Michael Faraday's
The Chemical History of a Candle

with Guides to Lectures, Teaching Guides & Student Activities

Articulate Noise Books

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A NOTE ON THE TEACHING GUIDE

Michael Faraday aimed his lectures toward those new to science, especially young people. He choose a candle to attract this younger audience: it was commonplace, but off limits. Every household had candles, yet how tantalizing a candle must have been for a young child in the nineteenth century. Although candles are not as commonplace today—most children see them only at birthday or holiday celebrations—a burning candle still fascinates any child. It can be used by teachers to guide students through the scientific method and as an entry point to the chemical sciences. So, in this section of the book we provide for teachers, or self-learners, the essential chemical background needed to understand the phenomena Faraday touches on in his lectures—see The Big Ideas of Chemistry. *Then following this section we detail six activities and one set of demonstrations teachers can use to help students investigate for themselves "the chemical history of a candle." Each activity has a student version followed by a teacher's guide. These teaching guides and student worksheets can be downloaded at* www.engineerguy.com/faraday.

THE BIG IDEAS OF CHEMISTRY: THE PARTICULATE NATURE OF MATTER

In this section we cover the essential ideas that should be shared with younger students in order to better understand the phenomena that Faraday addresses. Our goal here is not rigor, but instead a set of simple analogies that give students an entry point to understanding the particulate nature of matter. We will focus our discussion on the following "big ideas" in chemistry:

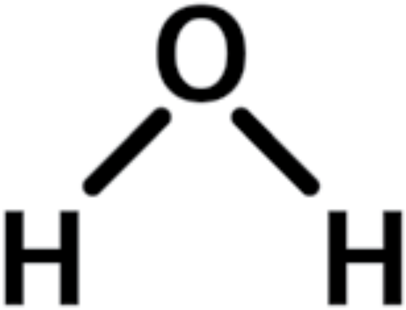
- All matter is made of atoms.
- Atoms are in constant motion.
- Atoms can stick together to become a liquid or solid, or bond together to form molecules.
- At normal conditions of temperature and pressure, some substances are solids, some are liquids, and others are gases. This has to do with how attractive ("sticky") the particles (atoms or molecules) are that make up the substance.
- Chemical reactions are the result of a rearrangement of atoms.

Atomic viewpoint essential to modern science

The importance of the particulate nature of matter cannot be overstated. Nobel Prize-winning physicist Richard Feynman once asked "if all scientific knowledge were lost in a cataclysm, what single statement would preserve the most information for the next generation of creatures?" He proposed the following:

> All things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed together. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied.

For many young students this notion of a microscopic world is too abstract to grasp, so it is often best to start with a rough analogy that shows how a commonplace object is built of small units. For example, a beach looks from afar as though it were a solid surface, yet when examined up close the individual particles of sand can be distinguished. Once this analogy is firm in student's minds, one should ask them to think about a chemical familiar to them: water. Explain that just as small pieces of sand comprise a beach, water is made of small molecules,which are composed of two hydrogen (H) atoms and one oxygen (O) atom. (See figure on next page.)



While the molecules that make up water are, as are all molecules, too small to see with the naked eye or even ordinary microscopes—scientists use a "scanning tunneling microscope" to image atoms and molecules—everyday observations support the idea of a particulate nature of matter.

Helping students "see" atoms in everyday life

With a little guidance students can "see" the effects of the particulate nature of matter. For example, the smells created by cooking waft through the house. The spreading of these aromas suggests that the molecules reach the olfactory sensors in our noses by floating through the air. Next, using another kitchen-based analogy, you can demonstrate the effects of the particulate theory: add a drop or two of food coloring to water, taking care to avoid disturbing it. Ask students to note the movement of the food coloring: it spreads in *all* directions. The food coloring does not simply "fall" through the water due to gravity, but its spreads sideways, and even ascends in the water so that, given time, the entire sample of water becomes colored. This observation suggests to students that the water molecules in the glass constantly move and that they move randomly. These moving water molecules, over time, "shove" the food coloring molecules to all sections of the glass until the water has a uniform color.

Relationship of motion to temperature

The diffusion of food coloring in water can next be used to introduce students to the idea that temperature is related to the motion of atoms or molecules. If students observe the diffusion of food coloring in hot and cold water they will note that the food coloring spreads more quickly in the hot water. Based on our analogy of moving water molecules spreading the food color, this implies that the water molecules in the hotter water move more quickly than the water molecules in the cold water. You can then explain with more precision the scientific basis of temperature: temperature is a measure of the average kinetic energy (motion) of the molecules or atoms.

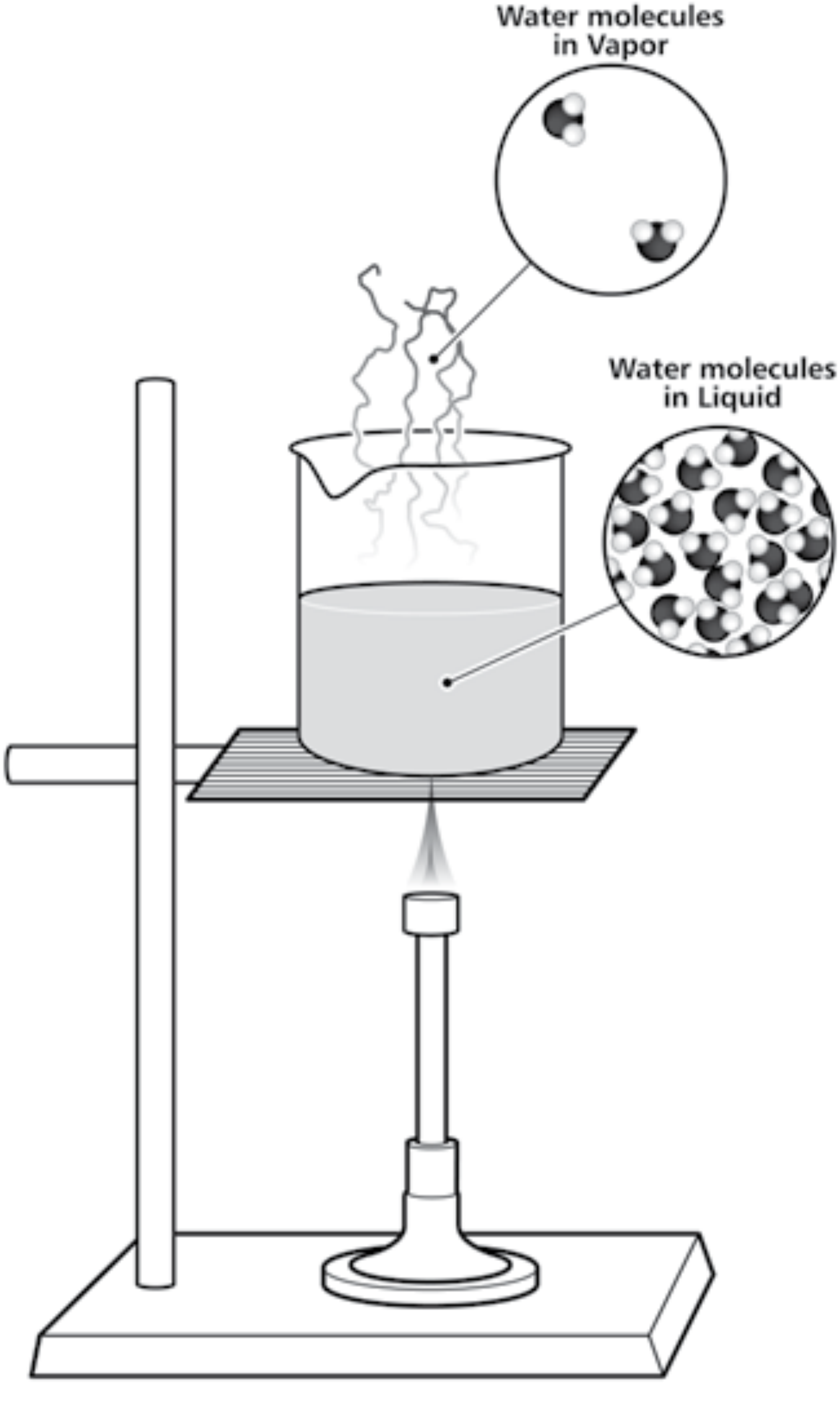
Physical changes versus chemical changes

A key concept in Faraday's lectures is the distinction between a physical and a chemical change. You can introduce students to a physical change by studying a sugar-water solution, and then to a chemical change with the electrolysis of water.

Physical changes

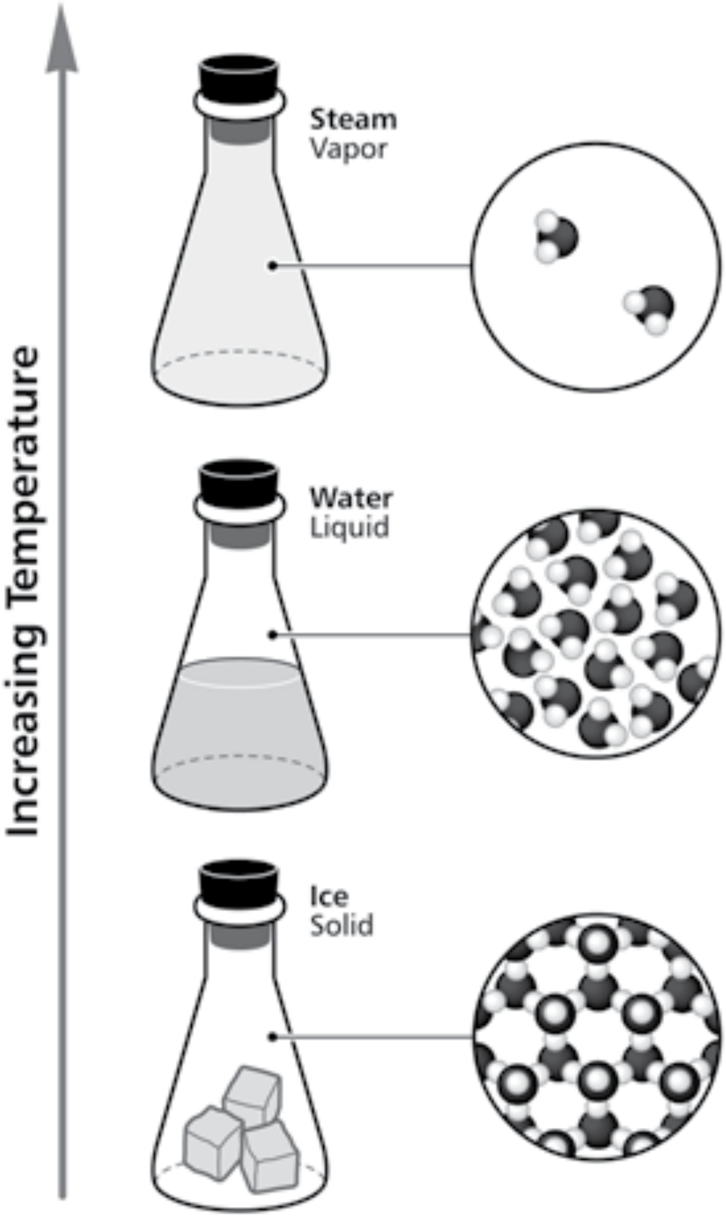
Ask students to dissolve sugar in water. Just as with the food coloring, students can use their senses to detect that the sugar dissolves and spreads through the water, this time, though, by taste. As with the food coloring, the moving water molecules disperse sugar molecules until they are distributed throughout the water. Next, have students either heat the solution and boil away the water, or let the solution sit overnight until the water evaporates. Either process will leave a residue of sugar. To effect either of these processes the liquid water must become a vapor. Note that the molecules (H_2O) are the same in both the liquid and vaporous states. The sugar molecules, as well, are the same whether sugar is a solid or is dissolved in water. Because the molecules stay intact this is called a *physical* change as opposed to a *chemical change*, as described in the next section.

Knowing that temperature increases molecular motion helps students to understand this phase change from liquid to vapor. In its liquid state the water molecules are attracted to one another and are touching, yet able to move past one another; that is, they are able to flow. When we add energy by heating, the water molecules move faster and travel further until their attraction for one another is overcome and they begin to separate. Students can see this when water boils: the vapor exits as bubbles. These bubbles are made because water molecules are separating from one another



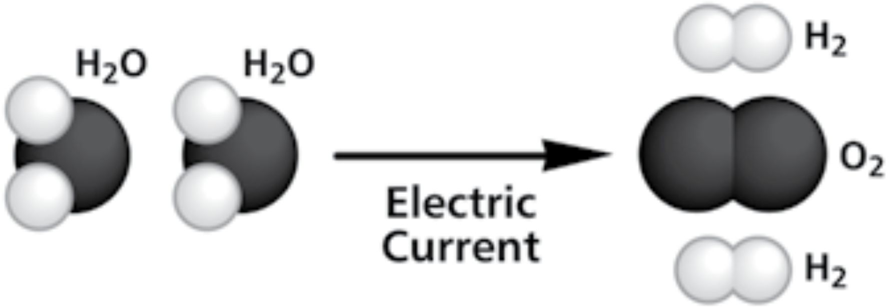
and spreading out. As the bubbles reach the surface of the water, the fast moving water molecules escape into the air.

We can reverse this process and lower the temperature of liquid water. In this case the motion of the water molecules slows down. The attractive forces between the molecules and the slower moving molecules result in ice, which is, of course, a solid. In the ice the molecules are still moving by vibrating, but they are no longer able to move past one another. The freezing of water, like the boiling of water, is a physical change because the molecules remain intact.



Chemical changes

While the molecules remain the same in a physical change, the same is not true for a chemical change. Passing an electric current through water produces hydrogen and oxygen gases. This is a chemical change because a substance is turned into something chemically different—in this case into two substances. The electrolysis of water highlights the profundity of a chemical change: water can put out a fire, yet the two products created, oxygen and hydrogen, are highly flammable.



Be sure to contrast for students how this differs from a physical change: when they boiled water to recover sugar they did not produce hydrogen and oxygen, but simply changed water from liquid to vapor. Note, too, that often a physical change is easily reversible by another physical process: water vapor can be returned to the liquid state by condensation. In contrast, to reverse the chemical change of water into oxygen and hydrogen requires another chemical change—we must ignite the gases.

Determining whether a physical or a chemical change takes place is often difficult for students. So, students find useful a few heuristics or clues that help them decide whether an event is a physical or a chemical change. The hallmark of a chemical change is a chemically new product and so often the result is a color change, an evolution of gas, emission of heat, or the formation of a solid.

Cohesion & adhesion: Intermolecular attraction

In a chemical change molecules broke apart and rearranged into other chemical species—that is, a bond was broken. In contrast to this *intra*molecular change, physical changes are controlled by *inter*molecular forces—the much weaker forces that cause molecules to be attracted or repelled to each other. The degree of attraction determines whether a substance is solid, liquid or gas at a particular temperature and pressure. For example, at room temperature and pressure oxygen exists as a gas, water as a liquid, and sugar as a solid. The existence of these chemically pure species as solids, liquids and gases at room temperature reveals to students that the attraction among molecules varies.

These differing amounts of attraction account for some common everyday observations. Open a bottle of fingernail polish remover, which is a mixture of acetone and water, and in a few minutes the odor of acetone fills the room. The acetone molecules in the remover are attracted to one another enough to be a liquid when the bottle is closed, but the acetone turns into a vapor because it evaporates quicker than water. This happens because water molecules attract each other more than do acetone molecules. The reason has to do with the structure of the atoms and the shapes of molecules, but for students at this stage it is enough to know that while molecules attract one another, they do so with varying degrees. For example, ask students to observe a drop of water and a drop of acetone on a clean glass slide. The water droplet will be larger than the acetone droplet because the surface tension of water is higher than for acetone. This occurs because water molecules are more strongly attracted to one another than acetone molecules are to each other.

The force that holds like molecules together is called *cohesion* while the force holding unlike molecules together is called *adhesion.* The interplay of these two forces results in the phenomenon of capillary action, which students will learn about in one of the activities described in the next section (and which is discussed in Lecture One). We can see the effects of cohesion and adhesion in a mixture of oil and water. These two substance do not mix readily, and even when shaken they separate into oil and water phases. This is not because water molecules and oil molecules repel one another, but partly because the water molecules stick together and the oil molecules stick together. That is, the force of cohesion of the water molecules and the force of cohesion of the oil molecules is greater than the force of adhesion for an oil and water molecule.

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STUDENT ACTIVITIES & DEMONSTRATIONS
WITH TEACHING GUIDES

OBSERVATIONS OF A CANDLE

Teacher's Guide

Observing a candle is a great way to get students to think about science as a process of better understanding the world around them. Most likely, they have all looked at candles, but they may not have really observed them. Explain to your students that observing is not just "seeing" but paying careful attention to details. We can use these observations to develop theories or explanations of *why* something is the way that it is. With incorrect or missing observations, our theories are more likely to be incorrect.

Provide as many different types of candles as you can for the students (birthday candles, tea lights, votive candles, etc.) and have them make observations before a candle is lit, while it is lit, and after the flame has been blown out. Students should focus on the wick, the wax, the flame, and the smoke. Note, for example, that the wick blackens after it is lit. The flame has a triangular shape and does not seem to touch the wax but appears to "float" above it. The flame is also blue closer to the wick, and yellow above it, with the brightest part of the flame being in the center. Most likely, little, if any, smoke is given off as it burns, and only appears after the flame is extinguished. The wax melts nearest to the flame, and "cups" may form depending on the shape of the initial candle. There may be "guttering" as Faraday calls it, or drips of wax down the side of the candle without these cups. These observations are made by Faraday and they will be more understandable and the lectures will be more engaging if the students note these before viewing the lectures.

Throughout the lectures, Faraday asks questions (such as "How does the flame get hold of the fuel?") and then proceeds to answer these questions by performing demonstrations coupled with explanations. This activity will have the students model this approach and you can make this explicit as they are watching the lectures. You will need glasses of some sort to cover the candles.

Observations of the unlit candle

These will vary depending on the candle used.

Observations of the lit candle

When the candle is lit, the students should notice that the flame is a triangular (conical) shape (depending on how still the air is in the room—it is best to observe when still). The outer part of the flame appears blue (especially at the bottom nearest the wax) and the part of the flame immediately surrounding the wick is a grayish yellow color. The middle part of the flame is the brightest (yellow).

The wick burns quickly (blackens) until it gets closer to the candle wax. The flame does not touch the top of the candle. The tip of the wick glows.

The wax at the top of the candle is turning into a liquid. It may drip down the side of the candle or a "cup" may be formed (depending on the candle).

Very little smoke is generally given off if the candle is burning undisturbed.

The variance in the flame is due to different temperatures and different processes occurring in various parts of the flame (which are discussed in the Lectures and in the Lecture Guides). This does not need to be discussed at this point of the activity unless prompted by student questions.

It would be helpful to draw a flame on the board to show the different colors.

Observations of the blown-out candle

When the candle is blown-out we see smoke. The amount produced depends on the size of the flame.

The wick may be a bit shorter. If you are using a previously burned candle, there will not be much difference in terms of the length sticking out the top if the candle (the wick and candle end up decreasing at the same rate).

The candle will be shorter and perhaps has "trails" of wax down the side.

Questions & experiments

In Part Four we provided a sample question: "What happens if you cover the lit candle with a glass?" It may be helpful to ask this question as a class and have each group try this before developing more questions (this activity may generate more questions, such as those suggested below). Students should notice fogginess on the inside of the glass and that the flame fades and eventually goes out. It is not necessary at this point to tell them that the fogginess is due to water or that the flame goes out from a lack of enough oxygen. The main point of this activity is to ask questions, make observations, and use these to ask more questions of the form "what would happen if?" This will make the material a bit more familiar to them so that the lectures make more sense.

If the students are struggling coming up with questions, you can follow-up with the suggested question on page 139: "Try this again, but before the flame goes out, lift the glass. What happens?"

In this case the flame will become brighter once the glass is lifted (due to the increase in available oxygen).

Have the students develop other tests and come up with other questions. For now, you can decide how much to explain, but again, it is a good idea to give the students some time to explore without being asked to explain at this point. Have them make careful observations, test different variables, and ask questions.

If students are struggling to come up with tests, you may wish to suggest these:

- What happens if you put two lit candles under the glass? Do they both go out at the same time? Do they go out more quickly, less quickly, or in the same amount of time as one candle? Does it matter if one candle is taller than the other?
- What happens if you cover the flame to put it out, relight, and then cover it with the same glass? Is it different if you use a fresh glass? Have the students cover a flame with a glass, let the flame go out, and then take off the glass and place it mouth side down on the table. Relight, and recover with the glass. See what happens to the time it takes to go out as you continue to do this.
- Does the size of the glass affect how long it takes for a candle to go out?

If you are willing and able, students will most likely want to replicate what Faraday discusses and try to blow out the flame and try to re-light it by igniting the smoke. There is some technique in doing this—you must blow the flame gently (Faraday uses the word "cleverly" in the original text) and there needs to be a fair amount of smoke coming from the wick. Light the smoke while the trail is relatively thick and reaches the wick. With practice, and the right conditions of the smoke, you can re-light the candle a few inches from the wick.

CONVECTION CURRENTS
& DENSITY
Teacher's Guide

Background. The characteristic triangular or conical shape of the flame is due to the convection currents. The heat of the flame causes the air directly around the flame (and carbon dioxide and water vapor products) to expand making these gases less dense. This draws in relatively cool air from below which pushes up the hotter gases and gives the shape to the flame.

If we place a flame in space (such as in a space shuttle), thus removing gravity as a factor, we no longer get these convection currents. The flame becomes more spherical, and, because the oxygen spends a longer time in the flame, there is more complete combustion. The yellow color gives way to blue because we do not have the "free carbon particles" glowing in the flame producing the bright light. The flame also does not last very long because, without convection currents, carbon dioxide is not carried away and it smothers the flame.

We can see the same phenomenon in a vacuum chamber. By removing air (but keeping enough oxygen to burn), we remove the convection currents and we see the same short-lived spherical blue flame as in space.

Details of the Student Activity. Have students cut out the spiral design; be sure that they cut along the line of the spiral: when they hold the center of the circle the paper will form a conical spiral. Students should poke a small hole in the top of the spiral and connect a length of thread so that they can hold the thread and allow the spiral to hang freely.

Show the students that if you hold the thread the spiral will not spin.

Next, light a candle and hold the center of the spiral above the flame of the candle. Be careful that the paper does not touch the flame. After a few seconds the spiral will start to spin.

Students can then either move the spiral from the candle or blow out the candle and the spiral will stop spinning after a few seconds.

This happens because heat from the candle flame is transferred to the air. The hot air is less dense than the room temperature air, and the hot air rises. Room temperature air moves in to fill this space, and this air is then heated and rises. This motion of the air goes through the spiral and makes it move.

This same current also gives the flame its triangular shape and also causes cooler room air to go up the sides of the candle to cool the wax. This allows the candle to keep its shape even though the heat is melting the wax on the inside of the candle.

Extension: Convection currents in water

For this demonstration you will show convection currents in water instead of air, and you will also dramatically show the difference in density between hot and cold water. You will need:

- Four identical bottles (it is crucial that the mouths be exactly the same size)
- Hot and cold water
- Food coloring (blue and yellow work well)
- An index card or playing card

Add a few drops (depending on the size of the bottle) of blue food coloring to each of two of the bottles, and a few drops of yellow food coloring to the other two bottles. Add warm water (tap water is fine—make it as warm as you can hold) to two of the bottles (so that the warm water is the same color) and cold water to the other two bottles. Cooling the water in a refrigerator or with ice is preferable to cold tap water (the bigger the difference in temperatures between the hot and cold water, the better). Make sure that the bottles are filled to the very top with water.

First, place the card over the mouth of one of the bottles with warm water. Hold the card and turn the bottle upside down over the bottle with cold water. Position the bottles so that they are mouth-to-mouth. While holding the bottles (you may use an assistant) carefully pull the card from between the bottles. If done carefully there will be very little mixing of the water (you may see a bit of green where the hot water meets the cold water) because the hot water is less dense that the cold water. Thus, the cold water stays in the bottom bottle and the hot water stays in the top bottle.

Next, repeat the demonstration but place the cold water on top of the hot water. In this case the cold water will sink and the hot water will rise and the two samples will mix, resulting in green water in both bottles.

CAPILLARY ACTION

Teacher's Guide

In Lecture One Faraday tells us that capillary action is responsible for transporting the melted candle wax up the wick and to the flame. He also shows us another common example of capillary action—that of water traveling up a towel that is hanging in a basin of water.

As we discussed in *The Big Ideas of Chemistry,* molecules are attracted to one another. Capillary action is due to the adhesion of the molecules of a liquid with the molecules in the surrounding solid (the towel, for example). Since the water molecules are also attracted to each other (cohesion) the water appears to climb. This occurs in a candle wick as the candle wax is heated until it is molten (a liquid) and the liquid wax "climbs" the wick. The fact that a wick allows for capillary action is the reason why sportswear that is meant to keep us dry is said to be "wicking."

Plants also use capillary action to transport water from the soil, through the roots, and throughout the plant.

We have included three activities for students to explore capillary action. The activities with the paper towel and the celery take thirty minutes of so for results, so you may wish to have the students set them up at the beginning of class time.

MOLECULES ARE “STICKY”

Teacher’s Guide

Part one: How many drops of H_2O can fit on a penny

The guess and actual number of water drops on a penny will vary. Students generally guess a number smaller than the actual and are quite surprised by how many drops of water they can fit on a penny. The average value is the sum of the two values divided by 2.

Part two: How big is your drop?

Students are generally surprised as well how big of a drop of water can hang from a dropper—the surface tension of water is greater than they imagine.

Touching water

The water drop will “bead up” on the wax paper, that is, it will not lie flat. It will form what looks like a ball. When the pipet touches the water, the plastic of the pipet will attract the water and “tug” at the drop (students will pull the water drops in the next section). When a drop of water from the pipet is touched to the drop of water on the wax paper, the water from the pipet will generally be pulled into the water drop to form a larger drop (aided by gravity).

Part three: Moving water by pulling

As seen in the previous section, the pipet will stick to the water drop. If the water drop is small enough, it can be pulled by the pipet. If the water drop is too large, it is possible to pull a smaller drop from the larger drop.

Moving water by tilting

Since a water molecule is much more attracted to another water molecule than the wax, we see "beading up" of the water, and so the water drop will easily glide over the wax paper.

Part four: Alcohol drops on a penny & comparing drops

Students will find that alcohol molecules are not as "sticky" as water molecules. They will be able to fit much fewer drops of alcohol than water on a penny, and the height of a drop of alcohol will be less than the height of the water drop.

Extension: Water down a string demo

1. Have two students perform this under your direction or get one student volunteer to work with you.
2. You will need two plastic cups. Add a cup of water to one of them. Also get a piece of wet string.

3. One person should hold one end of the string into the empty cup.
4. The other person should hold the other end of the string over the rim of the cup with water. Lift the cup with water and hold the cups far enough apart so that the string is tight.
5. Your goal is to pour as much of the water as possible down the string into the empty cup.
6. Ask the students: “Why were you able to pour water down the string?” Because water molecules attract one another, once the strong is wet (due to capillary action), the water that your pour from one cup “sticks” to the water that is in the string.

PHYSICAL CHANGES:
CHANGES OF STATE
Teacher's Guide

The diagrams will vary but should look like those of ice, liquid water, and steam in the *Big Ideas* section.

Process	**Name of Phase Change**
solid to liquid	melting
liquid to solid	freezing
liquid to gas	vaporizing
gas to liquid	condensation
solid to gas	sublimation
gas to solid	deposition

For heating water, actual temperatures over time will vary (but always increase) but you will notice that the temperature of ice will remain constant until the ice is melted. For the demonstration using the hotplate the glassware *must* be Pyrex because glass cannot withstand the heat and will shatter. The heat added to liquid water is making the molecules move more rapidly and temperature is a measure of kinetic energy (or energy of motion). For ice, the heat is used to break the forces holding the molecules together as a liquid, so the temperature doesn't change until the water molecules are able to move freely (flow).

Water as a solid, liquid, & vapor

Students should notice fogginess in the beaker, with liquid water collecting on the underside of the watch glass, and possibly near the top of the inside of the beaker. When ice is added to the watch glass, students will notice the ice melt and also notice faster accumulation of water on the underside of the watch glass and larger drops of water. Removing the watch glass will result in the water "disappearing" (less foggy) and replacing the watch glass will result in the reappearance of the water.

Students will see both evaporation

$$H_2O(l) \rightarrow H_2O(g)$$

and condensation

$$H_2O(g) \rightarrow H_2O(l)$$

of water, along with the melting

$$H_2O(s) \rightarrow H_2O(l)$$

of ice.

When food coloring is added to the water many students might think that colored water will appear on the underside of the watch glass. The food coloring does not evaporate, however, and so does not appear on the watch glass. This is a simple distillation of water.

The variation with the plastic cups is useful depending on your supplies. You can also add ice to the top of the upper cup, and use food coloring.

CHEMICAL CHANGES

Teacher's Guide

Physical change or chemical change?

When vinegar is added to the baking soda, students should notice the evolution of bubbles and the "disappearance" of at least some baking soda (depending on the relative amounts that are added). This is because there is a chemical change between baking soda and vinegar, resulting in the formation of a gas (carbon dioxide).

When water is added to the baking soda, no bubbles form and the water becomes cloudy with stirring. Some of the baking soda "disappears" as it dissolves in the water (but not to a great extent). This is a physical change.

Four clues that a chemical reaction has occurred are: formation of gas, formation of a solid, color change, and change in temperature.

Baking soda & vinegar

Carbon dioxide is produced by the reaction of baking soda and vinegar. While it is an invisible gas, students can observe its presence in a couple of ways. They will first collect it in a balloon and notice the increase in volume and pressure in the balloon. Next, they will test the gas with the flaming splint. Since carbon dioxide cannot support combustion (as Michael Faraday shows us), the flame will be extinguished when placed in an atmosphere of carbon dioxide. Since the mixing of baking soda and vinegar produced a gas with new properties, we can say this is a chemical reaction.

We can also see this is a chemical reaction by measuring the temperature of the vinegar before and after it reacts with the baking soda. Students should note that the temperature goes down. A temperature change is another clue of a chemical reaction.

Variations

You can also vary this by using solutions of Epsom salts (magnesium sulfate) and washing soda (sodium carbonate). You can dissolve a bit of each in water. When mixed, a solid forms (magnesium carbonate) and the temperature goes down.

Mixing baking soda into a solution of calcium chloride results in the formation of a solid (calcium carbonate), the formation of a gas (carbon dioxide), and an increase in temperature. Calcium chloride can be found commercially (such as in home improvement stores) as it is used in products such as DampRid™ and in products for snow removal.

TWO DEMONSTRATIONS TO SHOW THE PRESSURE CAUSED BY AIR

Demonstration one: Can crushing

In Lecture Four Michael Faraday boils a bit of water in a metal vessel to fill it with steam, removes it from the heat and seals the bottle. When the steam condenses back to a liquid, a partial vacuum is created and the air pressure crushes the bottle.

You can do a variation of this demonstration by using aluminum soft drink cans. Add a little water to an otherwise empty can and get the water to boil (you need to see a good amount of steam coming out of the top to ensure that the can is filled with steam and most of the air has been pushed out). Using a hot pad, very quickly pick up the can and invert it into a bowl of cold water. The can will be instantly, and dramatically, crushed.

Similarly to Faraday's demonstration, the steam condenses creating a partial vacuum. In this case, a good amount of water is also pushed into the can by air pressure, but because the aluminum is so thin, and the opening of the can is relatively small, the water cannot rush into the can quickly enough and the can is crushed by atmospheric pressure.

Demonstration two: Egg in a bottle

For this demonstration you will need a peeled hard-boiled egg, matches or a lighter, a piece of paper, and a glass bottle which has a mouth slightly smaller than the egg. Be sure to cover the bottle in transparent tape because the decreased pressure can cause the bottle to implode.

Set the piece of paper on fire and drop the burning paper into the bottle. Before the flame goes out, place the peeled hard-boiled egg on the mouth of the bottle. You may notice the egg “bounce” a couple of times and the egg is then forced into the bottle.

A common misconception is that the pressure decreases in the bottle due solely to the fact that oxygen gas is “used up” in burning. But as Faraday shows us, carbon dioxide gas is a product of combustion. While there is generally less carbon dioxide produced (by volume) than oxygen gas reacted, this does not by itself account for the difference in pressure.

By heating the air in the bottle, the molecules in the air move more quickly and farther apart from one another. Some of the molecules escape the bottle (which is why you may see the egg “bounce”). When the flame goes out, the air cools back to room temperature, but there is now less air in the bottle than before because the egg is blocking the air from returning. Thus, the air pressure outside the bottle is greater than the air pressure inside the bottle. The higher pressure pushes the egg into the bottle.

The egg can be removed from the bottle by holding the bottle upside down so that the egg is sitting inside the mouth of the bottle. Blow into the bottle and the egg should be pushed out. You will need to make a seal with your lips over the mouth of the bottle—expanding your lungs lowers the pressure, just like using a straw.