Water Biochemistry

This lesson is aimed at more able and post 16 students. In this lesson students are encouraged to understand how the chemistry of water makes it so essential for life on earth, with specific relevance to pond ecology.

Resources

- Starter Activity: Water Chemistry (see end of pdf)

  Why does ice float? Encourages students to think about why ice is less dense than water and introduces the concept of hydrogen bonding.

- Lesson Plan: Water Chemistry (see end of pdf)

  A circus of practical activities and demonstrations that are linked to understanding a range of concepts. Adaptations of freshwater invertebrates, behaviour and feeding relationships, and the abiotic advantages of temperature are all covered.

- Teachers' notes (see end of pdf)

  Further advice, support and background information for teachers delivering this aspect of the curriculum.

Lesson Plan: The biochemistry of water and pond ecology

Water is one of the smallest and lightest of molecules with a unique collection of properties.

Life in aquatic habitats has many advantages over life on land, but there are also a range of problems that come with living in such habitats.

Starter Activity: Hydrogen bonds

Demonstration of Water and Ice cubes in a beaker

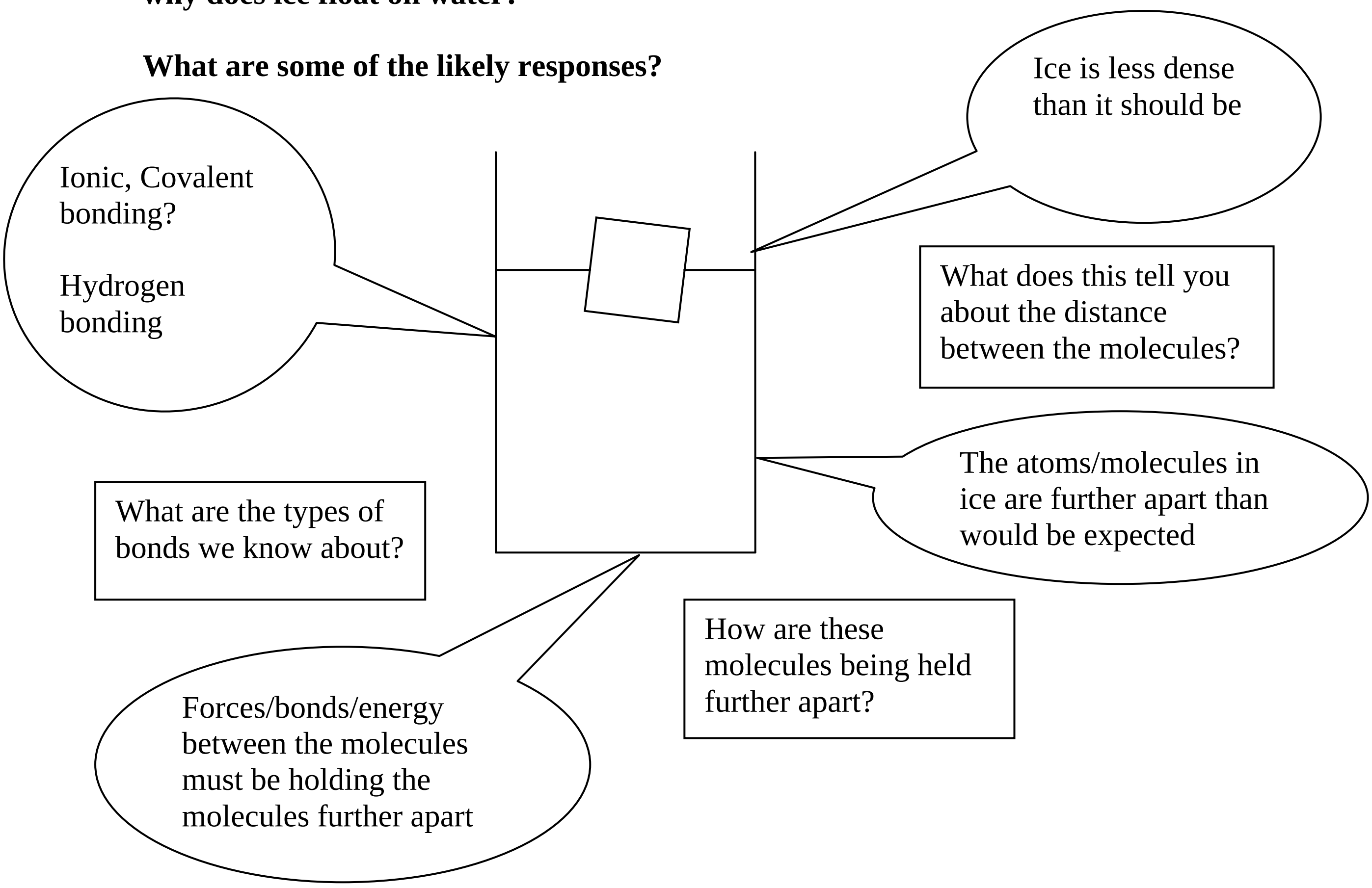
The ice should be clearly floating in the water for this demonstration.

The majority of students will be aware that solid water unlike other substances floats rather than sinks as it is regularly demonstrated at KS3/KS4. However they are unlikely to be able to explain why this is the case in detail.

This activity focuses on understanding the biochemistry of water and linking this to ecological concepts

Question- If the particles in a solid are more densely packed than in a liquid, why does ice float on water?

What are some of the likely responses?



Lesson plan: Chemistry of water and its effects on pond ecology

Main activity: The properties of water

This activity focuses on the main properties of water, includes a range of demonstrations and asks students to consider how the properties of water contribute to life in ponds.

It is useful for students if they are aware of hydrogen bonding before beginning this practical. The activities outlined below will provide a more visual representation of hydrogen bonding and how this contributes to the various properties of water.

Students will be aware of some aspects of these properties as they will have come across them throughout their science education.

A circus of activities is set up that demonstrates each property.

The abstract nature of hydrogen bonding requires some discussion of the various properties of water.

Students should be encouraged to develop their own ideas to explain their observations.

Activity 1: Demonstrating surface tension

Hydrogen bonding, Van der Waals Forces, the impact of detergents on aquatic environments

Activity 2: Demonstrating capillary action

Cohesion, adhesion, meniscus

Activity 3: Water as a temperature buffer

Specific heat capacity, Latent heat of vaporisation, heat of fusion

Activity 1: Floating a needle on water

Requires: Petri dish filled with distilled water,
Small needle,
Detergent

Distilled water
Students should first attempt to float a needle on distilled water; this should be a relatively easy task although they will need to think about how they manage this. There are a variety of methods but delicacy is the key!

Distilled water will have limited impurities, thus the hydrogen bonding and Van der Waals forces between water molecules will be strong and the surface tension high. Small objects can float on this even if technically they are denser than water.

Detergent

With the needle remaining floating a drop of detergent can be gently added to the water just behind the needle. The needle will immediately speed off away from where the detergent has just been added

Adding detergent to the water breaks the hydrogen bonding, significantly reducing the surface tension, initially this causes the needle to be pulled away by the remaining hydrogen bonds, eventually the majority of bonds break and the needle sinks.   Students will not be able to get the needle floating on the water surface again

This can be used to model the impact of pollutants on the properties of water

Discussion points:

Mobility
Organisms such as Pond Skaters use the surface tension to allow them to move across the surface of the water.   They are able to hunt for food (dead and dying animals) on the surface of the water.

Note: Pond skaters also have hairs on their feet and waxy cuticle making their legs hydrophobic as an additional adaptation to allow them to walk on the water surface

Interesting facts:

The bigger the organism, the bigger the surface area required for them to be able to walk on water……… If we were to be able to walk on water, our feet would need to be about 1.5 miles long.

Jet Propulsion? Some members of the Stenus species (Rove beetle) are able to secrete a chemical molecule reducing surface tension locally and therefore creating asymmetrical forces that cause them to move forwards with considerable greater speed as demonstrated by adding the detergent behind a floating needle

The molecule could be mimicked to spread on mosiquito infested waters (see below)

Respiration
A key adaptation to life in water is to find ways of breathing air by using snorkel like structures which mean submerged organisms can access the air above. Organisms such as mosquito larvae rely on this surface tension as a way of anchoring themselves to the underside of the water surface. This anchorage allows them to access the air for gaseous exchange with minimum effort. Reducing the surface tension reduces the ability of the organisms to remain at the surface and would cause suffocation

Additional resources for younger students:

http://www.stanford.edu/group/henrysplace/Activities/fall/2_Surface_Tension.doc

Activity 2: Capillary action as a result of Cohesion and Adhesion

Requires: Water (with food colouring added for visual impact if required),
Measuring cylinders of decreasing diameters,
Capillary tubes,
Mercury thermometer or barometer if available

Demonstrating the meniscus

All students will be familiar with the concept of the meniscus in a measuring cylinder where water forms a concave surface. Comparing this to the mercury in a thermometer or barometer they will notice that mercury forms a convex surface.

Students should compare the meniscus in decreasing measuring cylinders to determine if the radius of the container has any effect.

Capillary action

Placing a clean capillary tube in water, students will notice that the water appears to rise in the tube. The narrower the tube, the greater the height difference between the reservoir at the bottom and the height to which the water rises is likely to be.

Straws can be used to demonstrate drinking and also transpiration in plants as water is very easily drawn up through the straw.

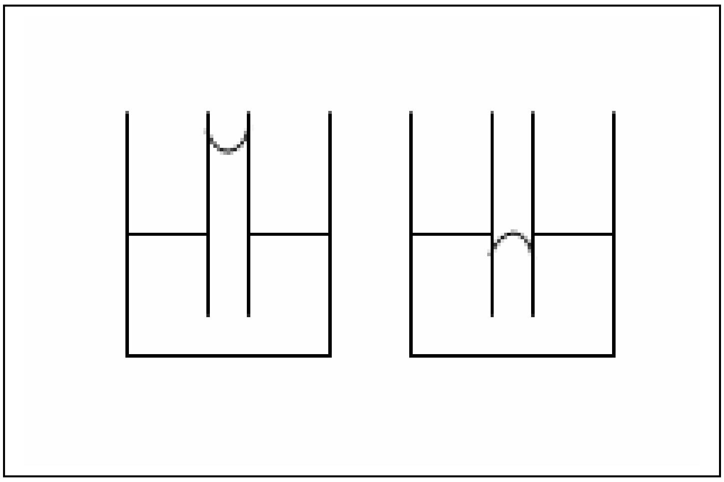
A subjective assessment can be made quickly between straws of varying diameter.

Discussion points

Both phenomena can be explained by cohesion and adhesion.

Cohesion is a measure of the ability of molecules within a liquid to bond (via hydrogen bonds) to each other where as adhesion refers to the bonding between the molecules in a liquid and an external substance (in this case, the sides of the measuring cylinder/thermometer/capillary tube)

When the forces of adhesion are stronger than the cohesion within the liquid a concave meniscus is formed. The water molecules are “sticking” more strongly to the surface of the container than they are to each other. If the sides of the measuring cylinder are greased, this adhesion is reduced and it’s possible to see a much reduced concave meniscus and even possible to observe a convex meniscus which is lower than that of the surrounding water



The concave and convex meniscus formed as a result of the varying forces of cohesion and adhesion

A convex meniscus occurs because the forces of cohesion between the molecules within the liquid are stronger than the adhesive forces of the liquid with the container sides

Cohesion and adhesion in ecology

Cohesion and adhesion help to explain why water moves up through the soil on dry land and contribute to the flow of water through the xylem vessels in plants.

The majority of aquatic organisms need to ensure that they reduce the adhesive properties of any structures which are in contact with the water, usually through production of waxy cuticles or production of oils to coat skin, fur and feathers.

Note: Oil pollution should based on the theory above reduce the adhesive properties actually damages the natural mechanism of such organisms in a number of ways thereby increasing the adhesion.

If you have access to feathers a good demonstration of the impact of oil on birds feathers can be found at http://www.biologycorner.com/worksheets/oilspill.htm

Activity 3: Water as a temperature buffer

Requires: Water,
Alcohol,
Hot lamp,
Thermometer/temperature probes,
Warmed tile

Observing specific heat capacity

Specific heat capacity can be measured in any number of ways, a good example can be found at http://timjoh.com/specific-heat-capacity-of-water-h2o/ should you wish to carry out a more detailed practical.

A simple and quick demonstration however that highlights the principle allows students to compare the temperature rises in water, alcohol and air under a simple heat lamp.

Three test tubes filled with air, alcohol and water should be left under a hot lamp, their temperature recorded at regular intervals

Care should be taken with the alcohol to monitor its temperature carefully and avoid accidental overheating

Heat of fusion

The practical above can also be carried out in reverse, with the water; alcohol and air cooled in beakers of ice or kept in a freezer compartment.

Latent heat capacity

The latent heat capacity can also be demonstrated by placing a single drop of alcohol and water onto a warmed tile. The alcohol will evaporate very quickly and the water much more slowly. On hot sunny days, a warmed tile is not necessarily required.

Discussion points

The practical ideas here demonstrate the transfer of energy between ponds and the environment, comparing water to the rates of transfer for air and alcohol.

It takes significantly more energy to heat water than other liquids or air. The Earth which already has a limited temperature range due to the unique nature of the atmosphere has and due to the high specific heat capacity of water an even more limited temperature range in its aquatic environments.

Reducing the effect of temperature rises

The high specific heat capacity means that the temperature in ponds on hot sunny days tends not to rise significantly, an almost constant temperature is maintained. The advantage of this is that the effect of temperature on respiratory, photosynthetic and gaseous exchange rates from air to water and water to air is avoided, i.e rising water temperatures often reduces oxygen concentration in water causing respiratory challenges for aquatic organisms.

Surviving the winter freeze

The heat of fusion in winter means that ponds are less likely to freeze. Due to the density of water when freezing occurs, ice floats on the surface and aquatic organisms can survive under the surface over winter

Ponds can freeze over, although they do not freeze completely. Pond organisms are moiré likely to be troubled by the reduced oxygen content of water during a winter freeze than the colder temperatures.

Surviving and adapting to summer droughts

The high latent heat of vaporisation means that the volume of water can remain reasonably constant and ponds tend not to dry out in hot summers however some ponds can and do dry out and in some cases the local ecology is highly dependant on this annual drying out. Temporary or seasonal ponds are an important and also threatened habitat often containing rare species, especially amphibian and invertebrate species. Such organisms prefer temporary ponds because the seasonal drying out kills off fish, their main predator.

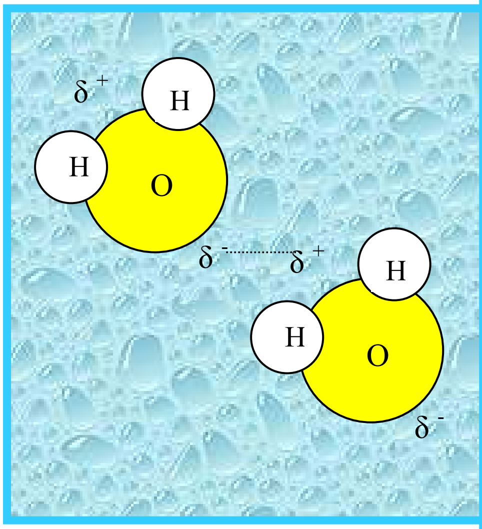
Chemistry and biochemistry of water and its effect on pond ecology

Teachers Notes

Water is one of the smallest and lightest of molecules with a unique collection of properties.

Life in aquatic habitats has many advantages over life on land, but there are also a range of problems that come with living in such habitats.

Water is essential to life on earth and much of the credit lies in the hydrogen bonding that exists between water molecules.



Each hydrogen atom is covalently bound to the oxygen through which electrons are shared, but the distribution of electrons throughout the molecule means that there is a slight polarity with the hydrogen areas being more positive and the remaining electron rich oxygen being more negative.

This polarity gives rise to the solvent properties of water and also enables the hydrogen bonding which results in the remaining properties of water.

These unique properties make *liquid* water the cornerstone of life on earth. Creating habitats for flora and fauna to live in whilst contributing a minimum 60% of all living biomass on the plant

Property		**Explanation**	**Keywords**
Cohesion and adhesion	**Formation of droplets**	Molecules of water are attracted to each other as a result of hydrogen bonding, in the case of water this means that up to 15% of water molecules in a glass of water are hydrogen bonded to their neighbours at any one time. This pulls the water molecules closer together than would other wise be expected and makes them “sticky” In cohesion, water molecules stick to each other, where as in adhesion the water molecules are sticking with other surfaces It causes rain drops to form and makes it possible for humans to drink through straws and in tall plants helps water move through the xylem tissues through transpiration	Hydrogen bonding Sticky Transpiration
	Surface tension	Hydrogen bonding infers that a water molecule is pulled equally towards all its adjacent neighbours but, at the surface of water, these molecules can only be pulled left, right and down. The pulling of the water molecules downwards means that a	Pond skater

		more solid surface is created, known as surface tension. Some aquatic invertebrates like the Pond Skater are able to make use of this surface tension and with additional physiological adaptations “walk” on water.	
Solvent	**Dissolved gases**	The transfer of oxygen and carbon dioxide in and out of all organisms as part of respiration. The greatest challenge for aquatic organisms is gaseous exchange. Gases like oxygen and carbon dioxide will dissolve in water meaning that some animals do not need to breathe air in order to respire but they must still be able to absorb oxygen and excrete carbon dioxide. There is always less oxygen in water than there would be in air and this makes animals very sensitive to factors that affect the rate at which oxygen might be dissolved in water. These include factors such as temperature, and organic content. Aquatic fauna have developed a wide range of strategies to increase the oxygen they can absorb	Respiration Dissolved gases
	Inorganic ions and nutrients	Pure water contains no nutrients and as such would be a very poor habitat for organisms. However water is an excellent solvent and never occurs in its pure form in the environment. The solvent properties of water are due to the polarity of the Hydrogen and oxygen molecules Inorganic ions dissolved in water mean that phytoplankton can photosynthesise forming the basis of an aquatic food web. Issues can be caused however by the ease of which such ions are dissolved in terms of pollutants from farming and industrial processes	Polarity Photosynthesis Pollutants
	Flotation	Because living things are mostly made up of water, in humans this is around 60-70%, they float very easily in water. Many aquatic organisms develop strategies to allow them to alter their ability to float and swim by having changeable air sacs within body cavities	Air sac
Density	**Ice formation**	Unlike all other liquids, the molecules in solid water are actually further apart than they are in liquid water. This makes ice less dense than liquid water and therefore ice will float on water. In winter this means that ponds freeze from the top down and ice even acts as an insulating layer protecting the water beneath from further freezing. Organisms can survive over winter without freezing. Without this feature there would be no life in water in temperate and polar regions	Ice as insulation
	Viscosity	Water is actually at its most dense at 4^{0}C, and therefore it’s most viscous. In winter, ponds are less likely to freeze but it does	Streamlining

		cause problems for the animals that have to swim through it. Most aquatic organisms have developed streamlined bodies to reduce the effect.	
Temperature buffer	**Specific heat capacity**	Specific heat capacity refers to the amount of energy required to increase the temperature of 1Kg of water by 1^0C. In the case of water this is 4.2 Kj and is significantly higher than would be expected and higher than most other liquids. In summer months this means that water must absorb a great deal of energy in the form of heat from the sun in order for the temperature to increase. Since most bodies of water are large enough not to be significantly effected by the heat from the sun, water provides an almost constant temperature for the plants and animals living there	Kj
	Latent heat of vaporisation	In summer small water bodies like ponds are at risk of drying out but again, the amount of energy required to vaporise or evaporate water is so high that the impact is less than would otherwise be expected. Making it rare for water bodies to dry up and so depriving organisms of their habitat.	
	Heat of fusion	As summer turns to winter, water that is already colder than the surrounding land should be at risk of freezing, however, the energy water must now loose in order to freeze is so high that the water temperature again remains roughly constant, as winter deepens in fact it could be higher than surrounding land.	