PEARSON

CHEMISTRY 11

WESTERN AUSTRALIA

STUDENT BOOK

Contents

UNIT 1: Chemical fundamentals: structure, properties and reactions

AREA OF STUDY 1 ATOMS AND ELEMENTS

How do atoms vary and what difference does this make?

AREA OF STUDY 2 COMBINING ELEMENTS

How are they held together?

AREA OF STUDY 3 INTRODUCING ORGANIC CHEMISTRY

What's special about carbon?

AREA OF STUDY 4 CHEMICAL REACTIONS AND ENERGY

How much? How hot?

UNIT 2: Molecular interactions and reactions

AREA OF STUDY 5: INTERACTING MOLECULES

How can opposite charges affect chemicals?

AREA OF STUDY 6 CHEMICALS IN THE ENVIRONMENT

How do our atmosphere and hydrosphere behave?

AREA OF STUDY 7 CHEMISTRY IN OUR WATER

What? How much? How do we know?

AREA OF STUDY 8 RATES OF CHEMICAL REACTIONS

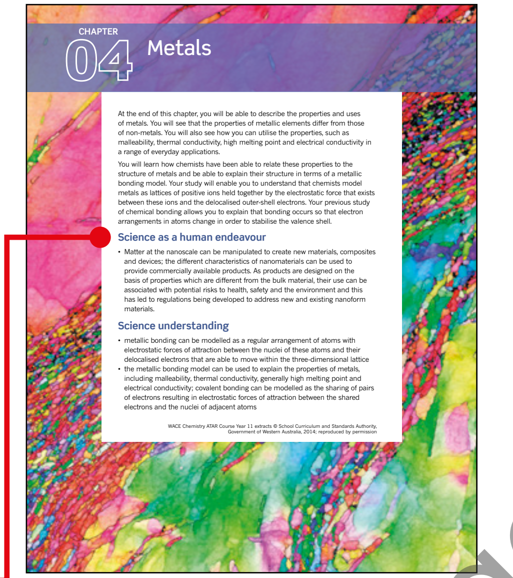
How can chemicals be forced to change?

AREA OF STUDY 9 SCIENCE INQUIRY SKILLS IN CHEMISTRY

How to use this book

Pearson Chemistry 11 Western Australia

Pearson Chemistry 11 Western Australia has been written to the *WACE Chemistry ATAR Course, Year 11 Syllabus 2015.* Each chapter is clearly divided into manageable sections of work. Best practice literacy and instructional design are combined with high-quality, relevant photos and illustrations. Explore how to use this book below.


CHAPTER 04 Metals

Science as a human endeavour

Science understanding

Chapter opening page

The chapter opening page links the syllabus to the chapter content. Science understanding and Science as a human endeavour addressed in the chapter are clearly listed.


4.3 Reactivity of metals

CHEMFILE

ChemFiles include a range of interesting information and real-world examples.

EXTENSION

Extension boxes include material that goes beyond the core content of the syllabus. They are intended for students who wish to expand their depth of understanding in a particular area.


EXTENSION

Extracting iron from iron ore

Highlight box

Focuses students' attention on important information such as key definitions, formulae and summary points.


CHEMISTRY IN ACTION

Saved by a very fast chemical reaction


4.3 Reactivity of metals

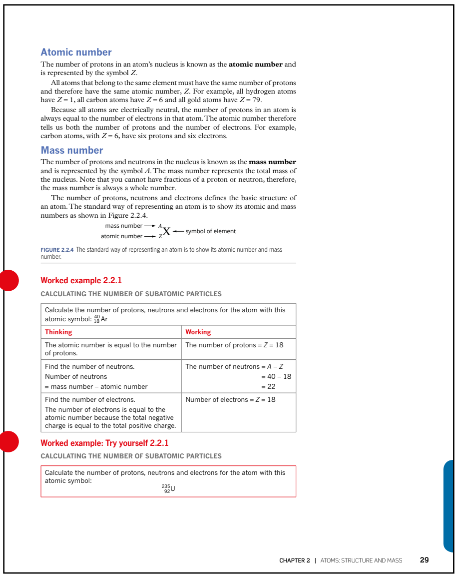
CHEMISTRY IN ACTION

Chemistry in Action boxes place Chemistry in an applied situation or relevant context and encourages students to think about the development of chemistry and its use and influence of chemistry in society.

Worked example

Worked examples are set out in steps that show both thinking and working. This enhances student understanding by clearly linking underlying logic to the relevant calculations.

Each Worked example is followed by a Worked example: Try yourself. This mirror problem allows students to immediately test their understanding.



Atomic number

The number of protons in an atom's nucleus is known as the **atomic number** and is represented by the symbol *Z*.

All atoms that belong to the same element must have the same number of protons and therefore have the same atomic number, *Z*. For example, all hydrogen atoms have $Z = 1$, all carbon atoms have $Z = 6$ and all gold atoms have $Z = 79$.

Because all atoms are electrically neutral, the number of protons in an atom is always equal to the number of electrons in that atom. The atomic number therefore tells us both the number of protons and the number of electrons. For example, carbon atoms, with $Z = 6$, have six protons and six electrons.

Mass number

The number of protons and neutrons in the nucleus is known as the **mass number** and is represented by the symbol *A*. The mass number represents the total mass of the nucleus. Note that you cannot have fractions of a proton or neutron, therefore, the mass number is always a whole number.

The number of protons, neutrons and electrons defines the basic structure of an atom. The standard way of representing an atom is to show its atomic and mass numbers as shown in Figure 2.2.4.

$${}^{A}_{Z}\mathrm{X}$$

FIGURE 2.2.4 The standard way of representing an atom is to show its atomic number and mass number.

Worked example 2.2.1

CALCULATING THE NUMBER OF SUBATOMIC PARTICLES

Calculate the number of protons, neutrons and electrons for the atom with this atomic symbol: ${}^{40}_{18}\mathrm{Ar}$	
Thinking	**Working**
The atomic number is equal to the number of protons.	The number of protons = $Z = 18$
Find the number of neutrons. Number of neutrons = mass number – atomic number	The number of neutrons = $A - Z$ $= 40 - 18$ $= 22$
Find the number of electrons. The number of electrons is equal to the atomic number because the total negative charge is equal to the total positive charge.	Number of electrons = $Z = 18$

Worked example: Try yourself 2.2.1

CALCULATING THE NUMBER OF SUBATOMIC PARTICLES

Calculate the number of protons, neutrons and electrons for the atom with this atomic symbol:

$${}^{235}_{92}\mathrm{U}$$

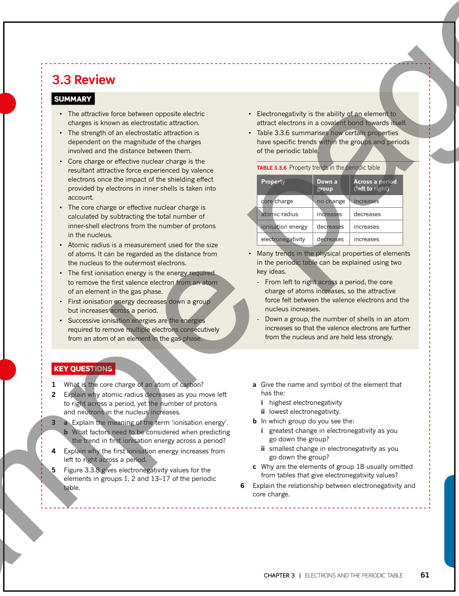
CHAPTER 2 | ATOMS: STRUCTURE AND MASS 29

Section **SUMMARY**

Each section includes a summary to assist students consolidate key points and concepts.

Section review
Key questions

Each section finishes with questions to test students' understanding and ability to recall the key concepts of the section.



3.3 Review

SUMMARY

- The attractive force between opposite electric charges is known as electrostatic attraction.
- The strength of an electrostatic attraction is dependent on the magnitude of the charges involved and the distance between them.
- Core charge or effective nuclear charge is the resultant attractive force experienced by valence electrons once the impact of the shielding effect provided by electrons in inner shells is taken into account.
- The core charge or effective nuclear charge is calculated by subtracting the total number of inner-shell electrons from the number of protons in the nucleus.
- Atomic radius is a measurement used for the size of atoms. It can be regarded as the distance from the nucleus to the outermost electrons.
- The first ionisation energy is the energy required to remove the first valence electron from an atom of an element in the gas phase.
- First ionisation energy decreases down a group but increases across a period.
- Successive ionisation energies are the energies required to remove multiple electrons consecutively from an atom of an element in the gas phase.
- Electronegativity is the ability of an element to attract electrons in a covalent bond towards itself.
- Table 3.3.6 summarises how certain properties have specific trends within the groups and periods of the periodic table.

TABLE 3.3.6 Property trends in the periodic table

Property	Down a group	Across a period (left to right)
core charge	no change	increases
atomic radius	increases	decreases
ionisation energy	decreases	increases
electronegativity	decreases	increases

- Many trends in the physical properties of elements in the periodic table can be explained using two key ideas.
  - From left to right across a period, the core charge of atoms increases, so the attractive force felt between the valence electrons and the nucleus increases.
  - Down a group, the number of shells in an atom increases so that the valence electrons are further from the nucleus and are held less strongly.

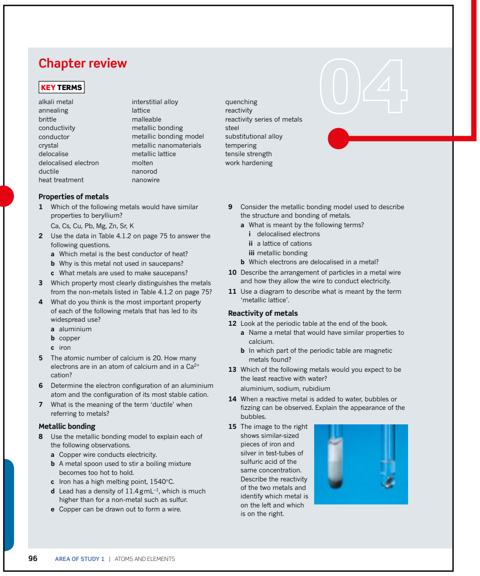
KEY QUESTIONS

1 What is the core charge of an atom of carbon?
2 Explain why atomic radius decreases as you move left to right across a period, yet the number of protons and neutrons in the nucleus increases.
3 **a** Explain the meaning of the term 'ionisation energy'.
  b What factors need to be considered when predicting the trend in first ionisation energy across a period?
4 Explain why the first ionisation energy increases from left to right across a period.
5 Figure 3.3.8 gives electronegativity values for the elements in groups 1, 2 and 13–17 of the periodic table.
  a Give the name and symbol of the element that has the:
    i highest electronegativity
    ii lowest electronegativity.
  b In which group do you see the:
    i greatest change in electronegativity as you go down the group?
    ii smallest change in electronegativity as you go down the group?
  c Why are the elements of group 18 usually omitted from tables that give electronegativity values?
6 Explain the relationship between electronegativity and core charge.

CHAPTER 3 | ELECTRONS AND THE PERIODIC TABLE 61

Chapter review

Each chapter finishes with a set of higher order questions to test students' ability to apply the knowledge gained from the chapter.



Chapter review

04

KEY TERMS

alkali metal
annealing
brittle
conductivity
conductor
crystal
delocalise
delocalised electron
ductile
heat treatment
interstitial alloy
lattice
malleable
metallic bonding
metallic bonding model
metallic nanomaterials
metallic lattice
molten
nanorod
nanowire
quenching
reactivity
reactivity series of metals
steel
substitutional alloy
tempering
tensile strength
work hardening

Properties of metals

1 Which of the following metals would have similar properties to beryllium?
  Ca, Cs, Cu, Pb, Mg, Zn, Sr, K
2 Use the data in Table 4.1.2 on page 75 to answer the following questions.
  a Which metal is the best conductor of heat?
  b Why is this metal not used in saucepans?
  c What metals are used to make saucepans?
3 Which property most clearly distinguishes the metals from the non-metals listed in Table 4.1.2 on page 75?
4 What do you think is the most important property of each of the following metals that has led to its widespread use?
  a aluminium
  b copper
  c iron
5 The atomic number of calcium is 20. How many electrons are in an atom of calcium and in a Ca^{2+} cation?
6 Determine the electron configuration of an aluminium atom and the configuration of its most stable cation.
7 What is the meaning of the term 'ductile' when referring to metals?

Metallic bonding

8 Use the metallic bonding model to explain each of the following observations.
  a Copper wire conducts electricity.
  b A metal spoon used to stir a boiling mixture becomes too hot to hold.
  c Iron has a high melting point, 1540°C.
  d Lead has a density of $11.4\,\mathrm{g\,mL^{-1}}$, which is much higher than for a non-metal such as sulfur.
  e Copper can be drawn out to form a wire.
9 Consider the metallic bonding model used to describe the structure and bonding of metals.
  a What is meant by the following terms?
    i delocalised electrons
    ii a lattice of cations
    iii metallic bonding
  b Which electrons are delocalised in a metal?
10 Describe the arrangement of particles in a metal wire and how they allow the wire to conduct electricity.
11 Use a diagram to describe what is meant by the term 'metallic lattice'.

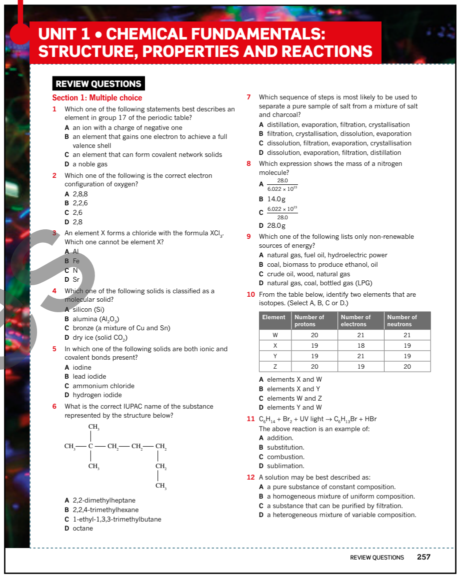
Reactivity of metals

12 Look at the periodic table at the end of the book.
  a Name a metal that would have similar properties to calcium.
  b In which part of the periodic table are magnetic metals found?
13 Which of the following metals would you expect to be the least reactive with water?
  aluminium, sodium, rubidium
14 When a reactive metal is added to water, bubbles or fizzing can be observed. Explain the appearance of the bubbles.
15 The image to the right shows similar-sized pieces of iron and silver in test-tubes of sulfuric acid of the same concentration. Describe the reactivity of the two metals and identify which metal is on the left and which is on the right.

96 AREA OF STUDY 1 | ATOMS AND ELEMENTS

Unit review

Each unit finishes with a comprehensive set of exam-style questions, which assist students to draw together their knowledge and understanding and apply it to this style of questions.



UNIT 1 • CHEMICAL FUNDAMENTALS: STRUCTURE, PROPERTIES AND REACTIONS

REVIEW QUESTIONS

Section 1: Multiple choice

1 Which one of the following statements best describes an element in group 17 of the periodic table?
  A an ion with a charge of negative one
  B an element that gains one electron to achieve a full valence shell
  C an element that can form covalent network solids
  D a noble gas
2 Which one of the following is the correct electron configuration of oxygen?
  A 2,8,8
  B 2,2,6
  C 2,6
  D 2,8
3 An element X forms a chloride with the formula XCl_3. Which one cannot be element X?
  A Al
  B Fe
  C N
  D Sr
4 Which one of the following solids is classified as a molecular solid?
  A silicon (Si)
  B alumina (Al_2O_3)
  C bronze (a mixture of Cu and Sn)
  D dry ice (solid CO_2)
5 In which one of the following solids are both ionic and covalent bonds present?
  A iodine
  B lead iodide
  C ammonium chloride
  D hydrogen iodide
6 What is the correct IUPAC name of the substance represented by the structure below?
  A 2,2-dimethylheptane
  B 2,2,4-trimethylhexane
  C 1-ethyl-1,3,3-trimethylbutane
  D octane
7 Which sequence of steps is most likely to be used to separate a pure sample of salt from a mixture of salt and charcoal?
  A distillation, evaporation, filtration, crystallisation
  B filtration, crystallisation, dissolution, evaporation
  C dissolution, filtration, evaporation, crystallisation
  D dissolution, evaporation, filtration, distillation
8 Which expression shows the mass of a nitrogen molecule?
  A $\frac{28.0}{6.022 \times 10^{23}}$
  B 14.0 g
  C $\frac{6.022 \times 10^{23}}{28.0}$
  D 28.0 g
9 Which one of the following lists only non-renewable sources of energy?
  A natural gas, fuel oil, hydroelectric power
  B coal, biomass to produce ethanol, oil
  C crude oil, wood, natural gas
  D natural gas, coal, bottled gas (LPG)
10 From the table below, identify two elements that are isotopes. (Select A, B, C or D.)

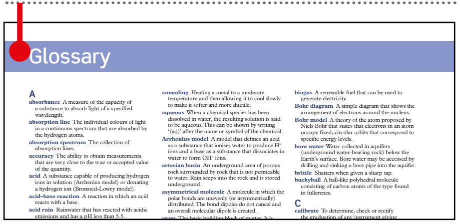
Element	Number of protons	Number of electrons	Number of neutrons
W	20	21	21
X	19	18	19
Y	19	21	19
Z	20	19	20

  A elements X and W
  B elements X and Y
  C elements W and Z
  D elements Y and W
11 $C_6H_{14} + Br_2 + \text{UV light} \rightarrow C_6H_{13}Br + HBr$
  The above reaction is an example of:
  A addition.
  B substitution.
  C combustion.
  D sublimation.
12 A solution may be best described as:
  A a pure substance of constant composition.
  B a homogeneous mixture of uniform composition.
  C a substance that can be purified by filtration.
  D a heterogeneous mixture of variable composition.

REVIEW QUESTIONS 257

Key terms and glossary

Key terms are shown in bold and listed at the end of each chapter. A comprehensive glossary at the end of the book includes and defines all the key terms.



Glossary

A

absorbance A measure of the capacity of a substance to absorb light of a specified wavelength.

absorption line The individual colours of light in a continuous spectrum that are absorbed by the hydrogen atoms.

absorption spectrum The collection of absorption lines.

accuracy The ability to obtain measurements that are very close to the true or accepted value of the quantity.

acid A substance capable of producing hydrogen ions in solution (Arrhenius model) or donating a hydrogen ion (Bronsted-Lowry model).

acid–base reaction A reaction in which an acid reacts with a base.

acid rain Rainwater that has reacted with acidic emissions and has a pH less than 5.5.

annealing Heating a metal to a moderate temperature and then allowing it to cool slowly to make it softer and more ductile.

aqueous When a chemical species has been dissolved in water, the resulting solution is said to be aqueous. This can be shown by writing '(aq)' after the name or symbol of the chemical.

Arrhenius model A model that defines an acid as a substance that ionises water to produce H^+ ions and a base as a substance that dissociates in water to form OH^- ions.

artesian basin An underground area of porous rock surrounded by rock that is not permeable to water. Rain seeps into the rock and is stored underground.

asymmetrical molecule A molecule in which the polar bonds are unevenly (or asymmetrically) distributed. The bond dipoles do not cancel and an overall molecular dipole is created.

atom The basic building block of matter. It is

biogas A renewable fuel that can be used to generate electricity.

Bohr diagram A simple diagram that shows the arrangement of electrons around the nucleus.

Bohr model A theory of the atom proposed by Niels Bohr that states that electrons in an atom occupy fixed, circular orbits that correspond to specific energy levels.

bore water Water collected in aquifers (underground water-bearing rock) below the Earth's surface. Bore water may be accessed by drilling and sinking a bore pipe into the aquifer.

brittle Shatters when given a sharp tap.

buckyball A ball-like polyhedral molecule consisting of carbon atoms of the type found in fullerenes.

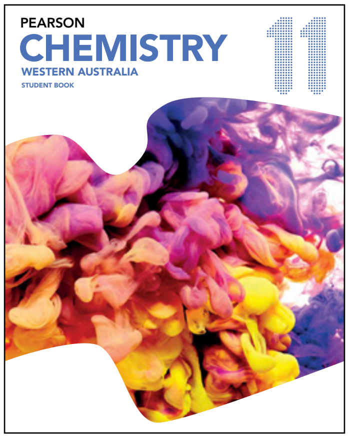
C

calibrate To determine, check or rectify the graduation of any instrument giving

Answers

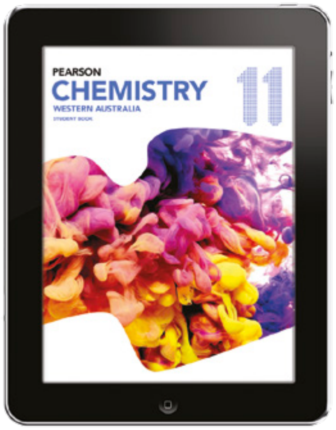
Numerical answers and key short response answers are included at the back of the book. Comprehensive answers and fully worked solutions for all section review questions, Worked example: Try yourself exercises, chapter review questions and unit review questions are provided via *Pearson Chemistry 11 Western Australia Teacher Reader+*.

Pearson Chemistry 11 Western Australia



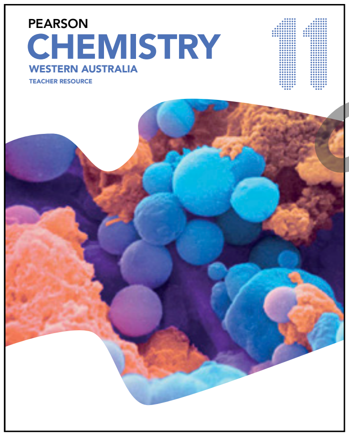
Student Book

Pearson Chemistry 11 Western Australia has been written to fully align with the *WACE Chemistry ATAR Course, Year 11 Syllabus 2015.* The series includes the very latest developments and applications of Chemistry and incorporates best practice literacy and instructional design to ensure the content and concepts are fully accessible to all students.



Reader+

Pearson Reader+ lets you use the Student Book online or offline on any device. Pearson Reader+ includes interactive activities and videos to enhance learning and test understanding. The teacher version includes support material to assist planning and implementing the syllabus.



Teacher Resource

The *Pearson Chemistry 11 Western Australia Teacher Resource* consists of a print book and online resources that provide comprehensive teacher support, including teaching programs, fully worked solutions to all questions, chapter tests and practice exams.

Access digital resources at **pearsonplaces.com.au**
Browse and buy at **pearson.com.au**

CHAPTER 01 Materials in our world

Many of the most significant scientific advancements of civilisation are related to the discovery, development, production or application of new materials. New materials are so fundamental to the advancement of technology that entire periods of history are known by the materials that proliferated in that age. And just as technological progress is highly dependent on the structure and properties of new materials, many of the scientific problems facing society today are the result of the limitations of existing materials.

At the end of this chapter, you will be able to identify how the structure of a material affects the material's properties and, therefore, its uses. Mixing substances can produce new materials with different properties. These mixtures include alloys, composites and materials containing nanoparticles.

In addition, you will learn how separating and purifying materials can lead to useful products. A variety of separation techniques use the different properties of mixed substances to separate and purify those substances.

Science as a human endeavour

- Matter at the nanoscale can be manipulated to create new materials, composites and devices; the different characteristics of nanomaterials can be used to provide commercially available products. As products are designed on the basis of properties which are different from the bulk material, their use can be associated with potential risks to health, safety and the environment and this has led to regulations being developed to address new and existing nanoform materials.

Science understanding

- materials are pure substances with distinct measurable properties, including melting and boiling points, reactivity, hardness and density; or mixtures with properties dependent on the identity and relative amounts of the substances that make up the mixture
- pure substances may be elements or compounds which consist of atoms of two or more elements chemically combined; the formulae of compounds indicate the relative numbers of atoms of each element in the compound
- differences in the physical properties of substances in a mixture, including particle size, solubility, density, and boiling point, can be used to separate them
- nanomaterials are substances that contain particles in the size range 1–100 nm and have specific properties relating to the size of these particles which may differ from those of the bulk material

WACE Chemistry ATAR Course Year 11 Syllabus © School Curriculum and Standards Authority,
Government ofWestern Australia, 2014; reproduced by permission

1.1 Materials science

Materials science is one of the most rapidly advancing areas of science in the world today. This interdisciplinary field uses chemistry to control the structure of materials down to the atomic (microscopic) level while utilising physics and engineering to control the structure of materials at a practical and visible (macroscopic) level. This gives materials scientists the ultimate control over the properties of materials.

Having control over the structure and properties of materials has led to the development of new and useful technologies. These technologies can be found in things you use every day, such as smartphones, LCD screens and even sunscreen. Today, materials science is also being used to create technologies that were once thought to be science fiction, such as 3D printers and artificial skin.

MATERIALS

The term **material** usually describes substances that are used to make objects. For example, wood, paper and nylon are all classified as materials because they can be used to create houses, books and clothes, respectively. Substances that are not considered materials include chemicals such as hydrochloric acid, chlorophyll and carbon dioxide. While these are all extremely useful substances, other objects are not made out of these substances. Therefore these substances are not usually classified as materials.

Materials are often mixtures of many substances—for example, cement or bitumen. However, materials can also be pure elements or compounds.

Elements are substances that are made up of just one type of atom. This means they consist of atoms with the same atomic number (the number of protons in the nucleus). Pure metals such as gold or silver are examples of elements that are also materials. Carbon is an example of a non-metallic element that forms a variety of materials such as charcoal, graphite, diamond and even nanotubes.

Compounds also make up a huge variety of materials. Compounds are pure substances made of more than one type of atom. They consist of more than one element in fixed proportions.

The formula of a compound indicates the relative numbers of atoms of each element in the compound. For example, silica (SiO_2) is a compound made up of silicon and oxygen atoms and is the main component of beach sand. The compound contains twice as many oxygen atoms as silicon atoms. Silica is a component of glass, quartz and gemstones. Calcium carbonate ($CaCO_3$) is another compound that makes up several different materials. These materials include chalk, limestone and marble.

The way in which a material is used is determined by the material's physical and chemical properties. These properties are special features of the material, such as its colour, hardness, melting and boiling points, whether it conducts electricity or heat and how easily the material reacts with other chemicals.

Elements and compounds are pure substances, and therefore their properties, such as melting point, boiling point and conductivity, cannot be altered. However, the properties of elements and compounds depend on the arrangement of their atoms and molecules. The properties of elements and compounds are distinct and measurable for a given arrangement of atoms or molecules.

Unlike elements and compounds, the properties of mixtures can be changed depending on how much of each component is added to the mixture. The ability to control the properties of mixtures makes mixtures very useful materials.

Although there are thousands of different pure materials and countless more materials that are mixtures, many that we use fall into one of three classifications: metals, polymers or ceramics.

Metals

Metals account for around 80% of all known elements and around 24% of the total mass of the Earth. Only a few metals are naturally found in their elemental metallic form. These metals, known as native metals, include gold and copper. Most metals are found as compounds, known as minerals, which make up the ores mined from the Earth's crust.

Metals (Figure 1.1.1) are valuable materials due to their useful set of properties including high tensile strength, ductility, malleability, shiny lustre, high melting points, and thermal and electrical conductivity.

The characteristic of a metal required for a particular application can often be improved, or its weaknesses mitigated, by using an alloy of that metal. An **alloy** is a mixture of a metal with other metals or small amounts of non-metals. For example, iron is an abundant and easily worked metal, which in its pure form is relatively soft and prone to corrosion. If iron is alloyed with other elements, primarily carbon, the result is a much stronger and corrosion-resistant alloy known as steel.

The key reason for the attractive set of physical properties demonstrated by metals and their alloys is the nature of the bonding that exists within metals. This will be examined in greater detail in Chapter 4.

FIGURE 1.1.1 An example of different metals (clockwise from the bottom left): copper, aluminium, zinc, iron and, in the centre, lead

Polymers

A **polymer**, from Greek *poly* meaning 'many' and *mer* meaning 'parts', is a material with a molecular structure that is composed of many repeating smaller units bonded together. Polymeric materials include plastics, such as polyethylene (polyethene) and nylon, and rubbers, such as latex. There are both natural polymers, such as wool, silk and paper (Figure 1.1.2), and synthetic polymers, such as polystyrene.

Polymers present a vastly different set of physical properties compared to metals: they are less dense and corrosion-resistant, offer excellent electrical resistance and polymers of a biological nature offer good compatibility with human tissue.

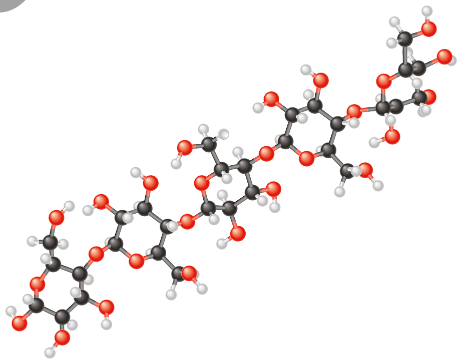


FIGURE 1.1.2 The pages of this book, the cotton used in clothes and the cell walls of green plants are all made of the naturally occurring polymer cellulose.

CHEMISTRY IN ACTION

3D printing

3D printing is a rapidly growing area of technology that started development in the early 1980s. It involves the manufacture of three-dimensional objects by the deposition or 'printing' of successive layers of a material controlled by a computer.

Initially 3D-printing materials were limited to various plastics (Figure 1.1.3), but this has since improved to include metals, ceramics and even biological polymers in the manufacture of replacement human tissue. 3D printing is becoming commonplace with many consumer-level 3D-printing machines available, and even a number of public libraries offering 3D-printing services.

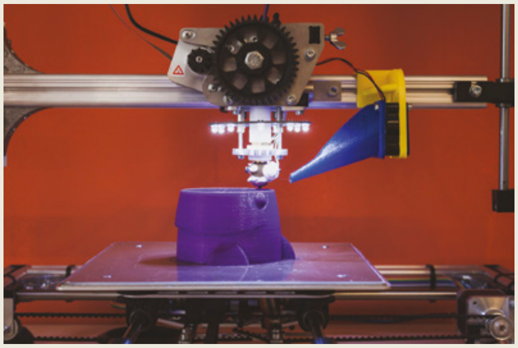


FIGURE 1.1.3 This 3D printer uses an acrylonitrile–butadiene–styrene polymer to make an object.

FIGURE 1.1.4 A small cylindrical magnet being levitated above a liquid nitrogen–cooled, superconducting ceramic by the Meissner effect

FIGURE 1.1.5 The steel rebar can be seen here embedded in the concrete structure.

Ceramics

A **ceramic** is an inorganic, non-metallic solid. Ceramics contain metal, non-metal and metalloid elements held together by ionic and covalent bonds (these types of chemical bonding are covered in Chapters 5 and 6). The degree of order within ceramic materials can range from highly ordered (crystalline) to highly irregular (amorphous). As with polymers, some ceramics such as kaolinite are naturally occurring and used to make porcelain, and others are synthetic, such as silicon carbide used as an abrasive.

As such a wide range of elements and bonding can occur in ceramics, they demonstrate a wide range of properties, but generally they are hard, have high compressive strength and are able to withstand high temperatures. Most ceramics are good insulators while others demonstrate semiconductor and superconducting properties (Figure 1.1.4).

COMPOSITES

A **composite material** is a combination of two or more distinct materials with significantly different physical and chemical properties. The resultant material demonstrates a range of properties that would be unobtainable by using one of the individual materials on its own.

Reinforced concrete (Figure 1.1.5) is a common example of a composite material. It consists of a concrete matrix with embedded steel bars (rebar). In this arrangement, the relatively low tensile strength of the concrete, which is a ceramic, is counteracted by the high tensile strength of the steel, an alloy, while maintaining the high compressive strength of the concrete.

CHEMFILE

Damascus steel

Damascus steel was a type of steel used for the manufacture of bladed weapons in the Middle East up until the 17th century. It is characterised by distinctive banding patterns reminiscent of flowing water (Figure 1.1.6). The performance of Damascus steel blades became almost legendary; they were reputed to be tough, resistant to shattering and able to hold a sharp edge far better than steel produced in other regions.

In 2006, a research team in Germany published an investigation into Damascus steel revealing a network of nanowires and carbon nanotube reinforcing, formed in the steel during the forging process. The presence of these reinforcing fibres to form a composite material is the likely reason for Damascus steel's legendary durability.

The knowledge of the forging of Damascus steel was lost in the mid-1700s. Many have tried to rediscover the original forging methods, but they remain a mystery.

FIGURE 1.1.6 The blade pattern typical of Damascus steel blades

1.1 Review

SUMMARY

- Materials are either pure substances or mixtures.
- The properties of materials determine how they are used.
- Materials can be mixed to produce new materials with different properties.
- Alloys are materials made by mixing metals with other metals or small quantities of non-metals.
- Polymers are large molecules made of smaller repeating units.
- Ceramics are inorganic, non-metallic solids formed from a mixture of metal and non-metal elements.
- Composite materials are materials made from two or more different materials, e.g. glass and plastic to make fibreglass.

KEY QUESTIONS

1 What is a material?

2 What are the typical physical properties of a metal?

3 What is an alloy?

4 What are the typical physical properties of a polymer?

5 What are the typical physical properties of a ceramic?

1.2 Nanotechnology

Chemistry is the study of the structure and behavior of matter, and traditionally chemists focused on the structure of atoms and the properties of bulk materials composed of countless molecules. However, there are particles and structures that fall between these two extreme sizes. These are particles that are larger than individual atoms, but still smaller than the wavelength of visible light and thus cannot be viewed even with the most powerful optical microscopes.

At these scales, properties such as the surface area to volume ratio of particles changes, allowing surface area effects, also known as quantum effects, to become more pronounced. The impact of these quantum effects can dramatically alter the properties of a material; for example, turning electrical insulators into superconductors or making visible substances seemingly invisible.

Nanotechnology is a branch of materials science that investigates the design, properties and applications of materials produced on this scale.

NANOSCALE

The term **nanoscale** refers to structures that are between 1 and 100 nanometres across. A **nanometre** (nm) is one billionth of a metre (10^{-9} m). To illustrate this scale, silicon atoms are around 0.2 nanometres across and a human hair is up to 100 000 nanometres in diameter (Figure 1.2.1).

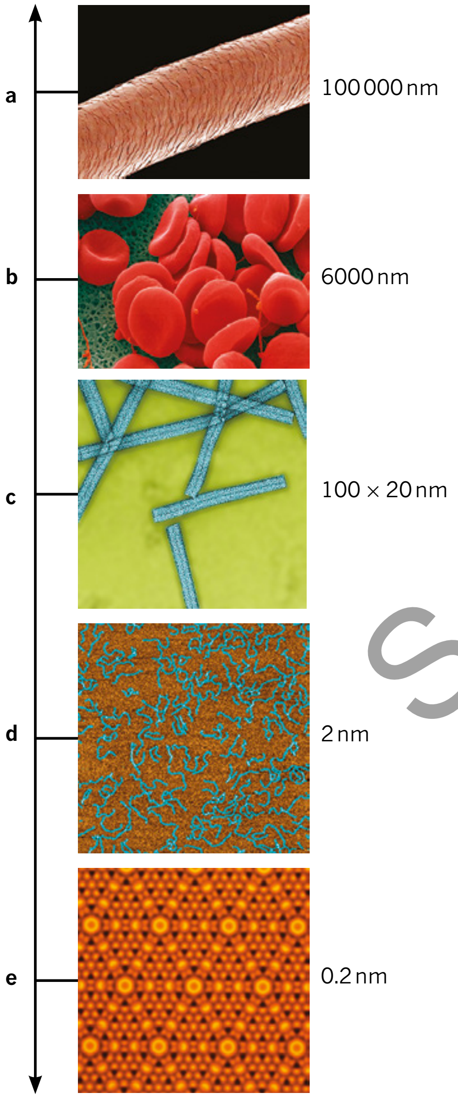


FIGURE 1.2.1 This scale compares the sizes of objects down to the nanometre size. (a) The width of a human hair is approximately 100 000 nm. (b) The diameter of red blood cells is 6000 nm. (c) Tobacco mosaic virus is 100 nm long and 20 nm wide. (d) DNA strands are about 2 nm wide. (e) Silicon atoms are 0.2 nm across.

The problem for scientists in the early days of nanotechnology was that the tools and techniques designed for working at this scale did not exist. In the early 1980s, the development of atomic force microscopes and scanning tunnelling microscopes allowed scientists to both view and manipulate individual atoms.

NANOMATERIALS

Nanomaterials are substances, both natural and synthetic, that are composed of single units that exist in the nanoscale. Although there is much discussion about the progress of synthetic nanomaterials, there are numerous examples of naturally occurring nanomaterials. For example, spider silk, butterfly wings and the bottom of gecko feet all have fascinating properties as a result of their nanostructure.

CHEMFILE

What do opals and butterflies have in common?

Opal is a nanomaterial made of tiny spheres of silica. These spheres diffract light to produce spectacular flashes of red, green and blue. Butterflies also get their coloured patterns from nanostructures on the surfaces of their wings.

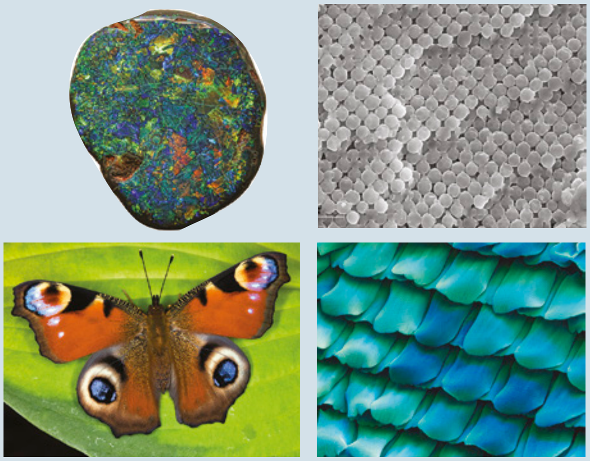


FIGURE 1.2.2 (Top) An opal is made of tiny spherical nanoparticles of silica. (Bottom) The colour of a butterfly's wing is due to nanostructures in the wing.

One naturally occurring nanomaterial that has been a hot topic of research for scientists over the past two decades is a family of carbon molecules known as the fullerenes. **Fullerenes** are three-dimensional structures formed by networks of carbon atoms. The fullerene that promises a wide range of applications is a cylindrical tube known as a **carbon nanotube** (Figure 1.2.3). These nanotubes are formed from a flat, two-dimensional layer of carbon atoms arranged in hexagons, known as **graphene**.

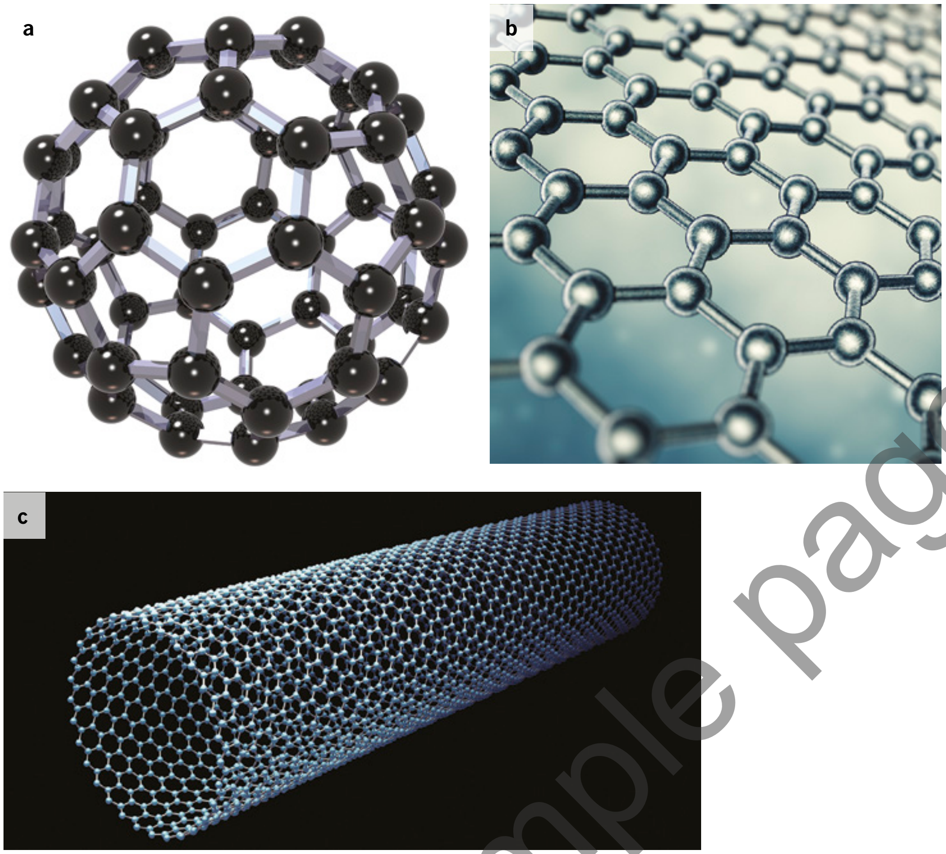


FIGURE 1.2.3 Example of different fullerenes: (a) the soccerball-shaped buckyball, (b) the flat chickenwire, like graphene and (c) the rolled, cylindrical nanotube

Carbon nanotubes have demonstrated exceptional strength and stiffness, finding use as reinforcement in composite materials. They also demonstrate interesting electrical properties and are the basis for a range of superconductor research. You will learn more about graphene and nanotubes in Chapter 7.

Materials on the nanoscale can be fabricated either using top-down or bottom-up techniques. Each technique is suited to particular applications and presents a different set of strengths.

Top-down fabrication

Top-down fabrication starts with material of a larger scale than desired. Material is then either selectively removed or the size of the material is progressively reduced, by grinding, until the required size and shape is achieved. An analogy for top-down fabrication would be a sculptor starting with a large block of marble and carving away pieces until the statue is formed.

Top-down techniques are currently the most commonly utilised methods and are used to make everything from computer chips to sunscreen. Some of the benefits of top-down fabrication are that large quantities of material can be produced relatively cheaply and the product demonstrates a good level of uniformity. Some disadvantages of top-down fabrication techniques are that they are limited to relatively simple structures and are limited by the scale of the tools used to remove material from the starting medium.

CHEMISTRY IN ACTION

Superhydrophobic coatings

One developing application of nanomaterials is superhydrophobic coatings. These are synthetic, nanoscopic, surface coatings that mimic the behaviour of leaves from the lotus plant, which trap an imperceptible layer of air on the surface, preventing contact with liquids.

FIGURE 1.2.4 The liquid repelling effect of a lotus leaf is due to naturally occurring hydrophobic waxes and microscopic hairs on its surface.

The coatings can be applied with a simple aerosol spray and once treated, demonstrate remarkable anti-wetting characteristics, repelling water and dirt and essentially becoming self-cleaning. Applications for such treatments include materials that never need cleaning, surgical equipment that never carries pathogens and tomato sauce bottles that always allow you to get the last bit out. Unfortunately, current coatings demonstrate extremely poor durability, making them unsuitable for most applications, but research is ongoing.

Bottom-up fabrication

Bottom-up fabrication is still in its early stages of development and involves physically building, or growing, the required material atom by atom or molecule by molecule. Individually selected atoms or molecules are successively built up until the required shape and size of material is formed. An analogy for bottom-up fabrication would be a sculptor joining individual calcium, carbon and oxygen atoms one at a time until the statue is formed. In this way, it is very much like existing chemical syntheses, but on a nanoscale.

One area of keen interest to scientists is the development of ‘self-assembling’ nanomaterials. It has already been demonstrated that molecules can be designed to arrange themselves in required shapes and structures, given appropriate conditions.

The advantage of bottom-up fabrication methods is they can be used for far more complicated structures than top-down methods due to the ability to manipulate individual atoms or molecules at the nanoscale. A disadvantage of bottom-up fabrication methods is they do not scale up to commercial levels efficiently and thus are only currently economical for research and niche applications.

NANOPARTICLES

Nanoparticles are a specific type of nanomaterial, which are currently the topic of intense scientific investigation. **Nanoparticles** are usually spherical particles with diameters of about 1–100 nm. It is in this size range that the properties of materials begin to change from those that are normally observed for bulk material to those that result from the greater contribution of surface effects. Nanoparticles have potential applications in medicine, physics, optics and electronics.

Although nanoparticles are a hot topic of cutting-edge scientific research at the moment, nanoparticles have been used throughout history. One of the curious properties of nanoparticles is how their optical properties are markedly different from the bulk material. For example, gold as a bulk material demonstrates a characteristic shiny yellow lustre valued for its appearance (Figure 1.2.5), yet gold nanoparticles can take on a range of different colours (Figure 1.2.6). The variable colours granted by gold nanoparticles of different sizes were used by artisans as far back as Rome in the 4th century for colouring glass and ceramics (Figure 1.2.7).

FIGURE 1.2.5 Bulk gold has a characteristic colour and typical metallic properties.

FIGURE 1.2.6 These vials contain gold particles of various sizes. The different-sized particles are different colours because they interact with light differently.

FIGURE 1.2.7 The red colour in this stained glass window is caused by gold nanoparticles trapped in the glass. The deep yellow colour is caused by silver nanoparticles.

One interesting application of nanoparticles that demonstrates different optical properties from the bulk is in sunscreens. Normally sunscreens contain metal oxides, such as zinc oxide, which appear white when applied to the skin (Figure 1.2.8). However, when zinc nanoparticles are used, they interact with light differently and appear clear.

CHEMFILE

Nanoparticles: risks to health and the environment

Nanoparticles have opened up a range of technological possibilities. However, the development of nanoparticles has also raised concerns about the possible dangers to humans and the environment.

In the past, other useful materials such as asbestos have been found to have devastating side effects. Therefore, the CSIRO (Commonwealth Scientific and Industrial Research Organisation) and other scientists around the world are studying the potential dangers associated with nanoparticles and their applications.

THE PROBLEM WITH NANOPARTICLES

Nanoparticles are so small that they can travel through the air, through skin and into your bloodstream and even into cells. Inside the body, the particles may interact with biomolecules to cause unwanted chemical reactions. This makes nanoparticles potentially dangerous if breathed in or if they are in contact with the skin (for example, in sunscreen, fabrics or cosmetics).

NANOPARTICLES IN SUNSCREENS

CSIRO scientists in Australia are looking at the zinc oxide nanoparticles used in sunscreens to determine whether they are safe. This research focuses on whether the nanoparticles can penetrate skin, their long-term health effects and how they might affect the environment.

Initial studies suggest that small amounts of zinc oxide from sunscreens are absorbed into the body and can be detected in the blood and urine. It is still not clear whether the absorbed zinc oxide has any harmful effects on the human body. The most recent research indicates that the cells of the immune system can break down the nanoparticles.

FIGURE 1.2.8 White zinc on faces is a common sight on Australian beaches during summer.

CHEMFILE

Why so blue?

A **colloid** is a mixture where one insoluble substance is dispersed through another. It is distinguished from a **suspension** in that colloids contain particles on the nanoscale that will not settle out of the mixture over time. For example, milk is a colloid of droplets of fat dispersed in water.

A common alternative medicine available at most pharmacies is colloidal silver. Colloidal silver consists of silver metal nanoparticles dispersed throughout a liquid, normally water. Although silver and silver compounds are toxic for bacteria, colloidal silver has been marketed as a cure-all for many conditions, with claims ranging from it being an essential dietary supplement to curing cancer.

One of the side effects of excessive silver consumption is a condition known as argyria, in which silver compounds accumulate in the skin, react to sunlight and turn the skin blue-grey (Figure 1.2.9). Although the condition is not life threatening, the effects are permanent and irreversible.

FIGURE 1.2.9 The blue-grey complexion of an individual suffering from argyria as a result of excessive colloidal silver consumption.

1.2 Review

SUMMARY

- Nanotechnology is the study of materials on the nanoscale.
- A nanometre (nm) is a billionth of a metre (10^{-9} m).
- Nanomaterials are materials with nanoscale features that give the material useful and important properties.
- Nanomaterials can be found in nature, manufactured in the laboratory or engineered from other materials.
- Nanoparticles are particles with diameters of about 1–100 nm.
- The properties of nanoparticles can be different from the bulk material that they are made from.
- Nanoparticles can travel through the air, through skin and even though cells, making them both potentially useful and dangerous for humans.

KEY QUESTIONS

1 Convert the following lengths into nanometres. Use scientific notation in your answers.
  a 8.35 cm
  b 1.35 mm
  c 4.2 mm

2 Explain why nanoparticles could play an important role in transporting medicines to certain regions of the body in treatments such as chemotherapy.

3 Why are the properties of nanoparticles so radically different from those of the bulk material?

1.3 Purifying materials

Alloys, composites and some nanomaterials are examples of how chemists can combine substances to create materials with different properties and for new applications. However, scientists can also develop new technologies by extracting, separating and purifying materials. For example:

- Separating crude oil: Crude oil is made up of a large number of useful compounds that can be separated into fuels, lubricants and chemicals to make plastics.
- Purifying silicon: 99.999% pure silicon can be used to make solar panels, but 99.9999999% pure silicon is required to make silicon microchips!
- Extracting DNA: The ability to extract and purify DNA from cells has fundamentally changed medicine, forensics and even agriculture.

Separation and purification techniques play an important role in many industries and laboratories. In each case, the separation technique uses differences in the physical and chemical properties of the mixed substances to separate the components of the mixture. Such differences in properties include particle size, density, solubility, boiling point and electric charge.

SEPARATION BY PARTICLE SIZE

One of the simplest separation techniques is to separate the substances on the basis of particle size. This is commonly done through sieving or filtration.

Sieving

Sieving is used to separate a mixture of solids with different particle sizes. The technique involves passing the mixture through a mesh. Particles that are smaller than the holes in the mesh pass through, leaving larger particles behind.

This simple technique is commonly used during baking to separate lumps from powders such as flour or cocoa. The technique is also an important tool in industries like mining. Figure 1.3.1 shows metal **ore** being poured into a hopper crusher, where it is crushed and passed through a sieve. The small particles that pass through the sieve move onto the next stage of processing. The larger particles remain in the hopper crusher to be crushed further.

FIGURE 1.3.1 After ore is mined, it is placed into a hopper crusher like this one. The ore is then pulverised. The smallest pieces fall through a sieve, while the larger pieces are crushed further.

Filtration

Filtration is used to separate solid particles from a liquid or gas. Air filters in vacuum cleaners, extraction fans or industrial chimneys are examples of filters that separate particles from air. Pool filters, coffee plungers and tea bags are domestic examples of filters that separate solid particles from liquids.

In the laboratory, scientists use filter paper to separate liquids and solids. This is normally done in one of two ways.

Gravitational filtration

Gravitational filtration uses the weight of the solid–liquid mixture to push the mixture through filter paper. The filter paper is first folded to produce a cone-shaped filter that fits into a funnel. The funnel is then placed into a conical flask, as shown in Figure 1.3.2. The solid–liquid mixture is then poured into the filter paper and left to run through the funnel. The purified liquid that collects in the flask is known as the **filtrate**. The solid collected in the filter paper is known as the **residue**.

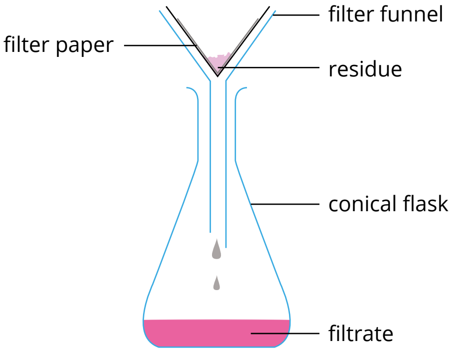


FIGURE 1.3.2 A gravitational filtration apparatus

Vacuum filtration

Vacuum filtration is faster than gravitational filtration and also helps to dry the residue more quickly. The apparatus for this technique is shown in Figure 1.3.3. The funnel, called a Büchner funnel, is usually ceramic, with a flat base and vertical sides. The flat base has many holes for the liquid to flow through. A flat piece of filter paper is placed at the bottom of the funnel. The funnel is then placed in a vacuum flask, which is a conical flask with a rubber seal and a side arm for attaching a vacuum tube. The solid–liquid mixture poured into the funnel is sucked into the flask by the vacuum. The solid residue is trapped by the filter paper.

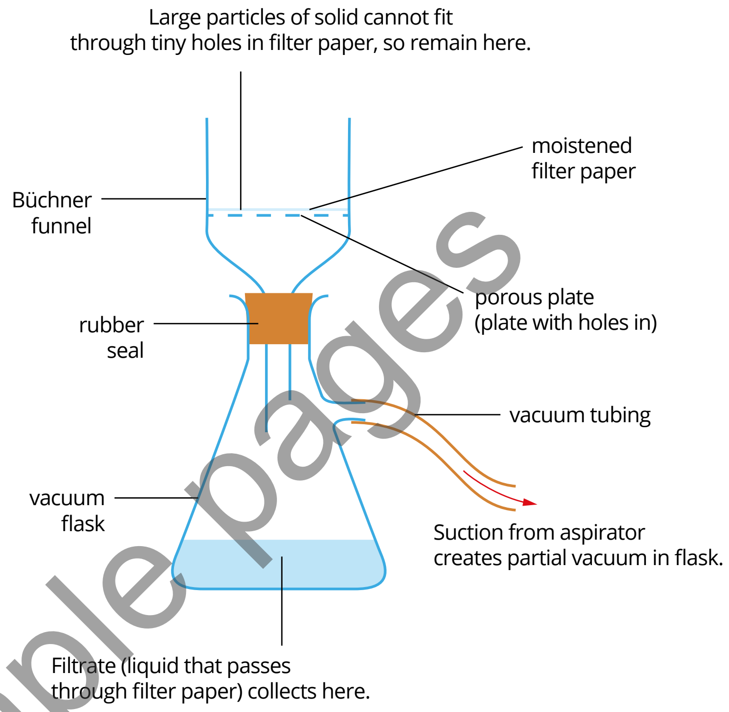


FIGURE 1.3.3 A vacuum filtration apparatus

SEPARATION BY DENSITY

Density is a measure of the mass per unit of volume of a substance. The difference in density between substances in a solid–liquid mixture determines whether each substance floats or sinks. The denser substance will sink and the less dense substance will float. Separating materials based on their density is relatively easy and cheap. However, the size of the particles in the materials also play a role. Even dense materials can stay suspended in a liquid if the particle size is very small, making it harder to separate very fine particles.

FIGURE 1.3.4 In this mixture of clay and water, while most of the clay has settled to the bottom, the smallest clay particles are still suspended in the liquid.

Sedimentation and decantation

If you drop a handful of sand, rocks and clay into a clear container of water, you will observe a few things. Firstly, the larger rocks will sink to the bottom, followed by the finer grains of sand. If you leave the mixture for days or weeks, you may also see that even finer particles start to settle. However, the finest particles will remain suspended in the liquid (Figure 1.3.4).

This process is known as **sedimentation**, or settling, and is a form of gravitational separation. The liquid can then be separated from the **sediment** by carefully pouring the liquid into another container. This process of pouring liquid from the sediment is known as **decantation**.

While not highly efficient, sedimentation is a cheap method of separating solid particles from liquids in large volumes.

- In water treatment plants, the sewage is first stored in large sedimentation tanks so that the solid waste can be separated from the liquid waste after it settles to the bottom of the tank (Figure 1.3.5).
- In wine production, the grape juices are stored in large settling tanks before being fermented. The solid particles sink to the bottom, allowing their separation from the grape juices.

FIGURE 1.3.5 Sedimentation tanks are used in water treatment plants to separate solid waste from liquid waste.

Separation funnels

If two liquids have different densities and are immiscible (don't mix), then the liquids can be separated with a separation funnel. The **separation funnel** (Figure 1.3.6) is a glass flask connected to a thin outlet tube with a small tap. When immiscible liquids are placed in the flask, two layers will form. The less dense liquid floats to the top and the denser liquid sinks to the bottom. When the tap is opened, the denser liquid flows out first and is separated from the less dense liquid.

Separation funnels are used in a process known as liquid–liquid extraction. This technique can be used to extract compounds like fragrances from plant oils. The plant oil containing the fragrance is mixed with water and a liquid known as ether. The water and the ether are immiscible but the fragrance will dissolve in the ether. The fragrance can be separated out of the oil and into the ether by gently shaking the water and ether in the separation funnel. After being left to stand for some time, the water and ether will separate. The ether, containing the fragrance, can then be poured out of the separating funnel and into a beaker.

FIGURE 1.3.6 Separation funnels are often used in organic chemistry where many organic solvents display significantly different densities from aqueous solutions.

Centrifugation

Spinning a mixture rapidly can speed up the sedimentation process and extract finer particles that may not settle out naturally. This process is known as **centrifugation**. Separation occurs because spinning the mixture results in the denser particles being pushed to the outside of the container by centrifugal force.

Centrifugation is used extensively in research and in medical and forensics laboratories since it is particularly useful for separating mixtures in small quantities. In Figure 1.3.7, vials of blood are placed in a centrifuge. This machine spins the vials around at up to 20 000 revolutions per minute.

FIGURE 1.3.7 Centrifuges like this one are used to separate the components of blood in small quantities. Blood that has been centrifuged separates into three distinct layers. The top layer is the plasma, the middle layer is the buffy coat and the bottom layer is composed of red blood cells.

The centrifuge separates the blood into three components—plasma, the buffy coat (a mixture of white blood cells and platelets) and a layer of red blood cells. The plasma and red blood cells can be used for blood transfusions. The buffy coat is used to extract DNA or detect some diseases.

SEPARATION BY BOILING POINT

For mixtures containing compounds that do not breakdown under heating, separation can be based on the difference in boiling points.

Evaporation

Some solids dissolve in liquids to form a solution. The liquid is known as the solvent and the dissolved solid is called the solute. Dissolved solids cannot be separated by filtration, sedimentation or centrifugation. Instead, the liquid solvent needs to be evaporated or boiled off in order to recover the solid solute. This technique is used in the Dampier salt mine in Western Australia and in the salt pans in Cusco Region, Peru (Figure 1.3.8). During the evaporation process, the water is lost to the atmosphere as water vapour. However, it is possible to collect both the solute and the solvent using the process of distillation.

FIGURE 1.3.8 Salt pans of Cusco Region, Peru

CHEMISTRY IN ACTION

Gas centrifuges

For the separation of substances in a mixture, such as isotopes where the differences in mass between the components are so minute, a gas centrifuge is employed. Gas centrifuges work on the same principle as traditional centrifuges except gases are used as the feed material and the process is conducted in multiple stages.

The most prominent use of gas centrifuges is the enrichment of uranium for nuclear power and weapons. This requires the separation of radioactive ^{235}U isotopes from the majority ^{238}U isotopes. The ^{235}U isotope represents only 0.72% of the atoms present in natural samples of uranium.

The difficulty of this process is the major hurdle for many nations who desire nuclear weapons.

FIGURE 1.3.9 The interior view of a gas centrifuge used for enriching uranium for nuclear power stations

Distillation

Distillation uses the same principle as evaporation but is performed in an apparatus (Figure 1.3.10) in such a way that the evaporated liquid can be recovered. The solution is heated in a flask known as the distillation flask to vaporise the liquid. The vapour passes through a condenser, which is a tube cooled with running water. The condenser cools the vapour, causing it to condense back into a liquid and form droplets along the inside of the condenser. The condensed liquid drips out of the condenser into a second flask, known as the receiving flask. The liquid collected is called the distillate.

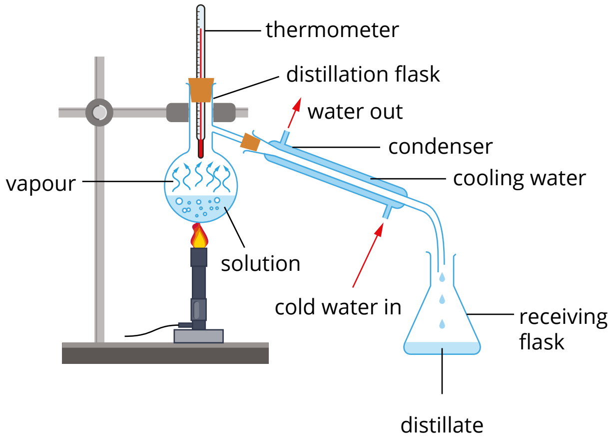


FIGURE 1.3.10 A set-up of a distillation apparatus

Fractional distillation

The distillation method can also be used to separate miscible (can mix) liquids that have boiling points that are only slightly different from each other. This technique is known as **fractional distillation** and uses the same apparatus as simple distillation with one important addition: a fractionating column is placed between the flask containing the mixture and the condenser. A fractionating column is a hollow column packed with high surface area material (Figure 1.3.11).

The fractionating column allows increased contact between rising vapour and falling condensate. This results in the more volatile component exiting the column as a vapour at the top and the less volatile component condensing back into the distillation flask.

FIGURE 1.3.11 A glass fractionating column filled with glass beads

CHEMISTRY IN ACTION

Distillation towers

One of the key structures in an oil refinery is the distillation tower. These towers are distillation columns that are up to 100 metres tall. They are heated from the bottom and allow the separation of crude oil into different fractions based on their different boiling points.

The highest boiling point fractions, such as asphalt and fuel oil, are collected at the bottom whereas the lowest boiling point fractions, such as petrol for cars and other gases, are collected at the top of the column.

FIGURE 1.3.12 The distillation tower at an oil refinery

SEPARATION BY ELECTRIC CHARGE

Electrostatic separation

Objects that have opposite electric charges attract each other. The force of attraction between opposite charges is known as the electrostatic force and can be used to separate charged particles from uncharged particles.

Electrostatic filters use the electrostatic force to separate solid particles from a gas. The technique is used in mineral processing and industrial chimneys to remove smoke particles from waste gases before releasing the gases into the atmosphere. The smoke is first passed through a negatively charged grid, which gives the smoke particles a negative charge. The smoke is then passed between positively charged plates or electrodes that attract and collect the particles.

Chromatography

Other important techniques are the various forms of chromatography, including thin layer chromatography (TLC), gas chromatography (GC), paper chromatography and high performance liquid chromatography (HPLC). Chromatography separates liquids or gases based on their differing affinity for various materials present in the chromatography apparatus.

All chromatography techniques employ a stationary and mobile phase. If a compound from the mixture introduced into a chromatography apparatus demonstrates a high affinity for the mobile phase and a low affinity for the stationary phase, it will be moved quickly through the system as the mobile phase moves. If a different component in the mixture demonstrates a high affinity for the stationary phase and a low affinity for the mobile phase, it will remain in the system longer, thus effecting a separation of the compounds. Chromatography will be covered in greater detail in Chapter 13.

EXTENSION

Electrophoresis

Electrophoresis is an electrostatic-based separation technique that relies on the different migration rates of particles dispersed in a fluid when exposed to an electric field.

Particles suspended in a fluid obtain a surface charge as a result of processes such as deprotonation (losing a hydrogen ion), protonation (gaining a hydrogen ion) or adsorption of other ions. This surface charge responds to an applied electric charge to the fluid in the same way as other charged particles interacting electrostatically; positively charged particles are attracted to the negatively charged terminal and vice-versa for negatively charged particles. This electrostatic attraction causes the particles to migrate, or move through the fluid, the rate of which depends on their charge and size. Over a period of time, particles of different sizes (and therefore roughly molecular weights) migrate different distances (Figure 1.3.13), affecting the separation of the components.

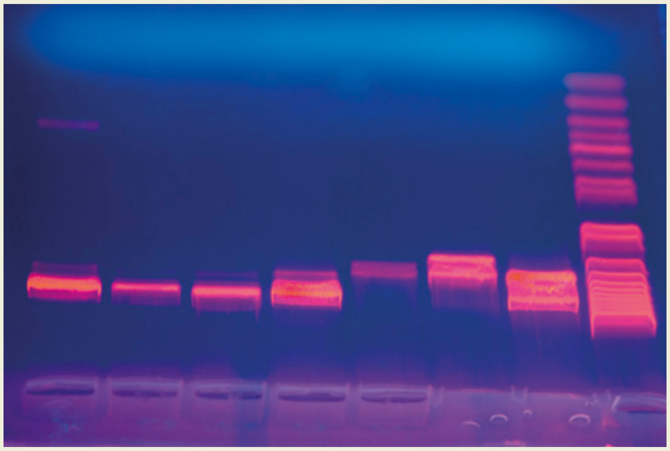


FIGURE 1.3.13 A type of electrophoresis known as gel electrophoresis is commonly used to analyse DNA and proteins.

1.3 Review

SUMMARY

- Useful materials can be created by extracting and purifying substances.
- Separation techniques use differences in the materials' physical and chemical properties in order to separate them. Such differences include particle size, density, boiling point and electric charge.
- Sieving can be used to separate mixtures of solids based on particle size.
- Filtration can be used to separate mixtures of solids and liquids based on particle size.
- Sedimentation and decantation can separate mixtures of solids and liquids based on density.
- Mixtures of immiscible liquids of different densities can be separated using a separation funnel.
- A mixture of components where the differences in density are very small can be separated by centrifugation.
- Evaporation can separate the solute from the solvent in solutions but the solvent is not retained.
- Distillation can separate the solute from the solvent in solutions, or even two miscible liquids, and all components are retained.
- Fractional distillation is effective at separating mixtures of miscible liquids with similar boiling points.
- A mixture of substances that respond differently to external electric fields can be separated by electrostatic means.

KEY QUESTIONS

1 Why would sieving a mixture of salt and pepper not be an effective separation technique?

2 Can you use sedimentation and decantation to separate the solvent from the solute of a solution? Why/why not?

3 Is it possible to use a separation technique outlined in this chapter to separate the hydrogen from the oxygen in water? Why/why not?

4 Draw a fully labelled scientific diagram of a distillation apparatus.

5 For each of the following sets of mixtures, outline what technique(s) could be employed to separate the components.

a water and oil
b water and sugar
c sand and gravel
d sugar and pebbles
e pebbles and woodchips

6 A mixture of four different hydrocarbons is to be separated by fractional distillation; their details are in the table below.

Hydrocarbon	Boiling point (°C)
pentane	36.1
heptane	98.4
octane	125.0
benzene	80.1

In what order will the hydrocarbons be collected in the receiving flask?

Chapter review

01

KEY TERMS

alloy
carbon nanotube
centrifugation
ceramic
colloid
composite material
compound
decantation
density
distillation
element
filtrate
filtration
fractional distillation
fullerene
graphene
material
mineral
nanomaterial
nanometre
nanoparticle
nanoscale
nanotechnology
ore
polymer
residue
sediment
sedimentation
separation funnel
sieving
suspension

Materials science

1 What is a composite material?

2 Papier mâché is a commonly used composite material composed of what two materials?

3 Classify each of the following materials as a metal, ceramic or polymer: aluminium, cotton, nylon, porcelain, stainless steel.

4 Gold is a precious, soft, yellow metal valued for its rarity and appearance. When used in jewellery, gold is often alloyed with other metals. Suggest a reason why.

5 Diamond, graphite and carbon nanotubes are all elemental forms of carbon. Suggest a reason why their physical properties differ so significantly when their chemical composition is identical.

6 In what way is the composite material known as reinforced concrete superior to normal concrete for construction?

7 Why are kitchen sinks made from stainless steel and not iron?

8 Conduct research to find out what are the major components of the following alloys.
   a bronze
   b pewter
   c white gold

Nanotechnology

9 Convert the following lengths into nanometres (express your answers in scientific notation).
   a 5 cm
   b 12 mm
   c 0.02 mm

10 Zinc oxide powder and zinc oxide nanoparticles both absorb UV light. What property of zinc oxide nanoparticles makes them more suitable than zinc oxide powder for use in sunscreen?

11 **a** Describe the difference between top-down and bottom-up fabrication methods of nanomaterials.
   b What are the advantages and disadvantages of each method?

12 What is a colloid and how is it different from a suspension?

Purifying materials

13 What is the main advantage of distillation over evaporation?

14 A common survival technique to obtain drinking water when lost in the outdoors is to dig a hole in the ground, fill it with waste or salt water, place a clean container in the centre of the hole and cover the hole with a piece of plastic weighed down with a small rock in the centre. Explain in terms of separation techniques how this apparatus can produce drinkable water.

15 Crystallisation is the evaporation of the solvent from a solution to form crystals of the solute. Explain why this method is not suitable for purifying mixtures of multiple soluble salts from solution.

16 Briefly outline the steps you would take in a laboratory to separate the following mixtures while retaining each component.
   a sawdust, sand and sugar
   b oil, water and ethanol
   c instant coffee and tea leaves

Connecting the main ideas

17 Research the composite materials produced with carbon-fibre reinforcing, stating their advantages over traditional materials.

18 Describe some of the concerns regarding the use of nanoparticles in consumer products.

19 One of the concerns raised regarding nanotechnology is the scenario suggested by early nanotechnology pioneers involving ‘grey goo’. Research the notion of ‘grey goo’, summarising the scenario.