# Important materials

# 2

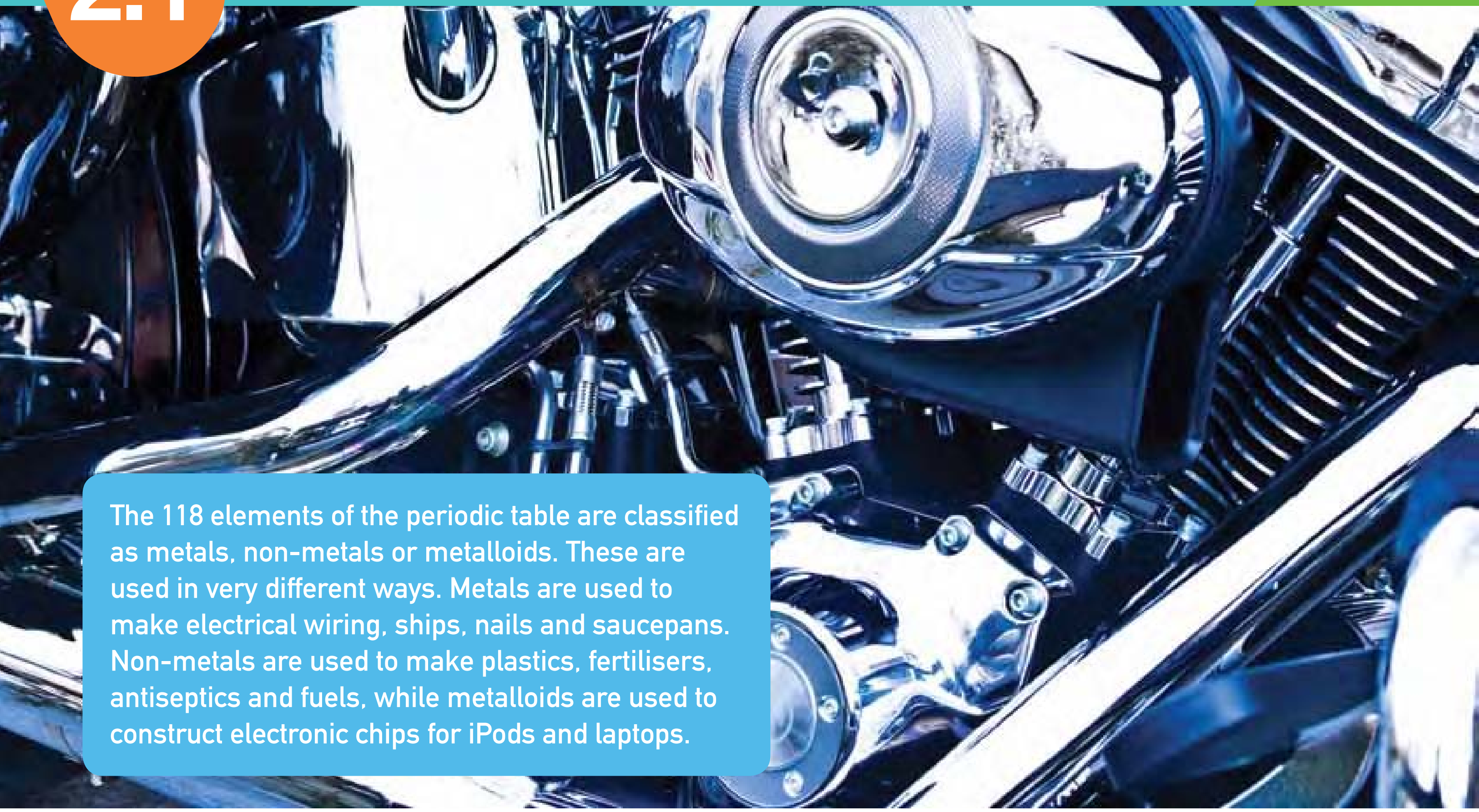

## HAVE YOU EVER WONDERED . . .

- why body piercings are usually made of stainless steel?
- if drugs can search for cancer and then destroy it?
- what the difference is between an acid and a base?
- what pH measures?

**After completing this chapter students should be able to:**

- describe the properties of different elements in the periodic table
- explain how properties of metals and non-metals are related to their uses
- outline the use of nanotechnology in medicine, such as the delivery of pharmaceuticals
- describe the properties of acids and bases.

# 2.1 Metals, non-metals and metalloids



The 118 elements of the periodic table are classified as metals, non-metals or metalloids. These are used in very different ways. Metals are used to make electrical wiring, ships, nails and saucepans. Non-metals are used to make plastics, fertilisers, antiseptics and fuels, while metalloids are used to construct electronic chips for iPods and laptops.

**KEY**

- Non-metals
- Metals
- Metalloids

atomic number — 13
symbol — Al
name — aluminium

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H hydrogen | | | | | | | | | | | | | | | | | 2 He helium |
| 3 Li lithium | 4 Be beryllium | | | | | | | | | | | 5 B boron | 6 C carbon | 7 N nitrogen | 8 O oxygen | 9 F fluorine | 10 Ne neon |
| 11 Na sodium | 12 Mg magnesium | | | | | | | | | | | 13 Al aluminium | 14 Si silicon | 15 P phosphorus | 16 S sulfur | 17 Cl chlorine | 18 Ar argon |
| 19 K potassium | 20 Ca calcium | 21 Sc scandium | 22 Ti titanium | 23 V vanadium | 24 Cr chromium | 25 Mn manganese | 26 Fe iron | 27 Co cobalt | 28 Ni nickel | 29 Cu copper | 30 Zn zinc | 31 Ga gallium | 32 Ge germanium | 33 As arsenic | 34 Se selenium | 35 Br bromine | 36 Kr krypton |
| 37 Rb rubidium | 38 Sr strontium | 39 Y yttrium | 40 Zr zirconium | 41 Nb niobium | 42 Mo molybdenum | 43 Tc technetium | 44 Ru ruthenium | 45 Rh rhodium | 46 Pd palladium | 47 Ag silver | 48 Cd cadmium | 49 In indium | 50 Sn tin | 51 Sb antimony | 52 Te tellurium | 53 I iodine | 54 Xe xenon |
| 55 Cs caesium | 56 Ba barium | 57–71 lanthanoids | 72 Hf hafnium | 73 Ta tantalum | 74 W tungsten | 75 Re rhenium | 76 Os osmium | 77 Ir iridium | 78 Pt platinum | 79 Au gold | 80 Hg mercury | 81 Tl thallium | 182 Pb lead | 83 Bi bismuth | 84 Po polonium | 85 At astatine | 86 Rn radon |
| 87 Fr franchium | 88 Ra radium | 89–103 actinoids | 104 Rf rutherfordium | 105 Db dubnium | 106 Sg seaborgium | 107 Bh bohrium | 108 Hs hassium | 109 Mt meitnerium | 110 Ds darmstadium | 111 Rg roentgenium | 112 Cn copernicium | 113 Uut ununtrium | 114 Uuq ununquadium | 115 Uup ununpentium | 116 Uuh ununhexium | 117 Uus ununseptium | 118 Uuo ununoctium |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lanthanides | 57 La lanthanum | 58 Ce cerium | 59 Pr praseodymium | 60 Nd neodymium | 61 Pm promethium | 62 Sm samarium | 63 Eu europium | 64 Gd gadolinium | 65 Tb trebium | 66 Dy dysprosium | 67 Ho holmium | 68 Er erbium | 69 Tm thulium | 70 Yb ytterbium | 71 Lu lutetium |
| Actinides | 89 Ac actinium | 90 Th thorium | 91 Pa protactinium | 92 U uranium | 93 Np neptunium | 94 Pu plutonium | 95 Am americum | 96 Cm curium | 97 Bk berkelium | 98 Cf californium | 99 Es einsteinium | 100 Fm fremium | 101 Md mendelevium | 102 No nobelium | 103 Lr lawrencium |

**Figure 2.1.1** The periodic table displays all 118 known elements. There are roughly four times as many metals as there are non-metals and metalloids in the table, but in the universe the number of non-metallic atoms is far greater than the number of metallic atoms. This is because stars are made mainly of hydrogen and helium.

# Elements and the periodic table

Elements are the building blocks from which everything else is made. As the **periodic table** in Figure 2.1.1 shows, elements are classified according to their properties as being metal, non-metal or metalloid.

# Metals

Metals are **lustrous** (they shine when polished), **malleable** (they can be bent into new shapes without breaking) and **ductile** (they can be stretched into wires). These are just three of the physical properties that have made metals invaluable to humans throughout history. They form the basis of much of our technology and art, from horseshoes, swords, electrical wiring and the frames of skyscrapers to jewellery, statues and the gold leaf on paintings.

Figure 2.1.2 outlines the physical properties shared by the metallic elements.

**Metals are dense.** Almost all metals are denser than water and so will sink when dropped into it. The only exceptions are lithium (Li), sodium (Na) and potassium (K). These float on water.

**Metals are thermal conductors.** They pass heat easily along and through them.

**Metals are electrical conductors.** They pass electricity along and through them.

**Metals are lustrous.** They shine when polished or freshly cut.

**Metals are malleable.** They can be hammered and squashed to form new shapes.

**Metals are ductile.** They can be stretched and drawn into long thin wires.

**Metals are solid at room temperature.** Mercury (Hg) is an exception because it is a liquid.

**Figure 2.1.2** The physical properties of metals

Table 2.1.1 Pure metals and their uses

| Pure metal | Element symbol | Uses | Properties that make it particularly suited to its use |
|---|---|---|---|
| Aluminium | Al | Overhead electricity cables, saucepans and cans, aluminium foil | Excellent conductor of heat and electricity, extremely light, non-toxic |
| Copper | Cu | Electrical wiring | Excellent electrical conductor, easily stretched into wires |
| Lead | Pb | Flashing around windows and roofs to stop water entry | Very soft and easily bent, resists corrosion |
| Mercury | Hg | Clinical thermometers | Liquid at room temperature, expands rapidly when heated, leaves tubes clean once it retreats, leaving no traces |
| Sodium | Na | Nuclear reactor coolant | Conducts heat well, melts at 98°C, allowing molten sodium to flow along pipes in the reactor. |
| Tin | Sn | Coating for steel cans used for storing food | Stops steel from rusting, doesn't react with food, non-toxic |
| Zinc | Zn | Coating for iron and steel (galvanised iron) | Is more reactive than iron and so protects it from rusting |

## Pure metals

Most metals cannot be used as pure elements because they have properties that make them impractical. For example, most pure metals are too soft to be made into anything useful. Table 2.1.1 shows metals that are often used in their pure form.

## Alloys

Most of the metals around you are not pure elements but are alloys. An **alloy** is a metal (known as the **base metal**) combined with small amounts of another element. The properties of the new alloy are usually an improvement over those of the base metal. For example, **steel** is much stronger and harder than its iron base metal, allowing it to be used in everything from paperclips, staples, nails and screws to cars, ship hulls and the frames of bridges and skyscrapers. Steel is an alloy of iron with small amounts of carbon added to it. Different amounts of carbon produce different alloys.

- Wrought iron contains almost no carbon and is the closest alloy to pure iron.
- Mild steel has only 0.5% carbon.
- Hard steel or tool steel has about 1% carbon.
- Cast iron has between 2.4% and 4.5% carbon. Cast iron is strong but **brittle**, shattering easily if hit or dropped.

Steel can be further improved by adding chromium and nickel to it. This addition produces rust-resistant **stainless steel**. Stainless steel is used in hot, wet and salty environments that would cause rapid rusting of other types of steel. This is why stainless steel is used in kitchens, on ships, for surgical instruments and for jewellery for body piercings like that in Figure 2.1.3.

Figure 2.1.3 High-grade stainless steel doesn't rust and so is ideal for body piercings.

Pure gold is so soft and fragile that any jewellery made from it would soon break. For this reason, silver and/or copper are added to it to create a stronger alloy. The **carat** scale measures the amount of pure gold in jewellery, with pure gold rated as 24 carat. Jewellery is often 18 carat, meaning that it is 18/24 (three-quarters or 75%) gold.

Other alloys are shown in Table 2.1.2.

**SciFile**

**Gold isn't always gold!**

Australian 'gold' $1 and $2 coins contain 92% copper, 6% aluminium and 2% nickel (and no gold). The 'silver' coins are 25% nickel and 75% copper. In contrast, the first circular 50 cent coins of 1966 were 80% silver! Eventually, this made them far more valuable as metal than as a coin!

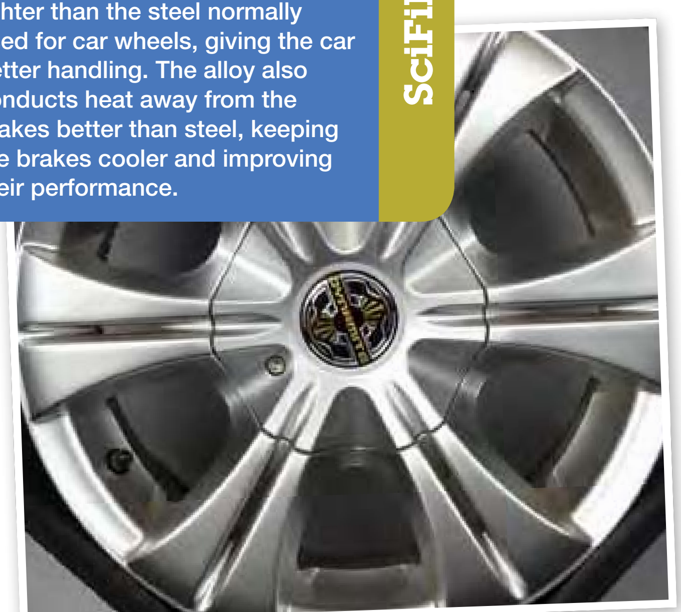
Table 2.1.2 Alloys and their uses

| Alloy | Composition | Uses | Advantages |
|---|---|---|---|
| Brass | 70% Cu, 30% Zn | Hinges, door handles, fittings on boats and ships, musical instruments, e.g. trumpets and trombones | • Good looking<br>• Doesn't corrode much<br>• Stronger than its base metal (copper) |
| Bronze | 95% Cu, 5% Sn | Statues, ornaments, bells | • Good looking<br>• Doesn't corrode easily<br>• Sonorous (makes a good ringing sound when struck)<br>• Harder than brass<br>• Stronger than its base metal (copper) |
| Duralumin | 96% Al, 4% Cu, traces of Mg and Mn | Aircraft frames | • Very light<br>• Stronger than its base metal (aluminium) |
| Solder | 60 to 70% Sn<br>30 to 40% Pb | Joining metals together, electrical connections,<br>low-friction bearings | • Easy to melt<br>• Easy to use |
| Cupronickel | 75% Cu, 25% Ni | 'Silver' coins (5, 10, 20 and 50 cents) | • Hard wearing<br>• Looks like silver |
| EPNS (electroplated nickel silver) | 46 to 63% Cu<br>18 to 36% Zn<br>6 to 30% Ni | Plated onto cutlery, plates and bowls | • Looks like silver<br>• Cheaper than silver<br>• Resists corrosion |
| Dental amalgam | 43 to 54% Hg<br>20 to 35% Ag<br>10% Cu<br>2% Zn<br>traces of Sn | Tooth fillings | • Hardens slowly after being mixed |

## SciFile

### Mag wheels

Mag wheels (alloy wheels) are made from an alloy of magnesium and aluminium. This alloy is much lighter than the steel normally used for car wheels, giving the car better handling. The alloy also conducts heat away from the brakes better than steel, keeping the brakes cooler and improving their performance.



## INQUIRY science 4 fun

### Rust away!

Can you get steel to rust in one day?

**Collect this …**

- steel wool (plain, with no soap)
- vinegar
- liquid bleach
- screw-top glass jar

**Do this …**

1. Put a lump of steel wool in the bottom of the screw-top jar.
2. Pour in enough water to cover the steel wool.
3. Add a little vinegar and a little bleach.
4. Screw on the top of the jar and check what happens to the steel wool over the next day.

**Record this …**

**Describe** what happened.

**Explain** why you think this happened.

# Non-metals

Most non-metals are found naturally as gases in the air. A few are solids found in the Earth's crust, such as the sulfur found around volcanoes. The physical properties of non-metals are very different from those of metals. You can see these properties in Figure 2.1.4.

**Non-metals are poor conductors of heat and electricity**. They are thermal and electrical insulators.

**Non-metals have relatively low melting and boiling points**. Bromine is a liquid at normal room temperature. The other non-metals are gases or easily melted solids.

**Non-metals are brittle**. Solid non-metals tend to crumble into powders.

**Non-metals are dull**. They have little or no shine.

**Figure 2.1.4** The physical properties of non-metals

**SciFile**

**Carbon wheels!**

In 2010, Deakin University in Geelong (Victoria) and research firm CFusion released the world's first car wheel constructed from a *single* carbon fibre. Being incredibly light yet strong, the wheel promises to dramatically enhance car performance. It is to be used in one of the world's fastest cars, the Shelby Ultimate Aero.

## Carbon

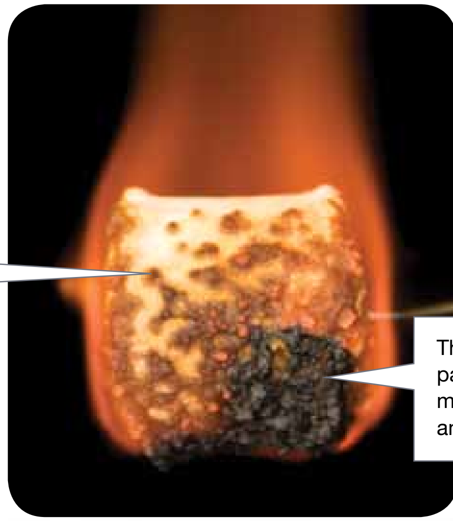
Carbon is an unusual element because its atoms combine with other carbon atoms and with atoms of other elements (usually hydrogen and oxygen) to form lattices, long chains and rings. Over 90% of all known compounds contain carbon, some of which are essential to life on Earth. Carbon exists in molecules in every living thing and anything that was once part of a living thing.

Pure carbon exists in several different forms, called **allotropes**. Three common allotropes are:

- amorphous carbon
- diamond
- graphite.

These are shown in Figure 2.1.5.

**Amorphous carbon:** black powder and burnt bits you find on burnt toast, after bushfires, in charcoal and in coal.

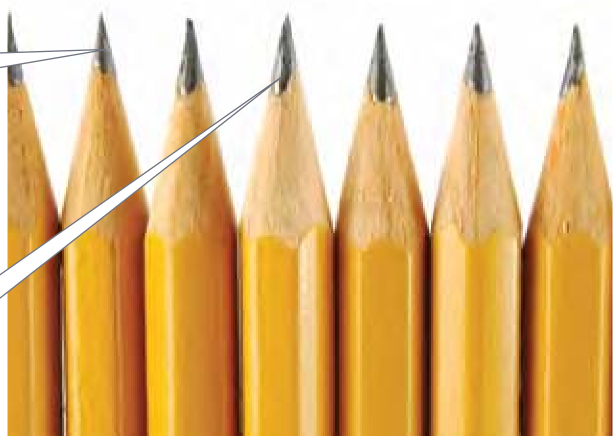


The black, burnt part of this marshmallow is amorphous carbon.

**Diamond:** the hardest known natural substance. Only 20% of diamonds are gem-grade. The rest are used to cut glass, metal and masonry or are crushed to make abrasives.

Dental drills often have diamond tips. This is a scanning electron microscope (SEM) image of a diamond tip.

**Graphite:** a soft, slippery solid that conducts electricity. It is an excellent lubricant and forms the electrodes in many batteries and the connection brushes in electric motors.



The grey ‘lead’ in pencils is a graphite/clay mix.

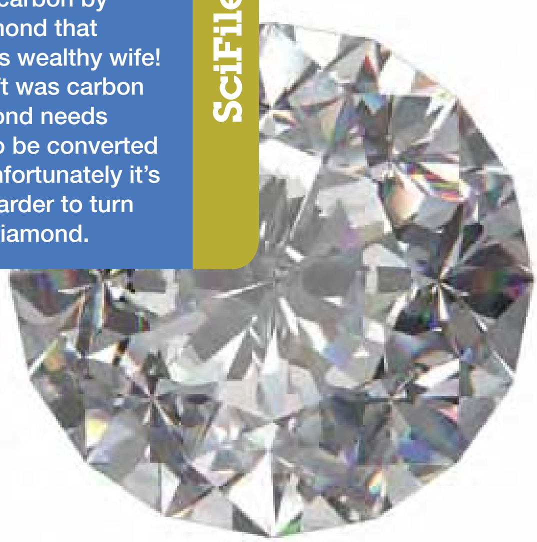
Figure 2.1.5 Some of the forms in which carbon exists

2 p46 2.3

**SciFile**

### Diamond destruction!

The English scientist Sir Humphry Davy (1778–1829) demonstrated that diamond was a form of carbon by burning a diamond that belonged to his wealthy wife! All that was left was carbon dioxide. Diamond needs about 800°C to be converted to graphite. Unfortunately it’s much, much harder to turn graphite into diamond.



## Metalloids

**Metalloids** (sometimes called semi-metals) act like non-metals in most ways. However, they do have some properties that are more like those of metals. Most importantly metalloids are semi-conductors, meaning that they can conduct electricity under certain conditions. This ability has made silicon and germanium ideal materials from which to build electronic components like the one shown in Figure 2.1.6. These components are used in devices such as laptops, LED TVs and iPads.

Figure 2.1.6 This electronic microprocessor chip is constructed using the metalloid silicon.

# 2.1 Unit review

## Remembering

1 **List** the names and symbols of three metals, three non-metals and three metalloids.

2 **List** the uses for:
  a graphite
  b silicon.

3 **Name** the only metal that is a liquid at normal room temperature.

4 **List** the different types of steel, from the lowest carbon content to the highest.

5 For stainless steel, **name** the:
  a base metal
  b added metals that give it rust resistance.

## Understanding

6 **Explain** why most metals sink in water.

7 **Define** the following terms:
  a lustrous
  b malleable
  c brittle.

8 **Explain** why gold is rarely used in its pure form.

9 **Explain** why the slipperiness of graphite makes it ideal for use in grey-lead pencils.

10 **Describe** how you can show that diamond and graphite are made from the same element.

## Applying

11 **Identify** two physical properties that make metals the ideal material from which to construct electrical wires.

12 **Identify** the metal common to both the alloys brass and bronze.

13 **Calculate** the fraction and percentage of pure gold in:
  a a 12-carat gold ring
  b a 9-carat gold nose stud
  c a 22-carat gold chain.

14 Wood, paper and food scraps all burn, leaving charcoal and ash behind. This suggests that they all have the same basic element in them. **Identify** what that element is.

## Analysing

15 **Compare** the number of elements that are metallic, non-metallic and metalloids.

16 **Classify** the following properties as normally belonging to metals or non-metals:
  a ductile
  b normally gas or liquid
  c dense
  d malleable
  e brittle
  f lustrous
  g dull
  h most are solid
  i thermal and electrical insulators
  j excellent thermal and electrical conductors

17 **Compare** three allotropes of carbon by listing their similarities and differences.

## Evaluating

18 Cans that contain soup, dog food or vegetables are made predominantly of steel, yet are often called tins. **Propose** a reason why.

19 Graphite is carbon (a non-metal) but it conducts electricity like a metal. **Use** this information to **propose** a reason why carbon could be classified as a metalloid instead of a non-metal.

20 **Propose** what would be the base metal in a ferrous alloy. (Use the element symbols for metals to help you.)

## Inquiring

1 Research why roof decking is corrugated or 'ribbed' and how Colorbond® roofing differs from other metal roofing materials.

2 Some people are now having the amalgam fillings in their teeth replaced with other materials. Research why.

3 Research the important non-metals chlorine, nitrogen and hydrogen. Find:
  a their melting point and boiling point
  b their state at normal room temperature
  c where they are found naturally
  d what they are used for.

4 Research what a buckyball and a nanotube are. Find what element forms their structure and find their properties and uses.

5 Design an experiment to test whether graphite or wood is a better conductor of heat and electricity. You could use 'lead' pencils in your experiment.

# 2.1 Practical activities

## 1 Making steel stronger

Heating changes the properties of steel because it changes the size of its crystals.

### Purpose

To determine which treatment makes steel tougher.

### Materials

- four steel hairpins
- steel wool
- Bunsen burner, bench mat and matches
- wooden peg
- beaker, tub or sink filled with cold water
- pliers (optional)

### Procedure

1. Copy the table from the results section into your workbook.
2. Count the number of bends it takes to snap a hairpin. One bend is out and in again. Enter the number in your table.
3. Hold another hairpin with the peg and heat the bend of the pin in a blue Bunsen burner flame until it is red hot (see Figure 2.1.7). Allow it to cool on the bench mat. This process is known as normalising or **annealing**.

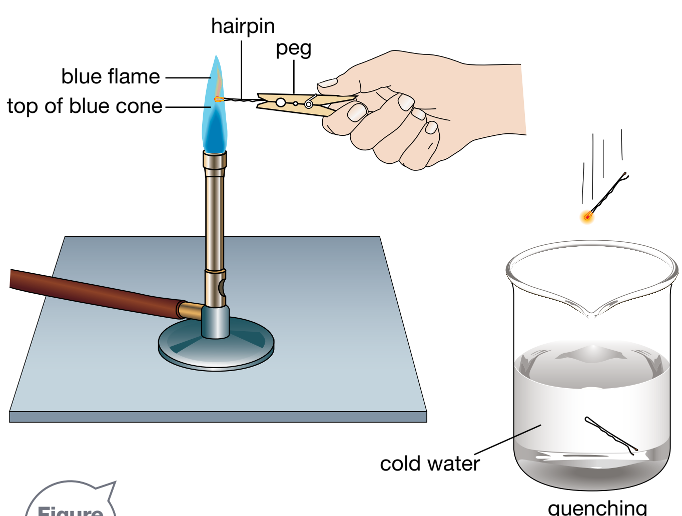



Figure 2.1.7

4. Heat another hairpin in the same way, then cool it rapidly by dropping it into a beaker of water. This process is known as **quenching**.
5. Repeat step 4 with the remaining hairpin, then polish the bend with steel wool. Re-heat the bend of the pin, removing it occasionally to check whether the bend has gone blue. Once it has, remove the pin from the flame and allow it to cool on the mat. This process is known as **tempering**.
6. Bend each of the pins as before, counting the bends until they break. Record your counts in the results table.

### Results

Use a table like this to record your observations.

| Treatment | Number of bends needed to break pin | Did the treatment make the pin tougher? |
|---|---|---|
| No treatment | | |
| Normalising/ annealing | | |
| Quenching | | |
| Tempering | | |

### Discussion

1. **Outline** the processes of annealing, quenching and tempering.
2. **State** which treatment caused your hairpin to become:
   a. more brittle (easier to snap)
   b. more malleable (more 'bendy' and less likely to snap).
3. Fast cooling produces small crystals; slow cooling makes bigger ones. **Predict** which of the treatments produced the biggest crystals.
4. **Propose** reasons why bigger crystals make steel tougher than small crystals.
5. Blacksmiths repeatedly heat, hammer and cool (quench) steel in the process of making horseshoes. **Propose** a reason why.

# 2.1 Practical activities

## 2 Making oxygen

### Purpose

To prepare and test oxygen gas.

### Materials

- 1 large test-tube, rubber stopper with opening and glass tube to fit
- hosing to fit glass tube
- 2 test-tubes with stoppers
- test-tube rack
- retort stand, bosshead and clamp
- large container (such as an ice-cream container)
- 10 mL measuring cylinder
- hydrogen peroxide solution
- manganese(IV) oxide pellets
- wooden splint
- access to electronic scales

**SAFETY**

Hydrogen peroxide burns. Wear safety glasses, a lab coat or apron, and rubber gloves.

### Procedure

**Part A: Preparation of oxygen**

1. Use the electronic scale to measure out approximately 1 g of manganese(IV) oxide pellets.
2. Use the measuring cylinder to carefully measure out 5 mL of hydrogen peroxide.
3. Set up the equipment as shown in Figure 2.1.8.

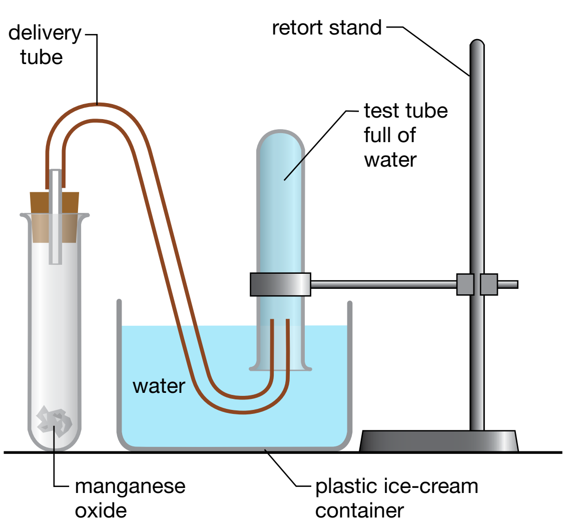



Figure 2.1.8

4. Fill both the two smaller test-tubes with water. Put your thumb over the end on one, upend it and clamp as shown. Put the other one in the test-tube rack for later on.
5. Remove the rubber stopper and drop the manganese(IV) oxide pellets into the large test-tube.
6. Add the hydrogen peroxide and replace the rubber stopper.
7. The inverted test-tube should fill with oxygen gas. Remove the test-tube when full of gas, stopper it and place it in the rack.
8. Fill the other test-tube with oxygen and store it in the rack.
9. The reaction in the large test-tube can be stopped by carefully adding water to it.

**Part B: Testing oxygen**

10. Use one tube of collected gas to make as many observations as you can about oxygen. For example, waft the gas towards you and attempt to smell it.
11. Light the wooden splint, allow it to burn for a few seconds and then blow it out. Insert the glowing end of the splint into the second test-tube of oxygen and record what happens.

### Results

1. Construct a table to record your observations.
2. Record the state, colour and smell of oxygen gas and what it did to the glowing splint.

### Discussion

1. **Use** your observations to **propose** why fanning a fire encourages it to burn.
2. **Propose** a reason why the burning splint doesn't burst back into flame when in air, despite air having oxygen in it.

# 2.2 Nano-materials

In recent years, a new branch of science has emerged: nanotechnology. Nanotechnology has led to the development of amazing new materials, such as paint and window glass that clean themselves, fabrics that kill bacteria and resist stains, alloys that can keep clogged arteries open and molecules that can help destroy cancer cells.

## What is nanotechnology?

**Nanotechnology** is the study of how to produce and control incredibly tiny structures. These structures are known as **nanoparticles** and are so small that they cannot be seen with a normal light microscope. However, they are big enough to be seen using a scanning tunnelling microscope (STM) or an atomic force microscope. The size of these structures is measured using a unit called the **nanometre** (unit symbol nm).

A nanometre is one-billionth of a metre. This makes a nanometre about one-hundred-thousandth the width of a human hair! Although tiny, a nanometre is still large compared with atoms: about 10 atoms could fit across it. The structures that nanotechnology produces are smaller than 100 nanometres in size. Figure 2.2.1 shows how small these structures are.

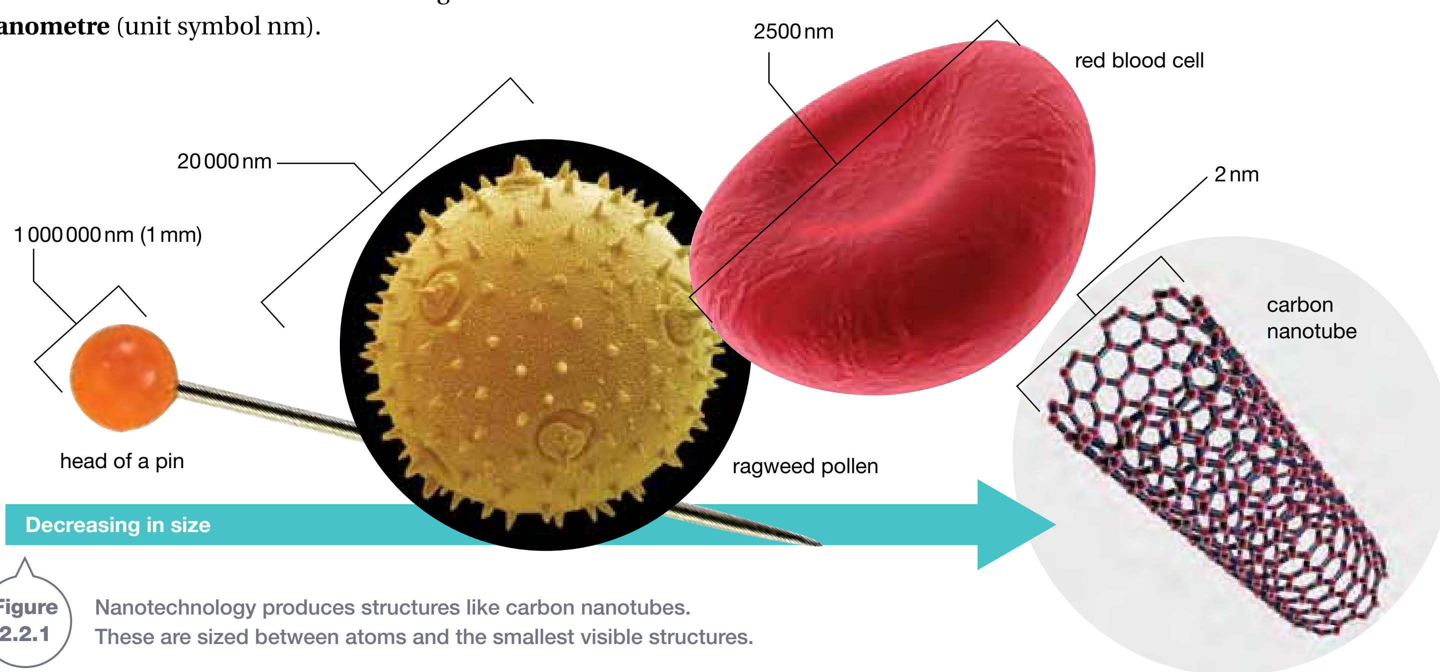



**Figure 2.2.1** Nanotechnology produces structures like carbon nanotubes. These are sized between atoms and the smallest visible structures.

INQUIRY science 4 fun

## Observing water

How well does water stick to surfaces?

Yes

### Collect this …

- eye dropper or pencil
- a selection of different surfaces (such as aluminium foil, plastic wrap, paper, raw timber, bark, different plant leaves)
- water

### Do this …

1. Place each of the surfaces horizontally on a table or bench.
2. Fill the eye dropper with water or dip the pencil into water. Use it to carefully place a drop of water on each surface.
3. View the water drop on each surface from its side and draw what it looks like.

### Record this …

**Describe** what you observed.

**Explain** why some materials might encourage drops to form, while others do not.

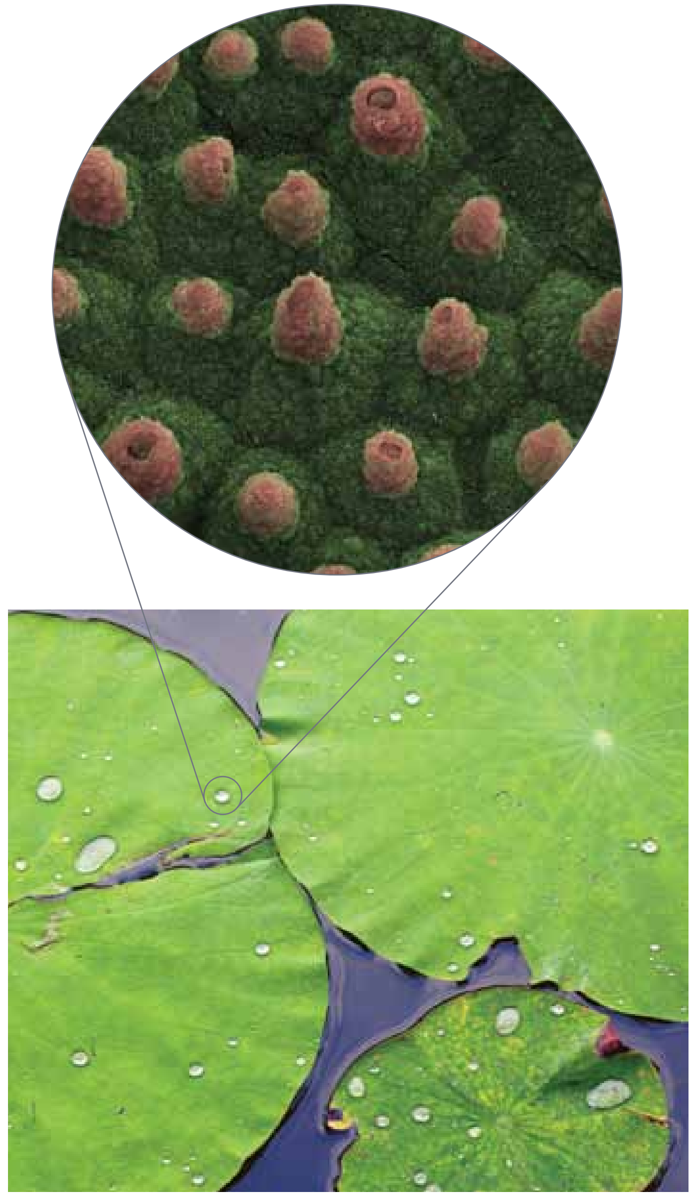


Figure 2.2.2 Lotus leaves are water-repellent. Water just forms beads and rolls off. Although the leaf looks smooth, an SEM view of it (top of picture) shows its surface to be very rough.

## Self-cleaning paint

The lotus plant is a like a water-lily in that it grows with its leaves floating on water. The surface of these leaves repels water. The water drops do not wet the surface but just roll off. In 1974, Wilhelm Barthlott, a German botany professor, became interested in why. His research led to the manufacture of the world's first self-cleaning paint, called Lotusan®.

Barthlott studied lotus leaves under a scanning electron microscope (SEM) and found that the leaf surface was very rough, not smooth as expected. Figure 2.2.2 shows how rough it is. It was a combination of the roughness of the surface and the material from which it was made that prevented the water sticking to the surface.

A surface is classified as **hydrophobic** if it does not allow water to stick to it. Hydrophobic is commonly referred to as 'water-hating'. The opposite is **hydrophilic** ('water-loving'). The roughness of the lotus leaf seemed to make the surface 'super-hydrophobic', much more hydrophobic than most other known surfaces. On super-hydrophobic surfaces, water forms nearly spherical drops. You can see this in Figure 2.2.3. The angle a drop makes to its surface is known as the **contact angle**. For super-hydrophobic surfaces the contact angle is almost 180°. On less hydrophobic surfaces, the drop is spherical but with a flattened base and a smaller contact angle. On hydrophilic surfaces, the drop is flattened, with an even smaller contact angle.

As Figure 2.2.4 shows, the spherical nature of water drops allows them to pick up and carry away dirt as the drops roll across a rough surface. Less spherical drops on a smoother surface pick up the dirt but then re-deposit it back onto the surface.

Lotusan is a self-cleaning paint that mimics the rough surface of the lotus leaf. Water on it forms near-spherical drops which then roll across the surface, picking up and washing away dirt as they go.

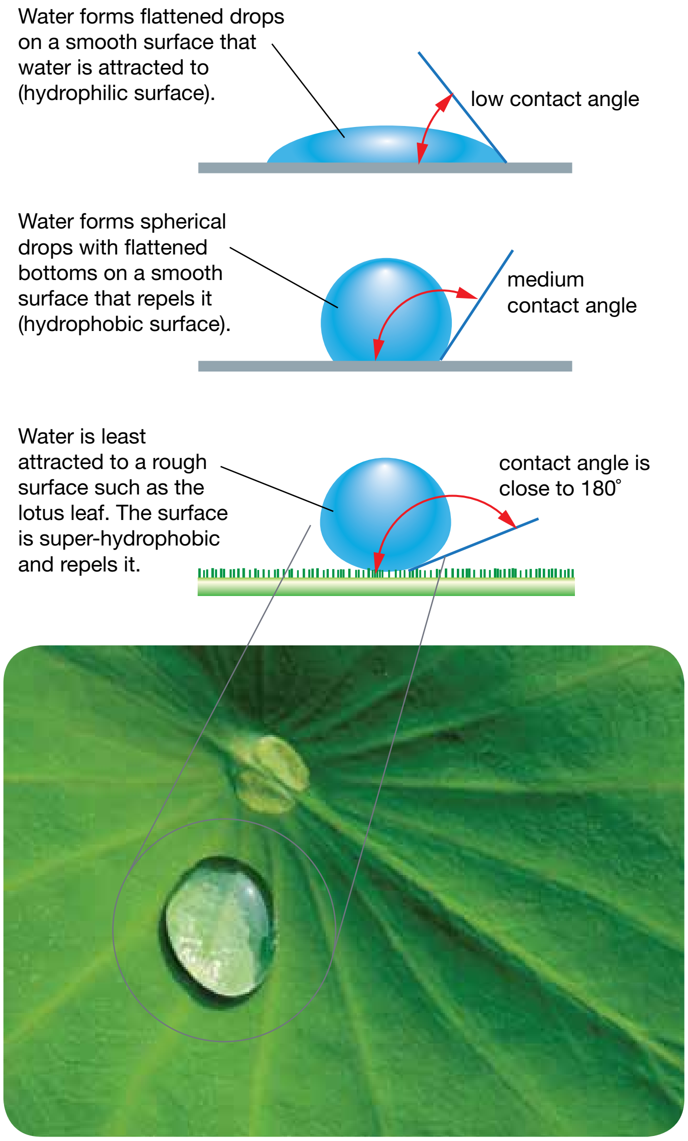



**Figure 2.2.3** The shape of a water droplet depends on whether it is attracted to or repelled by the surface it is on.

## Self-cleaning glass

The British company Pilkington has developed a self-cleaning glass that it calls Activ™ glass. To make the glass, Pilkington has used the opposite approach to the one used to make the self-cleaning paint. It has made the surface hydrophilic, or more attractive to water.

The scientists at Pilkington discovered the self-cleaning properties when they coated glass in titanium dioxide. In sunlight the titanium dioxide becomes electrically charged (called a **photocatalytic** effect). These electric charges destroy materials found in grease and fingerprints and change them into water-soluble substances. This makes the glass surface hydrophilic. Water spreads across the glass evenly, disolving dirt and helping to wash the glass clean. Figure 2.2.5 shows how this happens.

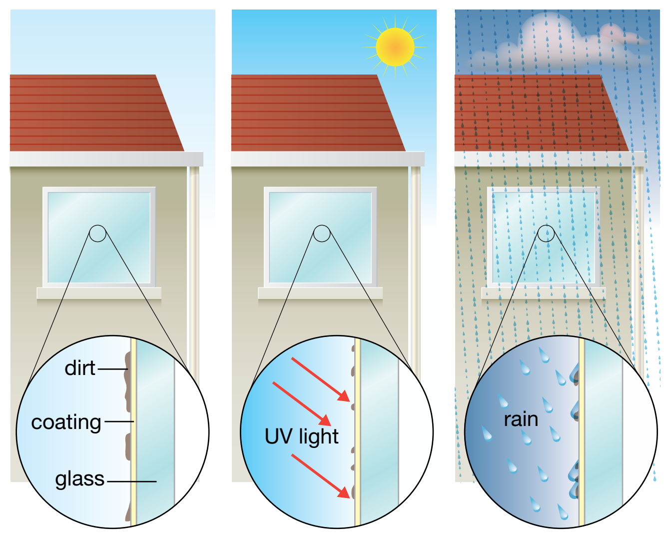



**Figure 2.2.5** Activ™ glass is a self-cleaning glass that uses a photocatalytic effect to allow water to evenly wet the surface and then run off.

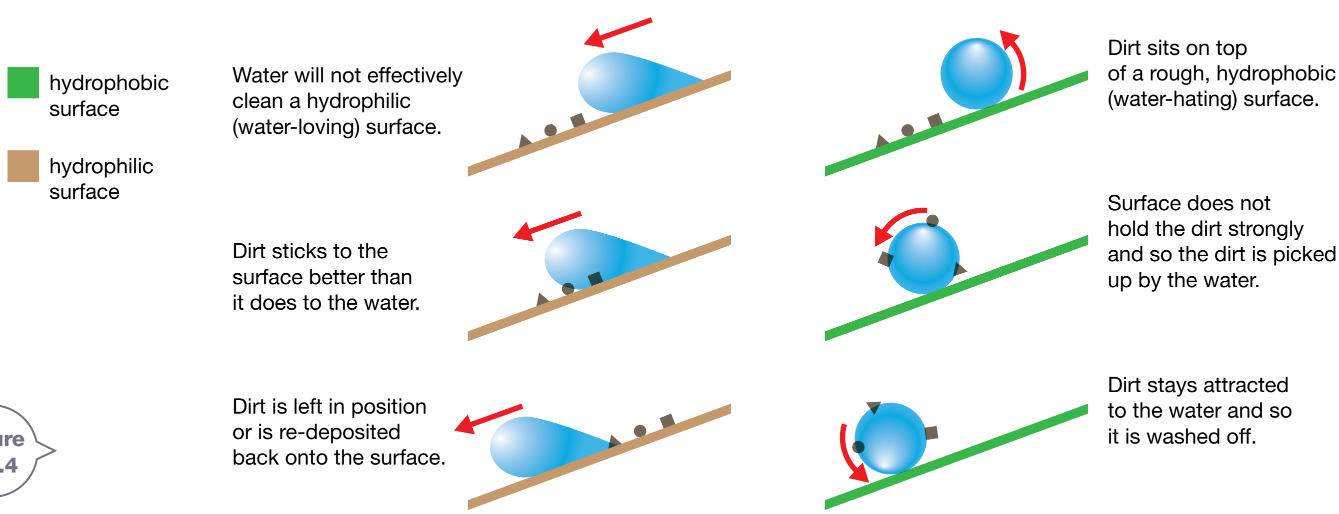



**Figure 2.2.4** Water can wash dirt off rough surfaces like the lotus leaf.

# Nanofabrics

Self-cleaning fabrics are coated in nanoparticles that produce a rough surface of super-hydrophobic, water-repelling material.

Nano-Tex® is one type of self-cleaning fabric that uses nanoparticles that take the form of whiskers. These whiskers cause water to wash dirt off the surface in the same way that it does on a lotus leaf. The whiskers also make the fabric stain resistant. Figure 2.2.6 shows how small these whiskers are.

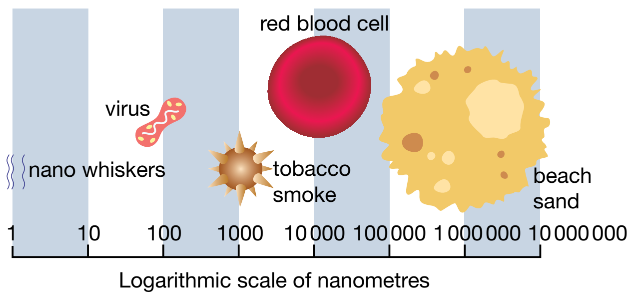



Figure 2.2.6 Nano-Tex® fabric uses tiny 'whiskers' of fabric to make the surface rough, like that of a lotus leaf. Nano-Tex treatment particles are one million times smaller than a grain of sand.

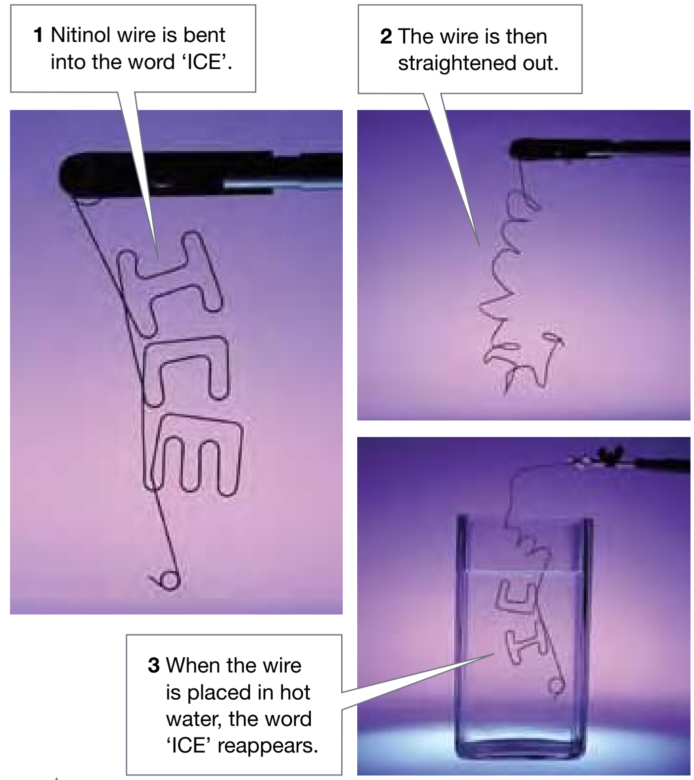



Figure 2.2.7 Nitinol is a shape memory alloy. When reheated, it 'remembers' its original shape.

Another substance used in self-cleaning fabrics is zinc oxide. Zinc oxide is resistant to ultraviolet (UV) light and so it protects the fabric from sunlight. Zinc oxide also has a photocatalytic effect, like the titanium dioxide used in self-cleaning glass. This effect kills bacteria, keeping the material hygienic. The photocatalytic effect also breaks down dirt, allowing it to be washed off by water.

# Shape memory alloys

**Shape memory alloys (SMAs)** are metal alloys that change shape as the temperature changes. An example is shown in Figure 2.2.7. Shape memory alloys are said to retain a 'memory' of the shape they were given when cold. If you bend them into a new shape, they return to their original shape when they are heated. The first SMA discovered was an alloy of nickel and titanium, called **Nitinol**.

Nitinol can be made with different properties by mixing different amounts of nickel and titanium. In this way, it can be made to remember its shape at different temperatures.

Nitinol and other shape memory alloys are being used in human surgery for a variety of purposes. For example, Nitinol is used to construct devices called stents. A **stent** is a small tube that is inserted into an artery clogged with fatty cholesterol. The stent is crushed to make it easier to insert into the artery. Once the stent is in place, the body warms it up. When the stent reaches the core body temperature of 37°C, it returns to its original tubular shape. The stent pushes on the artery walls, opening them and allowing blood to flow freely once again. The effectiveness of stents is shown in Figure 2.2.8. Stents are now commonly made from Nitinol.

Nitinol crystals take on three different structures depending on whether the metal is warm or cold and whether forces are being applied to it. The alloy changes shape because the metal atoms rearrange into the different crystal structures as the temperature changes. You can see this in Figure 2.2.9.

A cold wire has the twinned martensite crystal structure. Twisting the wire into a new shape changes the crystal structure into the deformed martensite shape. Heating the wire causes the crystal structure to adopt the austenite shape, and the wire returns to the shape it had before it was deformed.

To set the wire in a particular shape, you bend it into the shape you want, clamp it tightly, then heat it enough (over about 120°C) to rearrange the crystal structure to the austenite phase. You keep the wire clamped until it cools. When the wire cools, its crystal structure re-forms into the twinned martensite shape, but the wire stays the shape it was because it has been held in that shape. If you change the wire's shape again and heat it, the wire returns to the shape in which it had been set previously.

1 p55
2.4

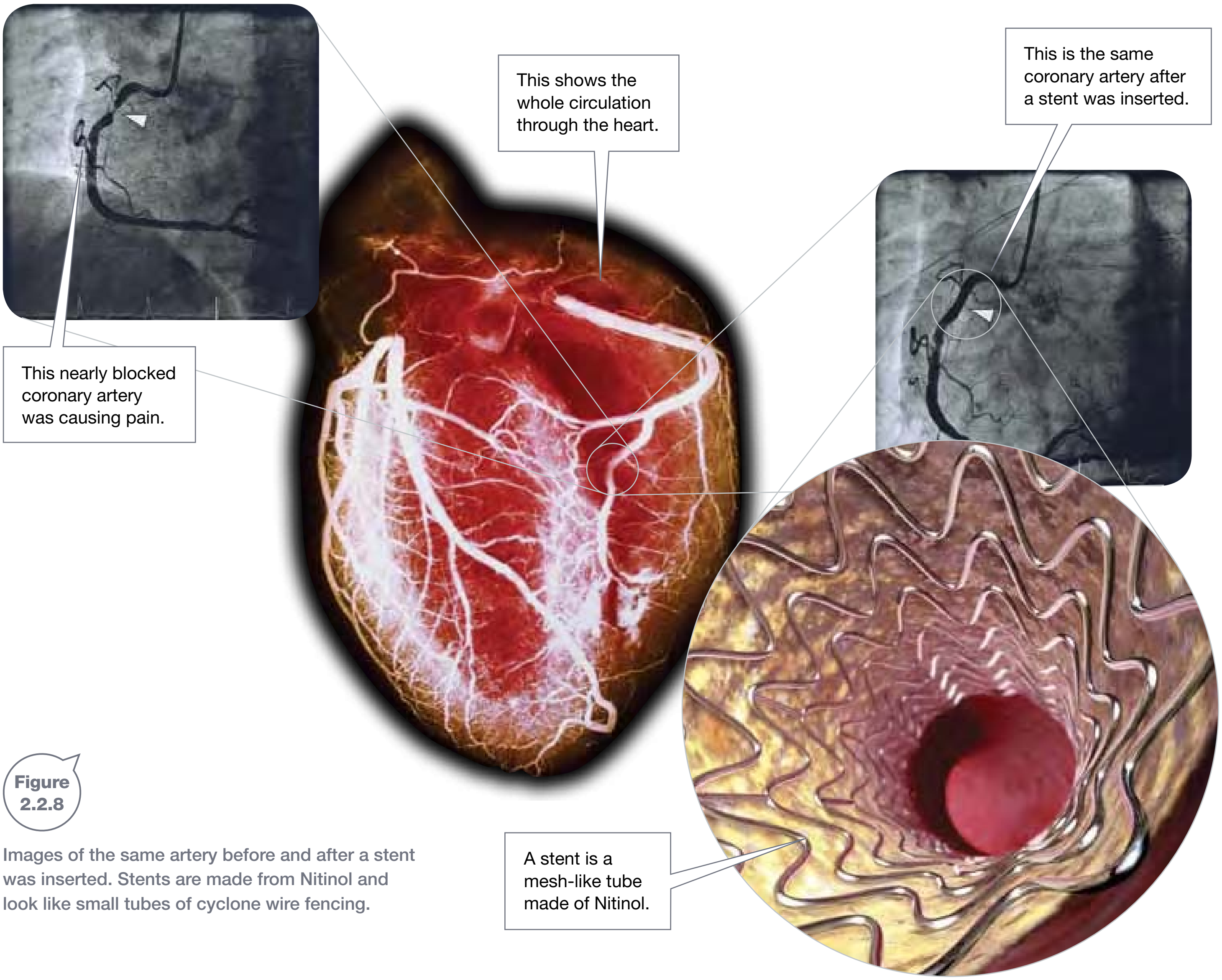



**Figure 2.2.8**

Images of the same artery before and after a stent was inserted. Stents are made from Nitinol and look like small tubes of cyclone wire fencing.

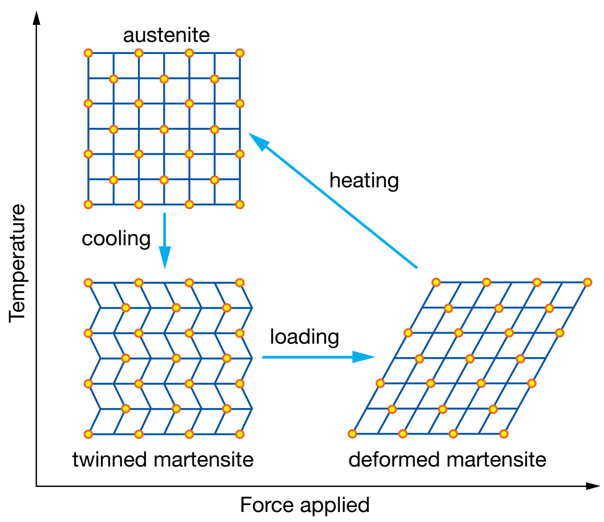



**Figure 2.2.9**

The crystal structure of Nitinol changes with temperature and how much force is being applied to it. Three shapes exist: austenite, twinned martensite and deformed martensite.

# The future of nanotechnology

## Carbon nanotubes

An exciting area of current nanotechnology research is **carbon nanotubes**. A carbon nanotube is a nano-sized cylinder of carbon atoms. Carbon atoms can join up to each other to form flat sheets of hexagons. These sheets can be rolled into tubes, like the one in Figure 2.2.10 on page 52. The properties of carbon nanotubes depend on how you roll the sheet. Rolling the sheet at different angles makes tubes with different properties and uses.

Carbon nanotubes are hundreds of times stronger than steel and are much lighter. For this reason they are being tried in the structures of cars, aircraft and buildings. Carbon nanotubes are also being researched for possible use in electronic devices such as semiconductors and microprocessors.

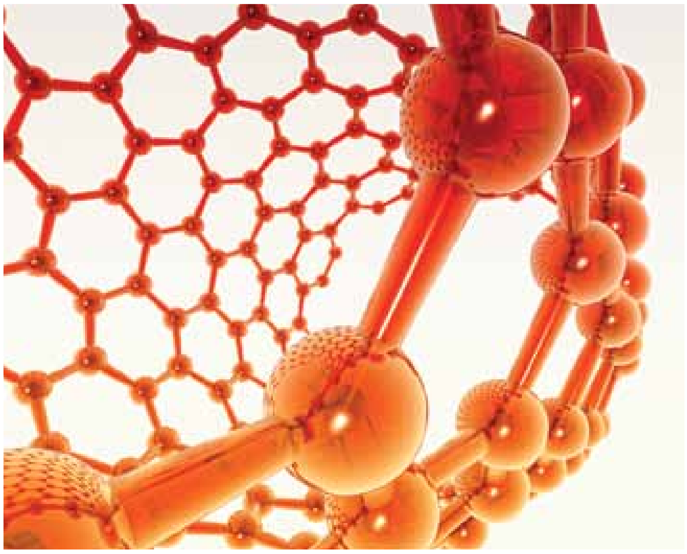


Figure 2.2.10 A model of a carbon nanotube. Carbon atoms are arranged in hexagonal units all joined together.

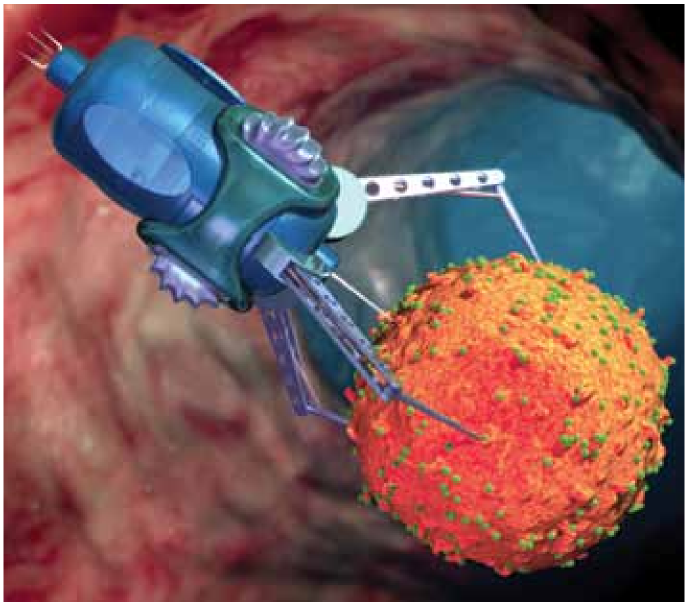


Figure 2.2.11 An artist's impression of a nanorobot targetting a particular cell

**SciFile**

**Power tennis**

A tennis racquet has been made with carbon nanotubes in the frame. It is as light as current carbon fibre racquets but is five times more rigid. Being flex resistant, these racquets are significantly more powerful than normal ones.

## Nanorobots

Nanotechnology may have its biggest impact on the medical industry. Scientists have predicted a future where patients might drink medicines, take capsules or receive injections that contain nanorobots. Nanorobots (or nanobots) are tiny devices that can get inside blood vessels and tissues to carry out a specific task, such as destroying cancer cells. Nanorobots (like the one in Figure 2.2.11) might also be able to perform surgery that is too complex and difficult for a human surgeon to do.

A major challenge is how to assemble such small robotic devices. Research has shown that it is possible to make molecular machines. One early success was to copy a protein 'motor' found both in cell membranes of bacteria and in the mitochondria of all other organisms. This protein acts like a tiny motor in that it spins around to move protons in or out of cells or mitochondria as part of energy production.

Scientists found that they could construct a nano-motor by:

- extracting the protein from the bacteria
- chemically sticking individual protein molecules to a block of silicon
- chemically attaching a tiny nickel rod to each protein.

Respiration is the chemical reaction that releases energy for the cells in your body to use. A vital part of this reaction is a molecule called ATP, which acts as an energy source for the reaction. If ATP is added to the nano-motor, then the proteins spin around like a fan. This simple motor is shown in Figure 2.2.12.

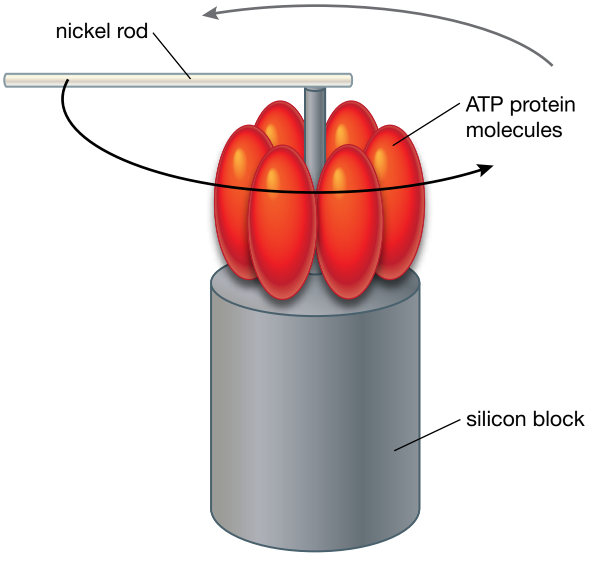



Figure 2.2.12 An artist's impression of a simple nanorobot made from the protein ATP-ase with a 750 nm nickel rod stuck to it. The nickel rod rotates like a fan.

# SCIENCE AS A HUMAN ENDEAVOUR

## Use and influence of science

### Nanomedicine

Figure 2.2.13 Chemotherapy kills healthy cells as well as cancerous ones. This makes the patient feel ill and often causes their hair to fall out.

Pharmaceuticals (medical drugs) attempt to ease or kill whatever is causing a person to be ill. Nanopharmaceuticals promise to remove many of the problems experienced with conventional drugs.

Antibiotics kill certain bacterial infections, ranging from ear infections to gangrene and stomach ulcers to sexually transmitted infections like chlamydia. Likewise, chemotherapy uses a series of poisons to kill **malignant** (rapidly growing and dangerous) cancerous cells. Unfortunately, most of these drugs do not target just the 'sick' cells but affect all the body's cells, including healthy ones. This means healthy cells are killed as well as cancerous ones, making the patient extremely ill (Figure 2.2.13).

### Nanopharmaceuticals

**Nanopharmaceuticals** are drugs that are nano-sized structures designed to deliver drugs directly to the 'sick' cells. These nanopharmaceuticals range in size from 5 nm to 300 nm and contain anything from ten or so atoms to hundreds of molecules. They can be made in different shapes such as spheres or crystals, or as needles. This allows them to target the specific surface of the 'sick' cell and leave healthy cells alone. These nano-sized drugs dissolve more easily than normal drugs, and so they are easier to prepare. Also a higher concentration of drug can be administered in a single dose.

Currently, twelve nanopharmaceuticals are approved for medical use or in human trials. One is Rexin-G®, a 100 nm wide particle that seeks out cancerous cells that have **metastasised** (spread throughout the body). These cells are usually impossible to find by medical imaging techniques and eventually cause new cancers around the body. Rexin-G® delivers a gene to the cancerous cells, destroying them while leaving healthy cells unaffected.

Cancerous tumours need a strong blood supply and cause the body to develop a mass of small blood vessels to help them grow. The drug fumagillin stops this development, but it tends to poison the patient after repeated doses. However, fumagillin can be attached to a nano-sized structure that delivers it directly to the blood vessels feeding a tumour. In this way, it can block the growth of cancerous tumours without making the patient ill.

These are two examples of what nanopharmaceuticals might do. Hormones and vaccines might also be delivered by a nanoparticle.

### Australian research

Malaria is one the world's deadliest diseases, killing up to 3 million people every year. Malaria is caused by the parasite *Plasmodium falciparum* and is passed on when an infected mosquito bites. The parasite then lives within the blood cells. Diagnosis is difficult, especially in the remote regions of Asia and central/southern Africa where malaria is common and pathology laboratories are rare. Dr Vipul Bansal is an expert in nanotechnology who lectures at RMIT University in Melbourne. In 2010, he was awarded a US$100 000 grant from the Bill and Melinda Gates Foundation to continue his research into a bandaid-like patch that would detect the presence of the malaria parasite. Infected blood cells tend to stick to the walls of blood vessels and tiny needles in his patch will test these cells for malaria. A nanochip in the patch will then analyse and record the data, which will give the result on a scanner passed over it.

2.5

2.2

# Unit review

## Remembering

1 a **State** the unit symbol for nanometre.
  b **State** approximately how many atoms would fit side-by-side across a nanometre.

2 **Name** a type of:
  a self-cleaning glass
  b self-cleaning fabric
  c shape memory alloy
  d nanopharmaceutical.

3 **State** the approximate contact angle for a water drop on a lotus leaf.

4 **State** what causes the photocatalytic effect in titanium oxide.

5 **List** the advantages that carbon nanotubes have over steel.

## Understanding

6 **Define** the term *nanotechnology*.

7 **Explain** why spherical drops are better than other drops in cleaning dirt off a surface.

9 **Outline** why self-cleaning glass washes clean.

10 **Describe** how nanofabrics behave differently from normal fabric.

11 **Outline** how shape memory alloys change shape as the temperature is changed.

12 a **Describe** what a stent is and what it is used for.
  b Nitinol stents are crushed before being inserted into an artery. **Explain** how they regain their shape.

13 **Outline** how Dr Vipul Bansal's malaria-detection patch will work.

14 **Describe** how carbon atoms are arranged in a carbon nanotube.

## Applying

15 **Calculate** how many nanometres are in:
  a 1 cm
  b 1 mm
  c 0.001 mm (1/1000th of a mm).

16 Velcro tape uses little hooks and loops of material that hold together (see Figure 2.2.14). You can see these hooks and loops when you shine a bright light on a strip of the tape. **Use** the definition of nanotechnology to **determine** whether Velcro qualifies as a nanomaterial.

## Analysing

17 **Contrast** the terms *hydrophobic* and *hydrophilic*.

18 **Contrast** the methods by which scientists produced self-cleaning glass and self-cleaning paint.

## Evaluating

19 Jesse heated a length of cold metal wire to 70°C but it did not change shape. Based on this evidence, he said that the wire could not have been Nitinol. However, the wire *was* Nitinol. **Propose** a reason why Jesse was incorrect.

20 **Propose** the advantages of a stent being made from Nitinol instead of a normal alloy like stainless steel.

## Creating

21 **Construct** a diagram to help you **define** the term *contact angle*.

## Inquiring

1 a Design a way of comparing hairy leaves with smooth leaves to determine whether either type is hydrophobic.
  b Show your teacher your plan and, if approved, carry out your experiment.

2 Use the key word Rexin-G to find an animated video showing how this nanopharmaceutical works.

Figure 2.2.14 Velcro tape

# 2.2 Practical activities

## 1 Nitinol

### Purpose

To investigate properties of Nitinol, a shape memory alloy.

### Materials

- 3 lengths of mid-temperature range Nitinol wire (1 × 10 cm and 2 × 30 cm lengths)
- beaker tongs
- 6V battery or portable power pack
- 2 electrical leads with alligator clips
- switch
- Bunsen burner, gauze mat and bench mat
- 250 mL beaker
- 0–110°C thermometer

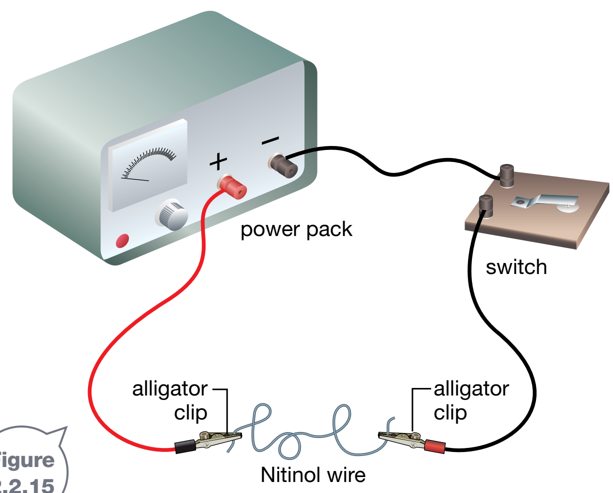



Figure 2.2.15

### Procedure

1 Bend the 10 cm length of Nitinol into any shape you choose.

2 Heat a beaker of water to 70°C.

3 Place your bent wire into the hot water and observe and record your observations.

4 Bend a 30 cm cool piece of Nitinol wire into any shape.

5 Set the power pack to 6 volts. Connect the Nitinol wire into a circuit as shown in Figure 2.2.15. Do *NOT* turn on the power yet.

6 Plug in the power pack and turn it on. Close the electrical switch for only as long as needed. Stop as soon as the Nitinol wire starts changing shape (the wire can be damaged by too much heat). Do *NOT* touch the wire, because it could be hot. Record your observations.

7 Wrap the remaining 30 cm length of Nitinol wire tightly around the end of a pair of tongs and grip it with the tongs so it cannot be moved.

8 Light the Bunsen burner, adjust the collar to half open and heat the Nitinol wrapped around the tongs for about a minute. Allow the wire to cool for several minutes and then remove it from the tongs.

9 When the wire is cool, bend it into any shape you like.

10 Reheat the beaker of water until it reaches 70°C, then drop the bent Nitinol in.

### Extension

11 Determine whether there is a critical temperature at which Nitinol behaves as a shape memory alloy. Do this by repeating steps 1 to 3 but with water heated to different temperatures.

### Results

Record your observations.

### Discussion

1 **Explain** the result seen in step 3 of the Procedure.

2 **Explain** the result seen in step 6 of the Procedure.

3 **Explain** the result from step 10 of the Procedure.

# 2.3 Acids and bases

Acids have a reputation for being extremely dangerous. But some, like those found in lemon juice and vinegar, are safe enough to eat and use in cooking. Bases also vary, from the caustic soda used to strip paint to gentler bases found in soap and disinfectant. Indicators show whether a solution is acidic or basic (alkaline). Some also measure how acidic or alkaline the solution is.

## Acids

An **acid** is a substance that releases hydrogen ions ($H^+$) into an aqueous solution (containing water). Examples are the hydrochloric acid that's in your stomach and the ethanoic acid (acetic acid) found in vinegar.

### Properties of acids

Acids share similar chemical properties. Acids:

- are corrosive. An acid burn is shown in Figure 2.3.1
- have a sour taste (think of the taste of vinegar)
- turn blue litmus paper red (shown in Figure 2.3.2)
- react with some metals, releasing hydrogen gas and leaving a salt behind
- conduct electricity
- are neutralised by bases, producing water and a salt.

Figure 2.3.1 Acid burns can be severe, particularly if the acid is spilt into sensitive tissue such as in the eye.

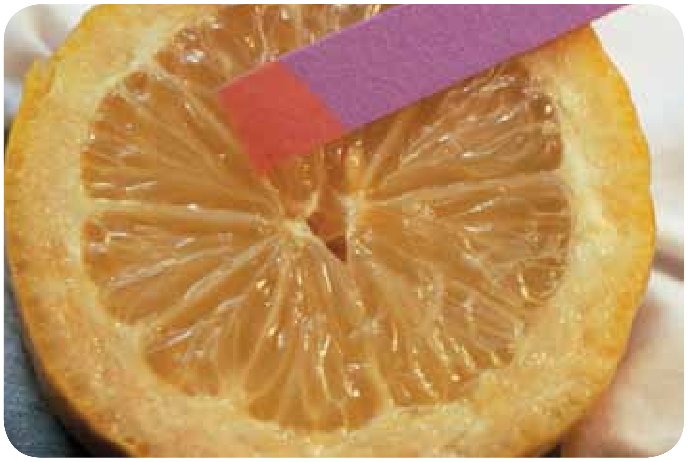


Figure 2.3.2 Acid turns blue litmus paper red.

**SciFile**

**Animal acids and bases**

A bite from a bull-ant hurts because the ant injects methanoic acid (also known as formic acid, HCOOH) into a cut made with its pincers. A bee sting also contains methanoic acid. Wasps and jellyfish inject a base. It's a different chemical but it still hurts!

## The strength of acids

Acids are molecular compounds made up of atoms from different elements. For example, a molecule of nitric acid ($HNO_3$) contains one hydrogen atom, one nitrogen atom and three oxygen atoms. Like nitric acid, all acids have hydrogen atoms in their molecules.

The acids you will work with in the laboratory (including nitric acid) are not pure substances but are solutions of acid mixed with water. When mixed with water, some of the hydrogen atoms in the acid molecule are released to form **hydrogen ions** ($H^+$).

The strength of an acid depends on how many hydrogen ions are released. An acid is a strong one if most of its molecules release hydrogen ions into solution. Nitric acid is an example of a strong acid, as are hydrochloric acid ($HCl$) and sulfuric acid ($H_2SO_4$). In contrast, an acid is weak if only a few of its molecules release hydrogen ions. An example of a weak acid is vinegar (ethanoic acid or acetic acid). Figure 2.3.3 compares a strong acid with a weak acid.

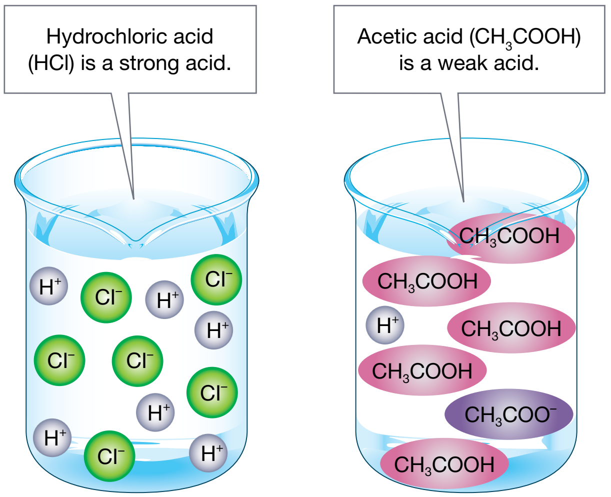



Figure 2.3.3 Strong acids like hydrochloric acid release lots of $H^+$ ions into solution. Weak acids like acetic acid (vinegar) release very few $H^+$ ions.

The number of hydrogen ions in an acid solution depends on:

- the strength of the acid. Solutions of strong acids have many more $H^+$ ions than weak acids of the same concentration. The strength of some different acids is shown in Table 2.3.1 on page 58.
- the concentration of the acid. This in turn depends on the amount of water mixed with it. If the acid solution is concentrated, there will be more hydrogen ions in the solution than in a dilute solution of the same acid.

Table 2.3.1 Examples of acids

| Strong acids | | |
|---|---|---|
| **Acid** | **Chemical formula** | **Used for/found in** |
| Hydrochloric | $HCl$ | • Cleaning mortar off bricks<br>• Your stomach (part of its gastric juices) |
| Nitric | $HNO_3$ | • Making fertilisers, dyes and explosives |
| Sulfuric | $H_2SO_4$ | • Making other chemicals, dyes, fertilisers, synthetic fibres and plastics |

| Weak acids | | |
|---|---|---|
| **Acid** | **Chemical formula** | **Use for/found in** |
| Ascorbic | $C_6H_8O_6$ | • Vitamin C |
| Acetylsalicylic | $C_9H_8O_6$ | • Making aspirin |
| Carbonic | $H_2CO_3$ | • Rain water<br>• Fizzy soft drinks and beer |
| Citric | $C_6H_8O_7$ | • Citrus fruits (such as lemons, limes, oranges)<br>• Tomatoes |
| Ethanoic (acetic) | $CH_3COOH$ | • Vinegar |
| Malic | $C_4H_6O_5$ | • Apples<br>• Most unripe fruits |
| Lactic | $C_3H_6O_3$ | • Milk, yoghurt<br>• Your muscles after heavy exercise, making them hurt |
| Tannic acid | $C_{76}H_{52}O_{46}$ | • Wood stains<br>• Tea |
| Tartaric | $C_4H_6O_6$ | • Grapes, bananas |

## Bases and alkalis

A **base** is a substance that releases **hydroxide ions** ($OH^-$). You use a weak base every time you use soap. If a base can be dissolved in water, it is also known as an **alkali**. The solution it forms is known as an **alkaline solution**. Bases such as caustic soda can burn you as badly as acids can, and so bases need to be treated with as much care as acids. All bases share similar chemical properties. Bases:

- are caustic
- have a soapy, slimy feel
- turn red litmus paper blue (shown in Figure 2.3.4)
- have a bitter taste
- conduct electricity
- are neutralised by acids, producing water and a salt.

Bases form hydroxide ions ($OH^-$) in solution. Strong bases produce lots of $OH^-$ ions, while weak bases only produce a few. The strength of different bases is shown in Table 2.3.2.

Figure 2.3.4 Alkaline solutions turn red litmus paper blue.

Table 2.3.2 Examples of bases and alkalis

| Strong bases/alkalis | | |
|---|---|---|
| **Base/alkali** | **Chemical formula** | **Used for/found in** |
| Calcium hydroxide | $Ca(OH)_2$ | • Cement, mortar and concrete<br>• Stripping hair from hides to form leather<br>• Paper production |
| Sodium hydroxide (caustic soda) | $NaOH$ | • Producing soap<br>• Paint stripper<br>• Drain and oven cleaner |

| Weak bases/alkalis | | |
|---|---|---|
| **Base/alkali** | **Chemical formula** | **Used for/found in** |
| Ammonia | $NH_3$ | • Household cleaners |
| Sodium hydrogen carbonate (sodium bicarbonate, bicarbonate of soda or baking soda) | $NaHCO_3$ | • Baking, to make cakes rise |
| Magnesium hydroxide (milk of magnesia) | $Mg(OH)_2$ | • Antacids |
| Sodium carbonate | $Na_2CO_3$ | • Washing powders |
| Ammonium hydroxide | $NH_4OH$ | • Household cleaners |

# pH

The concentration of hydrogen ions ($H^+$) in a solution is measured using the **pH** scale. In an acidic solution, there are more hydrogen ions than hydroxide ($OH^-$) ions. In contrast, an alkaline solution has more hydroxide ions than hydrogen ions.

Pure water is neither an acid nor a base. It's neutral, having equal numbers of hydrogen and hydroxide ions. It has a pH of 7. As Figure 2.3.5 shows, acids have a pH less than 7, while bases and alkaline solutions have a pH greater than 7.

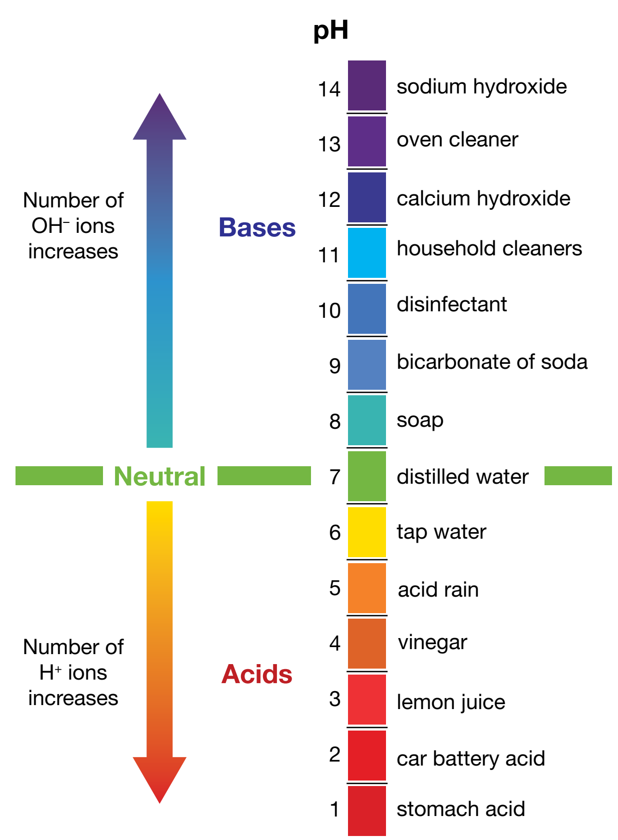



Figure 2.3.5 Neutral solutions have a pH of 7. Acidic solutions have a pH less than 7. Alkaline solutions have a pH greater than 7.

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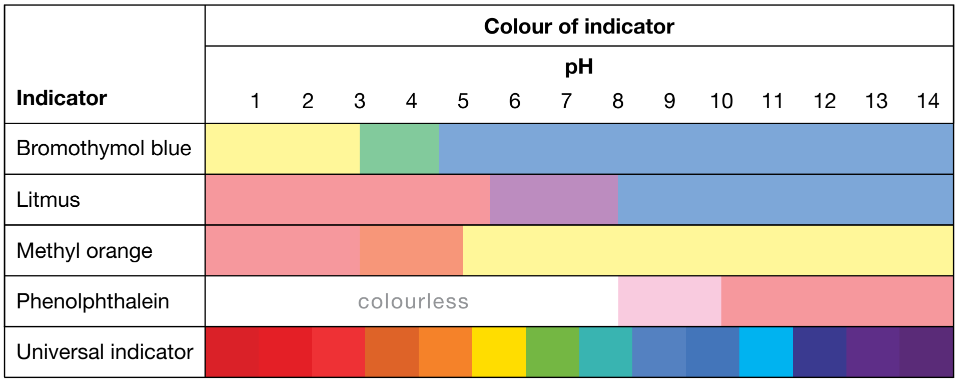
**Blood pH**

Human blood isn't neutral like pure water but is slightly alkaline, having a pH of between 7.3 and 7.4.




2.6
1 p62
2 p63
3 p63

Figure 2.3.6 Different indicators have different colours, allowing pH to be determined accurately.

## Measuring pH

**Indicators** are chemicals that change colour to show whether a substance is acidic, neutral or basic. A common indicator is **litmus paper**, which turns red when dipped into acids and blue when dipped into a base. While litmus doesn't tell you what the pH of a solution is, other indicators like universal indicator do. As Figure 2.3.6 shows, different indicators change colour at different pH values.

Another way of measuring pH is to use a pH meter. One is being used in Figure 2.3.7.

INQUIRY science 4 fun

### Testing household solutions

What is the pH of different solutions around your home?

No

#### Collect this ...

- samples of various household solutions (such as fruit juices, soft drink, sour and fresh milk, tap water, salad dressing, detergent, shampoo)
- litmus paper (blue and red)
- watch-glass or white tile

#### Do this ...

1 Pour a little of each solution onto the watch-glass or white tile.
2 Touch one end of a small strip of litmus paper into the solution and then remove it.
3 Record the colour change.

#### Record this ...

**Describe** what happened.

**Explain** what this tells you about each of the samples you tested.

## Monitoring pH

The pH of swimming pools should be between 7.4 and 7.6 to ensure that bacteria and algae can't grow. The pH of a pool changes continually when:

- people swim in it
- leaves and dust drop into it
- it is topped up with new water
- sunlight breaks down the chlorine that is added to it.

For these reasons, the pH of a pool needs to be regularly measured using a pH meter or by taking a small sample and using an indicator.

Figure 2.3.7 Pool water pH needs to be regularly monitored to ensure that the water is safe for swimmers.

Likewise, samples of river and creek water are taken regularly by environmental protection authorities to monitor pollution and the health of the water in them.

Nurseries, horticulturalists, market gardeners and home gardeners monitor the pH of the soil. Different plant types require particular pH ranges to grow well. For example, lemon trees produce more fruit when planted in an acidic soil. In contrast, fig trees produce more fruit when the soil is alkaline.

Particular care needs to be taken by anyone such as beauticians and hairdressers working with dyes, creams and lotions, because the wrong pH can burn or irritate the skin or hair. Although the pH of the materials might be known, how they react with the client's skin is not. For this reason, a small amount of chemical is usually tested on the skin and left for a short while.

# 2.3 Unit review

## Remembering

**1** **Name** the acid that is in:
- **a** vinegar
- **b** milk
- **c** lemons.

**2** **Name** the following acid and bases.
- **a** $CH_3COOH$
- **b** NaOH
- **c** $NH_3$

**3** **List** the names and chemical formulas of two strong:
- **a** acids
- **b** bases.

**4** **Name** the base that is in:
- **a** paint stripper
- **b** cement
- **c** baking soda.

**5** **Name** the type of ion formed by:
- **a** acids
- **b** bases.

## Understanding

**6** **Explain** why you have a sour taste in your mouth when you vomit.

**7** **Explain** the main advantage that universal indicator has over litmus.

## Applying

**8** **Use** Figure 2.3.6 on page 60 to **identify** the colour that the following indicators would be at pH 4.
- **a** blue litmus
- **b** phenolphthalein
- **c** universal indicator

## Analysing

**9** **Compare** the number of $H^+$ ions in a solution of nitric acid with the number found in ethanoic acid (vinegar) of the same concentration.

**10** Nitric acid is a strong acid but a solution of it might have exactly the same pH as a solution of vinegar, which is a weak acid.
- **a** **Analyse** what is happening here.
- **a** **Explain** why this can be.

## Evaluating

**11** Heartburn has nothing to do with your heart. It's caused by gastric juices rising from the stomach into the oesophagus. **Propose** what is causing the pain of heartburn.

**12** Urine has uric acid in it. **Use** this information to **propose** a reason why many gardeners encourage you to urinate near their lemon trees.

**13** The pH of most public pools is measured using a pH meter, not an indicator. **Propose** reasons why.

**14** Squashed ants have a distinctive smell. **Propose** what chemical the smell comes from.

**15** **Propose** reasons why bricklayers commonly wear gloves when working.

## Creating

**16** **Construct** a symbol (that uses no words) to be used on a sticker that would warn people that a bottle contained a concentrated solution of a strong acid like sulfuric acid.

## Inquiring

**1** Find the appropriate first aid procedures to help a person who has splashed an acid or a base in their eyes or on their skin.

**2** Research how to change soil that is too acidic or too alkaline for plant growth.

**3** Research how knowledge of soil pH is used in agriculture.

**4** Research the role of acids, bases and pH in the proper treatment of sewage.

**5** Use the key words *acid base videos* to find internet videos on acids, bases and pH.

**6** Use the key words *acid base games* to find interactive games on the internet. One you should try to find is the GEMS Alien Juice Bar Game.

**7** Design an experiment to test the hypothesis that pikelets or scones will be better using a raising agent such as sodium hydrogen carbonate than with plain flour.

# 2.3 Practical activities

## 1 Red cabbage indicator

### Purpose

To make an indicator from red cabbage.

### Materials

- red cabbage leaves (or red flower petals such as carnation, rose or geranium)
- 250 mL beaker
- hotplate or Bunsen burner, tripod, gauze mat and bench mat
- 8 test-tubes
- test-tube rack
- dilute (0.1 M) hydrochloric acid
- dilute (0.1 M) sodium hydroxide solution
- vinegar
- salt solution
- distilled water
- soft drink
- lemon juice
- antacid tablet (such as Alka Seltzer)

### Procedure

**Part A: Making the indicator**

1 Tear up one or two red cabbage leaves, and place them in the beaker with enough water so that the cabbage is just covered.

2 Heat the beaker until the water is gently boiling. Continue to boil until the water has been strongly coloured red by the cabbage leaves.

3 Allow to cool and then filter, strain or pick out the cabbage leaves.

**Part B: Testing the indicator**

4 Place 7 test-tubes in the test-tube rack and split your cabbage water equally between them. Top them up with water so that the test-tubes are about half full.

5 Use the eyedropper to put about 1 cm of the dilute (0.1 M) hydrochloric acid solution in the first of the cabbage water test-tubes. Record what colour it turns, in a table like the one opposite.

6 In the second cabbage water tube put 1 cm of vinegar. In the third tube put distilled water, in the fourth tube put salt solution, and in the fifth tube put sodium hydroxide solution. Record the results of these tests in your table.

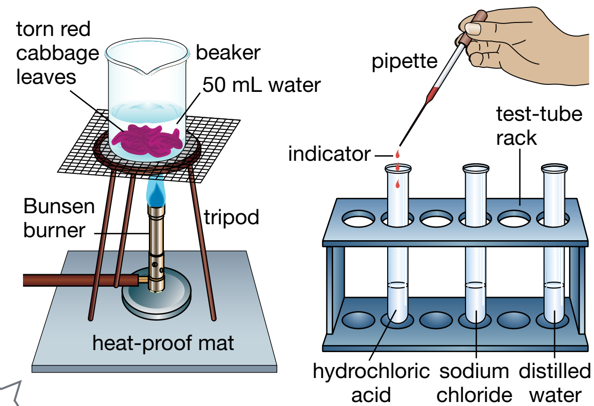



Figure 2.3.8

**Part C: Testing unknowns**

7 Add about 1 cm of lemon juice to the sixth test-tube.

8 Add about 1 cm of soft drink to the seventh test-tube.

9 Drop an antacid tablet into the eighth test-tube.

### Results

1 In your workbook, construct a table like this one.

| Test-tube/type of solution | Name of solution | Colour with red-cabbage/ petal indicator |
|---|---|---|
| 1 0.1 M strong acid | Hydrochloric acid solution | |
| 2 Weak acid | Vinegar | |
| 3 Neutral | Distilled water | |
| 4 Weak base | Salt solution | |
| 5 0.1 M strong base | Sodium hydroxide solution | |
| 6 (Unknown 1) | Lemon juice | |
| 7 (Unknown 2) | Soft drink | |
| 8 (Unknown 3) | Antacid | |

2 From their colours, identify which acid or alkaline solution the lemon juice, soft drink and antacid were most similar to.

### Discussion

Not all indicators are used in a liquid form. For example, litmus paper is used more often than liquid litmus. **Design** a way to make red cabbage indicator paper and then test it.

## 2 Green eggs

### Purpose

To use indicators to turn the whites of fried eggs green.

### Materials

- red cabbage indicator from Prac 1
- small aluminium foil pie flan
- cooking oil
- 1 raw egg
- eyedropper
- hotplate or Bunsen burner, bench mat, tripod and gauze mat
- digital camera or mobile phone

### Procedure

1. Put a little oil in the aluminium foil pie flan and crack an egg into it. Try to keep the egg yolk intact.
2. Place the pie flan on the hotplate or over the Bunsen burner on a gauze mat and tripod.
3. Gently cook the egg without stirring. As SOON as the clear liquid part of the egg starts to turn white, use the eyedropper to place a few drops of red cabbage indicator into it.

### Results

Use a digital camera or photo or film function on your mobile phone to record your observations in both parts of this experiment.

### Discussion

Red cabbage indicator turns red if it comes in contact with an acid, purple in a neutral solution and green in a basic (alkaline) solution. **Identify** whether egg white (the material that surrounds the yolk) is acidic, neutral or alkaline.

## 3 pH column

### Purpose

To construct a series of coloured layers of different pH.

### Materials

- 100 mL measuring cylinder
- universal indicator
- solid sodium carbonate
- vinegar
- spatula
- long stirring rod (such as a chopstick)

### Procedure

1. Add 90 mL water and 10 mL vinegar to the 100 mL measuring cylinder.
2. Add a drop of universal indicator.
3. Use the long stirring rod or chopstick to mix well.
4. Use the spatula to add a small amount (about the size of a couple of rice grains) of solid sodium carbonate ($Na_2CO_3$).
5. Stir again, but this time *lightly*.
6. Leave the measuring cylinder in a safe place where it won't be disturbed for at least a couple of days.

### Results

1. After a day, four or five differently coloured layers should be clearly visible. Construct a diagram showing these layers.
2. Identify and label the pH of each band.

### Discussion

1. **Describe** what happens to the pH as you move towards the top of the measuring cylinder.
2. **Explain** why the lower layers would be more basic (alkaline) and the top layers more acidic.

# 2 Chapter review

## Remembering

1 Not all diamonds are good enough to be used for jewellery.
   a **State** the percentage of diamonds that are good enough.
   b **List** what other diamonds are used for.

2 **Name** the following chemicals.
   a $CH_3COOH$
   b $H_2SO_4$
   c $NaOH$
   d $HNO_3$

3 **State** how small a nanometre is compared to a metre.

4 **List** four examples of products resulting from nanotechnology.

5 **Name** three indicators.

6 **State** the pH of pure water.

## Understanding

7 **Describe** the advantages that alloys have over their base metals.

8 **Explain** how titanium dioxide and zinc oxide can destroy matter in dirt.

9 **Explain** how nanopharmaceuticals target 'sick' cells.

## Applying

10 **Use** a diagram to **outline** how self-cleaning paint works.

## Analysing

11 A solution was tested with different indicators. The colours they turned were:

Litmus = red

Methyl orange = yellow

Phenolphthalein = colourless

Bromothymol blue = blue

   a **Use** this information to **identify** the pH of the solution.
   b **Classify** the solution as acidic, neutral or alkaline.
   c **Predict** the colour that universal indicator would turn if it was added to the solution.

12 **Compare** hydrophobic and hydrophilic surfaces.

13 **Compare** acids with bases by listing their similarities and differences.

## Evaluating

14 Carbon has been known about for over 2000 years. **Propose** reasons why it was found much earlier than most other non-metals.

15 The 'austentite start temperature' is the temperature at which Nitinol's crystal structure changes to austentite. **Propose** a suitable austentite start temperature for a Nitinol device that can be placed into the body when cold and then allowed to warm up.

16 The 'nano whiskers' on Nano-Tex fabric result in a hydrophobic surface. **Propose** reasons why.

## Creating

17 **Construct** a diagram that shows how contact angle changes as surfaces become more hydrophobic.

18 **Use** the following ten key words to **construct** a visual summary of the information presented in this chapter.

metals
carbon
Nitinol
non-metals
hydrogen ion
acids
alloys
nanotube
diamond
nanotechnology

2.7

# Thinking scientifically

**Q1** Nitinol wire can be made with different properties depending on how much nickel and titanium are included. Other elements can also be added to change its properties.The following table shows some types of Nitinol.

| Designation of Nitinol | Minimum temperature needed for shape memory effect (°C) | Description of type |
|---|---|---|
| H | 95 | High temperature range Nitinol |
| M | 45 | Mid temperature range Nitinol |
| B | 20 | Body temperature Nitinol |
| S | 10 | Super elastic Nitinol |

Imagine you wanted to do an experiment that demonstrated the shape memory effect of Nitinol using hot water from a tap. A hot water tap is typically at a temperature of about 55°C. Which of the types of Nitinol would work and why?

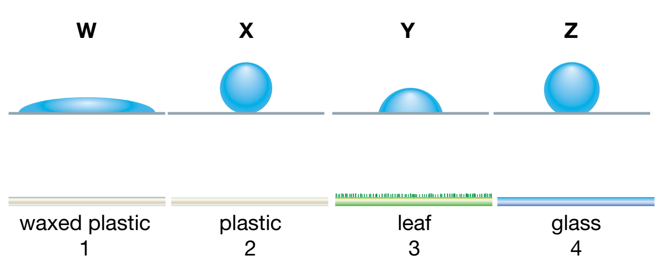
**A** H, because it will stay at the martensite crystal structure in the hot water

**B** M, because it will change to martensite crystal structure in the correct temperature range

**C** H and M, because they can change to austentite crystal structure when they cool

**D** M, B and S, because they will change to the austentite crystal structure when they are placed in the water

**Q2** Studies of the behaviour of water on four different surfaces showed water droplet shapes W, X, Y and Z as shown below. There were four different surfaces (1–4).




Which of the following is the most likely correct match of water droplet shape and the surface on which it would occur?

| Possible match | Droplet shape and surface type |
|---|---|
| **A** | W4, X3, Y2, Z1 |
| **B** | W1, X3, Y2, Z4 |
| **C** | W4, X1, Y2, Z3 |
| **D** | W3, X1, Y4, Z2 |

**Q3** Acids release hydrogen ions ($H^+$) into solution.

Use this information to identify which of the following substances could NOT be an acid.

**A** HCOOH

**B** $Fe_2O_3$

**C** $H_2CO_3$

**D** $NaHSO_4$

**Q4** pH measures the concentration of hydrogen ions ($H^+$) in solution. The more concentrated the solution is with $H^+$ ions, the lower the pH is.

An acidic solution has a pH of 5. Water is then added to it. Predict what will happen to the $H^+$ concentration of the solution.

**A** It will stay the same as before.

**B** It will increase.

**C** It will decrease.

**D** It will become the same as water.

**Q5** Predict the pH of the new solution in question 4.

It will most likely be:

**A** 4

**B** 5

**C** 6

**D** 7

# Glossary

## Unit 2.1


Allotrope

**Allotropes:** different forms of carbon

**Alloy:** a mixture of a base metal and small amounts of other elements

**Annealing:** a process in which a metal is heated until red-hot, then allowed to cool naturally; also known as normalising

**Base metal:** the main metal in an alloy

**Brittle:** shatters if hit

**Carat:** a scale for measuring the purity of gold

**Ductile:** able to be stretched into wires

**Lustrous:** shines when polished or freshly cut

**Malleable:** able to be hammered into new shapes

**Metalloid:** an element that usually displays the properties of a non-metal but conducts electricity like a metal under certain conditions; also known as a semi-metal

**Periodic table:** a list of all the known 118 elements

**Quenching:** a process in which a heated metal is cooled rapidly by dropping it into water


Tempering

**Stainless steel:** a rustless alloy of steel that includes chromium and nickel

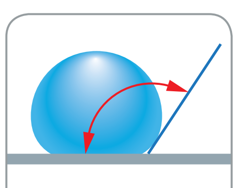
**Steel:** an alloy of iron and carbon

**Tempering:** a process in which a metal is heated, cooled rapidly (quenched) and then reheated

## Unit 2.2

**Carbon nanotube:** a nano-sized cylinder of carbon atoms

**Contact angle:** the angle that the base of a drop of water makes with the surface it is on


Contact angle

**Hydrophilic:** surfaces that attract water and allow it to stick to them; commonly referred to as 'water-loving'

**Hydrophobic:** surfaces that do not allow water to stick to them; commonly referred to as 'water-hating'


Hydrophobic

**Malignant:** rapidly growing and dangerous cancerous cells

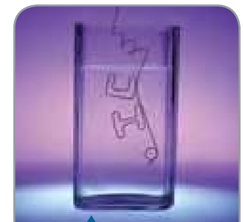
**Metastasise:** when cancer cells spread beyond their original site into the rest of the body

**Nanometre (nm):** unit of length equal to one-billionth of a metre or one-thousandth of a millimetre; unit symbol nm

**Nanoparticle:** a particle or structure that is too small to be seen with a normal light microscope

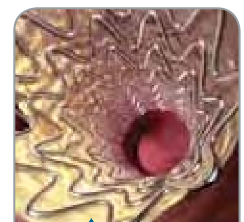
**Nanopharmaceutical:** a medical drug that is a nanoparticle or is delivered by a nano-sized structure

**Nanotechnology:** the study of how to produce, and control, structures at a scale below the size of visible particles but larger than atoms


Nitinol

**Nitinol:** a shape memory alloy made of nickel and titanium

**Photocatalytic:** an effect where sunlight causes materials to become electrically charged and able to react with organic matter and other particles


Stent

**Shape memory alloy (SMA):** a mixture of metals that changes shape as the temperature changes

**Stent:** a mesh sleeve that is inserted into clogged arteries to keep them open; commonly made of Nitinol

## Unit 2.3

**Acid:** a substance that releases hydrogen ions into an aqueous solution

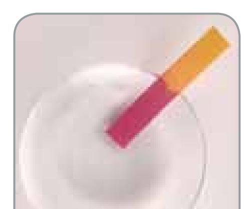
**Alkali:** a base that dissolves in water

**Alkaline solution:** a solution made of a base/alkali and water

**Base:** a substance that releases hydroxide ions

**Hydrogen ion:** $H^+$, released by acids

**Hydroxide ion:** $OH^-$, formed by bases


Litmus

**Indicator:** a chemical that changes colour to show whether a substance is acidic, neutral or basic

**Litmus paper:** a common indicator that turns red in the presence of an acid and blue in the presence of a base

**pH:** a scale used to measure the concentration of $H^+$ ions in a solution


pH