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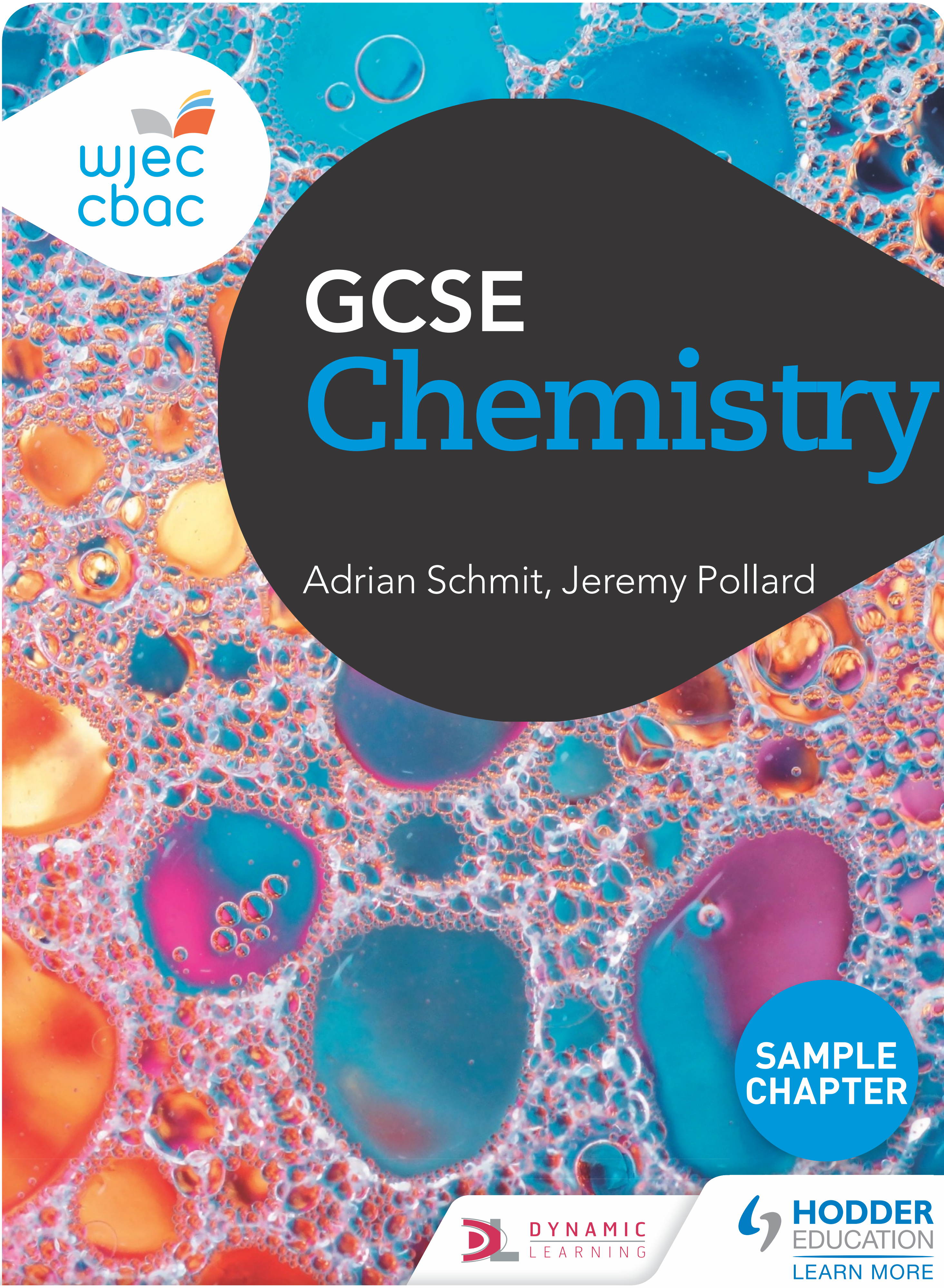
GCSE Chemistry

Adrian Schmit, Jeremy Pollard



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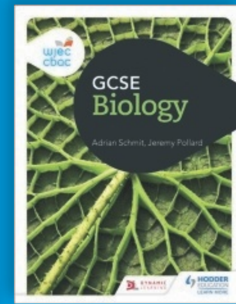

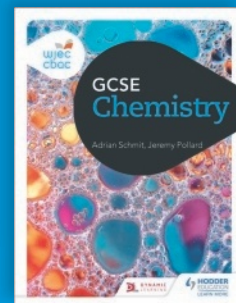

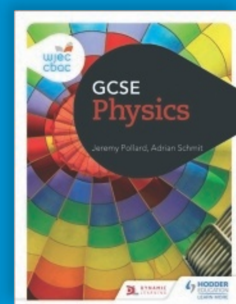

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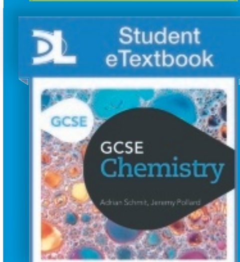
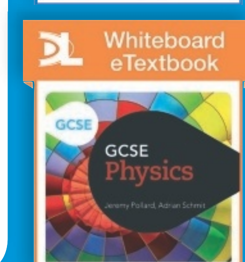




Contents

3 Water

Specification coverage

This chapter covers specification **Unit 1, Topic 1.3 (Chemistry) and Unit 2, Topic 2.3 (Double award)** and is called Water.
It covers the composition and treatment of the water supply, including fluoridation. Different types of water hardness are described, related to the ions and equations involved.

What's in our water?

The one chemical formula that almost everyone knows is the one for water, H_2O. That is the formula for the compound, but the water we encounter every day has a lot more in it than just hydrogen and oxygen. Whether it is tap water, rain, spring water, river water or the sea, the water is far from 'pure'. In science lessons, you will often use distilled water rather than tap water, because distilled water has many of the impurities removed. So, what are these impurities? We will look at tap water later in this chapter, but for the moment, let's just consider what is in 'natural' water supplies (Figure 3.1):

Key term

Solute Chemical which is dissolved in a solvent to form a solution.

- **Solvents**. Water is a great solvent, and all sorts of things dissolve in it. The **solutes** fall into two categories:
  - **Ions** of many sorts. As water runs over or through the ground, it dissolves many chemicals, which form ions in the water. Some of the most common ions found are sodium, calcium, magnesium, sulfate, hydrogencarbonate and chloride.
  - **Dissolved gases**. The gases in the atmosphere can dissolve in water to different extents. The most important dissolved gases are oxygen (which aquatic organisms need for respiration) and carbon dioxide (needed by plants to make food by photosynthesis).
- **Microorganisms**. Microorganisms inhabit every place on Earth, including water. Natural supplies of water will contain vast numbers of bacteria and other forms of microscopic life. Some of these microorganisms can cause disease and so it is inadvisable to drink untreated water from rivers, lakes and streams. Water treatments remove harmful, but not all microorganisms.
- **Pollutants**. Most of the water in rivers and lakes arrives there by travelling over or through soil and rock, and en route it can pick up pollutants. Chemical fertilisers and pesticides applied to farm land and animal wastes can be washed through to rivers and lakes by rainfall. Sometimes, pollutants may be deliberately dumped into water, although there are legal measures in the UK to try to prevent this.

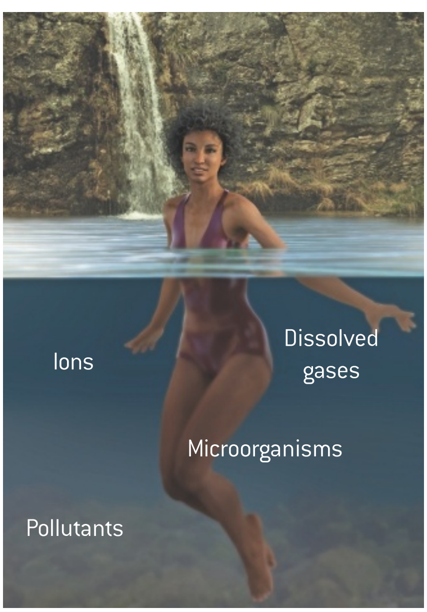


Figure 3.1 Swimming in a complex solution.

Drinking water

Water is essential for life and so it is important that everyone has access to enough clean drinking water. Already, in many areas of the world, people are struggling to get enough good quality drinking water. Even in developed countries, increasing demands for water for a variety of uses are putting strains on the water supply. Global warming has affected rainfall patterns and, if these effects continue, there could be problems in supplying water to some populations.

This section describes the main issues in the future for drinking water.

Reducing water consumption

Over the last 100 years, water consumption has steadily risen across the world (see Figure 3.2). Some of this rise has been due to increased use of water in homes, but there has also been a steep rise in the amount of water used by industry. In the home, people are encouraged to reduce water consumption by taking the following measures:

- Taking shorter showers.
- Re-using bath or sink water for watering plants.
- Having toilets with a setting to allow a smaller flush.
- Insulating water pipes to reduce the chances of bursting in winter.
- Not leaving water running when cleaning your teeth or rinsing vegetables.
- Having a water meter fitted so that water use can be monitored.
- Ensuring your washing machine or dishwasher has a full load before using it.

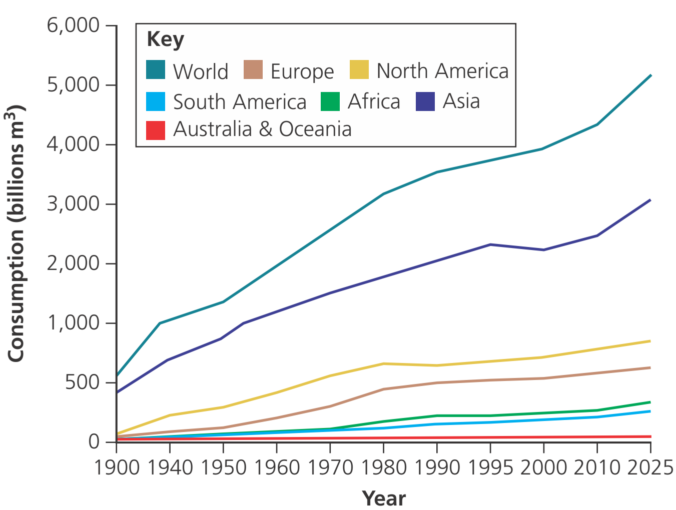


Figure 3.2 Global water consumption and projection of future use 1900–2025

Abstracting water

Abstraction is the term used for extracting water (either temporarily or permanently) for human use. This includes things like pumping underground water to the surface, building dams and reservoirs, taking water from rivers or lakes, collecting rainwater and **desalinating** sea water.

Some of these measures may be opposed by local populations because of their environmental impact. This is especially the case with the building of dams and reservoirs, both of which require the flooding of large areas of land, destroying habitats and altering the appearance of the area.

Discussion points

Why do you think water consumption has increased steadily over the last 100 years?

Key term

Desalination Removing salt from sea water to convert it into water fit for drinking.

Distributing water

Water can only be extracted or collected in certain places. Some locations may be many miles away, and water has to be piped to those areas to provide irrigation, sanitation and drinking water. This can be expensive and unfortunately some of the driest countries in the world are also some of the poorest. Approximately 1.1 billion people in the world have no access to treated drinking water, and the use of untreated water is responsible for millions of cases of death and disease every year. The United Nations Millennium Development Goals aimed to get clean drinking water to 88.5% of the world's population by 2015 but in almost half the areas of the world, that target has not been reached. Water is not only needed for drinking, but also for irrigation, so that crops can be grown and starvation is less likely.

Treating water to make it safe

As far as drinking water goes, the water not only has to be delivered but also treated to make it safe. This has cost implications and some environmental implications, as water treatment plants have to be built. Apart from the treatment of drinking water, where there is sanitation sewage also needs to be treated before the water is recycled into the environment. Water polluted with human sewage is very dangerous to health. The details of treatment are given in the next section.

Test yourself

1. How can fertilisers applied to fields end up in rivers and lakes?
2. State **three** ways in which home owners can conserve water.
3. What does the term 'abstraction' mean?
4. Why might local populations object to the building of a reservoir in their area?

The public water supply

In Britain, almost everybody gets water piped into their homes, and this water is fit to drink straight from the tap. The water originates mainly as rainfall, but it has to be cleaned and treated before it is safe to drink. The rainfall is collected in lakes or man-made reservoirs where it is stored. Alternative water supplies are rivers and underground water. The Caban Coch dam in the Elan valley is shown in Figure 3.3; water from the Elan valley is used by the city of Birmingham in England. There are around 2000 such reservoirs supplying drinking water in the UK.

Figure 3.3 The Caban Coch dam in the Elan Valley in Powys.

The water coming from a reservoir will contain a lot of suspended particles and bacteria. These have to be removed to make the water palatable and safe to drink. This happens in water treatment plants, and the main stages are shown in Figure 3.4.

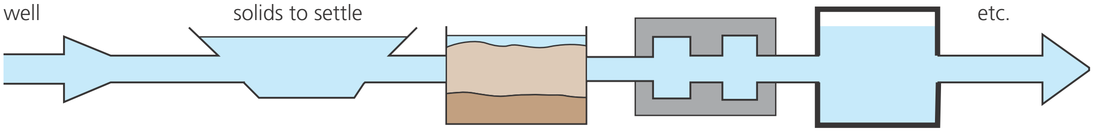


Figure 3.4 Stages in the treatment of drinking water.

While the water is in the reservoir, the larger solid particles will settle to the bottom (**sedimentation**). When the water is extracted from the reservoir, it is filtered to remove smaller insoluble particles (**filtration**), but these filters cannot remove bacteria. To kill the bacteria, the water is **chlorinated** (chlorine is added). The treated water is then stored in a water tower or tank until it is needed. A reservoir is not always used, in which case the water goes through a settling or sedimentation tank instead.

Fluoridation

In some areas of the UK, fluoride is added to drinking water. Fluoride is added in small amounts and is known to be helpful in preventing tooth decay. Tooth decay starts when the outer surface (enamel) of the tooth is attacked by acid produced by bacteria that live on the surfaces of the teeth in a layer known as plaque. These bacteria convert the sugars in our food into acid. The acid causes calcium and phosphates, of which enamel is largely composed, to dissolve and enter the plaque. This process is called **demineralisation**. The saliva will eventually neutralise the acid and the minerals then re-enter the enamel – a process called **remineralisation**. Fluoride has several benefits in this process.

- In young children, who are developing their layer of enamel, fluoride alters the structure of the enamel so it is more resistant to acid attack.
- Low levels of fluoride encourage remineralisation.
- Fluoride reduces the ability of plaque bacteria to form acid.

The role of fluoride in preventing tooth decay is largely undisputed, but some people do not believe it should be added to drinking water. Some of the issues are listed below.

- A condition called **dental fluorosis** can occur if teeth are exposed to high levels of fluoride. Fluorosis is a condition where the enamel gets white patches on it. It does not damage the teeth nor cause any health problems. It can be a problem in some areas of the world where the water contains naturally high levels of fluoride, but in Europe a number of studies have shown that the incidence of fluorosis in areas where water is not fluoridated is no lower than in areas where it is fluoridated.

- There is fluoride in around 90% of toothpastes, at a much higher concentration than in fluoridated water. Some people argue that fluoridation is unnecessary, yet there is less dental decay in children in fluoridised areas than in those without fluoridation. The exact reasons for this difference are not clear.
- Some people believe that drinking water should be as natural as possible. They accept the addition of chlorine as a necessary safety measure, but believe that people should not be forced to take in any artificial additives like fluorine.

Drinking water from the sea

Although the UK is surrounded by sea, we cannot drink sea water. The salt in it makes it taste unpleasant, but it also means that, if you did drink it, it would actually dehydrate you.

However, in various parts of the world, some countries are looking at the possibility of removing the salt from sea water (**desalination**) so that it can be used for drinking. The first desalination plant in the UK opened in 2010 (Figure 3.5).

The usual process for desalination is called reverse osmosis. The sea water is filtered under pressure through a membrane that acts like a molecular filter, letting only the small water molecules go through, and keeping the salt back.

There are a number of problems with using desalination for supplying drinking water:

- The process uses a lot of energy because of the need to generate high pressures – much more than other processes that are used to produce drinking water.
- The process is expensive because of the energy needed.
- The desalination plants produce greenhouse gases, whereas normal water treatment plants produce very little.
- The very salty water left when the fresh water has been extracted is a pollutant and needs to be disposed of carefully.
- Some countries with a drought problem are very poor and could not afford desalination, while others do not have a coastline, so the water would have to be piped long distances.

Desalination is extensively used in the Middle East, where rainfall is very low and the states tend to be wealthy. Many countries there have coastlines, and many produce oil meaning that their energy costs are not so high.

Figure 3.5 The first desalination plant in the UK, which opened near London in 2010.

Test yourself

5 In the treatment of drinking water, what is 'sedimentation'?
6 Why is chlorine added to drinking water during treatment?
7 Why is fluoride more effective in reducing tooth decay in children rather than adults?
8 What is the condition that can be caused by consuming very high levels of fluoride?
9 Why is sea water not fit for drinking?

Purifying water by distillation

During the treatment of water for drinking, solid particles are separated by filtration. If something is dissolved in water, we can extract the water by evaporating it and then condensing the vapour, leaving the solute behind. But what if the water is mixed with another liquid? This requires a different technique – **distillation**.

Each chemical has its own boiling point, and for water this is 100 °C. If you heat a mixture of liquids to 100 °C, then any vapour coming off at that point is water. Other liquids will boil off at lower or higher temperatures.

Practical

Separating ethanol and water

This practical may be done as a class experiment, or your teacher may show you a demonstration.

Apparatus

- Clamp stand × 2
- Gauze
- Bunsen burner
- Distillation flask
- Thermometer
- Condenser
- Conical flask
- Ethanol/water mixture

Risk assessment

Your teacher will provide a risk assessment for this experiment.

Procedure

1 Set up the apparatus as shown in Figure 3.6.
2 Gently heat the distillation flask, keeping an eye on the thermometer.
3 The boiling point of ethanol is 78 °C. When this temperature is reached, ethanol vapour should start to reach the condenser where it will be cooled and therefore form the liquid. Keep the temperature as close as possible to 78 °C by removing and replacing the Bunsen burner as necessary.
4 Stop when you have collected a few drops.
5 When the distillation flask has cooled, compare the smell of the liquids in the distillation flask and the conical flask.

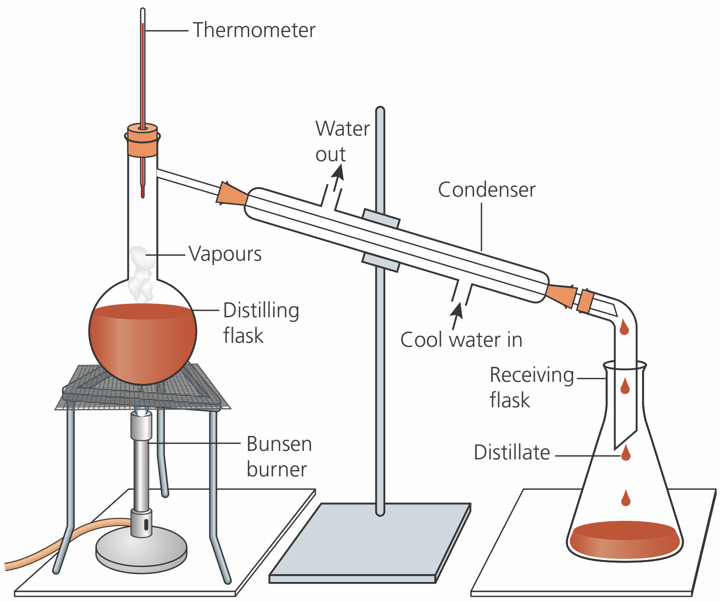


Figure 3.6 Experimental set-up for simple distillation.

This simple distillation procedure is fine for separating two liquids with clearly different boiling points. For mixtures of several different liquids, a fractionating column is used (see Figure 3.7).

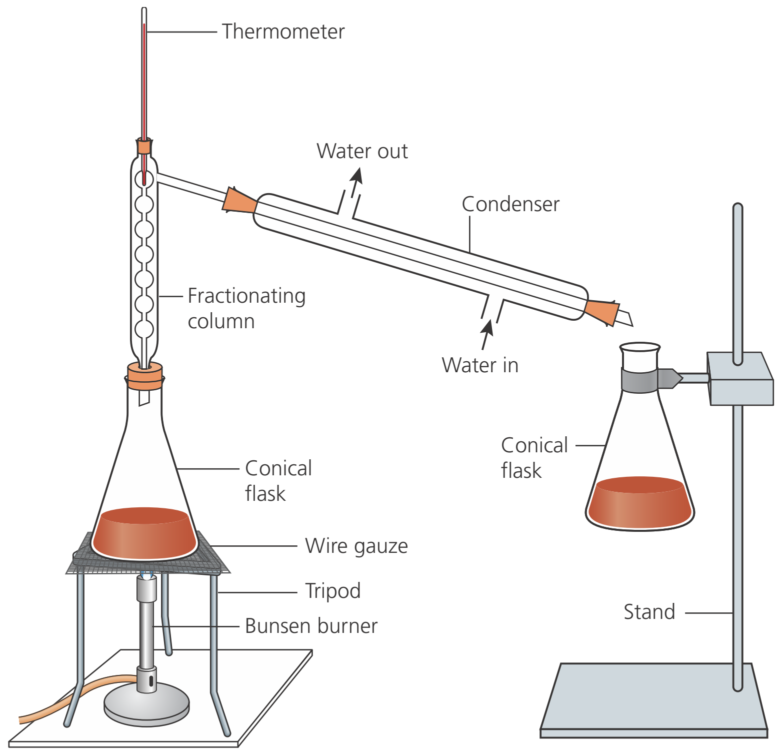


Figure 3.7 Fractional distillation using a fractionating column.

Solubility curves

Water has been described as the 'universal solvent'. A wide variety of substances dissolve in it, to different extents. A chemical that dissolves in a solvent is called a **solute**. For each solute, there is a limit to how much can dissolve in a solvent. When no more can dissolve, the solution is said to be **saturated**, although under certain circumstances it is possible to increase the amount of solute, giving a **supersaturated** solution.

Solubility is measured in g/100 g water. Measurement involves gradually adding known amounts of solute until no more will dissolve. The solution is then filtered, dried and weighed to determine the excess of solute. By subtracting this excess from the total amount added, the weight of dissolved solute is obtained.

Note: A graph of solubility curves and an Activity will be included in the full version.

Hard and soft water

The water that comes out of your tap may be 'hard' or 'soft' depending on what area of the country you live in and where your water comes from. Hard water is water that contains dissolved calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions.

Hard water can be **temporary** or **permanent**, or a mixture of the two. Temporary hard water contains calcium hydrogencarbonate and/or magnesium hydrogencarbonate. When this water is boiled, the hardness is removed, with the formation of soild calcium carbonate.

Figure 3.8 The effect of hard water on a heating pipe.

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

This can cause a problem in boilers, hot water tanks and cooling systems, because the calcium carbonate formed clogs up the pipes and restricts flow (see Figure 3.8). This is referred to as **limescale**. Similar deposits will also build up in domestic appliances such as kettles, washing machines and dishwashers in hard water areas.

Permanent hard water contains chlorides and/or sulfates of calcium and magnesium, and boiling does not soften this water. Of course, it is possible for water to contain a variety of calcium and magnesium compounds, and so its hardness may be a mixture of temporary and permanent. In such cases, heating will remove some of the hardness, but not all.

Specified practical

Testing water hardness

Soft water lathers easily with soap but hard water does not. Soap reacts with hard water to form the calcium or magnesium salt of the organic acid in the soap. These salts are insoluble and form greyish soap scum, but no lather. We can therefore test the hardness of water by seeing how well it lathers when soap is added. Remember that temporary hardness can be removed by boiling but permanent hardness cannot.

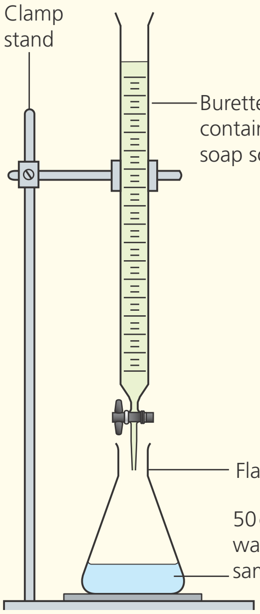


Figure 3.9 Experimental set-up to test water for hardness.

Apparatus

- Conical flask and stopper
- Burette
- 100 cm^3 measuring cylinder
- Water samples, labelled A, B, C and D
- Boiled samples of A, B, C and D
- Stop watch
- Soap solution

Procedure

1. Wear eye protection.
2. Measure 50 cm^3 of water sample A into a conical flask (Figure 3.9).
3. Using the burette, add 1 cm^3 of soap solution, insert the stopper and shake vigorously for 5 seconds.
4. Repeat step 3 until a lather forms and lasts for 30 seconds.
5. Record the total volume of soap solution added.
6. Repeat steps 3 to 5 with 50 cm^3 of the boiled sample of A.
7. Repeat steps 2 to 6 with water samples B, C and D.
8. Record all your results in a table.
9. Draw a bar graph of the results.

Analysing your results

1. Use your results to describe the hardness of each water sample, and whether this hardness is temporary or permanent. Explain the reasons for your identification.
2. This method works fairly successfully for *comparing* the hardness of the water samples. Suggest an improvement that could be made if you wanted a more accurate *measure* of water hardness.

Softening hard water

There are three main ways of softening water, each with their own advantages and disadvantages.

Boiling

Boiling removes hardness and is relatively easy and cheap, but it is only practical for small quantities of water, and it also causes deposits on the water container. It cannot remove permanent hardness. Boiling converts the calcium and magnesium hydrogencarbonates into the respective carbonates, which are insoluble and so precipitate out (see page 9).

Adding sodium carbonate

Sodium carbonate can be purchased as washing soda and is added to washing machine loads to soften the water. It can be used to soften both temporary and permanent hard water. It prevents the calcium and magnesium ions bonding to the washing detergent, meaning that less detergent has to be used. The carbonate ions from sodium carbonate react with the calcium and magnesium ions in the water to produce **insoluble precipitates**. For example:

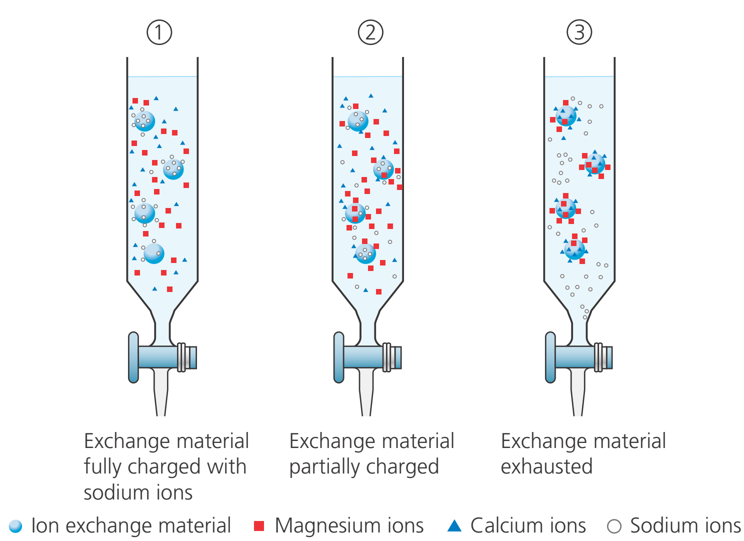
$$Ca^{2+}(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + 2Na^+(aq)$$

Sodium carbonate is cheap and can remove permanent hardness, but limescale is still formed.

Ion exchange columns

An ion exchange column is a tube filled with a resin (Figure 3.10). Water is passed through the column and sodium ions on the resin are exchanged for calcium and magnesium ions, so removing them from the water and softening it. Eventually the resin has to be 'regenerated' by passing concentrated sodium chloride through it to replace the lost sodium ions. Water softeners are quite expensive but can treat a large amount of water, and can remove both temporary and permanent hardness.

Figure 3.10



Activity

Is hard water good for you?

Although inconvenient in a number of ways, hard water is not a health hazard, and it often tastes rather better than soft water. There have been some claims that hard water might actually benefit health. Calcium and magnesium are essential minerals in our diet, and in areas where the water is very hard, drinking water may provide a substantial amount of the dietary needs.

In recent years, there have been other claims about the health benefits of hard water, such as: '*Hard water has some fantastic health benefits that seem to encourage longer life expectancy and improved health*'. The evidence for these health claims needs to be examined.

People living in hard water areas across the world seem to have lower rates of heart disease and the proportion of people dying from heart disease is lower than that in soft water areas.

The differences in heart disease in hard and soft water areas are quite small, and some studies have found no link at all.

There are a number of other diseases that are more common in soft water areas, and some of these diseases are not thought to be linked with the drinking water.

Four controlled experimental studies have shown no link between either water hardness in general or calcium levels in water, and heart disease.

Seven controlled experiments have looked at the effects of magnesium in drinking water on the amount of heart disease. While results were mixed, overall there does seem to be a protective effect against heart disease if the magnesium level in the water is 10 dm^3 or greater.

The World Health Organization (WHO) has concluded that: '*Although a number of epidemiological studies have shown a statistically significant inverse relationship between the hardness of drinking water and cardiovascular disease, the available data are inadequate to permit the conclusion that the association is causal*'.

Questions

1 Rewrite the WHO's conclusions in your own words.
2 Why do you think the fact that hard water areas of the world tend to have lower rates of heart disease than soft water areas is considered rather weak evidence for the hypothesis that drinking hard water reduces heart disease?
3 On the basis of the evidence, do you think there is a case for adding calcium and magnesium salts to drinking water in soft water areas?

Test yourself

10 How does distillation separate a mixture of liquids?
11 What is a supersaturated solution?
12 What chemicals make up limescale?
13 What is the chemical difference between temporary and permanent hard water?
14 Which softening methods can be used with permanent hard water?

Chapter summary

- Water in 'natural' water supplies contains dissolved gases, ions, microorganisms and pollutants.
- To achieve a sustainable water supply measures need to be taken, including reducing our water consumption and reducing the environmental impacts of abstracting, distributing and treating water.
- The treatment of the public water supply uses sedimentation, filtration and chlorination.
- There are arguments for and against the fluoridation of the water supply in order to prevent tooth decay.
- Desalination of sea water can be used to supply drinking water but there are issues about the sustainability of this process on a large scale.
- Water and other miscible liquids can be separated by distillation.
- Solubility can be measured at different temperatures to produce a solubility curve.
- Hardness in water is caused by calcium and magnesium ions and it is possible to distinguish between hard and soft waters by their action with soap.
- Temporary hard water contains calcium and magnesium hydrogencarbonates; permanent hard water is caused by calcium and magnesium chlorides and/or sulfates.
- The processes used to soften water include boiling, adding sodium carbonate and ion exchange; there are advantages and disadvantages of different methods of water softening.
- Hard water has health benefits and harmful effects.

Practice questions

1 Three samples of tap water, **A**, **B** and **C**, are to be tested for hardness using soap solution. It is suspected that sample **A** is the most hard and sample **C** the least hard.

a) Describe an experiment you would carry out to show that the above statement is true. Include your expected observations. *[4]*

b) State why hard water is considered to be:

i) good for our health. *[1]*

ii) a problem in kettles and boilers. *[1]*

2 The following processes are used in the treatment of our water supply.

sedimentation filtration chlorination

a) State the purpose of each process. *[3]*

Drinking water can be obtained by desalination.

b) State what is meant by *desalination* and name a process by which it can be carried out. *[2]*

3 The graph in Figure 3.11 shows the solubility curves of two substances.

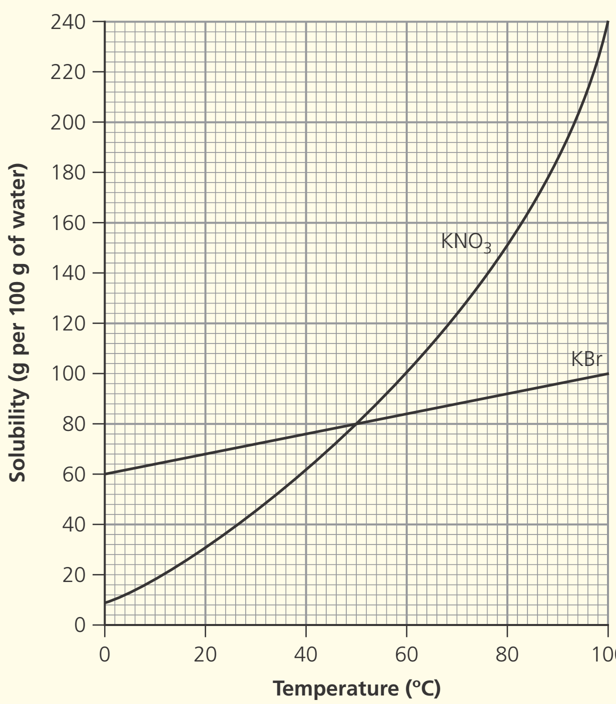


Figure 3.11

a) Use the graph to find the solubility of potassium bromide, KBr, at 60 °C. *[1]*

b) A student places 200 g of potassium bromide in 200 g of water at 60 °C and stirs until no more dissolves. Calculate the mass of solid that remains undissolved. *[2]*

c) Compare the solubilities of potassium bromide and potassium nitrate between 0 °C and 100 °C. *[3]*

(From WJEC GCSE Chemistry C2 higher, summer 2015 Q5)

4 Just over 6.1 million people in the UK receive drinking water which contains fluoride. In some of those areas the fluoride occurs naturally, but elsewhere fluoride is added artificially to the water. About 5.8 million people get drinking water to which fluoride has been added artificially.

Fluoride helps to reduce tooth decay in several ways. Decay occurs when the surface of the tooth is attacked by acid produced by bacteria in plaque. The acid causes demineralisation – the dissolving of calcium salts and phosphates out of the protective enamel covering of the tooth. This effectively breaks down the enamel and weakens the tooth. However, the dissolved chemicals stay in the plaque and, when the acid is neutralised, some of them can return back into the enamel (remineralisation).

Fluoride promotes remineralisation and also improves the quality of the enamel. It also makes developing enamel more resistant to acid attack, and inhibits the ability of plaque bacteria to produce acid.

In 2014, Public Health England (PHE) published a report which indicated that fluoridisation of water not only reduces tooth decay but may also have other beneficial effects on health. The report compared the population of Newcastle (where water is fluoridated) to non-fluoridated Manchester. 28% fewer 5 year olds had tooth decay in Newcastle compared to Manchester. The number of people suffering from kidney stones and bladder cancer was found to be lower in Newcastle than in Manchester.

a) What percentage of the people who get fluoridated drinking water have it added artificially? *[1]*

b) Which ion would be formed when calcium dissolves? *[1]*

c) Use the information in the passage to suggest why fluoridation seems to be particularly beneficial to the dental health of young children. *[2]*

d) Suggest a reason why we can have some confidence in the conclusion about tooth decay from the PHE data. *[1]*

e) The report made no claim that the reduction in kidney stones or bladder cancer were directly due to fluoridation. Suggest a reason for this. *[1]*

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