SUPERCHARGED SCIENCE

Unit 8: Chemistry

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Appropriate for Grades:
Lesson 1 (K-12), Lesson 2 (K-12)
Duration: 10-25 hours, depending on how many activities you do!

This unit on chemistry is chock full of demonstrations and experiments for two big reasons. First, experiments are fun. But more importantly, the reason we do experiments in chemistry is to hone your skills of observation. Chemistry experiments really speak for themselves, much better than I can ever put into words or show you on a video. And I'm going to hit you with a lot of these chemistry demonstrations to help you develop your observation techniques.

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Key Vocabulary

Acids are sour (like a lemon), react with metals, and can burn your skin. They register between 1 and 7 on the pH scale.

Atoms are made of a core group of neutrons and protons, with an electron cloud circling the nucleus.

Bases are bitter (like baking soda), slippery, and can also burn your skin. They measure between 7 and 14 on the pH scale.

A **chemical change** rearranges the molecules and atoms to create new molecule combinations (like a campfire).

Chemists study **chemical kinetics** when they want to control the speed of a reaction as well as what gets generated from the process (the products of the reaction). Several factors affect the speed of a chemical reaction, including catalysts, surface area, temperature, and concentration.

Chemicals form various **crystal structures** when they freeze. Water is one of the few molecules which expand when changing from a liquid to a solid.

Endothermic reactions are reactions that absorb heat when they react (like a cold compress).

Splitting the water molecule into parts (hydrogen and oxygen) requires power, or **electrolysis**, to break the bonds.

Thin layers of metal can be moved from one object to another using the **electroplating** technique.

Exothermic reactions release energy in the form of heat, light, and sound (think fireworks).

The jiggling motion in atoms is called **heat**.

Different **indicators** are used for specific ranges of acids and bases. Phenolphthalein changes from clear to pink when added to a base.

A **physical change** happens when the molecules stay the same, but the volume and/or shape change (like wadding up tissue).

Polymers are long chains of slippery molecules. Coagulation happens when you cross-link the chains into a fishnet-looking design.

Unit Description

This unit on chemistry is chock full of demonstrations and experiments for two big reasons. First, experiments are fun. But more importantly, the reason we do experiments in chemistry is to hone your skills of observation. Chemistry experiments really speak for themselves, much better than I can ever put into words or show you on a video. And I'm going to hit you with a lot of these chemistry demonstrations to help you develop your observation techniques.

In most standard chemistry lessons, a teacher walks in and says, "Now I will demonstrate the insolubility of barium sulfate by mixing equal volumes of zero point one molar barium chloride and zero point one molar sodium sulfate and observe what happens." *Anyone still awake?*

In this unit, you'll be mixing up things that bubble, ooze, slither, spit, change color, crystallize, and fizz. (I think there's even one that belches.) And rather than announcing things in a dull and boring fashion, I'm just going to outline the steps and ask YOU to notice any and all changes, no matter how strange, weird, or small. Even a tiny temperature difference can indicate something big is about to happen.

A Note about Safety

A lot of folks get nervous around chemistry. You can't always see what's going on (are there toxic gases generated from that reaction?), and many people have a certain level of fear around chemicals in general. Dr. Walker, a professor of physics at Cleveland State University (and the editor of *Scientific American*), states, *"The way to capture a student's attention is with a demonstration where there is a possibility that the teacher may die."*

I don't want you dipping your hands in molten lead or lying on a bed of nails while someone with a sledgehammer breaks a cinder block on your stomach. (It turns out that Dr. Walker has been injured multiple times, mostly through accidents.)

I strongly disagree with his approach—demonstrations that result in injury are the ones forever burned in the memory of the audience, who become fearful and make the generalization that chemicals are dangerous and their effects are bad. In fact, every chemical is potentially harmful if not handled properly. That is why I've prepared a special set of chemistry experiments that include step-by-step demonstrations on how to properly handle the chemicals, use them in the experiment, and dispose of them when you're finished.

Chemistry is predictable—just as predictable as the fact that dropping a ball from a height will result in it always hitting the floor. Every time you add 1 teaspoon of baking soda to 1 cup of vinegar, you get the same reaction. It doesn't simply not work one time and explode the next. I'm going to walk you through every step of the way, and leave you to observe the reactions and write down what you notice. At first, it's going to seem like a lot of disjointed ideas floating around but, after awhile, you'll start to see patterns in the way chemicals interact with each other. It's just like anything else that you try for the first time—you're not very good when you're new at it. Keep working at chemistry and eventually it will click into place. And if there's an experiment you don't want to do, just skip it (or just watch the video).

One of the best things you can do with this unit is to take notes in a journal as you go. Snap photos of yourself doing the actual experiment and paste them in alongside your drawing of your experimental setup. This is the same way scientists document their own findings, and it's a lot of fun to look back at the splattered pages later on and see how far you've come. When I do an experiment, I always jot down my questions that didn't get answered across the top of the page so I can research them more extensively later. Are you ready to get started?

Objectives

Lesson 1: Molecules

By studying tiny bits of matter called atoms you can figure out why chemicals do what they do—some explode when they touch water (like cesium), while others just sit there for years (like a Twinkie). Some chemicals are particularly nasty, like sodium (which explodes on contact with water) and chlorine (which is lethal). But when you combine these two together, you get table salt. So what gives?

If you've ever wondered *why* two hydrogen atoms stick to an oxygen atom to form water, then you're in the right place. Let's start by taking a look at the highlights for understanding molecules, atoms, and the tiny universe inside matter.

Highlights

- Atoms are made of a core group of neutrons and protons, with an electron cloud circling the nucleus.
- The jiggling motion in atoms is called heat.
- Chemicals form various crystal structures when they freeze. Water is one of the few molecules which expand when changing from a liquid to a solid.
- Endothermic reactions are reactions that absorb heat when they react (like a cold compress).
- Exothermic reactions release energy in the form of heat, light, and sound (think fireworks).
- A physical change happens when the molecules stay the same, but the volume and/or shape change (like wadding up tissue).
- A chemical change rearranges the molecules and atoms to create new molecule combinations (like a campfire).
- Acids are sour (like a lemon), react with metals, and can burn your skin. They register between 1 and 7 on the pH scale.
- Bases are bitter (like baking soda), slippery, and can also burn your skin. They measure between 7 and 14 on the pH scale.

Objectives

Lesson 2: Chemical Kinetics

By figuring out how to change the speed at which a reaction takes place as well as what gets created in the process, you can get a better handle on creating the things you want.

We're going to learn why fish don't drown, and how you can create glowing slime, turn water into ink you can really write with, make a solution that appears by breathing on it, make rubber-like bouncy balls out of clear liquid, and shake up a rainbow of colors. You will also learn how to get a lemon to light up a light bulb and discover what fire really is made of.

It all comes down to controlling the reaction and figuring out what you want to get out of the process. Are you ready?

Highlights

- Different indicators are used for specific ranges of acids and bases. Phenolphthalein changes from clear to pink when added to a base.
- Splitting the water molecule into parts (hydrogen and oxygen) requires power (electrolysis) to break the bonds.
- Thin layers of metal can be moved from one object to another using the electroplating technique.
- Chemists want to control the speed of a reaction as well as what gets generated from the process (the products of the reaction).
- Several factors affect the speed of a chemical reaction, including catalysts, surface area, temperature, and concentration.
- Polymers are long chains of slippery molecules. Coagulation happens when you cross-link the chains into a fishnet-looking design.

Textbook Reading

Matter

Why study chemistry? Baking is chemistry. Cars use chemistry to zip down the street. Your body converts food into energy using chemistry. Everything you see, touch, taste, and smell is a chemical.

Studying chemistry is like peeking under the hood of a racecar—you know you put gas in and it goes, but that's all you can tell from the outside. Chemistry gets you into the inner workings on the molecular level.

Soon you'll be able to explain everyday things, like why baking soda and vinegar bubble, why only certain chemicals grow crystals, what fire really is made of, how to transform copper into gold, and how to make cold light. Once you wrap your head around basic chemistry ideas (like acids, polymers, and kinetics), you can make better choices about the products you use every day like pain relievers and cold compresses. And you also may finally get a loaf of bread to rise!

What is stuff made of?

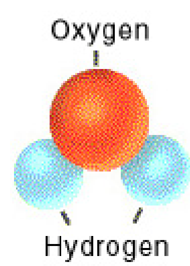
Let's find out by using a thought experiment (Einstein called these "gedanken experiments"—he really hated to *do* experiments, and would rather just *think* about them instead).

Suppose we have a drop of water. If we look at it very closely, we'll see a drop of water, nice and smooth. If we grab a microscope and magnify it roughly 2,000 times (the drop is now 40 feet across, the size of a large classroom) and look very closely, we'll still see relatively smooth water, but there will be wiggly things floating around (paramecia).

We could stop here and study these interesting little critters, but then we'd sidetrack ourselves into biology, so let's focus more on the water.

Let's magnify the water 2,000 times more, so that it's roughly 15 miles across. When we look at it very closely now, we see what looks like a teeming mob of Super Bowl fans making their way to the nearest exit. There is lots and lots of movement, but it's still fuzzy and hard to make out. Now we'll magnify it another 250 times, for a total magnification of 1 billion times, and we'll see two kinds of "blobs": hydrogen atoms and oxygen atoms arranged in a little group like an upside-down Mickey Mouse (see the image below). Each little group of these atoms is called a *molecule.*

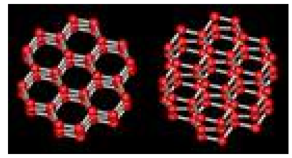
This picture on the right is idealized in a few ways, but most important is that the picture of the molecule



doesn't move on the page, whereas the real molecule wiggles and jiggles as we watch it magnified 1 billion times. Another way this picture is not quite right is that it looks as if the atoms are really stuck together like glue, much the same way magnets attract each other. But unlike magnets, if you squeeze these atoms together too hard, they repel each other.

So the molecules dance and jiggle around all the time, and the jiggling motion is what we call *heat*. When we increase the temperature (say, by putting a pot full of water on a hot stove), the jiggling increases, and the volume between the atoms also increases. When enough energy (from the gas flame on the stove) is pumped into the water molecules, they dance around so much that they jiggle themselves free and zoom into the air as steam.

Suppose we decrease the temperature of our water. Now we find that the jiggling motion decreases, and the attractive force between the atoms takes over. As a matter of fact, at very low temperatures, the atoms lock together into a new pattern called ice. The interesting thing is that there is a place for every atom in its solid form (a crystalline array). Water is one of only a few molecules to expand when solidified. You can see that each of the crystal structures has a big hole in the center, making it larger when it's a solid. The crystal pattern of ice is shown at right—it has many holes in it.



This open structure collapses when the atoms jiggle hard enough to shake themselves loose (*melting*) and rush to fill in the gaps as the temperature (and jiggling) increases. So the water shrinks when it turns into a liquid.

How big is an atom? If an apple were magnified to the size of the earth, the size of the atoms in the apple would be the size of the original apple. Look out over the horizon and imagine you're walking along not on the surface of the Earth, but on the surface of a gigantic apple. The size of an apple atom is now about the size of your fist.

How far away is the electron from the nucleus? The distance from the electron to the nucleus is very great. If you further magnified the atom itself so that now the atom (say, a hydrogen atom) were magnified to the size of the Earth, the nucleus (in this case, only one proton) would be only about the size of a basketball at the center of the earth, and the electron would be found somewhere in Earth's atmosphere.

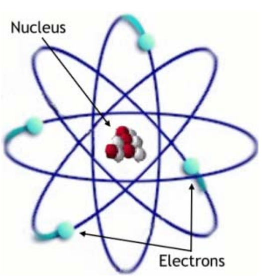
What is an Atom?

We've covered this stuff before, but let's review for a moment as it's probably been a little while since we tackled these ideas together. Are you ready?

My definition of an atom is the smallest part of stable matter. There are things smaller than an atom, but they are unstable. (Not like my Aunt Edna is unstable but rather like they can't be around for long on their own.) Atoms are very stable and can be around for long, long, long periods of time. Atoms rarely hang out on their own though. They are outgoing little fellows, on the whole, and love to get together in groups. These groups of atoms are called molecules. A molecule can be made of anywhere from two atoms to millions of atoms. Together these atoms make absolutely everything.

All matter is made of atoms. Shoes, air, watermelons, milk, wombats, you—everything is made of atoms. Hundreds, billions, and zillions of atoms make up everything. When you fly your kite, the atoms moving against the kite are what keep it in the air. When you float in a boat, it's the atoms under your boat that are holding it up.

What's Inside an Atom?

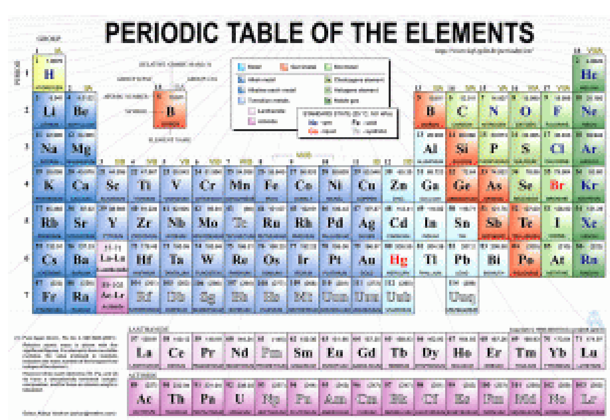


Atoms are made up of bunches of particles, but we will concern ourselves with only three of those particles for now. Atoms are made of protons, neutrons, and electrons. The protons and neutrons make up the nucleus (the center) of the atom.

The electron wanders around outside the nucleus and, as we'll see in the next lesson, is a wacky little fellow. Protons and neutrons are made up of smaller little particles, which are made of smaller little particles and so on. Atoms can have anywhere from only one proton and one electron (a hydrogen atom) to over 300 protons, neutrons, and electrons in one atom. It is the number of protons that determines the kind of atom an atom is or, in other words, the kind of element that atom is. We'll talk more about elements in a bit.

Here science does us a bit of a favor since it's relatively easy to tell how many electrons, protons, and neutrons are in an atom. The number of protons basically tells you how many neutrons and electrons are in the atom. If an atom has 4 protons, it probably has 4 neutrons and 4 electrons. I say probably because in the world of atoms you can never be completely sure. These guys do some wacky stuff. The number of protons and electrons are usually equal in an atom, but the number of protons and neutrons are not necessarily equal in some of the larger atoms.

So how do you know how many protons are in an atom? Look at the periodic chart.



A periodic chart has a bunch of boxes. Each box represents one element. Each box has a ton of information about each element. In the upper left hand corner of each box is what's called the atomic number. The atomic number is the same as the number of protons in the atom.

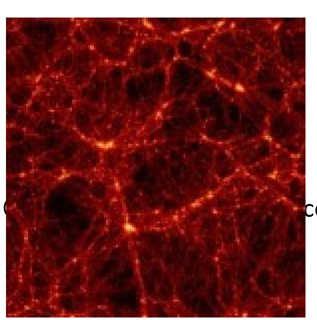
Once you know that, you know the probable number of electrons and neutrons in that atom! Let's take oxygen for example. Oxygen's atomic number is eight so you know there are eight protons, neutrons, and electrons. Isn't it nice when nature makes things simple?

We will talk more about this in future lessons but just to let you know, protons have a positive charge, neutrons have no charge, and electrons have a negative charge. Atoms like to be electrically neutral so that's why the number of protons and electrons tend to be equal. Ten positive protons plus ten negative electrons equals zero net electrical charge, making it a neutral atom. An atom that is not neutral is called an ion.

(You can read more about elements and electron shells in Unit 3: Matter.)

Different States of Matter

Now, that you've spent some quality time with atoms and that wacky electron fellow, you have a bit of an understanding of what is inside everything. The next thing you need to know is...*what's everything?*



Everything is matter. Well, except for energy, but that's everything else (and we'll get to that later). Everything you can touch and feel is matter. It is made up of solid (kind of) atoms that combine and form in different ways to create light poles, swimming pools, poodles, Jello, and even the smell coming from your pizza.

Traditionally, there have been three states of matter. State of matter means the way the atoms tend to hang out together, which is not to be confused with a state like Utah, Wyoming, or confusion. The three states are solids, liquids, and gases. However, leave it up to a science teacher to tell you that that's not the whole story.

There are two more states of matter. They are *plasma* and (are you ready for this next one?) the *Bose-Einstein condensate*. I'm just going to spend a little bit of time talking about these last two states of matter since they are both pretty uncommon on Earth.

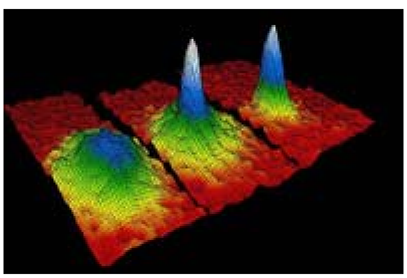
Plasma

Believe it or not, plasma makes up a very large percentage of the matter in the universe. Are you wondering how come you've never heard of it before? (By the way, blood plasma is different from this stuff, and a good thing too!) Plasma doesn't have a definite shape or volume.

Well, there is very little of it on Earth and the plasma that is here is very short lived or stuck in a tube. Plasma is basically ionized gas or, in other words, gas that is electrically charged. The stuff in florescent light bulbs is plasma. Plasma TVs have plasma (go figure) inside of them. Lightning and sparks are actually plasma! Would you like to see some plasma right now? Then try the Plasma Grape Experiment in Unit 3!

Bose-Einstein Condensate

Now let’s talk a bit about the Bose-Einstein condensate, or the BEC if you want to be hip. Each form of matter corresponds with a level of energy. Plasma is the highest energy state of matter. It is so energetic, in fact, that it can give off light. BEC is the lowest energy state of matter.



In fact, BEC only happens at energy levels that are almost as low as possible. Basically, temperature is a measurement of energy, and the higher the temperature, the higher the energy of something and vice-versa. Theoretically the coldest anything can ever get is 0 degrees Kelvin, which is the same as -273 degrees Celsius, or -459 degrees Fahrenheit. This temperature is called “absolute zero”. At absolute zero, there is no energy and no atomic movement. Space is 3 degrees Kelvin. (We’ll get deeper into this concept when we get to the thermal energy lessons.)

Scientists have discovered that if you get certain types of atoms cold enough (less than one millionth of a degree above absolute zero) you get this bizarre thing called a Bose-Einstein condensate. When the atoms get that cold they move so slowly that they kind of blend together into one big atomic mush. Satyendra Nath Bose and Albert Einstein predicted that this state of matter existed in 1924. Seventy-one years later, in 1995, two scientists at the University of Colorado using magnets and lasers made it happen.

Solids

So now that we’ve gotten those bizarre states of matter out of the way, let’s talk about some stuff that really matters (haha...couldn’t resist at least one pun). Something to keep in mind is that everything is made of the same stuff—atoms. What makes the solids, liquids, gases, etc. different is basically the energy (motion) of the atoms, and that motion ranges from BEC, where they are so low energy that they are literally blending into one another, to plasma, where they are so high energy they can emit light. Solids are the lowest energy form of matter that exists in nature (BEC only happens under laboratory conditions).

In solids, the atoms and molecules are bonded (stuck) together in such a way that they can’t move easily. They hold their shape. That’s why you can sit in a chair. The solid molecules hold their shape and so they hold you up. The typical characteristics that solids tend to have are they keep their shape unless they are broken and that they do not flow. Let's take a look at a couple of terms that folks use when talking about solids.

Liquids

A liquid has a definite volume (meaning that you can't compress or squish it into a smaller space), but takes the shape of its container. Think of a water-filled balloon. When you smoosh one end, the other pops out. Liquids are generally incompressible, which is what hydraulic power on heavy duty machinery (like excavators and backhoes) is all about.

Gases

A gas doesn't have a definite volume or shape. You can squish it, expand it, or shove it into a hole and it'll happily go there. Gases you are already familiar with are air (nitrogen and oxygen), helium (in balloons), and neon (the red OPEN signs in stores). There's also xenon (in photography flash lamps), argon (in fire extinguishers and incandescent light bulbs), and krypton (used in high-speed photography flash lamps and by astronomers for measuring stars).

What is an acid?

When dissolved in water, an acid has more hydrogen ions than regular water and a pH lower than 7.0. Generally, acids are sour in taste, change pH indicators red or pink, react with metals to produce a metal salt and hydrogen, react with bases to produce a salt and water, and conduct electricity. Strong acids often produce a stinging feeling on mucus membranes.

What is pH?

pH stands for "power of hydrogen" and is a measure of how acidic a substance is. We can make homemade indicators to test how acidic (or basic) something is by squeezing out a special kind of juice (dye) called anthocyanin. Certain flowers have anthocyanin in their petals, which can change color depending on how acidic the soil is (hibiscus, hydrangeas, and marigolds for example). The more acidic a substance, the more red the indicator will become. We'll be making several different indicators in our experiments soon.

Polymers

When you think of slugs, snails, and puppy kisses, what texture do you imagine? Is it sticky, slithery, or slippery? Any way you picture it, slime is just plain icky—and a perfect forum for learning about polymers.

Imagine a plate of spaghetti. The noodles slide around and don't clump together, just like the long chains of molecules (called **polymers**) that make up slime. They slide around without getting tangled up. The pasta by itself (fresh from the boiling water) doesn't hold together until you put the sauce on. Slime works the same way. Long, spaghetti-like chains of molecules (called polymers) don't clump together until you add the sauce—something that cross-links the molecule strands (polymer) together.

If you've ever mixed together cornstarch and water, you know that you can get it to be both a liquid and a solid at the same time. (If you haven't you should definitely try it! Use a 2:1 ratio of cornstarch:water.) The long molecular chains (polymers) are all tangled up when you scrunch them together and the thing feels solid, but the polymers are so slick that as soon as you release the tension, they slide free and drip between your fingers like a liquid.

Scientists call this a non-Newtonian fluid. You can also fill an empty water bottle or a plastic test tube half-full with this stuff and cap it. Notice that when you shake it hard, the slime turns into a solid and doesn't slosh around the tube. When you rotate the tube slowly, it acts like a liquid.

Reaction Rates

Chemical kinetics is the study of the speed that chemical reactions happen on a molecular level. Chemical kinetics also deals with the control of reaction rates and the products we get out of the reaction. Why do we want to control the speed of a reaction? Think of air pollution. If we could control the reaction rate of the ozone depletion, we could control the problem better.

Chemical reactions can happen slowly (think of a boat on the ocean rusting away) or quickly (like an explosion). The speed of the reaction depends on a lot of different things, including the temperature, how much of each chemical used, whether the chemicals are powdered or solid chunks, and other things like that.

We are going to learn how to control the rate of a reaction so we can direct what comes out the other end. If we figure out what has the greatest effect on the reaction speed, then we can use that to hurry up or slow down the process. (You wouldn't want your car to rust in the rain overnight, would you?) Let's take a look at what affects the reaction rates.

A catalyst is something you add to a mixture, and the only thing it affects is the speed. It doesn't get used in the process, so it's completely recoverable. For example, hydrogen peroxide normally decomposes (transforms) on its own into water and oxygen, but it does this very slowly.

If you toss a chunk of carbon (like charcoal or graphite) into a water bottle filled with hydrogen peroxide, you'll see oxygen bubbles forming, which tells you that this reaction is going along much quicker than usual. If you clamp a balloon onto the neck of the bottle, you'll get a balloon full of pure oxygen. The carbon will still be there next week in the same amounts, as none of it reacted with the peroxide. That's what a catalyst is all about. It changes the speed of the reaction without getting used up.

Do you think surface area matters? It sure does! If you try to ignite a pile of flour (with very little surface area), it will sit there and burn. However, if you blow a fine mist over a candle flame, it will explode with a flash (you don't have to do this one at home—it's on video for you!) The more surface area you expose to react, the faster the reaction will occur. This is why we dissolve chemicals (reactants) in a solvent (liquid, usually water), so the particles are fully exposed to interact with each other.

If you have a cup of vinegar, does it matter how much baking soda you add? Sure it does! If you only sprinkle in a tiny bit, you'll get only a few bubbles surfacing. However, if you dump the whole box in there, you'd better get the mop. The more chemical you use, the more it's going to react. A bottle of 50% rubbing alcohol is actually half water, while a 91% rubbing alcohol solution is mostly alcohol (so if you're using the 50% alcohol solution in our Burning Money experiment, you'll need to omit the water as it's already included in the bottle).

Electrochemistry

If you guessed that this has to do with electricity and chemistry, you're right! But you might wonder how they work together. Back in 1800, William Nicholson and Johann Ritter were the first ones to split water into hydrogen and oxygen using electrolysis. (Soon afterwards, Ritter went on to figure out electroplating.) They added energy in the form of an electric current into a cup of water and captured the bubbles forming into two separate cups, one for hydrogen and another for oxygen.

But how did they know which bubbles were which? You can tell the difference between the two by the way they ignite (don't' worry—you're only making a tiny bit of each one, so this experiment is completely safe to do with a grown up).

It takes energy to split a water molecule. On the flip side, though, when you combine oxygen and hydrogen together, it makes water and a puff of energy. That's what a fuel cell does. But back to splitting the water molecule—as the electricity zips through your wires, the water molecule breaks apart into smaller pieces: hydrogen ions (positively charged hydrogen) and oxygen ions (negatively charged oxygen). Remember that a battery has a plus and a minus charge to it, and that positive and negative attract each other.

So, the positive hydrogen ions zip over to the negative terminal and form tiny bubbles right on the wire. The same thing happens on the positive battery wire. After a bit of time, the ions form a larger gas bubble. If you stick a cup over each wire, you can capture the bubbles and, when you're ready, ignite each to verify which is which.

