It falls from the sky, makes up about 60% of our bodies, and just about every chemical process related to life takes place with it, or in it: dihydrogen monoxide. Without it, none of the chemical reactions that keep you alive would happen. None of the reactions that sustain any life form on earth would happen. Not even the majority of inorganic chemical reactions that shaped the surface of the earth would happen. Water is the key to nearly everything. And one of the reasons it's the key, is because it's really good at dissolving stuff. We need it so bad, that we dump over 180 gallons of it into our bodies every year, and we do that to maintain an aqueous or water based solution inside our cells, because aqueous environments are pretty much the best for cool chemistry. Each and every one of us uses water for all kinds of chemistry every single day. Our body chemistry, our food chemistry and yes, [pulls out laundry basket] our laundry chemistry, all take place in water. [animatied flies buzz around the basket of dirty laundry] Ewww.

[Intro Music]

(01:09)

=====Laundry=====

This [holds up sock] use to be a white sock. It is now a little bit of gray sock, and in places a little bit of a yellow sock. But anyway, I want it to be white again, and to do that I'm gonna need some chemistry. To whiten whites, you might use a solution of sodium hypo-chlorate, better known as bleach. What makes bleach so good at it's job is that it's a really strong oxidizer, meaning that the oxygen atom is really good at pulling electrons away from other compounds making them break apart. This is really handy for getting rid of stains but as you can tell by the formula, sodium hypo-chlorate also contains chlorine, which happens to be really good at killing things. That's why we use it in swimming pools and as a disinfectant.

But there are lots of other good oxidizing agents, and one that doesn't contain chlorine is hydrogen peroxide. And it can be used as a bleach too, but it's only components are hydrogen and oxygen, just like water. We'll talk about oxidation and other kinds of reactions in a couple weeks, but before we get to that you have to understand solutions, and before we do that I'm just gonna get rid of the laundry because it's kinda stinky.

This bottle of hydrogen peroxide contains a solution and not just the solution to my problem of stained laundry. By solution, I mean a solution of liquid with another substance dissolved in it. Here water is the liquid, or solvent, and hydrogen peroxide is the solute, or dissolved material. And water is an amazing solvent, possibly, arguably, the best solvent on earth. Why? A lot of reasons. There's a lot of it on the surface of the earth, that helps. Just abundance is good. It's liquid at a very wide range of temperatures and being liquid is what you need to be able to be a solvent. But also because it's polar; it's a very polar molecule

(02:40)

=====Polarity=====

Remember how I said that oxygen is very good at pulling electrons toward it? Well, oxygen atoms are more electronegative than hydrogen. The oxygen atom pulls harder on the molecule's electrons than the hydrogen does. As a result, the electrons in a water molecule tend to spend most of their time near the oxygen, giving the oxygen end a partial negative charge, and the hydrogens, a somewhat positive charge. This polarity makes water extremely effective at dissolving things, especially other polar things. The sugar we mixed into our tea last week, for example, was polar. When you mix a polar solid, like sugar, into a polar liquid, like water, the molecules of the water surround the sugar molecules. The negative side of the water molecules is attracted to the positive side of the sugar molecule and vice versa. In interacting with the sugar molecules, the water inserts itself between all of the individual molecules of the sugar that were once clumped together in the sugar crystals. A liter of water can dissolve as much as 1800 grams of sucrose.

Water based solutions, earlier I called them aqueous solutions. And I'm calling it an aqueous solution again so that you remember it's called an aqueous solution. Aqueous. You can create all sorts of aqueous solutions using salts or minerals, even acids. Ethanol, which composes 95% of this grain alcohol, is polar. So it dissolves easily in water. But water does not dissolve non-ionic, nonpolar substances. Oil, for instance, doesn't have any polarity. So it has no interest in interacting with water. So when you mix them, they separate.

(04:13)

=====Dielectric Property=====

Water's polarity also gives it lots of other super useful properties. For example, water can decrease the attraction between ions of different charges. We call this it's dielectric property. Take table salt, for example. It's made of positively charged sodium ions and negatively charged chlorine ions.

(04:29)

=====Electrolytes=====

When it's mixed with water, the water dissolves the salt into it's component ions. The water molecules then surround the individual ions and shield them from eachother's electric charges. These ions in water are called electrolytes; literally, loosened electricity, because separating through dissolution frees them to act independently and carry their electrical charge around. You've probably heard about electrolytes in biology class, but you've definitely heard about electrolytes in Gatorade commercials. Your body needs electrolytes to carry electrical signals that help your muscles twitch, and your brain cells fire and get all the business of living done. In addition to helping you live, electrolytes are one of the most important ways chemists have of classifying solutions.

Pure water, on it's own, does not conduct electricity, which seems a little weird to us--the whole hairdryer in the bathtub thing still being a terrible idea. But if you put a bit of salt or any ionic solid in the water, they dissolve into those component electrolytes. It's the electrolytes that are conducting the electricity.

It's not what you might expect, but we have Swedish physicist Svante Arrhenius to thank for figuring this out. While doing his doctoral research in the 1880s, he first developed the idea that a solution's electrical conductivity could be linked to the concentration of ions in the solution. It was one of his predecessors, British super-genius Michael Faraday, who discovered that substances dissolved in water conduct electric currents. Faraday was terrible at naming stuff, so he wrote to a guy who was known for coining terms, William Whewell. You may have heard of his most famous creation, the word "scientist." Whewell wrote back to Faraday saying, "I would propose for the two elements resulting from electrolysis the terms 'anion' and 'cation.' And for the two together, you might use the term 'ions.'"

And there's something interesting here, and I didn't pick up on it at first, but Whewell said, "The things resulting from electrolysis." Faraday, thought that the electric current is what produced the ions. What Arrhenius discovered, was that water simply dissolves certain substances, like salts, into their constituent ions, which themselves carry the charge. And since electrolytes carry electric charge, the higher the concentration of electrolytes in a solution the higher it's electrical conductivity. Arrhenius found that you can even reverse engineer your study of a solution and by measuring it's electrical conductivity, figure out how concentrated it is. Despite the importance of his work, Arrhenius' chemistry professors didn't think much of it and he got a mediocre grade, which is why it must have been particularly sweet when he won the Nobel prize in 1903 for that very same research.

Today, we know a little bit more about how electrolytes work, and we've learned that the relationship between their concentration and their conductivity is not always straightforward, because not all electrolytes dissolve equally well in water. A strong electrolyte, for example, is one that dissociates, or breaks apart, completely when dissolved in water and conducts electricity very well. Salts do this. So do strong acids like hydrochloric, and sulfuric, and nitric acid. As well as strong bases, like sodium and potassium hydroxide. Weak electrolytes only dissociate partially when dissolved in water, so they're only somewhat conductive. Most of the solute's molecules stay stuck together, remaining neutral. Acetic acid, the active ingredient in vinegar, and ammonium hydroxide are examples of this. And of course, some things dissolve in water but don't conduct electricity at all, because they don't dissociate into ions. Alcohol and sugar, for example, are nonelectrolytes.

Now, what does any of this have to do with my laundry? Well, hydrogen peroxide is a polar molecule so it dissolves really well in water. But it's a very weak electrolyte. When it dissolves, it tends to dissociate into a water molecule and a lone oxygen ion. Since the dissolved peroxide creates even more water, the concentration of ions is quite low. But that lone oxygen ion is not happy by itself. It goes on an oxidizing rampage, swiping electrons from anything it can find. It's especially good at tearing up the tricky double bonds that tend to give laundry stains their color. When that rampaging ion destroys the double bond, the stain disappears.

We're used to thinking of hydrogen peroxide as a fairly mild chemical, but that's because the over the counter stuff is pretty dilute. Too much peroxide could actually dissolve my clothes and some of my favorite shirts are in here, so we need to dilute this stuff to make the solution the right strength.

(08:46)

=====Molarity=====

And as you might expect, if you joined me on my recent foray into stoichiometry, when chemists think about the strength of a solution, they think about moles.

So before we can dilute this formula, first we have to figure out how many moles of solute, of hydrogen peroxide, we're working with here. You'll remember, I hope, that one mole of a compound equals 6.022×10^{23} molecules. That is a big number. So to make it easier on ourselves, we usually figure out how much a mole of a particular substance weighs. In our case, a mole of hydrogen peroxide weighs 34.014 grams. The number of moles of solute that are in a solution is known as it's molar concentration, that's also known as a solution's molarity. As a rule, molarity equals the number of moles of solute divided by liters of solution. So a one molar solution, contains one mole of solute per one liter of solution. Do not confuse this with another way of measuring concentrations based on mass, instead of based on volume. This is known as molality and it's expressed as the number of moles of a solute in a kilogram of a solution, rather than in a liter. *Molality* refers to moles per unit mass and *molarity* refers to moles per unit volume. Sorry, scientists are bad at naming things sometimes. You just have to remember this stuff.

So now that we know what molarity is, let's figure out the molarity of this hydrogen peroxide solution. The label on the bottle says a 3% solution, weight per volume. Technically that's terrible chemistry because it's expressing a percentage in terms of two different sorts of units, but it does let us know how much solute went into the solution: 30 grams of H_2O_2 per one liter of water. I mean, just to be clear, it makes no sense to have a percentage with two different units and maybe these folks need to watch some Crash Course Chemistry.

So to calculate the molarity of this solution we first need to figure out how many moles of hydrogen peroxide are in 30 grams of hydrogen peroxide. If we divide the 30 grams in the solution by it's molar mass of 34.014 grams per mole, we have 0.88 moles of hydrogen peroxide per liter of solution. Or, so you get used to the lingo, a 0.88 molar solution of H_2O_2 in this little brown bottle.

(10:56)

=====Dilutions=====

Now that we know the molarity of the original formula we can start thinking about how to dilute it. To dilute a solution you either have to add more solvent or reduce the amount of solute. Since I'm already starting with a solution, I need to add even more solvent, water, probably in this tub right here, so let's just get that out of there. And there's a handy chemical rule for understanding dilutions: the moles of solute before dilution is equal to the moles of solute after dilution. Think about it, the total amount of hydrogen peroxide is going to stay the same, no matter how much water it's diluted with. But as you dilute a solution, it's volume grows, the moles stay the same, and it's molarity thus shrinks.

To calculate precisely how much one affects the other, we use a standard, and super simple, dilution equation. Here M_1 and V_1 are the molarity and volume of the original concentration, sometimes called the stock solution. In this case, it's what's in the bottle. M_2 and V_2 are the molarity and volume of the dilute solution. So in our case, M_1 equals 0.88, that's the molarity of the hydrogen peroxide solution that we've got. And to bleach the stains out of laundry we need a 0.1 molar solution, that's M_2, the molarity we want to get to. And the tub that I'll be soaking my whites in, holds 38 liters of liquid, so that's our $V_{2.}$ All that's missing is the volume of the peroxide solution that we must add to 38 liters of water to get to our target molarity. Do the math and you get V_2 equalling 0.24 liters of hydrogen peroxide or 250 milliliters. And we just fill this right on up here, hopefully we have enough. Annnddd, that's what we need. And while I wait a few hours for the peroxide to do it's work, I'm going to enjoy another of my favorite aqueous solutions: tea.

=====Summary=====

Today here at Crash Course Chemistry we learned about some of the properties of water that make it so special: it's polarity and it's dielectric property. We learned how electrolytes can be used to classify solutions. And we discovered how to calculate a solution's molarity, as well as how to dilute a solution using the dilution equation.

=====Credits=====

This episode of Crash Course Chemistry was written by Kim

Krieger. The script was edited by Blake de Pastino and myself, and our chemistry consultant is Dr. Heiko Langner. Our director, cinematographer and editor is Nicholas Jenkins. Script supervisor is Michael Aranda, who also is our sound designer. And our graphics team is Thought Cafe.