Water's Molecular Shape – Video Tutorial

Let's talk about water! **H-2-O**. What does that mean? Water is a liquid made up of billions of molecules of H-2-O, all swirling around at the molecular level like partners in a square dance or marbles in a shaking box. If we look more closely at one of these molecules, we see that it is made up of three individual atoms bonded together in a particular shape. Two hydrogens, each bonded to a central oxygen. Hence the chemical formula – H-2-O.

Notice that in this model of a water molecule, the shape is bent. Why? To understand why water has this shape, we need to look even closer – inside the individual atoms – and study the atomic bonds. First, let's review the components of a single atom. All atoms are made up of three subatomic particles – neutrons, protons, and electrons. Neutrons and protrons are trapped in the nucleus. They are not involved in the bonds that form between atoms. That role goes to electrons! Electrons do not reside in the nucleus. Instead they reside in energy shells that surround the nucleus. The innermost shell is the smallest. It can contain at most two electrons. The next one out can hold at most eight. That's also true for the next one. It gets more complicated after that, so let's keep it simple and look at just these inner most shells. Remember, **electrons** have a negative-one charge, and **protons** a positive-one charge. **Neutrons** have no charge. As long as the number of electrons and protons in an atom or molecule are equal, that atom or molecule has no net charge. If it did, it would be called an **ION**. Because electrons reside outside the nucleus, they can freely move from one atom to another. If they do migrate, they will produce unequal charges (remember, protons aren't moving, only electrons). When electrons transfer from one atom to another, they, thus, produce IONS.

Pause now.

How many electrons in an **atom**? As long as it's neutral, the number of electrons = the number of protons. How do we know the number of protons? The periodic chart of the elements describes the number of protons in the nucleus of all elements. For oxygen, the number is 8. For Hydrogen 1. These numbers, also known as **atomic numbers**, are the most important identifier of atoms. Any atom with 8 protons MUST be oxygen. And if it's neutral oxygen, it will also have 8 electrons. Let's look closer at the neutral oxygen atom. Where do its electrons reside? The first two go in the innermost shell, which leaves 6 for the outer shell. This is a neutral oxygen atom, but it's not chemically stable. To be stable it wants to have a full outer electron shell. In fact, that goal is what underlies basic chemistry. Atoms bond with each other in ways to help create full outer electron shells. For example, oxygen wants two more electrons. If oxygen could get two more electrons would it be neutral any longer? No. What would be its net charge?

Pause now.

-2. Would it be stable? Yes. So how can it arrange to get two more electrons? Two basic ways or bonds: sharing electrons (a covalent bond) or transferring electrons (an ionic bond). Since in ionic bonds, electrons are given from one atom to another, they produce two equal but oppositely charged ions. These opposite charges attract one another – forming an ionic bond.

Let's look closer at the water molecule and see what kinds of bonds it has. Remember that neutral Hydrogen atoms have only one electron, which sits in the innermost shell that can hold at most two. What does hydrogen want to be stable chemically? One more electron. What if oxygen, which wants two more electrons gets together with two hydrogens? Each shares one of its electrons with the other creating a covalent bond for a total of two covalent bonds in one water molecule. Those shared electrons orbit both nuclei and act as a glue holding the atoms tightly together. The result? There are 8 total electrons orbiting the oxygen in its outer shell and 2 electrons orbiting each hydrogen in its outer shell. All atoms have filled outermost shells, and the molecule is chemically stable.

The shape of the water molecule comes from the shape of the underlying electron shells, which in the outermost energy shell of the oxygen are lobe-shaped, like a pyramid or a jack made of four points. In the hydrogen, the tiny inner electron shell is shaped like two lobes (barbells). To bond, one electron in one lobe of each atom overlap. That means the oxygen has two lobes that are bonding to one hydrogen each. The remaining two lobes are unbonded, but filled with electrons and stable. The two covalently bonded lobes thus produce a bent-shaped molecule. The higher electronegativity of oxygen (a characteristic of an atom that describes its propensity to hold tight to electrons), causes a drawing of electrons away from the hydrogens and towards the oxygen. Combined with the molecule shape, this drawing away of electrons means that the electron density is highest on the side opposite the hydrogen. The result is the molecule has a slightly positive side and a slightly negative side. Two oppositely charged sides or poles. Thus we describe the water molecule as polar.

Pause now.

So what?! Why is it important that water is polar and has a bent shape? Because that shape GREATLY impacts its behavior, a behavior that is different than almost any other common substance, and that behavior is what allows life to function. Let's learn more.

You'll notice in this picture that because water molecules have oppositely charged sides, they like to stick to each other. Because the charges are only partial, the attraction here is not as strong as a full ionic bond. However, the slightly positive hydrogen of one molecule is attracted to and sticks to the negative side of a neighboring molecule. This stickiness creates a bond called a **hydrogen bond**. This stickiness of water causes some amazing behaviors upon which we all depend.

The hydrogen bonds between water molecules mean water sticks together and forms a surface, or skin. As long as the pressure on this surface isn't too great, the skin can withstand that pressure and remain connected. The water strider can walk on water because it is lightweight and distributes its weight over a large area through its body design. There's never enough pressure on any one point to puncture the surface and fall through. We call this property of water **surface tension**, and it is what causes water droplets to form (instead of a sheet of water running down your window, it collects in drops). It's also what allows you to overfill a glass of water without it overflowing. If we were to add more water to this glass, its weight would produce a gravitational force stronger than the hydrogen bonds, and it would overflow.

Capillarity is a term we use to describe how water bonds itself to its surroundings (assuming the surroundings also have a charge or are also polar), and in the process can move against the force of gravity – uphill! This property allows water from the soil to reach the top of the Giant Redwood trees, over 300 feet above the ground. The water molecules are attracted to the sides of the thin capillaries and move upward molecule by molecule as they feel continued attraction. You can experience this at home if you hold a paper towel over a puddle of water or if your curtains get wet from a puddle on the floor of your living room. The water moves UP the curtains. These two images from the Austin's Children Museum demonstrate this property. You can try this at home. Take two glasses – one dry – one with water. Place a paper towel between the two. Watch over time as the water moves against gravity, UP the papertowel, through the paper towel, and eventually into the empty glass – all due to the hydrogen bonding capability of water.

Water is sometimes called the **universal solvent**, because it can dissolve more substances than any other common liquid. Why? Let's drop a particular kind of solid into water – a solid that is made of **ionic bonds** where the outer bits of that solid will be made of ions – atoms with a net charge. Water molecules are attracted to that net charge and stick to the ions. When enough water molecules "gang up" and stick to the outside of an ion, they can overcome the strength of the ionic bond and pull the ion out of its crystalline structure. That ion is now what we refer to as dissolved in water. It is a single ion, surrounded by a sphere of water molecules, called a **hydration sphere**. As long as there's enough water molecules available, the entire solid can dissolve through this process.

Water is a good dissolver of any substance with full or partial ionic bonds, like salt – which is made of Na – sodium – and Cl – Chloride. Instead of sharing electrons, the sodium atom gives up one of its electrons to the chloride. The sodium now has a net positive-one charge and the chloride has a net negative-one charge. As long as those charged ions are close enough together and moving slowly enough (it's cool enough) they will arrange themselves in an orderly pattern – and produce a solid salt crystal. When salt water is boiled, and the water evaporates, the dissolved ions within will no longer be separated by water molecules – they will find each other again – bond into an orderly pattern and precipitate as a salt crystal. **Precipitation** is the reverse of dissolution.

Every year in Death Valley, California, waters rich in dissolved ions run out of the nearby mountains and collect in lakes in the valley floor. These waters are trapped in an inland valley that is lower than sea level and quite hot. High evaporation during the Summer creates layers of evaporite deposits including salt.

Pause now.

For more information and more detail, continue on to the next video in this series.

[End credits]

<u>Seawater Physical Properties Series:</u>
Part I: Water Molecule Shape
Part II: Water Phases
Part III: Water Density
Part IV: Heats of Water
Part V: Light, Viscosity, & Pressure
Part VI: Heat Transfer

Water Molecule Shape
Geoscience Video Tutorial
Produced by Katryn Wiese
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