thing happens when the earth spins. Now the earth isn't as flexible as the two strips of paper in your experiment, but it does have some flexibility to it. As a result, when it spins, it bulges out a bit at the equator and flattens out a bit at the poles. If it were to start spinning faster, the equator would bulge out more and the poles would flatten out more.

Being in charge of the expeditions that determined the actual shape of the earth was Maupertuis's greatest accomplishment in natural philosophy, but it wasn't his only one. He did a detailed study involving several generations of a family that lived in Berlin, Germany. Some members of the family were born with more than five fingers on at least one of their hands. Have you ever heard of such a condition before? It is called **polydactyly** (pol ee dak' tuh lee), and it can refer to someone being born with more than five fingers on a hand or more than five toes on a foot. While it is rare, it does happen from time to time. In studying various people with polydactyly, he noticed that sometimes the condition was passed from the father to the child. However, at other times, it was passed from the mother to the child. This led Maupertuis to conclude that children inherit traits from


This is the hand of a man with polydactyly.

both their mother and their father. In fact, he concluded that there must be specific particles in each parent that end up in each child, and those particles determine the traits that the child will have.

This idea represented a very important step in understanding **heredity** (huh red' ih tee), the process by which the traits of the parents are passed on to their children. For example, you have probably heard someone say, "She has her mother's eyes" or "He has his father's nose." It is often obvious that children end up looking a bit like each parent. Maupertuis's work on polydactyly (and other traits in families) represents an important attempt at understanding how that happens.

Maupertuis also had an odd idea about how living things came into existence. Rather than suggesting that a Creator produced the incredible mix of living organisms in nature, he thought that nature randomly produced a lot of different living things. However, because most of these random organisms didn't have what they needed to survive, they simply died out. For example, in his mind, animals without mouths could have been formed by chance, but such animals could not survive, because they could not eat. As a result, the animals we see in nature are but a small sample of the many random animals that were produced by nature. They are the ones who just happened to have all the traits they needed in order to survive.

This idea was not thought of very favorably at the time, because most natural philosophers were willing to admit that nature was the result of God's deliberate act of creation. However, as the number of natural philosophers who did not want to consider the idea of a Creator God grew, it became more popular.

LESSON REVIEW

Youngest students: Answer these questions:

1. (Is this statement True or False?) Two thousand years ago, natural philosophers thought the earth was flat.

2. Fill in the blanks: The earth is ______ at its poles and ______ around its middle.

Older students: Draw two pictures to represent your experiment. One should be when the pencil wasn't spinning, and the other should be when the pencil is spinning. Explain how those drawings relate to the shape of the earth.

Oldest students: Do what the older students are doing. In addition, define polydactyly and explain how Maupertuis used it to determine that children must inherit traits from both their father and their mother.

Lesson 7: Anders Celsius (1701 – 1744)

Anders Celsius (sell' see us) was born in Uppsala, Sweden, and his father was a professor of astronomy at the local university. Not surprisingly, he decided to study astronomy and eventually became a professor at the same university. He made a lot of astronomical observations and even published some of his astronomical work, but that's not what made him famous. He became famous because he was on Maupertuis's expedition that determined the shape of the earth.

This portrait of Anders Celsius was made by Swedish painter Olof Arenius.

He wasn't in charge, of course. Maupertuis was. However, his participation in the expedition was enough to give Celsius some respect among government officials in Sweden. He ended up using that respect to convince them to donate money that allowed him to build an observatory in Uppsula. From that observatory, he was able to make even more important astronomical observations.

Although determination of the earth's actual shape and his astronomical observations made him famous in his time, those aren't the accomplishments for which he is best known today. Instead, he is remembered mostly for the temperature scale that bears his name. In Lesson 3, you learned about Daniel Gabriel Fahrenheit, who defined a temperature scale based on the freezing point of water (which he called 32) and the normal temperature of a person's body (which he called 96). Celsius didn't like that kind of definition, because the temperature of a person's body is variable. If a person is sick, he is often warmer. Also, some people are just naturally warmer or cooler than others, so one person's body temperature isn't exactly the same as another person's body temperature.

Celsius wanted to make a temperature scale that wouldn't vary from person to person. He decided to still use the point at which water freezes as a reference, because the temperature at which that happens seemed to be the same no matter where it happened or what the weather conditions were at the time. However, he needed one more reference point. As you learned in Lesson 3, the way you make a temperature scale is to choose two temperature points, mark them on your thermometer, and then divide them into equal segments. Thus, Celsius needed something that happens at a much warmer temperature to be the other point of reference on his temperature scale. However, it had to be something that didn't change from person to person or place to place.

That proved to be a bit of a problem. He ended up deciding to use the temperature at which water boils as his second reference point, but unfortunately, that is not unchanging. Depending on certain conditions, the temperature at which water boils changes. Perform the following experiment to see one important condition that changes the temperature at which water boils.

Boiling Water with Ice

What you will need:
- A canning jar (It needs to be a transparent jar with an airtight lid that can withstand big temperature changes.)
- A plastic bag
- Ice
- Water
- A microwave oven
- A few small pebbles
- Pot holders
- An adult to help you

What you should do:
1. Put the pebbles into the jar.
2. Fill the jar about halfway with the hottest water that comes from the tap.
3. Put the jar in the microwave and run the microwave on high for a minute and a half.
4. While the microwave is running, put a few ice cubes in the plastic bag.
5. When the microwave is done, open the door and see if the water is boiling. If not, add more time and run the microwave again.
6. Once you see that the water is boiling, have an adult use the pot holders to pull the jar out of the microwave and wait for the water to stop boiling.
7. Once the water has stopped boiling, have the adult put the airtight lid on the jar.
8. Have the adult turn the jar upside down and set it on the counter so it is sitting on its lid.
9. Put the bag of ice cubes on what is now the top of the jar. Since the jar is upside down, the top is actually the jar's bottom.
10. Watch the water in the jar. You should eventually see that it starts to boil again.
11. Clean up your mess.

How in the world did ice cause the water in the jar to start boiling again? Well, as soon as the microwave stopped, the water started to cool. It was still boiling when you opened the microwave, but eventually, it cooled enough to stop boiling. Of course the water was still really hot, which is why the adult had to use the pot holders to handle it. However, it was cooler than when it was boiling. When the adult sealed the jar and turned it upside down, the water was still really hot, but once again, it was under the temperature needed to boil it.

When you put the ice on top of the jar, it rapidly cooled the gas above the jar. Since the water had been boiling, the gas in the jar was mostly water vapor. When water vapor cools, what happens? It condenses back into a liquid. Well, since the jar was airtight, no air could come in to replace the water vapor that condensed. As a result, what happened? *The pressure inside the jar went down*. It turns out that the lower the air pressure, the lower the temperature at which water boils!

Celsius knew that, so he had to define exactly how you had to measure the temperature of boiling water so that you would always get the same result no matter what. First, he knew that air pressure changes with your elevation – the higher you are, the lower the air pressure. So he said that in order to make a good temperature scale, you had to measure the temperature of boiling water at a place where the elevation is the same as that of the ocean's surface. We call that **sea level**.

In addition, air pressure changes based on the weather. Thus, you had to measure the temperature of boiling water when the atmospheric pressure was at its average value. If you did those two things, you would always get the same temperature for boiling water. Celsius defined that temperature as zero. He defined the temperature of freezing water as 100. In making a thermometer, then, he would put it in freezing water and make a mark that meant 100. He would then put it in boiling water at sea level during a day when the atmospheric pressure is at its average value, and he would make another mark that meant 0. He would then put 100 divisions between the two marks, and he had his temperature scale.

The odd thing about his temperature scale is that *higher* temperatures were represented by *lower* numbers. In the scales we use today, water freezes at a lower temperature than it boils, but in Celcius's original scale, water's freezing temperature was 100 points *higher* than its boiling temperature. This wasn't very useful for most situations, so not long after Celsius's death, a famous natural philosopher you will read about later (Carl Linnaeus) decided to reverse it, defining water's boiling temperature as 100 and its freezing temperature as 0. That's what we call the Celsius temperature scale today.

This photo of the Northern Lights was taken in Iceland.

Now remember, Celsius was an astronomer, so he also contributed to our knowledge of that field. For example, people through history had been fascinated by the **Northern Lights**, a lovely display of colors that appears in the night sky from time to time. You are more likely to see them the farther north you travel. Celsius noticed that when the Northern Lights occurred, the needle on a compass would wiggle back and forth, and the more brilliant the display of colors, the more the compass needle would wiggle. He concluded that they must have something to do with the earth's magnetic field. It would take a while to confirm this, but we now know that the Northern Lights are, indeed, related to the magnetic field of the earth.

LESSON REVIEW

Youngest students: Answer these questions:

1. (Is this statement True or False?) The temperature at which water freezes is the same everywhere.

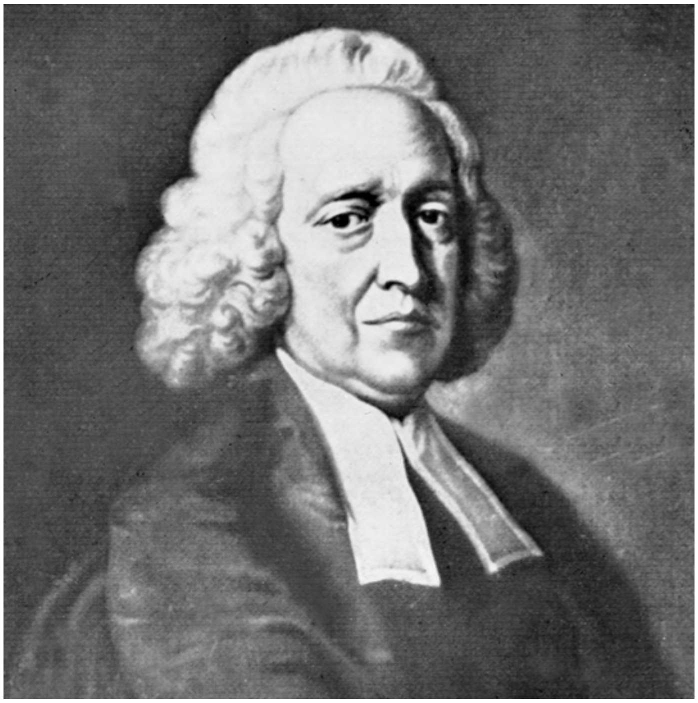
2. Fill in the blanks: The lower the pressure, the ________ the temperature at which water boils.

Older students: Define the Celsius temperature scale as it is used today, noting why the temperature of boiling water must be measured at a specific elevation and atmospheric pressure.

Oldest students: Do what the older students are doing. In addition, think about the differences between the Fahrenheit and Celsius temperature scales. Suppose I tell you it's 35 degrees outside. Would that be hot or cold if I were using the Celsius temperature scale? What if I were using the Fahrenheit scale? Check your answers and correct them if they are wrong.

NOTE: The experiment in the next lesson has to sit for 4 hours. Please plan your day accordingly.

Lesson 8: Stephen Hales (1677 – 1761)



This portrait of Stephen Hales can be found in *Makers of British Botany*, which was published in 1913.

Stephen Hales was the sixth son of an English nobleman. He studied at Corpus Christi College in Cambridge University. While studying theology, he became fascinated with science. As a result, he began blending his theological studies with studies of nature. Eventually, he was appointed as a parish priest in an English town called Teddington, Middlesex (a suburb of London). He was devoted to serving his church and studying nature, and as a result, he was one of a group of ministers known as **parson-naturalists**. These people were ministers who were devoted to studying both nature and the Scriptures in order to learn all they could about God.

Hales was strongly influenced by the works of Isaac Newton, which convinced him that natural philosophers must carefully measure the things they study. In a book published in 1727 he wrote, "And since we are assured that the all-wise Creator has observed the most exact proportions, of number, weight and measure, in the make of all things; the most likely way therefore, to get any insight into the nature of those parts of the creation which come within our observation, must in all reason be to number, weigh and measure." (*The Enlightenment: A Sourcebook and Reader*, Paul Hyland (Ed.), Routledge 2003, p. 97)

With that in mind, he started weighing plants in order to learn what happened to the water that everyone knew they needed in order to survive. Perform the following experiment, which illustrates what he discovered.

Water Transport in Plants

What you will need:

- Three stalks of celery with some of the leaves still on them (They don't need a lot of leaves.)
- Three small glasses, like juice glasses, that are all the same size
- A spoon
- A sharp knife
- A small plastic sandwich bag
- Cellophane tape
- Water
- Blue food coloring (Blue is the color that shows up best.)
- A fan

What you should do:

1. Add enough blue food coloring to each glass so that when you fill it ¾ of the way with water, the result will be a dark blue solution. Add the same amount to each glass so the color will be the same in all three glasses.

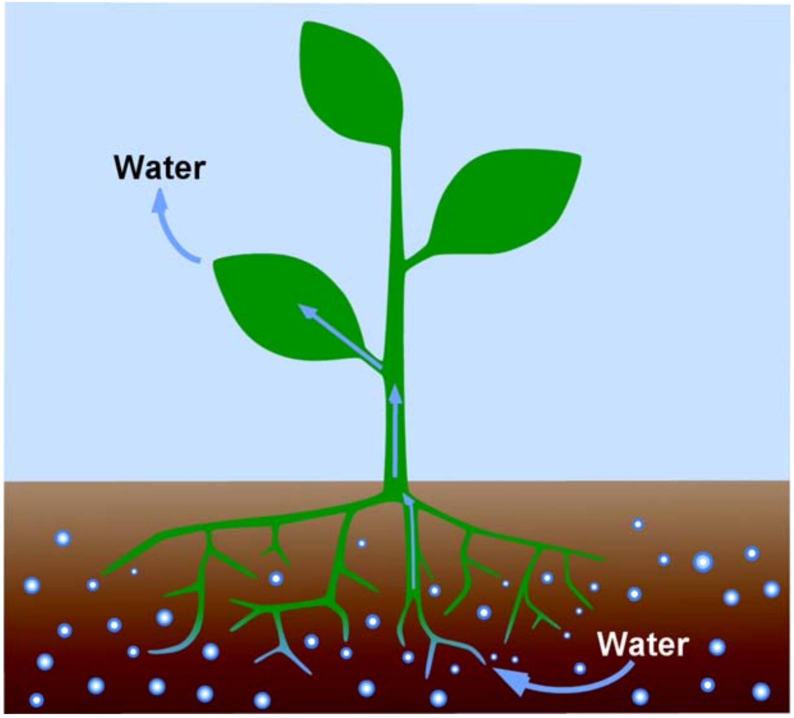
2. Add enough water so that each glass is ¾ full.
3. Use the spoon to stir the solution in each glass so the food coloring is evenly distributed.
4. Have the adult help you cut the three celery stalks into equal lengths. Cut them from the bottom so that the leaves on the top remain intact. They should be cut so that when you stand them in the glasses, the leafy ends will stick up about 10 centimeters (4 inches) above the top of the glasses.
5. Stand each stalk of celery in its own glass, with the leafy end up.
6. Choose one stalk of celery and use the plastic bag to completely cover all its leaves. Use the tape to seal the bottom of the bag so it encloses the leaves of the celery stalk. The seal shouldn't be airtight. It should just be secure so that the leaves stay inside the bag throughout the course of the experiment.
7. Find a room that won't be disturbed for several hours.
8. Arrange one of the glasses that has a celery stalk whose leaves are not covered in plastic so that the fan will blow on it. Turn the fan on so it is blowing on the stalk. That way, the stalk is exposed to a constant breeze. The fan should be blowing strongly enough that you can see the leaves moving in the breeze.
9. Put the other two glasses far from the fan so that they don't feel the breeze.
10. Let the entire experiment sit for 4 hours.
11. After four hours, compare the leaves on the celery that was in front of the fan to the leaves on the uncovered celery stalk that was sitting far from the fan. Do you notice a difference? If you don't notice a difference, sit the same stalk and glass back in front of the fan and wait another 2 hours.
12. If you did see a difference, remove the plastic bag from the other stalk of celery and compare it to the other two stalks. What difference do you see?
13. Clean up your mess.

What did you see in the experiment? If all went well, you should have seen that there were blue splotches on the leaves of the celery that was in front of the fan and the other uncovered stalk of celery. However, you should have noticed that the stalk of celery in front of the fan had a lot more blue splotches that were bigger. In addition, if there were any blue splotches on the leaves of the celery that had been covered by the plastic bag, they were few compared to the other two stalks of celery.

How do you explain the results of the experiment? Most likely, you already know that plants have tubes in them through which water travels. Those tubes allowed the stalks of celery to pull blue water up from the glasses and into their leaves. When Hales was doing his experiments, natural philosophers knew about the tubes and the fact that they carried water. However, no one knew how the water traveled up the tubes. After all, water flows downwards, not upwards. Hales wanted to know what caused the water to flow upwards through a plant.

He ended up showing that water evaporates from inside the leaves of a plant. As you may already know, that's called **transpiration** (tran' spuh ray' shun). Leaves have tiny pores in them, and when those pores are open, water evaporates from inside the leaves. Hales reasoned that the evaporation pulled water up through the plant. So the reason water travels upwards in a plant is not because the plant is pushing it that way. It's because the evaporation of water from the leaves is pulling the water that way.

Your experiment shows this because the fan caused a breeze that increased the rate at which evaporation occurred. The plastic bag trapped water inside, slowing down the rate at which evaporation occurred. The fact that evaporation was happening quickly in the stalk that was



Water travels upwards in a plant because transpiration from the leaves pulls it up through the plant.

experiencing a breeze caused more water to be pulled up the stalk of the celery, which resulted in more blue splotches on the leaves. The fact that very little evaporation was occurring in the plastic bag caused very little water to be drawn up from the glass, which resulted in few (if any) blue splotches on those leaves. The third stalk had more blue splotches than the plastic-covered stalk but fewer than the one in front of the fan because it experienced a rate of evaporation that was in between.

Now Stephen Hales didn't use this kind of experiment to draw his conclusions. Instead, he carefully measured the weight of water that a plant used as it grew. He showed that the weight of water it used was much greater than the weight that the plant gained as it grew. As a result, he realized that the plant must be losing a lot of water. In addition, he showed that once you cut off the leaves of a plant, the amount of water it used dropped to almost nothing. That demonstrated to him that the leaves were responsible for the water loss. He then carefully observed the leaves giving off water vapor and came to the conclusion that this process was responsible for the way water traveled up through a plant.

Stephen Hales's conclusion that water moves up a plant because transpiration pulls it up was not the only thing he added to our knowledge of how plants work. He also concluded that plants must draw something they need from the air. As natural philosophers studied plants more carefully, his conclusion was confirmed. Because of his detailed work with plants, Hales is often called the father of plant **physiology** (fih' zee ah' luh jee), which is the study of how plants work.

LESSON REVIEW

Youngest students: Answer these questions:

1. What is transpiration?

2. What causes water to move up the tubes in a plant?

Older students: Draw a picture of a stalk of celery in a glass of water. Use wavy lines to indicate water evaporating from its leaves. Use that to explain how water travels upwards in a plant. Be sure to use the term "transpiration" in your explanation.

Oldest students: Do what the older students are doing. In addition, suppose you measured the water used by a plant on a very humid day and a very windy day. How would they compare? Check your answer and correct it if it is wrong.