International Journal of Scientific Research in Science and Technology
© 2018 IJSRST | Volume 4 | Issue 11 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X

Water Molecule : Chemical and Physical Properties

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ABSTRACT

Water is a chemical compound and polar molecule, which is liquid at standard temperature and pressure. It has the chemical formula H_2O, meaning that one molecule of water is composed of two hydrogen atoms and one oxygen atom. Water is found almost everywhere on earth and is required by all known life. About 70% of the Earth's surface is covered by water. Water is known to exist, in ice form, on several other bodies in the solar system and beyond, and proof that it exists (or did exist) in liquid form anywhere besides Earth would be strong evidence of extra-terrestrial life.
Keywords : H_2O, Chemical Compound, Polar Molecule, Extra-Terrestrial Life

INTRODUCTION

Introduction to the properties of water

You are a talking, tool-making, learning bag of water. Okay, that’s not completely fair, but it's close since the human body is 60 to 70% water. And it's not just humans—most animals and even tiny bacteria are made up mostly of water^11start superscript, 1, end superscript. Water is key to the existence of life as we know it. That may sound dramatic, but it’s true—and dramatic things that are true are what make life interesting! Most of an organism’s cellular chemistry and metabolism occur in the water-based “goo” inside its cells, called cytosol.

Water is not only very common in the bodies of organisms, but it also has some unusual chemical properties that make it very good at supporting life. These properties are important to biology on many different levels, from cells to organisms to ecosystems. You can learn more about the life-sustaining properties of water in the following articles:

- Solvent properties of water: Learn how and why water dissolves many polar and charged molecules.
- Water can stick to itself (cohesion) and other molecules (adhesion).

- Water has a high heat capacity and heat of vaporization, and ice—solid water—is less dense than liquid water.

Water owes these unique properties to the polarity of its molecules and, specifically, to their ability to form hydrogen bonds with each other and with other molecules. Below, we'll look at how this hydrogen bonding works.

Water molecules of Polarity

The key to understanding water's chemical behavior is its molecular structure. A water molecule consists of two hydrogen atoms bonded to an oxygen atom, and its overall structure is bent. This is because the oxygen atom, in addition to forming bonds with the hydrogen atoms, also carries two pairs of unshared electrons. All of the electron pairs—shared and unshared—repel each other.

The most stable arrangement is the one that puts them farthest apart from each other: a tetrahedron, with the \H{O}-\text{H}O–H start text, O, end text, minus, start text, H, end text bonds forming two out of the four "legs". The lone pairs are slightly more repulsive than the bond electrons, so the angle between the \text{O}-\text{H}O–H start text, O, end text, minus, start text, H, end text bonds is slightly less than the 109° of a perfect tetrahedron, around 104.5°.

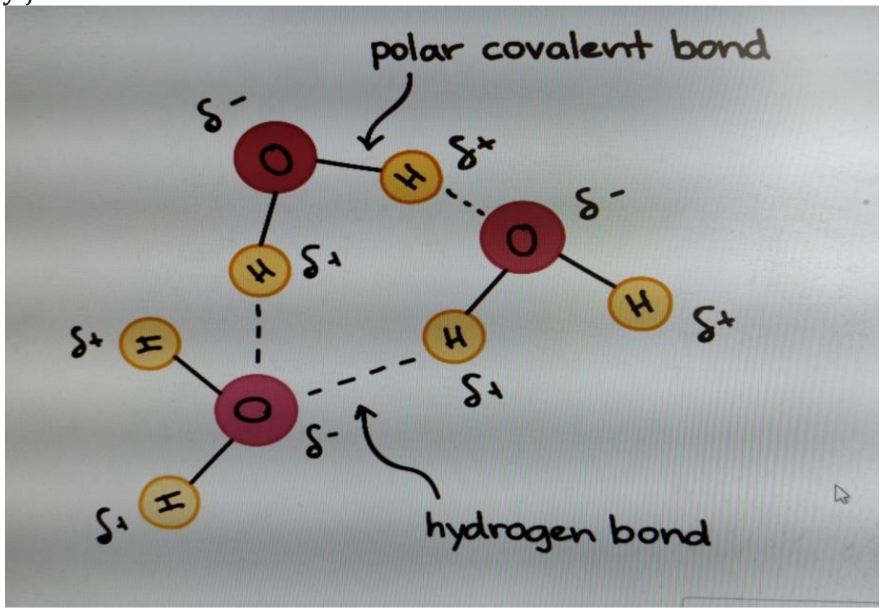
Because oxygen is more electronegative—electron-greedy—than hydrogen, the \text{O}Ostart text, O, end text atom hogs electrons and keeps them away from the \text{H}Hstart text, H, end text atoms. This gives the oxygen end of the water molecule a partial negative charge, while the hydrogen end has a partial positive charge. Water is classified as a **polar molecule** because of its polar covalent bonds and its bent shape.

Hydrogen bonding of water molecules

Thanks to their polarity, water molecules happily attract each other. The plus end of one—a hydrogen atom—associates with the minus end of another—an oxygen atom.

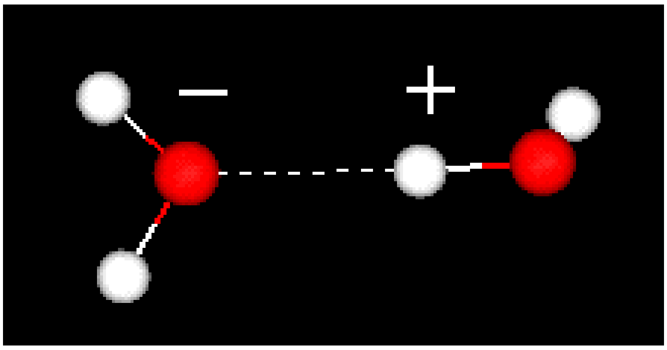
These attractions are an example of **hydrogen bonds**, weak interactions that form between a hydrogen with a partial positive charge and a more electronegative atom, such as oxygen. The hydrogen atoms involved in hydrogen bonding must be attached to electronegative atoms, such as \text{O}Ostart text, O, end text, \text{N}Nstart text, N, end text, or \text{F}Fstart text, F, end text.

Water molecules are also attracted to other polar molecules and to ions. A charged or polar substance that interacts with and dissolves in water is said to be **hydrophilic**: *hydro* means "water," and *philic* means "loving." In contrast, nonpolar molecules like oils and fats do not interact well with water. They separate from it rather than dissolve in it and are called **hydrophobic**: *phobic* means "fearing." You may have noticed this as a not-so-handy feature of oil and vinegar salad dressings. Vinegar is basically just water with a bit of acid.



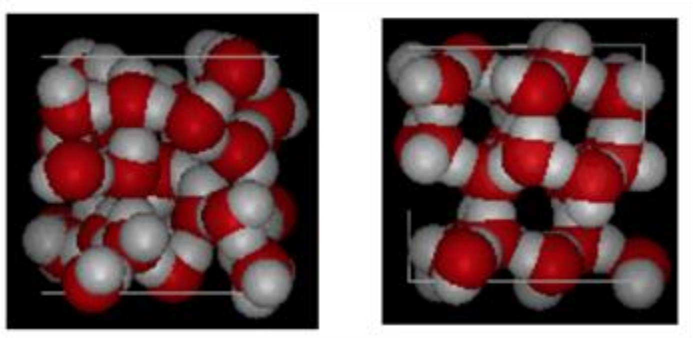
The dipolar nature of the water molecule

An important feature of the water molecule is its polar nature. The water molecule forms an angle, with hydrogen atoms at the tips and oxygen at the vertex. Since oxygen has a higher electronegativity than hydrogen, the side of the molecule with the oxygen atom has a partial negative charge. A molecule with such a charge difference is called a dipole. The charge differences cause water molecules to be attracted to each other (the relatively positive areas being attracted to the relatively negative areas) and to other polar molecules. This attraction is known as hydrogen bonding.



This relatively weak (relative to the covalent bonds within the water molecule itself) attraction results in physical properties such as a relatively high boiling point, because a lot of heat energy is necessary to break the hydrogen bonds between molecules. For example, sulfur is the element below oxygen in the periodic table, and its equivalent compound, hydrogen sulfide (H_2S) does not have hydrogen bonds, and though it has twice the molecular weight of water, it is a gas at room temperature. The extra bonding between water molecules also gives liquid water a large specific heat capacity.

Hydrogen bonding also gives water molecules an unusual behaviour when freezing. Just like most other materials, the liquid becomes denser with lowering temperature. However, unlike most other materials, when cooled to near freezing point, the presence of hydrogen bonds means that the molecules, as they rearrange to minimise their energy, form a structure that is actually of lower density: hence the solid form, ice, will float in water. In other words, water expands as it freezes (most other materials shrink on solidification). Liquid water reaches its highest density at a temperature of 4 °C. This has an interesting consequence for water life in winter. Water chilled at the surface becomes denser and sinks, forming convection currents that cool the whole water body, but when the temperature of the lake water reaches 4°C, water on the surface, as it chills further, becomes *less dense*, and stays as a surface layer which eventually forms ice. Since downward convection of colder water is blocked by the density change, any large body of water frozen in winter will have the bulk of its water still liquid at 4°C beneath the icy surface, allowing fish to survive. This is one of the principal examples of finely-tuned physical properties that support life on Earth that is used as an argument for the anthropic principle.



Shown above is a side by side comparison of a box 10 Angstroms across. It clearly shows that ice takes up more space because of the hydrogen bonding that occurs when the state changes from liquid to solid. In ice Ih, each water forms four hydrogen bonds with O---O distances of 2.76 Angstroms to the nearest oxygen neighbor. Because of ordered structure in ice there are less H20 molecules in a given space of volume.

Water as a solvent

Water is also a good solvent due to its polarity. The solvent properties of water are vital in biology, because many biochemical reactions take place only within aqueous solutions (e.g., reactions in the cytoplasm and blood). In addition, water is used to transport biological molecules.

When an ionic or polar compound enters water, it is surrounded by water molecules. The relatively small size of water molecules typically allows many water molecules to surround one molecule of *solute*. The partially negative dipoles of the water are attracted to positively charged components of the solute, and vice versa for the positive dipoles.

Purifying water

Purified water is needed for many industrial applications, as well as for consumption. Humans require water that does not contain too much salt or other impurities. Common impurities include chemicals or harmful bacteria. Some solutes are acceptable and even desirable for perceived taste enhancement. Water that is suitable for drinking is termed **potable water**.

Six popular methods for purifying water are:

1. **Filtering**: Water is passed through a sieve that catches small particles. The tighter the mesh of the sieve, the smaller the particles must be to pass through. Filtering is not sufficient to

completely purify water, but it is often a necessary first step, since such particles can interfere with the more thorough purification methods.

2. **Boiling**: Water is heated to its boiling point long enough to inactivate or kill microorganisms that normally live in water at room temperature. In areas where the water is "hard", (containing dissolved calcium salts), boiling decomposes the bicarbonate ion, resulting in some (but not all) of the dissolved calcium being precipitated in the form of calcium carbonate. This is the so-called "fur" that builds up on kettle elements etc. in hard water areas. With the exception of calcium, boiling does not remove solutes of higher boiling point than water, and in fact increases their concentration (due to some water being lost as vapour)
3. **Carbon filtering**: Charcoal, a form of carbon with a high surface area due to its mode of preparation, adsorbs many compounds, including some toxic compounds. Water is passed through activated charcoal to remove such contaminants. This method is most commonly used in household water filters and fish tanks. Household filters for drinking water sometimes also contain silver, trace amounts of silver ions having a bactericidal effect.
4. **Distilling**: Distillation involves boiling the water to produce water vapour. The water vapour then rises to a cooled surface where it can condense back into a liquid and be collected. Because the solutes are not normally vaporized, they remain in the boiling solution. Even distillation does not completely purify water, because of contaminants with similar boiling points and droplets of unvaporized liquid carried with the steam. However, 99.9% pure water can be obtained by distillation.
5. **Reverse osmosis**: Mechanical pressure is applied to an impure solution to force pure water through a semi-permeable membrane. The term is *reverse osmosis*, because normal osmosis would result in pure water moving in the other direction to dilute the impurities. Reverse osmosis is theoretically the most thorough method of large-scale water purification available, although perfect semi-permable membranes are difficult to create. **on exchange chromatography**: In this case, water is passed through a charged resin column that has side chains that trap calcium, magnesium, and other heavy metal ions. In many laboratories, this method of purification has replaced distillation, as it provides a high volume of very pure water more quickly and with less energy use than other processes. Water purified in this way is called *deionized water*.

Wasting Water

Wasting water is the abuse of water, i.e. using it unnecessarily. An example is the use of water, particularly water purified to human safe drinking standards, in unnecessary irrigation. Also, in homes, water may be wasted if the toilet is flushed unnecessarily or the tank leaks. Causing water to become polluted may be the biggest single abuse of water. To the extent that a pollutant limits other uses of the water, it becomes a waste of the resource, regardless of benefits to the polluter.

Mythology

Water is one of the four classical elements along with fire, earth and air, and was regarded as the ylem, or basic stuff of the universe. Water was considered cold and moist. In the theory of the four bodily humours, water was asssociated with phlegm. Water was also one of the Five Elements in Chinese Taoism, along with earth, fire, wood, and metal.

Water rights and development

UNESCO's World Water Development Report (WWDR, 2003) from its World Water Assessment Program indicates that in the next 20 years the world is facing an unprecedented lack of drinking water. The quantity of water available to everyone is predicted to decrease by 30%. The causes are contamination, global warming and political problems. More than 2.2 million people died in 2000 from illnesses related to the consumption of contaminated water. In 2004, the UK charity WaterAid reported that a child dies every 15 seconds due to easily preventable water-related illnesses.The report indicates large global disparities in the raw volume of available water: from 10 m^3 per person per year in Kuwait to 812.121 m^3 in French Guiana. However, richer countries such as Kuwait can more easily cope with low water availability. In the United States water law is divided between two legal doctrines: riparian water rights, used in the eastern and southern states where there is an abundance of water and the appropriation doctrine (or Colorado doctrine) used in the arid western states.

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