Water

Introduction

This topic explores the key concepts of water as they relate to:

- functional uses of water
- properties of water
- solutes, solvents and solutions
- solubility and concentration
- reactions in solution.

Key concepts of water

The activities in this topic are designed to explore the following key concepts:

- Water is an essential component of all living things.
- Water is a good solvent.
- Water exists as molecules of H_2O.
- The water molecule is polar in structure; this concept explains many of water's properties.
- Water has relatively high melting and boiling points.
- Water expands on freezing. Ice is less dense than liquid water.
- Large amounts of energy (latent heat) are required for a change of state of water.

Students' alternative conceptions of water

Research into students' ideas about this topic has identified the following non-scientific conceptions:

- Water is something different from H_2O molecules.
- Water molecules have different sizes and shapes.
- There is no space between water molecules in ice.
- Water vapour molecules weigh less than ice molecules.
- The 'skin' of a water drop or water surface is a different kind of water.
- Oil doesn't mix with water because oil and water molecules repel each other.
- Water molecules are largest and heaviest when in the solid phase.
- Water molecules can be seen with an optical microscope.

Functional uses of water

Water is one of the most important substances on Earth as it is an essential component of all living systems. It is the most abundant liquid on Earth and constitutes between 65% and 95% of all living things (67% of a human body is water—half of the water resides in the cells, the rest is in the blood and other body fluids). Water fulfils several functions in plants and animals. Some of these functions include:

- providing a transport system
- providing a heat-transfer system
- shaping the environment
- acting as a chemical agent.

Water provides a transport system

Water can act as a solvent, which means that many substances dissolve in water. As water is a liquid, it flows. Chemicals that are dissolved in the water flow with the water. Water (in the blood) transports nutrients, oxygen and soluble wastes around the human body. Water fulfils a similar transport role in other animals and plants.

Water provides a heat-transfer system

Water transfers heat energy in all but the smallest living organisms. The water in our blood allows heat energy to be transferred to various places in our bodies to maintain a constant internal body temperature of 37 °C. The maintenance of a constant body temperature allows for optimum performance of the body processes, many of which involve chemical reactions. When we feel hot, the blood comes to the surface of our skin (we become flushed) to allow heat energy to be released from the skin. Alternatively, if we feel cold, the blood concentrates around the important internal organs to maintain body temperature (we become pale).

Water shapes the environment

From a geological perspective, water is a main contributor to shaping the environment, through rain, rivers flowing and ice forming. A particular characteristic of water is that it expands upon freezing. Water, in a liquid state, flows between the tiny cracks in rocks, but if it then freezes, the ice causes the rocks to split.

Water is a chemical agent

Water takes part in many important chemical reactions, one of which is photosynthesis. In simple terms, photosynthesis is the process by which plants make food. In this process, carbon dioxide gas (CO_2) reacts with water (H_2O) in the presence of sunlight and the plant pigment chlorophyll to produce glucose ($C_6H_{12}O_6$) and oxygen (O_2). Glucose polymerises (forms long molecular chains) to form complex sugars, starch and cellulose—the basis of much of our food.

The chemical equation for the reaction is given below (this equation can be better understood after you have read the topic ‘Chemical change’).

$$6\ CO_2 + 6\ H_2O \xrightarrow{\text{Chlorophyll \& sunlight}} C_6H_{12}O_6 + 6\ O_2$$

Properties of water

Before explaining the various properties of water, we need to look at the molecular structure of the water molecules. Water exists as molecules of H_2O that are composed of two hydrogen (H) atoms covalently bonded to one oxygen (O) atom. Because of the electronic configuration of oxygen and hydrogen, the electron dot formula and structural formulae are pictured in Figure 1.

FIGURE 1: REPRESENTATIONS OF THE WATER MOLECULE

Electron dot formula **Structural formula**

The polar nature of water

The structural arrangement of the atoms within the water molecule makes the molecule polar. This means that one side of the molecule is negatively charged (on the side of the oxygen atom containing a lone pair of electrons) and the other side is positively charged (on the side of the hydrogen atoms). This model of the water molecule can explain a number of properties of water, including that :

- it has relatively high melting and boiling points
- it expands on freezing
- its changes of state require large amounts of energy
- large amounts of energy are involved in a change in the state of water
- it is a good solvent.

ACTIVITY: EXPLORING THE POLAR NATURE OF WATER

The observations in the following activity can be explained by the water molecules being polar in structure.

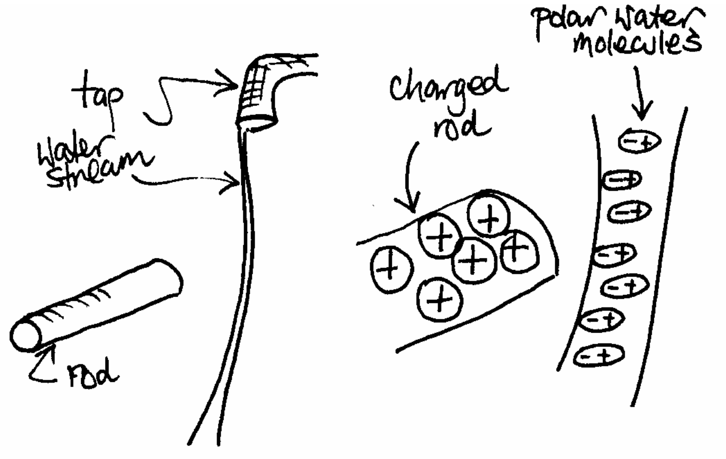
You will need:

- **a plastic ruler or rod**
- **wool or fur**
- **a tap with a fine stream of water.**

Rub the plastic ruler vigorously with the wool or fur. This action rubs electrons off the plastic to make it positively charged. Now bring the charged ruler close to, but not touching, a fine stream of water flowing from a tap. Observe what happens.

Explanatory note: The water stream veers towards the ruler. The negatively charged ends of the polar water molecules are attracted to the positively charged ruler. This is shown in the figure *Stream of water attracts charged rod*.

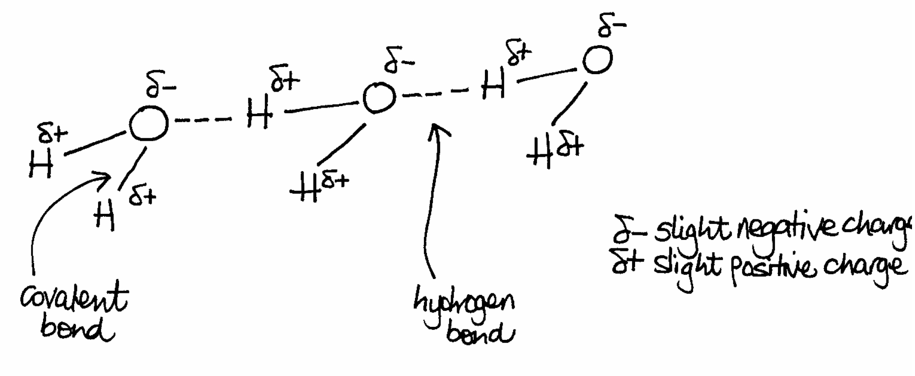
FIGURE:
STREAM OF WATER
ATTRACTS
CHARGED ROD



Hydrogen bonding

The polar nature of water molecules allows them to bond with other water molecules. This type of intermolecular bonding is called 'hydrogen bonding'. This type of bonding is shown in Figure 2.

FIGURE 2:
HYDROGEN
BONDING
BETWEEN WATER
MOLECULES

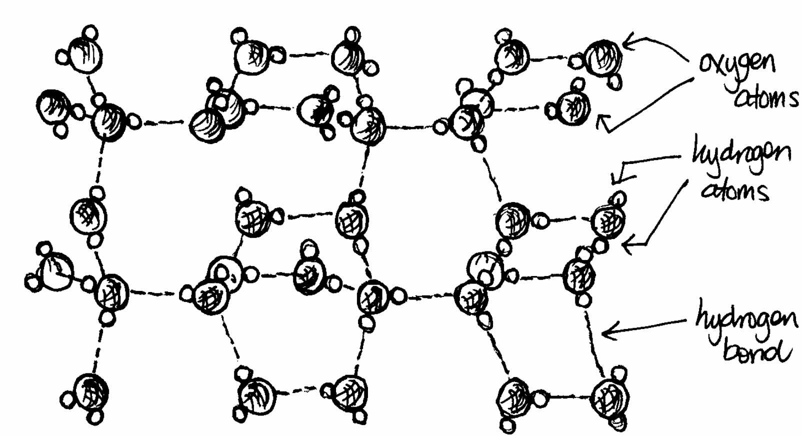


A lot of energy is required to break the hydrogen bonds. This explains why water has relatively high melting and boiling points compared with other substances with similarly sized molecules.

Just as lots of energy is taken from the environment to change state in the processes of melting and boiling, a lot of energy is released to the environment in the change-of-state processes of condensation and freezing. For example, when heating ice at a constant rate, the temperature of the ice-water will not change until the change of state occurs. A similar effect is observed when boiling water. After 100 °C is reached, the extra energy put into the liquid water goes to breaking the hydrogen bonds in the process of changing state. A steam burn at 100 °C is more serious than a hot water burn at 100 °C. The steam condenses on the skin releasing a large amount of energy. During frosts, plants take in the energy that is released in the change of state. This may cause structural problems in some plants after being 'burnt' by the frost.

The polar nature of water can produce three-dimensional crystal lattices like those in ionic compounds. This is what occurs when water freezes. The water molecules arrange themselves in a crystal lattice with hydrogen bonds forming the scaffold. Each water molecule forms hydrogen bonds to four close neighbours. This is a very open arrangement in which the water molecules are more widely spaced than in the liquid state. This more open arrangement accounts for the expansion of water when freezing occurs. This structure is shown in Figure 3.

FIGURE 3: MOLECULAR ARRANGEMENT IN ICE



The polar nature of water also makes it a very good solvent. A number of substances dissolve in it. The intermolecular or ionic bonds of substances are broken by the attractions or repulsions of the presence of the polar water molecules. For example, in solid salt, ionic bonds exist between the sodium and chloride ions. When salt is placed in water, the attraction between the water molecules and the individual ions is greater than between the ions themselves. This results in the ionic bonds breaking and the salt crystals dissolving.

ACTIVITY: HEATING WATER

To convince you that water does not change temperature while changing state, complete the following activity.

You will need:

- **ice**
- **water**
- **a saucepan**
- **a heat source (electric frying pan)**
- **a thermometer**
- **a stirring rod.**

Place some water into the saucepan on the frying pan or heat source. Half fill the saucepan with ice. Put in the thermometer and take readings over a few minutes until the temperature reaches a minimum. Turn on the heat and take temperature measurements every 30 seconds. Stir the mixture regularly (do not use the thermometer as a stirring rod). Note the time when the ice begins to melt and when it finishes melting. Continue to take readings until the water begins to boil (take note of the time). Keep taking readings a few minutes after the water has boiled (do not let the saucepan boil dry).

Use the data you collected to draw a line graph of temperature versus time (temperature is on the vertical axis, while time is on the horizontal axis). On your graph indicate when changes of state occurred. The graph should show a steady rise between changes of state and flat sections at the changes of state.

ACTIVITY: DIFFUSION OF MOLECULES

This activity illustrates the following concepts:

- **Molecules in a liquid move.**
- **Molecules do not move in any specific direction in a liquid.**
- **Heat will increase the speed of molecular movement in water.**
- **Stirring will increase the speed of molecular movement and the speed with which a substance will dissolve.**
- **Alcohol and soap make molecules move faster in water.**
- **Diffusion of a substance in a liquid is where the substance dissolves and distributes itself throughout the liquid.**
- **Diffusion of a dissolved solute can be explained by the particle model of matter.**

You will need:

- **food colouring**
- **a watch**
- **water (cold and warm)**
- **eye-droppers**
- **rubbing alcohol**
- **detergent**
- **ice cubes**
- **plastic cups.**

Place a drop of food colouring in a cup of water. How many seconds did it take to completely diffuse in the water? Place one or two ice cubes in the cup of water. Place a drop of food colouring on an ice cube. What happens? Place a drop of food colouring in the cold water. How many seconds did it take for the food colouring to completely diffuse throughout the cold water?

Place a drop of food colouring in a cup of water. Add a few drops of alcohol. How did the alcohol affect the solution? Add a drop of food colouring to a cup of warm water. How many seconds did it take for the colouring to diffuse throughout the water? Add another drop of food colouring to the water. Then add a few drops of detergent to the water. What happened?

Solutes, solvents and solutions

A solvent is a substance, usually a liquid, that will dissolve another substance. The substance that dissolves in a solvent is called the ‘solute’. Together, the solvent and the solute make up a mixture called a ‘solution’. Some examples of common solutions are given in Table 1.

TABLE 1: COMMON SOLUTIONS

Common name of solution	Solvent	Solute
Sea water	Water	Salt
Cup of coffee	Water	Coffee grounds
Beer	Water	Alcohol, carbon dioxide
Blood	Water	Nutrients and wastes
	Methylated spirits	Paint (oil-based)
	Nail-polish remover	Nail polish

A solution is a homogeneous mixture of substances, uniformly dispersed at the molecular or ionic level (that is, individual molecules or ions are thoroughly mixed). Solutions are usually grouped according to their physical state:

- Solid solutions*:* for example, alloys of metals such as the metal in five-, ten-, twenty- and fifty-cent pieces. The alloy consists of 75% copper (Cu) and 25% nickel (Ni).
- Liquid solutions: for example, sea water. These solutions may comprise a liquid dissolved in another liquid, a gas dissolved in a liquid, or a solid dissolved in a liquid.
- Gaseous solutions: for example, the air we breathe consists mainly of oxygen (O_2) and Nitrogen (N_2). All gases are completely soluble in each other.

In this section we will concentrate on liquid solutions in which the solvent is water.

Suspension

A substance may not dissolve to the extent that individual ions or molecules are mixed with the water molecules. Such a mixture is called a ‘heterogenous mixture’. Suspended particles are larger than molecules or ions of the liquid. The particles may be so large that they settle on the bottom of a container through gravity. This mixture is called a ‘suspension’. For example, a suspension is formed when chalk is shaken with water.

ACTIVITY: SUSPENSIONS

You will need:

- **2 tbsp flour**
- **2 tbsp any large dried beans**
- **1 L glass jar with a lid.**
- **water.**

Place the beans and the flour in the jar and fill with water. Screw on the lid and shake the jar until all the materials are thoroughly mixed. Let the jar stand for 20 minutes undisturbed. What do you observe?

Explanatory note: The beans settle first with a fine layer of flour on top. The beans and flour are not soluble in water, and so combining them with water makes a suspension.

Colloid

The particles in the heterogenous mixture may be larger than the molecules in the liquid but may not settle on the bottom. The mixture is then said to be a 'colloid'. To understand the colloid state we need to use the particle model of matter. The vibrating water molecules keep the other particles off the bottom of the container by continually colliding with them. The Yarra and Murray rivers are good examples of colloidal solutions. The tiny particles of soil do not settle. Ink is another example of a colloidal solution.

Sometimes it can be difficult to determine if a mixture is a solution, a colloid or a suspension. A good test for a suspension is to leave the mixture undisturbed for several hours. If sediment forms on the bottom of the container the mixture is called a 'suspension'. To distinguish between a solution and a colloid or suspension, shine a bright light through each mixture. When light shines through a colloidal solution or a suspension, tiny bright spots appear. This is because the light is reflecting off the particles. This 'scattering' of light in all directions, known as the Tyndall effect, does not occur with solutions.

ACTIVITY: SOLUTION, COLLOID OR SUSPENSION?

You will need:

- **a bright light**
- **a clear container, holding a mixture of flour and water**
- **a clear container, holding clear water.**

Try shining light through a container of a mixture of flour and water (after shaking it) versus a container of clear water.

Why do substances dissolve?

A substance that dissolves in a solvent to produce a solution is considered 'soluble'. A substance that does not dissolve into a solution is 'insoluble'.

Covalent compounds and ionic compounds are soluble in water. In all cases bonds are broken and reformed due to the attractive forces of the polar ends (charged ends) of the water molecules. If the hydrogen bonds (attractive forces between the water molecules) are weaker than the bonds in the substance, then it will dissolve.

Covalent compounds can dissolve in water in two different ways. In the first way the intermolecular bonds between the solute molecules break as well as the hydrogen bonds between the water molecules. New hydrogen bonds are then formed between the molecules of the solute and the molecules of the water.

The second manner in which a covalent compound may dissolve is where covalent bonds are broken. Not all covalent compounds have bonds of the same strength. This is because some bonds (dipoles) are more polar than others. The more polar the covalent bond (dipole), the easier it is for water molecules to break. In these circumstances some bonds will break when the compound is placed in water and others will not. When this occurs, part of the covalent molecule breaks off producing poly-atomic ions (one part is positively charged and the other part is negatively charged). These ions form bonds with the water molecules.

When ionic compounds dissolve, their lattice structure breaks down, leaving ions to form hydrogen bonds with water molecules. Not all ionic compounds are water soluble. For example, limestone ($CaCO_3$), although ionic, is almost insoluble in water.

Solubility and concentration

Solubility

The solubility of a substance is a measure of how easily it will dissolve in a solvent. There is a maximum amount of solute that can dissolve in a given volume of solvent (at a given temperature). When the solute reaches this maximum, the solution is saturated. Adding any more solute to a saturated solution will not dissolve it. However, in most cases the solubility increases with temperature so, if a saturated solution is heated, more solute will be dissolved. Conversely, if a heated saturated solution is cooled, some of the solute comes out of the solution (that is, it becomes insoluble). In this situation the solution is ‘supersaturated’. Supersaturated solutions are made to produce large crystals of ionic compounds. As the supersaturated solution cools, crystals will form around a dust particle or a tiny seed crystal. See the activities that describe techniques to grow crystals in the topic ‘Chemical reactions’.

The concentration of a solution is a measure of how much solute there is to the amount of solvent. When solute is added to a solution the solution becomes more concentrated. Where more solvent is added to the solution, it becomes more diluted. We are all familiar with making up cordial. Adding cordial makes the drink more concentrated, while adding water makes the drink more diluted.

There are various ways of expressing concentration units. A common form is to give the ratio of the mass of solvent per unit volume of the solvent. For example, grams per litre (g/L), milligrams per litre (mg/L) or grams per 100 millilitre (g/100 mL).

When very small quantities of solute are dissolved to form a solution, the concentration can be measured in parts per million (ppm). The concentration of chemicals in the environment and trace elements in the soil are often expressed in ppm. Our drinking water is treated with chlorine in very small concentrations to kill bacteria. The concentration of chlorine is about 1 ppm, which means that for every gram of chlorine there is 1 million grams (1 tonne) of water.

Another unit of concentration is '%w/w', which is commonly used on household cleaners and solutions of concentrated acids. The %w/w expresses the concentration of the solute as a percentage of the mass (or weight) of solution. Thus 98%w/w means that 98% of the total mass of the solution is sulphuric acid. This means that in 100 g of solution, 98 g is sulphuric acid.

The unit of concentration '%w/v' expresses the percentage mass in grams of the solute per 100 mL of solution. For example, a bathroom cleaner states on its label 'active ingredient 1%w/v sodium hydroxide'. This means there is 1 g of sodium hydroxide for every 100 mL of solution.

The unit of concentration '%v/v' expresses the volume of liquid in millilitres per 100 mL of solution. These concentrations are often placed on labels of alcohol drinks. For example, a bottle of Grand Marnier liqueur is labelled 40 alc/vol. This means there is 40 mL of alcohol per 100 mL of liqueur. 'Heavy' beer is labelled 4.9%v/v alcohol. This means that for every 100 mL of beer there is 4.9 mL of alcohol (called 'ethanol').

ACTIVITY: THE DISSOLVING PROCESS

The purpose of this activity is to explore the variables that affect the rate of dissolving of a substance (solute) in water (solvent).

You will need:

- **clear drinking glasses**
- **a spoon**
- **water (cold and hot)**
- **sugar cubes**
- **a watch.**

Predict the order in which sugar cubes will completely dissolve when:

- **dropped into a glass of water**
- **broken up and dropped into the glass**
- **dropped into a glass of hot water**
- **dropped into water and then stirred.**

The amount of water needs to be the same in each glass. Record the time for the sugar cube to dissolve and compare with your predictions. Investigate if the amount of water has an effect on the rate of dissolving. What about a combination of techniques? Can you explain why some techniques produce a faster rate than others?

Explanatory note: Dissolving occurs when water particles break the weak bonds between the sugar molecules. Therefore, if the water molecules are faster (through stirring or heating) then extra collisions with the sugar molecules occur, increasing the rate of bond breaking. Increasing the surface area of the sugar to the water also increases the rate of bond breaking.

ACTIVITY: TASTY SOLUTION

A similar activity can be undertaken with lollies.

You will need:

- **Fruit Tingles.**

Investigate the dissolving rate of Fruit Tingles by placing them in your mouth:

- **without chewing or moving your tongue around**
- **by moving your tongue, but not chewing**
- **by chewing (do not swallow any solid pieces).**

Discuss (using the terms 'solvent', 'solute' and 'solution') factors affecting the rate of dissolving.

ACTIVITY: FALLING SNOW

You will need:

- **a glass jar with a lid**
- **boric acid crystals**
- **a teaspoon**
- **water.**

Put five teaspoons of boric acid crystals into the glass jar. Fill the jar to overflowing with water and tightly screw on the lid. Shake the jar to mix the crystals and water, then allow the jar to stand undisturbed. Some of the crystals dissolve in the water, but most of them float to the bottom like snowflakes.

Explanatory note: Boric acid does not dissolve well in water. It takes only a few crystals to dissolve to make a saturated boric acid solution.

Hydrophobic and hydrophilic substances and surfactants

Substances that do not dissolve in water are insoluble or hydrophobic (water hating). These substances are generally non-polar and so do not interact with the polar nature of the water molecules. Substances that are soluble in water are called 'hydrophilic' (water loving). These substances are generally polar and so in the electrostatic interaction with the polar water molecules, bonds are broken and the substance dissolves.

There are large molecules called 'surfactants' that are both hydrophilic and hydrophobic in different parts of the same molecule. This means that surfactant molecules are polar at one end of the molecule and non-polar at the other end. An example of a surfactant is a detergent.

When added to water, surfactants congregate at the surface. This is because the hydrophobic parts of the molecules are 'water hating' and so keep near the air while the hydrophilic parts of the molecules are 'water loving' and so stay submerged in the water. This process of molecules concentrating at the surface is called 'adsorption'.

Surfactants lower the surface tension of the water and so water does not readily form droplets when placed on surfaces. An application of the use of surfactants is in spraying with herbicides. The leaves of weeds are hydrophobic (often waxy) and so water forms large droplets on them. Adding a surfactant to herbicide sprays makes them spread out on plants more effectively.

Detergents as surfactants

In general, hydrophobic substances (salt, sugar) dissolve in hydrophilic substances (water), and hydrophilic substances (grease, oil, dirt) dissolve in hydrophilic substances. Surfactants, because of their dual nature, can dissolve in both water and oil. This is why detergents are good at removing insoluble substances in water. When detergent (surfactant) is added to water and dirty clothes, the hydrophobic ends of the detergent molecules attract the grease and dirt. The hydrophilic ends of the molecules interact with the water molecules and so the grease and dirt particles come off the fabric and get suspended in the water. Detergents lather with water which helps to hold the suspended particles of grease and dirt. Surfactants lower the surface tension of the water creating thin films and producing bubbles.

Natural surfactants, including lecithin, are present in the moisture that lines the lungs. As the lung expands, the film of moisture must increase in surface area, assisted by the presence of the surfactants. Hair conditioners contain surfactants that attach themselves (via their polar or hydrophilic ends) to charges on the surface of the hair fibre. This leaves the hydrophobic ends of the surfactant molecules facing out from the hair fibres. In this way the hair gets effectively coated with a thin, wax-like layer that gives it an attractive, shiny appearance and reduces tangling.

A number of activities related to detergents, surface tension and bubbles can be found in other topics in these materials.

Emulsions

Emulsions are colloidal solutions of a liquid in a liquid. One of the liquids is insoluble in the other but with the addition of a surfactant one liquid forms tiny droplets that are suspended in the other liquid. There are two types of emulsions: oil-in-water emulsions (that are made up of oil dispersed as droplets throughout the water) and water-in-oil emulsions (that are made up of water dispersed as droplets throughout oil).

The surfactant that is added to these emulsions undertakes the same processes as detergents when removing grease and dirt from clothes. One part of the surfactant molecule (hydrophobic end) attaches to the oil and the other part (hydrophilic end) to the water. In this way the oil gets suspended in the water, or the water gets suspended in the oil, depending on the emulsion type.

We use emulsions every day. The surfactants used in these emulsions are also called ‘emulsifiers’. Table 2 gives some examples of common emulsions.

TABLE 2: COMMON EMULSIONS

Type of emulsion	Product
Oil in water	Mayonnaise
	Ice-cream
	Toothpaste
	Cosmetic cleaning creams
	Water-based paints
Water in oil	Butter
	Waterproof sunscreen
	Hand cream
	Oil-based paints

The bile produced in our stomachs assists in the digestion of food by acting as a surfactant. Bile emulsifies the oils and fats in our diets, which means that the fats and oils form tiny droplets. This increases the surface area of the fats and oils and thus allows for chemical reactions to occur more readily in the digestion process.

ACTIVITY: IMMISCIBLE LIQUIDS

In this activity you will observe the separation of an emulsion.

You will need:

- **¼ cup vegetable oil**
- **½ cup water**
- **blue food colouring**
- **an egg**
- **an eye-dropper**
- **a spoon**
- **a 1 L jar with a lid.**

Pour the water into the jar. Add some drops of food colouring and stir. Slowly add the oil and secure the lid on the jar. Shake the jar vigorously ten times and put the jar on the table. What do you observe?

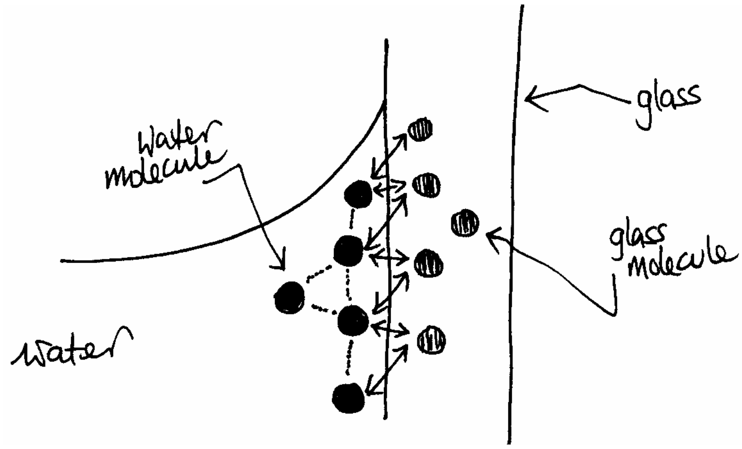
Oil and water are immiscible, meaning they do not mix. The combination of the two liquids makes them an emulsion but they soon separate after mixing. The difference between French dressing (where the vinegar is separated from the oil) and mayonnaise is the addition of a surfactant in the form of lecithin in egg yolks.

So, to your mixture add some egg yolk and once again shake the jar vigorously and put the jar on the table. Do you observe anything different this time? Did the egg yolk act as a surfactant (or emulsifier) so that a colloidal suspension is formed?

Menisci and capillary action

Look very carefully at a glass of water, particularly the surface of the water near the edge of the glass. You should observe that the water rises slightly up the sides of the container. This curving of the surface in containers is called a 'meniscus'. The reason for this is that the water molecules are attracted more to the molecules on the sides of the container than to themselves. This is shown in Figure 4.

FIGURE 4: WATER RISES UP THE SIDE OF THE CONTAINER



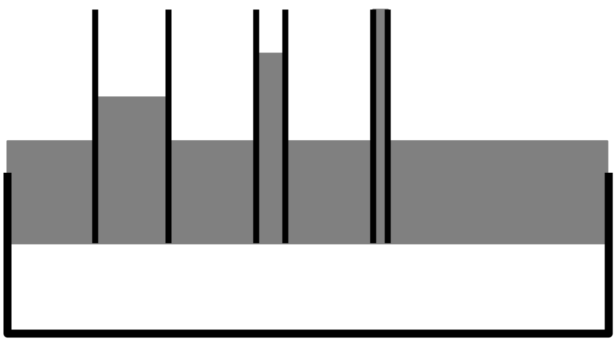
When mercury is placed in a container, its surface curves the opposite way. This is because the atoms of mercury are attracted more to themselves than to the sides of the container. The two types of menisci (curved surfaces) are called 'concave' and 'convex'. These menisci are illustrated in Figure 5.

FIGURE 5: DIFFERENT TYPES OF MENISCI

Concave meniscus Convex meniscus

As water molecules are attracted more to the container that holds them they can rise up the container walls defying the pull of gravity. However, this only occurs to a great extent in narrow tubes called 'capillaries'. Figure 6 shows that, as the internal diameter of a capillary decreases, the water level rises higher. This is because the smaller the diameter, the less weight of water there is to overcome the pull of gravity.

FIGURE 6: CAPILLARIES



Water can rise to great heights in very fine capillaries. Capillaries are present in roots, stems and leaves of plants. Water rises through them, providing water and nutrients to cells throughout the plant. Humans have capillaries that carry the blood to the cells of the body. Capillary action probably occurs to some extent to move the blood, although the major factor is the pumping action of the heart. Try out the following activities that can be attributed to capillary action.

ACTIVITY: CAPILLARY RACES

You will need:

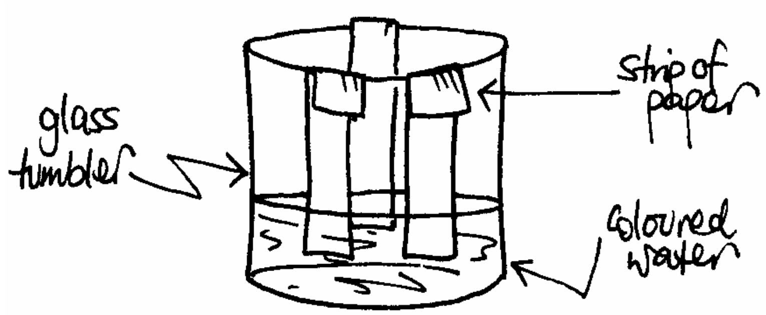
- **a selection of types of paper (writing paper, tissues, filter paper, paper towelling, cardboard, etc.)**
- **glass tumblers or beakers**
- **water**
- **food colouring**
- **scissors**
- **detergent.**

Cut up strips of paper about 10 cm long and 2 cm wide. Pour about 2 cm of water into the beakers and add some food colouring. Now place one end of a strip of paper into the water (about 1 cm) and fold the other end on the side of the beaker. Determine how fast and how high the water rises up the paper.

Test and compare the results from different types of paper. You may like to place different strips in the water at once and make a race for the water to reach a certain height. Which paper performed the best? Why?

Try adding some detergent to the water and compare your results with those found earlier. Given that detergent is a surfactant, can you explain why you get different results? Compare the menisci of a glass of water with a glass of water containing detergent. You will find that the meniscus is not there with the detergent and water.

FIGURE: CAPILLARY RACES



ACTIVITY: GOING UP!

You can observe capillary action in plants. When you have completed these activities discuss how water gets to the leaves and flowers of a plant.

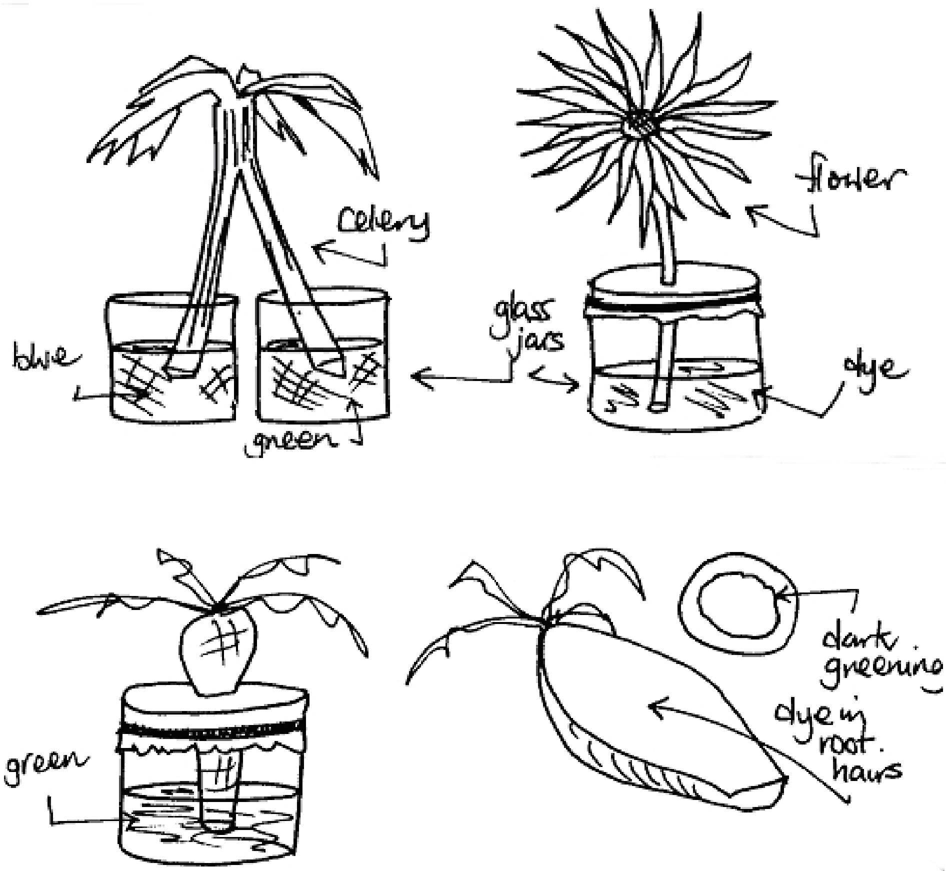
You will need:

- **small glass jars**
- **scissors and a knife**
- **red, green and blue food colouring**
- **water**
- **celery, with the leaves still attached**
- **white flowers on stalks (e.g. daisy, rose, impatiens)**
- **carrot, with green top.**

Make up solutions of food colouring in the jars (for best results make the solution about 50/50 dye and water). Cut the celery up the middle to about 3 cm from the leaves. Cut a small slice off the flower stems just before placing the flowers in the coloured water. Place the two ends of the celery into different coloured solutions. Place the stems of the flowers into different coloured solutions.

After about half an hour, remove the celery from the food colouring. Take a slice off the end of the stalk and observe the cells inside. You should see the capillary tubes (called ‘xylem vessels’) coloured blue and green. The dye from the food colouring should be seen on the petals of the flowers. Leave celery and flowers in coloured water overnight and observe the changes that take place.

FIGURE: CAPILLARY ACTION IN PLANTS



You can also observe the movement of water in plants by capillary action using a carrot (preferably one that still has a green crown), green food colouring and a knife. Cut 2 cm off the end of the carrot and place it in a container of undiluted green food colouring. Leave for about 20 minutes and remove the carrot from the food colouring. Cut a small slice off the end that was in the food colouring. What do you see?

Return the carrot for another 20 minutes, remove, and cut a second slice. What has changed? Slice the carrot in half along its length. What do you see? Can you explain your observations in terms of capillary action?

Reactions in solution

Water is a very good solvent for many solutes and is therefore a good environment for chemical reactions. A great number of biological and industrial processes occur in solutions containing water (aqueous solutions). In this section we will only look at one type of reaction, called 'precipitation reaction'. Later sections will deal in more detail with other chemical reactions that occur in aqueous solutions.

Precipitation reactions

Precipitation occurs when ions in solution combine to form a new ionic compound of low solubility in water. This low-solubility compound, called a 'precipitate', forms as solid particles that eventually settle.

We have already established that when ionic compounds dissolve in water the ionic bonds between the ions are broken by the water molecules and form hydrogen bonds with them. In some circumstances certain combinations of ions can form ionic bonds in other arrangements to produce ionic compounds that are insoluble in water (precipitates).

For example, silver nitrate ($AgNO_3$) and sodium chloride (NaCl) are both soluble in water and form colourless solutions individually. However, if you put silver nitrate ($AgNO_3$) and sodium chloride (NaCl) into water together, a cloudy solid is formed in solution. This is the precipitate called 'silver chloride' (AgCl).

To understand this reaction you need to consider that when silver nitrate ($AgNO_3$) dissolves there will be silver (Ag^+) and nitrate ions (NO_3^-) in solution. When sodium chloride (NaCl) dissolves there will be sodium (Na^+) and chloride ions (Cl^-) in solution. The solution contains four types of ions: Ag^+, NO_3^-, Na^+ and Cl^- ions. In this situation Ag^+ and Cl^- ions form ionic bonds which are stronger than the hydrogen bonds between the water molecules and so will form a solid that is known as a precipitate with the name silver chloride (AgCl). The other two ions (NO_3^- and Na^+) do not form ionic bonds and so remain in solution. The whole chemical reaction can be written as:

$$NaCl\ (aq) + AgNO_3\ (aq) \longrightarrow AgCl\ (s) + AgNO_3\ (aq)$$

In this equation the abbreviation 'aq' means the ionic compound dissolves in solution whereas the symbol 's' means the ionic compound is a solid in solution (precipitate or insoluble).

To determine if a precipitate reaction is going to occur, you first need to know the combination of ions that will be present in solution. Then, by knowing which ionic compounds are insoluble in water you can determine the name of the precipitate (if any) that will be produced. Table 3 gives the solubility for common ionic compounds (taken from Elvins et al. 1999, p. 114).

TABLE 3: SOLUBILITY GUIDE

A solubility guide for common ionic compounds	
General rule	**Exceptions**
Compounds containing these ions are soluble:	
Na^+, K^+, $NH4^+$, NO_3^-, CH_3COO^-	Very rare
Cl^-, Br^-, I^-	When combined with Ag^+
SO_4^{2-}	When combined with Ag^+, Pb^{2+}, Ca^{2+}, Ba^{2+}
Compounds containing these ions are insoluble:	
S^{2-}, CO_3^{2-}, PO_4^{3-}	When combined with Na^+, K^+, NH_4^+
OH^-	When combined with Na^+, K^+, NH_4^+, Ba^{2+}, Ca^{2+}

Examples of soluble and insoluble ionic compounds are KCl (potassium chloride), which is soluble, and AgBr (aluminium bromide), which is insoluble.

Water treatment

The water we drink from the tap is the end of a process that has involved precipitate reactions. The steps involved in the purification of water in most cities are:

- flocculation
- settling of the ‘floc’
- filtering
- chlorination.

Flocculation is a process whereby small suspended particles in the water join together to form larger, heavier particles which settle on the bottom of the container that holds the water. To achieve this state, two ionic compounds are dissolved in the water. These are alum (aluminium sulphate $Al_2(SO_4)_3$) and lime (calcium hydroxide $Ca(OH)_2$). This produces four types of ions in solution, two of which combine to form the precipitate aluminium hydroxide $Al(OH)_3$ (Table 3 states that compounds containing $OH^–$ are insoluble and aluminium is not an exception). This precipitate is jelly-like and is called ‘floc’. It attaches to the suspended particles in the water, making larger and heavier particles that settle.

After settling of the ‘floc’, the mixture is filtered through a bed of sand over gravel. This removes any of the remaining suspended matter. After filtering, the water is usually chlorinated and sometimes fluoridated. These two processes put $OCl^–$ (hypochlorite) ions and $Fl^–$ (fluoride) ions into the solution. The hypochlorite ions kill bacteria and the fluoride ions find their way into teeth, thus reducing tooth decay.

The following activities are precipitate reactions that students can do at home.

ACTIVITY: SINKING GEL

You will form a white insoluble gel (precipitate) from a precipitate reaction.

You will need:

- **½ tspn alum**
- **2 tspn household ammonia**
- **a spoon**
- **a small jar**
- **water.**

Half-fill the jar with water. Add the alum to the water and stir. Stir in the ammonia and allow the solution to stand for 5 minutes. Observe what change occurs.

Explanatory note: The household hydroxide part of the ammonium hydroxide reacts with the aluminium in the alum to produce an insoluble gel called 'aluminium hydroxide'—a precipitate.

ACTIVITY: MAGNESIUM MILK

This experiment produces a milky solution (precipitate).

You will need:

- **1 tspn Epsom salts**
- **2 tspn household ammonia**
- **a small jar**
- **water**
- **a spoon.**

Half-fill the jar with water. Stir in the Epsom salts. Pour in the ammonia but do not stir the solution. Allow the solution to settle for 5 minutes. What do you observe? What changes have taken place?

Explanatory note: The household ammonia (ammonium hydroxide) reacts with the Epsom salts (magnesiun sulphate). This produces magnesium hydroxide—a white substance that is insoluble and is therefore a precipitate. After a while the white floating particles settle on the bottom of the jar. Magnesium hydroxide is part of the medicine known as 'milk of magnesia'. The reference to milk comes from its milky appearance.

Given the information in the previous section, you should be able to predict that magnesium hydroxide is the insoluble ionic compound (precipitate). To do this, complete the following steps:

- **List the reactants (initial substances).**
- **Are they soluble? Check the solubility guide in Table 3.**
- **What ions do they form in solution?**
- **Which ions will form bonds to form the precipitate (which ionic compound is insoluble)?**

ACTIVITY: SOFT WATER AND SUDS

This activity is taken from the website 'Science is fun' <http://scifun.chem.wisc.edu/HOMEEXPTS/SOFTWATR.html> (viewed 8 March 2005).

Tap water in many parts of the country contains minerals that can interfere with the cleaning ability of detergents. That's why water softeners are popular in these locations. Water softeners remove these minerals. In this experiment, you will make 'hard' water from distilled water, which contains no minerals and is therefore 'soft'. You can then compare the sudsing ability of a detergent in soft and hard water.

You will need:

- **500 mL (2 cups) distilled water**
- **5 mL (1 tspn) Epsom salts**
- **two empty and cleaned 2 L plastic soft-drink containers, with screw caps**
- **several drops of liquid detergent (not the kind for automatic dishwashers).**

Pour 250 mL (1 cup) of distilled water into each of the empty soft-drink bottles. Add 5 mL (1 tspn) of Epsom salts to one of the bottles. Swirl the bottle until the Epsom salts dissolve. Add several drops of liquid detergent to both bottles. Seal the bottles with their caps. Shake both bottles. A large amount of suds will form in the bottle without Epsom salts. Far fewer suds will form in the bottle containing the Epsom salts.

The suds formed in this experiment are made of tiny bubbles formed when air is shaken into the water and trapped in a film of liquid. The film of liquid surrounding each bubble is a mixture of water and detergent. The molecules of detergent form a sort of framework that holds the water molecules in place in the film. If there were no detergent, the bubbles would collapse almost as soon as they were formed. You can see what this would look like by repeating the experiment, but leaving out the detergent.

This experiment will not produce suds if detergent for a dishwashing machine is used. (Try it and see.) Automatic dishwasher detergent is formulated so that it does not form suds, which interfere with the movement of the washing arms and are difficult to rinse off the dishes.

Hard water

The following is an extract from the website 'Science is fun' <http://scifun.chem.wisc.edu/HOMEEXPTS/SOFTWATR.html> (viewed 8 March 2005).

> The minerals that make water hard usually contain calcium and magnesium. In the previous experiment, you made water hard by adding Epsom salts, which is magnesium sulfate. Calcium and magnesium in water interfere with the cleaning action of soap and detergent. They do this by combining with soap or detergent and forming a scum that does not dissolve in water. Because they react with soap and detergent, they remove the soap and detergent, thereby reducing the effectiveness of these cleaning agents. This could be overcome by adding more soap or detergent. However, the scum that is formed can adhere to what is being washed, making it appear dingy.
>
> Water can be softened in a number of ways. An automatic water softener connected to water-supply pipes removes magnesium and calcium from water

> and replaces them with sodium. Sodium does not react with soap or detergents. If you don't have an automatic water softener, you can still soften laundry water by adding softeners directly to the wash water. These softeners combine with calcium and magnesium, preventing the minerals from forming a soap scum.
>
> (http://scifun.chem.wisc.edu 2005)

ACTIVITY: BUBBLE TROUBLE WITH HARD WATER

You may have heard that the chemical element calcium (Ca) is very important for strong bones and teeth. Excellent sources of calcium in our diets include milk, broccoli, salmon and sardines. Calcium is also a major part of things like cement, seashells, limestone, chalk, marble, eggshells, and de-icer for icy roads. Sometimes when water flows over limestone or other materials with a lot of calcium in them, the calcium gets into the water. Water that contains a lot of calcium or other minerals is called 'hard' water. One characteristic of hard water is that it makes a soap scum when mixed with soap. It also makes a soap solution much less bubbly. But don't just take our word for it—let's check it out!

You will need:

- **paper towels**
- **three clear 8 oz plastic cups.**
- **a tablespoon**
- **labels**
- **warm water**
- **plaster of Paris powder**
- **plastic straws**
- **a grater**
- **a bar of soap**

Cover a work area with paper towels. Label three clear 8 oz plastic cups as 'water', 'water and plaster' and 'soapy water'. Pour half a cup of warm water into each cup. Add about a quarter of a teaspoon of plaster of Paris powder to the cup labelled 'water and plaster'. Stir thoroughly with a plastic straw.

Grate one to two tablespoons of soap from a bar of soap. Put about one tablespoon into the 'soapy water' cup. Stir thoroughly with a new straw. Add one tablespoon of your soapy water to the 'water' and 'water and plaster' cups. Do not stir right away, and closely observe what happens. Is there a difference? What do you see happening in one of the cups?

Now stir each cup with a separate straw. Do they still look different? Next use a new clean straw to blow gently into each cup. Warning: Please be sure to *blow into* the liquids. *Do not suck* the liquid into the straws at all.

Do you notice a difference in the bubbling? What do you think is the reason? It will help you to know that plaster of Paris is a chemical compound called 'calcium sulfate' (made from gypsum).

References

Elvins, C, Jones, D, Lukins, N, Ross, B & Sanders, R 1999, *Chemistry one*, 3rd edn, Addison Wesley, Melbourne.