Episode 215—The Magic of Water

Hi—I'm Steve Shepard, and this is the NCP, the Place for Stories that Matter.

How about a chemistry lesson? Okay, not really a chemistry lesson. Okay, it IS a chemistry lesson. But a painless one. It's one of those lessons where you're going to want to go find somebody you know to share it with, I promise.

Every few years, a petition appears, usually on college campuses, arguing that a fairly common compound known as dihydrogen monoxide, sometimes called dihydrogen oxide, and hydric acid, is responsible for the accelerated corrosion of metal parts, countless injuries, and the suffocation of hundreds of people every year. As a result, the petition argues, the compound should be banned, regulated, or at the very least, labeled as a hazardous substance.

But here's the deal. Dihydrogen monoxide is the chemical name for the compound known as … water.

[Collage of water sounds in background]

Loren Eiseley, whom you've heard me refer to countless times on this Podcast because he's one of my scientific and literary heroes said, "If there is magic on this planet, it is to be found in water." Well, he's right, and in this program, I want to show you why water is, in fact, imbued with magic.

H_2O. When these two hydrogen atoms and one oxygen atom come together, they create what's called a polar covalent bond. Polar simply means that there are recognizable positive and negative sides to the water molecule; covalent just means the three atoms share electrons, But they share them unequally, in sort of a magnetic tug-o'war. But here's the thing: oxygen always wins. Why? Because of a property called electronegativity, which is a measure of the degree to which an element will hold onto its electrons—or attract them away from others. Fluorine, nitrogen, and, you guessed it, oxygen, have the strongest electronegativity of all elements. So, when hydrogen comes together with oxygen, the two elements share the electrons between them, but it's not oxygen's first choice. It would rather have all of them to itself, but it grudgingly shares them with the two hydrogen atoms.

The other interesting thing about the molecular structure of water is that the bonds between the hydrogen and oxygen atoms are very strong and are called hydrogen bonds. They only form between hydrogen atoms and atoms that have high degrees of electronegativity, which, as we said, includes oxygen. This is the reason that water is so stable. It's also the reason we'll most likely never see a flux capacitor-powered car that runs on water, because the amount of energy you get from breaking apart water molecules to create burnable hydrogen and oxygen gas is about one one-hundredth the amount of energy that's required to break it apart in the first place. So, don't hold your breath on that one.

But there's more to the magic of water than hydrogen bonding. For example, everybody knows that when things get colder, they shrink—they contract. But apparently, somebody forgot to tell water. It's the only known substance that expands when it gets colder. And here's another weird thing: liquid water is slightly heavier than the same amount of frozen water. This is why lakes and ponds freeze from the top-down—water actually becomes less dense as it transitions from liquid to solid, so ice floats on top of the liquid water. Water also has tremendous heat capacity, which is why it takes forever to get it to boil, and why it makes such a great insulator and coolant.

The reason this happens is because when liquid water freezes, it rearranges itself, again, thanks to hydrogen bonding, into a lattice of four-sided structures, with every oxygen atom sitting so that it's surrounded by four hydrogen atoms. This happens because in this state, every water molecule is hydrogen-bonded to its four nearest neighbors. This lattice-shaped structure leaves open spaces, increasing the volume but decreasing the density, which is why ice floats on water.

And, water is the only substance in the known universe that has a slippery surface when it's frozen.

Another weird thing about water is that it shouldn't exist at all in liquid form, and based on the literature, scientists still aren't quite sure why it does. It should either be a gas, water vapor, or a solid, ice. But because of the hydrogen bonding and electronegativity that are a big part of its personality, the dipole molecules stick to each other, preventing the instantaneous transition to gas and keeping it in a liquid state. Again, this is why it takes so much energy to boil water and make it go from a liquid to a gaseous state.

But it gets even weirder. Based on the size of the water molecule, water should actually boil at 62 degrees Celsius, not 100. Again, this is attributable to the nature of the molecule and the enormous amount of energy required to get it to change its state because of those hydrogen bonds. This is part of the reason that our atmosphere is such a magical thing, and why we're even capable of existing on this planet. It's all about water's incredible heat capacity. Every 90 minutes, the water in the Atlantic Gulf Stream releases as much energy into the atmosphere as humans produce in an entire year by burning coal. *Every ninety minutes!* So, as water moves around the planet in the great gyres that we know as oceanic current systems, the energy that the water releases keeps the planet's climate temperate—unless, of course, we screw it up.

This weird characteristic leads to a set of qualities that make water—dihydrogen monoxide—pretty unique, especially for such a simple molecule. For example, there's adhesion, which is what happens when you see that drop clinging and clinging and clinging to the faucet and it just won't let go. Or cohesion, which is what causes those drops to form in the first place, as the negative and positive ends of water molecules stick to each other. Or how about capillary action, which is what makes it possible for water to climb the tallest tees in the forest. Or surface tension, which is why some insects can walk on the surface of water, or why you can carefully place a needle on the surface of water, and it won't sink to the bottom of the water glass—it stays there, floating, just depressing the surface. It's also why water forms and soap bubbles form themselves into round shapes. In fact, water has the strongest surface tension of any known substance.

A big part of the reason for water's weird behavior is its molecular structure. Remember, it's made up of one oxygen atom and two hydrogen atoms, and because of the strong electronegativity of the oxygen molecule and the weaker positive charge of the two hydrogens, the molecule bends itself into a V—its natural shape—where the angle between the two hydrogens is exactly 104.5 degrees—a little wider than a 90-degree right angle. So, if you can imagine the V, with the oxygen atom at the bottom and the two hydrogens at the top, the molecule has a slight magnetic polarity to it—the oxygen is slightly negative, while the hydrogens are slightly positive. This results in what's called a dipole, which is what magnets are with their north and south poles. And the fact that water is a dipole, or what chemists call a 'dipole moment,' is extremely important, and has some very serious implications for us—in fact, for every living thing on the planet.

For example, the dipole nature of water is the main reason that it's known in chemistry circles as the universal solvent—it will dissolve just about anything, more things, in fact, than any known substance—period. It's also why there's no such thing as pure water in the natural world: the instant it comes in contact with just about anything, it dissolves it and forms a solution, in the process losing any purity it might have had. In a sense, water is sort of a pirate. It overwhelms other compounds—take table salt, for example, which is sodium chloride, NaCl, and, because of its powerful hydrogen bonding, the water molecule rips the weaker bonds asunder that exist between the sodium and chlorine atoms. And just like that, water becomes salt water.

We hear all the time that water is essential to life. But it's more than having something to drink or a pool to jump into in the summer. Something on the order of 70 percent of our bodies is made up of water. Brain and muscle tissues have the most, while bone and fat have the least. And its job is pretty important. On the one hand, it serves us in its role as the universal solvent, dissolving metabolites so that they can be carried throughout the body so that it can do its chemical magic to keep us alive. It also helps us to regulate our bodies. Every day, we dump about a gallon of water through respiration, perspiration, and excretion, and then replace it through what we eat and drink. The eating and drinking part is obviously critical to our survival, but it also has the potential to wipe us out. Eating and drinking, and then metabolizing what we take in to create nutrients, requires an enormous amount of energy to process, and in the process produces a lot of heat. Were it not for the body's water-dependent cooling system, our internal body temperature would go up about 79 degrees, from 98.6 to around 160. That's a hell of a fever.

Finally, one more weird and amazing thing about water. Water, like all liquids, is pretty much incompressible. As a result, when it's confined inside a closed space and has no place to go, it can create enormous pressure, including inside biological channels, like the water-carrying xylem of plants or blood capillaries in the bodies of animals. In a seed case that's just getting ready to germinate, the water inside the pod can reach an internal pressure of 400 atmospheres (that's 5,880 PSI) at the moment of germination, which gives the tiny, helpless seedling the ability to do some pretty industrial things, like shattering concrete and asphalt on its way to the surface and the sunlight.

Pretty cool, huh? I knew you'd find this interesting. Now if you'll excuse me, I'm off to have a nice, cool glass of dihydrogen monoxide.

[glass filling at faucet]

[NCP outtro]