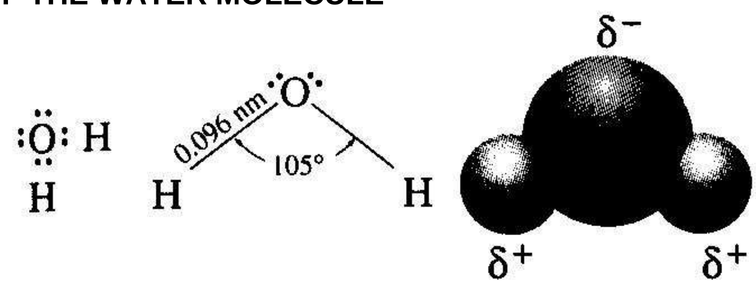
THE MACROSCOPIC PROPERTIES OF WATER

The macroscopic properties of the three phases of a compound such as water, determines many of its chemical and physical properties. Water is one, if not the most, important compound on earth. The properties of water are one of the reasons for its involvement in many chemical reactions. So, to understand the behaviour of water, we need to look at the physical properties also and relate them to the behaviour of water during chemical reactions.

STRUCTURE OF THE WATER MOLECULE



Water is a chemical compound that consists of the elements oxygen and hydrogen. Two atoms of hydrogen combine with one atom of oxygen to form the molecule water. The chemical formula of water is H_2O. The shape of the water molecule is nonlinear. It has a bent structure with an angle of about 105 degrees between the two bonds. There are two lone pairs of electrons, belonging to the oxygen atom, in the structure. These lone pairs 'push' the two covalently bonded electron pairs between the oxygen and the two hydrogen atoms closer together. This is why water does not form a linear structure.

Since oxygen is the second most electronegative element, the two covalent bonds in water are highly polar bonds. The polar nature of water is responsible for many of its properties. The electrostatic force that causes the pull by the nucleus of the oxygen atom on the two shared electron pairs in the chemical bond formed between the oxygen and the two hydrogen atoms is the main reason for the polarity of the water molecule. This polar nature of the water molecule is the reason why water forms hydrogen bonds.

THE HYDROGEN BOND

If we compare the physical properties of H_20, H_2S, H_2Se, and H_2Te it is apparent that four physical properties of water—melting point, boiling point, heat of fusion, and heat of vaporization—are extremely high and do not fit the trend relative to the molar masses of the four compounds. If the properties of water followed the progression shown by the other three compounds, we would expect the melting point of water to be below -85℃ and the boiling point to be below -60℃.

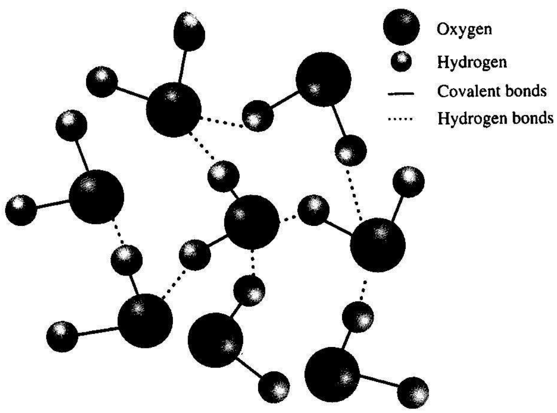
Why does water exhibit these anomalies? It is because liquid water molecules are held together more strongly than other molecules in the same family. The intermolecular force acting between water molecules is called a **hydrogen bond**, which acts like a very weak bond between two polar molecules. A hydrogen bond is formed between polar molecules that contain hydrogen that is covalently bonded to a small, highly electronegative atom such as fluorine, oxygen, or nitrogen (F—H, O—H, N—H). A hydrogen bond is actually the dipole-dipole attraction between polar molecules containing these three polar elements.

Compounds that have significant hydrogen-bonding ability are those that contain H covalently bonded to F, O, or N.

Because a hydrogen atom has only one electron, it forms only one covalent bond. When it is attached to a strong electronegative atom such as oxygen, a hydrogen atom will also be attracted to an oxygen atom of another molecule, forming a dipole-dipole attraction (H-bond) between the two molecules. Water has two types of bonds: covalent bonds that exist between hydrogen and oxygen atoms within a molecule and hydrogen bonds that exist between hydrogen and oxygen atoms in different water molecules.

Hydrogen bonds are intermolecular bonds; that is, they are formed **between** atoms in different molecules. They are somewhat ionic in character because they are formed by electrostatic attraction. Hydrogen bonds are much weaker than the ionic or covalent bonds that unite atoms to form compounds. Despite their weakness, they are of great chemical importance.

The oxygen atom in water can form two hydrogen bonds—one by each of the lone electron pairs.



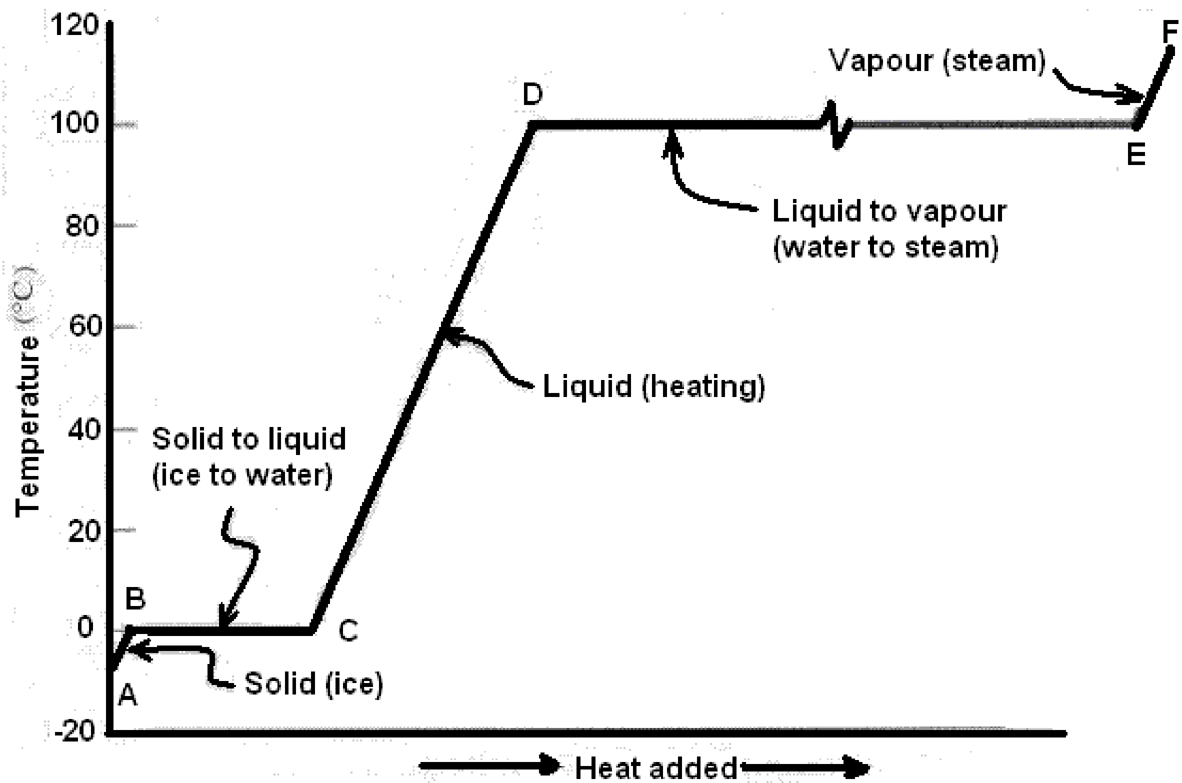
This figure shows eight water molecules linked by hydrogen bonds. A dash (—) is used for the covalent bond and a dotted line (••••) for the hydrogen bond. In water each molecule is linked to others through hydrogen bonds to form a three-dimensional aggregate of water molecules. This intermolecular hydrogen bonding effectively gives water the properties of a much larger, heavier molecule, explaining in part its relatively high melting point, boiling point, heat of fusion, and heat of vaporization. As water is heated and energy absorbed, hydrogen bonds are continually being broken until at 100℃, with the absorption of an additional 2,26 $kJ.g^{-1}$, water separates into individual molecules, going into the gaseous state. Sulfur, selenium, and tellurium are not sufficiently electronegative for their hydrogen compounds to behave like water. The lack of hydrogen bonding is one reason why H_2S is a gas and not a liquid at room temperature.

LATENT HEAT OF FUSION

When a solid is slowly and carefully heated a solid-liquid equilibrium is achieved and then maintained, the temperature will remain constant as long as both phases are present. The energy is used solely to change the solid to the liquid. The melting point is another physical property that is commonly used for characterizing substances.

The most common example of a solid-liquid equilibrium is ice and water. In a well-stirred system of ice and water, the temperature remains at 0℃ as long as both phases are present.

The majority of solids undergo two changes of state upon heating. A solid changes to a liquid at its melting point, and a liquid changes to a gas at its boiling point. This warming process can be represented by a graph called a **heating curve**.



This figure shows ice being heated at a constant rate. As energy flows into the ice, the vibrations within the crystal increase and the temperature rises (A → B). Eventually, the molecules begin to break free from the crystal and melting occurs (B → C). During the melting process all energy goes into breaking down the crystal structure; the temperature remains constant.

The energy required to change exactly one gram of a solid at its melting point into a liquid is called the **heat of fusion**. When the solid has completely melted, the temperature once again rises (C → D); the energy input is increasing the molecular motion within the water.

At 100 ^oC the water reaches its BP. The temperature remains constant while the added energy is used to vaporize the water to steam (D → E). The **heat of vaporization** is the energy required to change exactly one gram of liquid to vapour at its normal BP. The attractive forces between the liquid molecules are overcome during vaporization. Beyond this temperature all the water exists as steam and is being heated further (E → F).

HEAT CAPACITY

The values for water for both the heat of fusion and the heat of vaporization are high compared with those for other substances. This indicates strong attractive forces between the molecules. The strong forces of attraction – hydrogen bonding – between water molecules causes water to have this

- high latent heat
- high specific heat
- high heat of vaporization, and
- large difference between the melting point and the boiling point.

Heat is energy that is transferred from a body at a higher temperature (a hot object) to a body at a lower temperature (a cold object). The heat lost by one body is always equal to the amount of heat gained by another.

The heat transferred to or from a body - due to work performed on a body - causes a change in temperature. It can also cause a change in phase, for example from water to steam.

When you heat water on an electric stove plate, energy is transferred from the hot rings, through the pan and into the water.

The unit of both work and heat is joule (J). Different substances require different amounts of heat energy to raise the temperature by 1 ℃. T his is called the **heat capacity** of a substance. The specific heat capacity is the heat energy required to raise the temperature of 1 kg of a substance by 1 K (or 1 ℃).

Water has a very high specific heat capacity of 4 200 $J.kg^{-1}.K^{-1}$. To raise the temperature of the water, we must first break the many intermolecular hydrogen bonds. Water can therefore absorb a lot of heat while its temperature only rises slightly.

The opposite is also true - water can give off much heat with only a slight decrease in its temperature. For this reason, the water in lakes and oceans can moderate the climate of adjacent land areas by absorbing heat in the summer and giving off heat in the winter, with only small changes in the temperature of the water.

LATENT HEAT

When you heat a beaker of pure water by using a Bunsen burner, the temperature increases steadily. The water molecules gain more and more kinetic energy and move faster and faster. When the temperature reaches 100 ℃, the heat from the Bunsen burner breaks the attractive forces between the water molecules. The molecules break free and they fly off into the air. The water boils.

Throughout the time during which the water is boiling, the temperature stays at 100 ℃. All the heat from the Bunsen burner is being used to break the attractive forces between the water molecules. Because the temperature stays constant, it seems as if the heat energy becomes "hidden" in the water. Another word for "**hidden**" is "**latent**." We call this "disappearing" energy latent heat, or **latent heat of vaporisation**.

When you heat something, one of two things can happen: the temperature rises while the substance remains in the same phase, or a phase change occurs.

The heat from the sun enters the atmosphere of the earth where it is trapped by carbon dioxide molecules. The IR (infra red) radiation from the sun is the heat waves that we need to warm the planet and to maintain life as we know it. The heat capacity of water allows the water to absorb the IR but maintain its phase and keep the temperature constant. So the heat (IR) becomes trapped due to the latent heat inside water molecules.

DENSITY OF WATER

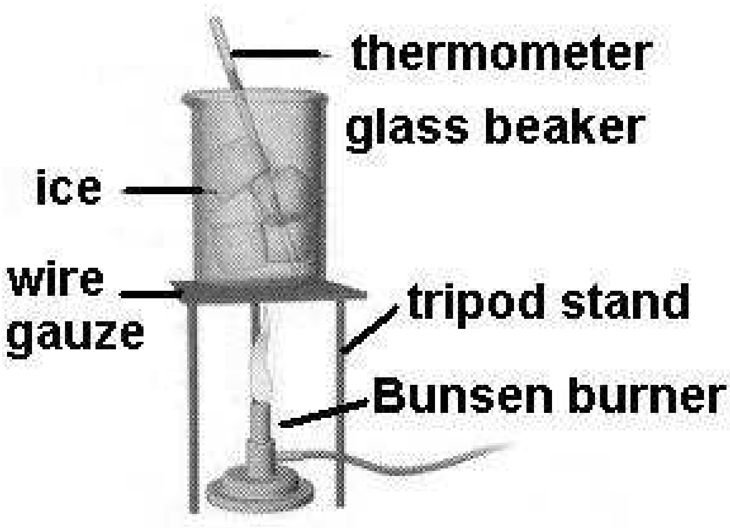
The density of water is 1 $g.cm^{-3}$ at 4 ^{o}C. Water has this unusual property of contracting in volume as it is cooled to 4 ^{o}C and then expanding when cooled from 4 ^{o}C to 0 ^{o}C, when it starts to solidify.

The density of ice at 0 ^{o}C is 0,917 $g.cm^{-3}$, which means that ice, being less dense than water, will float in water. This has important repercussions for aquatic life. The water will not freeze below the top layer and the bottom layers will not change in temperature due to the high latent heat. All these properties of water enable the earth to maintain a moderate stable temperature and climate.

When you want to heat water to boiling point you should keep the lid on to allow the process to continue faster. Why? The answer to this question is that the closed container causes an increase in the vapour pressure and keep the heat inside the pot and not allow high kinetic energy vapour to escape, lowering the pressure inside the pot.

Experiment: Investigating the change in temperature when heating ice

- Fill a glass beaker half with crushed ice. Measure the temperature with a thermometer and note it in a table.
- Set up the apparatus as shown in the sketch below.



- Place the beaker on a gauze wire on a tripod stand. Gently heat the beaker using a Bunsen burner.
- While stirring continuously, measure the temperature every 30 seconds.
- Continue stirring and measuring the temperature until the water has boiled for 3 minutes.
- Make observations of the change in the phases as you continue heating the mixture of ice and water.
- Note all your temperature readings in a table.

When doing a simple experiment as the one described above, learns us a little bit more about what scientist do to approach a problem. They ask themselves questions such as

- What do you want to measure?
- What variables do you need to take into account?
- Which factors could influence the results?

Writing a hypothesis takes these questions into consideration. Once the experiment is set up and performed, data is obtained. The date is usually noted in a table. From the table, a graph is plotted. Information could be obtained from the graph. Examples of questions could be

- At what temperatures does heating not result in a temperature rise?
- What changes occur at these temperatures?

Interpretation means you proof you hypothesis right or wrong and you have to explain what happens when the water molecules are changing phase.

CONCLUSION

These properties of water play an important role in the atmosphere, where it forms part of the water cycle.

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