THE WATER CYCLE: PROPERTIES OF WATER^{*}

Free High School Science Texts Project

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1 The microscopic structure of water

In many ways, water behaves very differently from other liquids. These properties are directly related to the microscopic structure of water and more specifically to the *shape* of the molecule and its *polar nature* and to the *bonds* that hold water molecules together.

1.1 The polar nature of water

Every water molecule is made up of one oxygen atom that is bonded to two hydrogen atoms. When atoms bond, the nucleus of each atom has an attractive force on the electrons of the other atoms. This 'pull' is stronger in some atoms than in others and is called the **electronegativity** of the atom. In a water molecule, the oxygen atom has a higher electronegativity than the hydrogen atoms and therefore attracts the electrons more strongly. The result is that the oxygen atom has a slightly negative charge and the two hydrogen atoms each have a slightly positive charge. The water molecule is said to be **polar** because the electrical charge is not evenly distributed in the molecule. One part of the molecule has a different charge to other parts. You will learn more about this in Grade 11.

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Figure 1: Diagrams showing the structure of a water molecule. Each molecule is made up of two hydrogen atoms that are attached to one oxygen atom.

1.2 Hydrogen bonding in water molecules

In every water molecule, the forces that hold the individual atoms together are called *intra*molecular forces. But there are also forces *between* different water molecules. These are called *intermolecular* forces (Figure 2). You will learn more about these at a later stage, but for now it is enough to know that

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in water, molecules are held together by **hydrogen bonds**. Hydrogen bonds are a much stronger type of intermolecular force than those found in many other substances and this affects the properties of water.

TIP: Intramolecular and intermolecular forces

If you find these terms confusing, remember that 'intra' means within (i.e. the forces within a molecule). An **intro**vert is someone who doesn't express emotions and feelings outwardly. They tend to be quieter and keep to themselves. 'Inter' means between (i.e. the forces between molecules). An **inter**national cricket match is a match between two different countries.

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Figure 2: Intermolecular and intramolecular forces in water. Note that the diagram on the left only shows *intermolecular* forces. The intramolecular forces are between the atoms of each water molecule.

2 The unique properties of water

Because of its polar nature and the strong hydrogen bonds between its molecules, water has some special properties that are quite different to those of other substances.

1. Absorption of infra-red radiation The polar nature of the water molecule means that it is able to absorb infra-red radiation (heat) from the sun. As a result of this, the oceans and other water bodies act as heat reservoirs and are able to help moderate the Earth's climate.

2. Specific heat

Definition 1: Specific heat

Specific heat is the amount of heat energy that is needed to increase the temperature of a substance by one degree.

Water has a high specific heat, meaning that a lot of energy must be absorbed by water before its temperature changes. Refer to Section 2.1 (Demonstration : The high specific heat of water) for activity.

You have probably observed this phenomenon if you have boiled water in a pot on the stove. The metal of the pot heats up very quickly, and can burn your fingers if you touch it, while the water may take several minutes before its temperature increases even slightly. How can we explain this in terms of hydrogen bonding? Remember that increasing the temperature of a substance means that its particles will move more quickly. However, before they can move faster, the bonds between them must be broken. In the case of water, these bonds are strong hydrogen bonds, and so a lot of energy is needed just to break these, before the particles can start moving faster. It is the high specific heat of water and its ability to absorb infra-red radiation that allows it to regulate climate. Have you noticed how places that are closer to the sea have less extreme daily temperatures than those that are inland? During the day, the oceans heat up slowly, and so the air moving from the oceans across land is cool. Land temperatures are cooler than they would be if they were further from the sea. At night, the oceans lose the heat that they have absorbed very slowly, and so sea breezes blowing across the land are relatively warm. This means that at night, coastal regions are generally slightly warmer than areas that are further from the sea. By contrast, places further from the sea experience higher maximum temperatures, and lower minimum temperatures. In other words, their temperature range is higher than that for coastal regions. The same principle also applies on a global scale. The large amount of water across Earth's surface helps to regulate temperatures by storing infra-red radiation (heat) from the sun, and then releasing it very slowly so that it never becomes too hot or too cold, and life is able to exist comfortably. In a similar way, water also helps to keep the temperature of the *internal* environment of living organisms relatively constant. This is very important. In humans, for example, a change in body temperature of only a few degrees can be deadly.

3. Melting point and boiling point The melting point of water is 0^oC and its boiling point is 100^oC. This large difference between the melting and boiling point is mostly due to the strong intermolecular forces in water (hydrogen bonds) and is very important because it means that water can exist as a liquid over a large range of temperatures. The three phases of water are shown in Figure 3.

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Figure 3: Changes in phase of water

4. High heat of vaporisation

Definition 2: Heat of vaporisation

Heat of vaporisation is the energy that is needed to change a given quantity of a substance into a gas.

The strength of the hydrogen bonds between water molecules also means that it has a high heat of vaporisation. 'Heat of vaporisation' is the heat energy that is needed to change water from the liquid to the gas phase. Because the bonds between molecules are strong, water has to be heated to 100° C before it changes phase. At this temperature, the molecules have enough energy to break the bonds that hold the molecules together. The heat of vaporisation for water is 40,65 kJ · mol. It is very lucky for life on earth that water does have a high heat of vaporisation. Can you imagine what a problem it would be if water's heat of vaporisation was much lower? All the water that makes up the cells in our bodies would evaporate and most of the water on earth would no longer be able to exist as a liquid!

5. Less dense solid phase Another unusual property of water is that its solid phase (ice) is *less dense* than its liquid phase. You can observe this if you put ice into a glass of water. The ice doesn't sink to the bottom of the glass, but floats on top of the liquid. This phenomenon is also related to the hydrogen bonds between water molecules. While other materials contract when they solidify, water expands. The ability of ice to float as it solidifies is a very important factor in the environment. If ice sank, then eventually all ponds, lakes, and even the oceans would freeze solid as soon as temperatures dropped below freezing, making life as we know it impossible on Earth. During summer, only the upper few inches of the ocean would thaw. Instead, when a deep body of water cools, the floating ice insulates the liquid water below, preventing it from freezing and allowing life to exist under the frozen surface.

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Figure 4: Ice cubes floating in water

NOTE: Antarctica, the 'frozen continent', has one of the world's largest and deepest freshwater lakes. And this lake is hidden beneath 4 kilometres of ice! Lake Vostok is 200 km long and 50 km wide. The thick, glacial blanket of ice acts as an insulator, preventing the water from freezing.

- 6. Water as a solvent Water is also a very good solvent, meaning that it is easy for other substances to dissolve in it. It is very seldom, in fact, that we find pure water. Most of the time, the water that we drink and use has all kinds of substances dissolved in it. It is these that make water taste different in different areas. So why, then, is it important that water is such a good solvent? We will look at just a few examples.
 - Firstly, think about the animals and plants that live in aquatic environments such as rivers, dams or in the sea. All of these living organisms either need oxygen for respiration or carbon dioxide for photosynthesis, or both. How do they get these gases from the water in which they live? Oxygen and carbon dioxide are just two of the substances that dissolve easily in water and this is how plants and animals obtain the gases that they need to survive. Instead of being available as gases in the atmosphere, they are present in solution in the surrounding water.
 - Secondly, consider the fact that all plants need nitrogen to grow, and that they absorb this nitrogen from compounds such as nitrates and nitrates that are present in the soil. The question remains, however, as to how these nitrates and nitrites are able to be present in the soil at all, when most of the Earth's nitrogen is in a gaseous form in the atmosphere. Part of the answer lies in the fact that nitrogen oxides, which are formed during flashes of lightning, can be dissolved in rainwater and transported into the soil in this way, to be absorbed by plants. The other part of the answer lies in the activities of nitrogen-fixing bacteria in the soil, but this is a topic that we will return to in a later section.

It should be clear now, that water is an amazing compound and that without its unique properties, life on Earth would definitely not be possible.

2.1 Demonstration : The high specific heat of water

- 1. Pour about 100 ml of water into a glass beaker.
- 2. Place the beaker on a stand and heat it over a bunsen burner for about 2 minutes.
- 3. After this time, carefully touch the side of the beaker (Make sure you touch the glass very lightly because it will be very hot and may burn you!). Then use the end of a finger to test the temperature of the water.

What do you notice? Which of the two (glass or water) is the hottest?

2.2 The properties of water

- 1. A learner returns home from school on a hot afternoon. In order to get cold water to drink, she adds ice cubes to a glass of water. She makes the following observations:
 - The ice cubes float in the water.
 - After a while the water becomes cold and the ice cubes melt.
 - a. What property of ice cubes allows them to float in the water?
 - b. Briefly explain why the water gets cold when the ice cubes melt.
 - c. Briefly describe how the property you mentioned earlier affects the survival of aquatic life during winter.

Click here for the solution¹

2. Which properties of water allow it to remain in its liquid phase over a large temperature range? Explain why this is important for life on earth. Click here for the solution²

 $^{^{1}}$ See the file at <http://cnx.org/content/m39913/latest/http://www.fhsst.org/l3E>

 $^{^{2}} See \ the \ file \ at \ <\!http://cnx.org/content/m39913/latest/http://www.fhsst.org/l3m\!>$