WJEC Wales Chemistry GCSE

1.3: Water

Detailed notes

Natural water

Water is first collected from natural sources, like rivers and lakes, and is then treated so it is safe for use. Water from these natural sources contains other substances that could be harmful to health, including:

- Microorganisms - natural water is the habitat for large numbers of bacteria and other microorganisms. Some of these are safe inside humans; however, many are disease-causing so the water must be treated, most commonly with chlorine, to kill these microorganisms.
- Ions - water dissolves ions from rocks and other material as it flows within rivers or to reach lakes/rivers. Although a small amount of dissolved ions is important in water, too much is dangerous for your health.
- Dissolved gases - natural water contains dissolved oxygen and carbon dioxide, a byproduct of respiration from the microorganisms living in natural water; this is also required for photosynthesis in aquatic plants. Other gases from the atmosphere can dissolve into natural water.
- Pollutants - in the same way water dissolves ions as it runs over land on the way to the water source, it also dissolves many pollutants such as pesticides, herbicides and chemical fertilisers. In high concentrations, these can affect health.

Water is an essential resource

- Water covers about 2/3 of the Earth, but the majority cannot be drunk directly.
- Humans need drinking water with low levels of dissolved salts and microbes for drinking and sanitation.
- We also need water for irrigating crops and agriculture.
- The industry uses water as a cooler or solvent.

Potable water

- Potable water is water that is safe to drink.
- Potable water is not ‘pure’ because it contains dissolved substances, although to be safe it must have sufficiently low levels of dissolved salts and microbes.
- The methods used to produce potable water depend on available supplies of water and local conditions.

Sustainability

The demand for water has risen considerably across the world over the last 100 years, meaning there is a greater need than ever for a sustainable water supply. This includes:

Reducing water consumption

- Taking short showers instead of baths
- Turn off taps when they’re not being used
- Installing a short flush button on toilets
- Using leftover bath water for things like watering plants
- Eat less meat
- Only boil the amount of water you need
- Put on full machine washing loads

- Use dishwashers instead of washing by hand

The methods of abstraction and distribution of water must also be evaluated to make them as sustainable as possible:

Abstracting water (the removal of water from water sources):

- Desalination of seawater
- Building dams and reservoirs
- Collecting from surface sources such as rivers, lakes and streams
- Collecting rainwater
- Accessing underground sources

Distributing water

Once the water has been collected and cleaned it has to be distributed to where it is needed. This is done via underground piping systems that take water directly to people's houses, business and farms etc.

Water treatment

The 3 main steps for treatment of water are sedimentation, filtration and chlorination. At the end of this process water is considered safe to use and can then be distributed.

1. Sedimentation:
    - Water is added to a large tank.
    - This stops it from flowing, allowing large, insoluble particles to sink to the bottom of the tank.
2. Filtration:
    - Water is flown through beds of sand and gravel of different sizes which removes small insoluble particles.
3. Chlorination:
    - Chlorine gas is bubbled through the water to kill bacteria and other microorganisms.

Fluoridation

Water fluoridation is a process where fluoride is added to water, different areas of the UK have different amounts of fluoride added to the water.

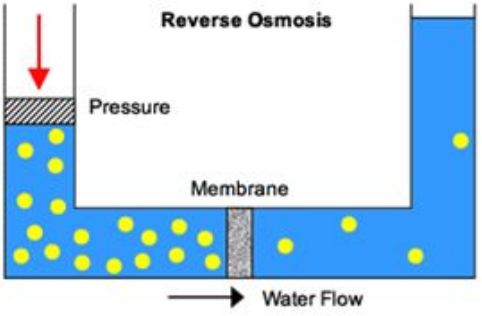
There is a debate on whether water should be fluoridated or not because there are both disadvantages and advantages to the process, as shown in the table:

Advantages	Disadvantages
• Strengthens the enamel of teeth which prevents tooth decay and cavities • Protects teeth from demineralisation	• It is a form of mass medication as people have no say on how much fluoride is in their water • If children's teeth are exposed to too much fluoride they can develop

	fluorosis • People can make a choice themselves about fluoride by using toothpaste that contains it • Links have been made between fluoride and thyroid problems, neurological disorders and some cancers - although there is no concrete evidence.

Methods of purification

Oceans contain 96.5% of the Earth's total water, so taking seawater and making it safe to drink seems a good idea, especially in coastal places. Desalination is the removal of salt from seawater and can be done via 2 main methods - distillation and reverse osmosis.



Science of Water. Chemistry Behind Reverse Osmosis Water Purification. URL: http://scienceofwater.com/chemistry-behind-reverse-osmosis-water-purification/

Reverse Osmosis

Reverse osmosis uses a selectively permeable membrane that only allows water molecules to pass through and not other chemicals and ions. The seawater must be pushed through the membrane at very high pressure.

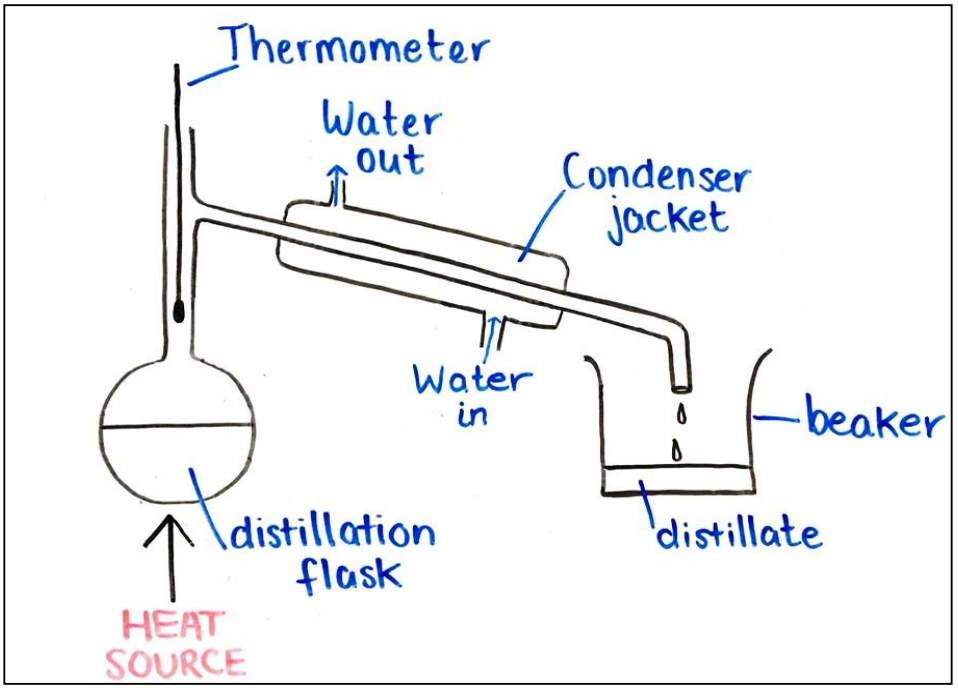
Distillation

1. The seawater is heated causing pure water to evaporate.
2. The water vapour is collected and cooled, causing it to condense back into a liquid, giving distilled water.
3. The leftover salt may be used for various purposes.

Distillation is not only used to separate pure water from salt ions; it can also be used to separate miscible liquids by heating to certain temperatures to individually evaporate and condense different liquids.

For instance, the boiling point of ethanol is 78°C and the boiling point of water is 100°C, so by heating a mixture of ethanol and water to around 85°C the ethanol would evaporate into a vapour which could be condensed and collected as a pure liquid while the water will remain as a liquid, thus separating the two liquids.

The apparatus used for distillation is:



The sustainability of desalination

Advantages	Disadvantages

• It is a useful water supply in countries with low rainfall and lots of coastline
• The water produced from desalination is of a higher quality than the required standards of potable water
• Using water from the ocean can help protect habitats for animals in natural sources such as rivers and lakes that can also be used to supply potable water
	• Desalination processes require a lot more energy than the typical water treatment process
	  ○ This makes it expensive and harder for poorer countries to afford
	  ○ This increases greenhouse gas emissions as a lot of fuel is required to heat the water in distillation and to create a high pressure in reverse osmosis.
	• Desalination plants are often far from where the water is needed, so lots of piping must be installed
	• Building of desalination plants is an expensive and high energy process

Solubility

What is solubility?

A substance (called the solute) is described as soluble if it will dissolve in another substance, known as the solvent. So when sugar dissolves in a cup of water, the solute is sugar and the solvent is water.

- Solubility depends on:
  - The identity of the solute
  - The identity of the solvent
  - The temperature
- Solubility is measured in terms of the maximum mass of solute (in grams) that will dissolve in a given volume of solvent.
  - For example, the solubility of sodium chloride, NaCl, is 36g/100g of water at 20°C
- A solvent is saturated when no more solute will dissolve in it

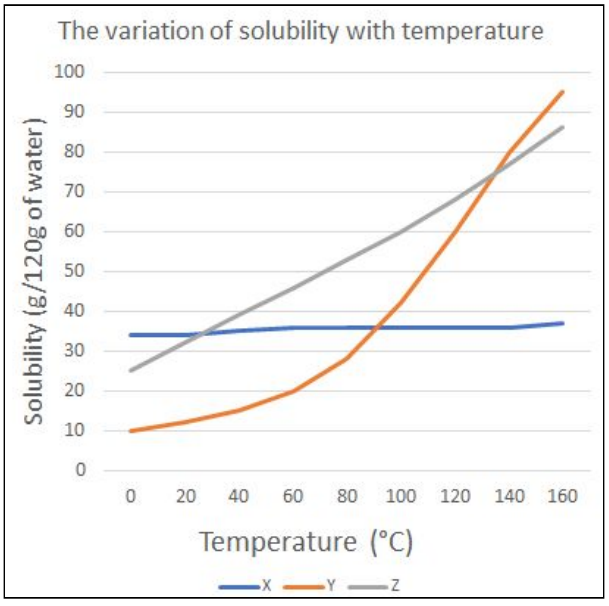
How to Measure Solubility

Method:

1. Gradually add solute to a known volume of solvent using a spatula and stir so it dissolves.
2. Add solute until no more solute dissolves - you will see the solute collecting at the bottom of the beaker.
3. Weigh a weighing boat and record its mass.
4. Filter the undissolved solute and discard it.
5. Heat the left over to solution to evaporate the solvent, leaving behind the solute that had dissolved. Add this to the weighing boat.
6. Reweigh the weighing boat and calculate the mass of solvent that was dissolved.

Solubility Curves

Solubility varies with temperature and a solubility curve shows this variation. Generally speaking, solubility increases as temperature increases. An example solubility curve is shown for 3 different solutes - X, Y and Z.



A solubility curve tells you many things:

- All 3 solute's solubility increases with temperature.
- The solubility of solute X varies very little with temperature.
- At lower temperatures solute X is most soluble whereas at higher temperatures solute Y is the most soluble.
- The solubilities of X and Z are the same at around 25°C

Hard water

Hard vs. soft water

	Hard water	Soft water
Composition	Contains dissolved magnesium ions and calcium ions. Water dissolves these ions as it runs over rocks such as limestone	Contains low concentrations of ions, magnesium and calcium ions in particular. It commonly contains sodium ions.
Action with soap	It is difficult to form a lather with hard water. Forms scum instead.	Readily forms a lather with soap

Temporary and permanent hardness

There are 2 types of hard water - temporary and permanent

- Temporary hardness is caused by dissolved calcium hydrogencarbonate - $Ca(HCO_3)_2$
  - This hardness can be removed by boiling the water, when the following thermal decomposition reaction occurs:

$$Ca(HCO_3)_2\,(aq) \rightarrow CaCO_3\,(s) + H_2O\,(l) + CO_2\,(g)$$

  - The calcium carbonate, $CaCO_3$, is a solid and is what forms on kettles when hard water is boiled. This decreases the efficiency of the heating element.
  - Calcium hydrogencarbonate forms in water when rainwater dissolves carbon dioxide from the atmosphere which reacts with calcium carbonate (found in limestone and other rocks), according to the following reaction:

$$CaCO_3\,(s) + H_2O\,(l) + CO_2\,(g) \rightarrow Ca(HCO_3)_2\,(aq)$$

- Permanent hardness is caused by dissolved calcium sulphate - $CaSO_4$
  - This hardness cannot be removed by boiling the water.

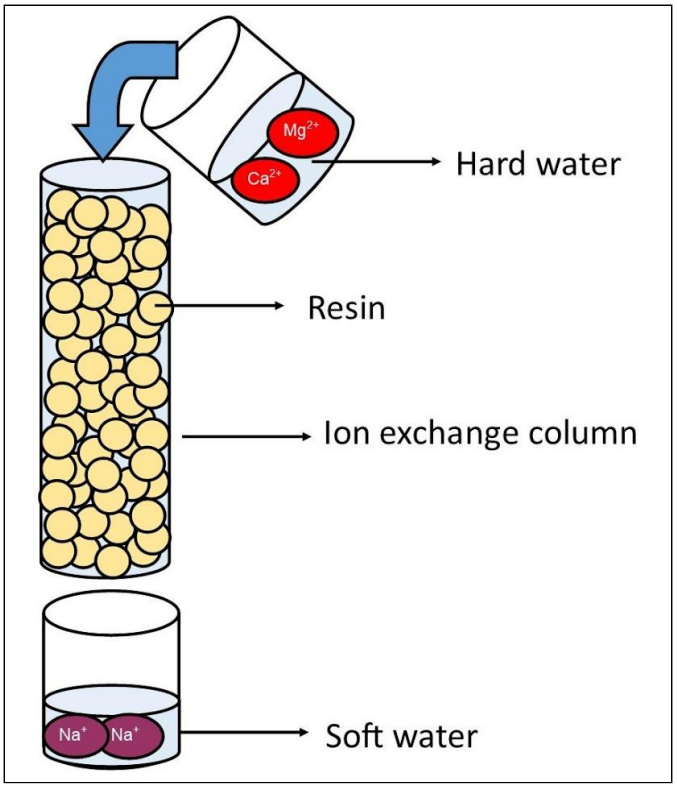
How to remove hardness

- Sodium carbonate - Na_2CO_3 (washing soda) can remove both temporary and permanent hardness.

- **HIGHER TIER: Adds carbonate ions to the water which react with calcium ions to form solid calcium carbonate:**

$$CO_3^{2-}(aq) + Ca^{2+}(aq) \rightarrow CaCO_3(s)$$

- Ion exchange column - a column is packed with resin which contains sodium ions, as hard water flows through the column, Mg^{2+} and Ca^{2+} ions are exchanged for Na^+ ions, removing the magnesium and calcium ions.
  - **HIGHER TIER: As the water flows through the column Na^+ ions leave the resin and Mg^{2+} and Ca^{2+} ions instead get stuck to the resin. Overtime the column becomes saturated with calcium and magnesium ions and sodium chloride is run through the column to flush out the hard ions and replace them with Na^+ ions.**



- Distillation - the hard water is heated so the water evaporates and is then condensed and collected, leaving behind the ions that made it hard.

Water softening technique	Advantages	Disadvantages
Sodium carbonate	Cheap and easy Removes both temporary and permanent hardness	The calcium carbonate (limescale) builds up can block pipes
Ion exchange column	Removes both temporary and permanent hardness	The ion exchange column is expensive The column becomes saturated and less efficient

		over time
Distillation	Removes both temporary and permanent hardness	High energy process and therefore high cost

Advantages and disadvantages of hard water

While there are many methods for removing hardness from water, some people like to leave hardness in their water, as there are many advantages to it:

	Advantages	Disadvantages
Hard water	• The mineral ions in hard water help prevent some heart and cardiovascular diseases. Conversely the sodium ions in soft water can increase the risk of many of these diseases and cause high blood pressure • Many people prefer the taste of hard water • Calcium ions help strengthen teeth and bones	• Limescale forms when hard water is used, reducing the efficiency of heating elements and potentially blocking water pipes • It is difficult to form a lather with soap but it is easy with soft water • Scum forms, wasting soap