

SCIENCE
FOR PRIMARY TEACHERS

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THIRD EDITION

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The authors dedicate this book to master educator

Dr Cedric Grieve

whose enthusiastic and effective science presentations at many levels over four decades have been an inspiration.

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Why This Unit?

Introduction

People come is all shapes and sizes. As you may have noticed, they also vary greatly in their scientific interest and ability. You may be one of those who really enjoyed science over your school experience and pulled in some great marks. If so, you should naturally enjoy this unit. However, you may be among those who hated science in school and never could understand it. And as for marks – well the less said the better! If so, you may be shuddering even as you open this textbook.

So what is this unit about, you may be asking? Why does a primary teacher like me need to know anything about science? Is there any chance of my enjoying it if I am not a scientific nerd? Fair questions. Here are the answers.

Our general aim in writing this textbook material was to provide some basic knowledge about how science works. After all, we live in a very science-oriented and techno world, and it would be nice, surely, to understand a bit about how it all works. We are also wanting to make it easier for you to get your pupils interested in science. We all start our learning experience in primary school classrooms taught by teachers like you. Your likes and dislikes are all too easily transmitted to your pupils, including loves and hates of science and maths. If you have long harboured a negative attitude to these subjects we hope that this textbook and study unit will cure it a bit. If that is too hopeful we hope that we can help you disguise it. After all, what a dreadful thing it would be if you killed off the next Einstein because of a negative attitude imparted early on. The thing hardly bears thinking about.

In our choice of topics we have been guided by the NSW Science and Technology K-10 Syllabus, from Early Stage to Stage 3, also the new Australian Science Curriculum. Further, we have done our best to choose topics within science which obviously impact our daily lives. Also things for which the explanation is not too hard. We have left out most of the maths, although we couldn't get rid of it entirely. This wouldn't be right – or even possible, since maths is one of the major languages of science. So our specific aims are to:

- help you understand what science is and how it works, using both "constructivist" and "realist" strategies,
- provide some background on how it first emerged and how it is being continually developed and advanced,
- help you understand how some common phenomena work. Things in the playground, on the road, in the home, on the sports field,
- give you some confidence as you present science in your classes,
- provide a range of ideas on do-able classroom activities which have solid scientific value, and

- introduce you to the NSW Science and Technology Curriculum, also the emerging Australian Curriculum. You will note that at the end of many chapter sections there are codes. Those within square brackets, [ ], refer you to the *NSW K-6 Science and Technology Syllabus*. Those within curly bracket, {}, refer you to the March 14, 2013 draft of the *Australian Curriculum*.

All this so that you can, in turn fire up your primary students, as outlined on p14 of the NSW K-6 Science and Technology Syllabus, i.e.

- foster their sense of curiosity, wonder and enthusiasm,
- develop their science competence,
- increase their confidence, and
- help prepare them to contribute in areas of science and technology.

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Chapter 1

The Process of Scientific Inquiry

1.1 What is Science?

Many people think of science as a collection of facts about our universe. And certainly, facts are important to scientists. But actually, science is more correctly understood as the basic method by which we discover such facts. It is a way of thinking. Since this approach has been so influential in creating our modern lifestyle, it is important that we understand something about it, even if we never aim to become scientists ourselves! Much of what we accept as common knowledge as well as our means of communication, entertainment and getting about are just flow-ons from science. So what makes science tick?

1.2 Three Different Levels of Science

There are three main levels of activity within science: the collection of data, the searching of that data for regularities and patterns, and the searching of these regularities for explanations. Sometimes these are known as *collective*, *descriptive* and *causal* science respectively.

Collective Science

This activity is generally the most simple of the three, although these days very sophisticated equipment is required to collect certain data. Also great care and precision. By the way, it is important to remember that "data" is the plural. A single bit of information is called a "datum". The main question at this stage is, "What are the facts?" Data collection generally involves practical activities such as travelling, building and repairing apparatus, data recording and the keeping of careful experimental notes. Sometimes data collection involves measuring some object which is just "there" or recording some process which is happening anyway. It may also involve the planning and construction of special "experiments". More will be said about experiments later in this chapter.

Collective science is very important and it can be done without being a maths freak! Often this work is directed by those operating at higher scientific levels, such as happens in a research team. At other times information is collected just for the sake of collecting it because it seemed like a good idea at the time. It transpires that good data is seldom wasted. It generally turns out to be useful in some way, sometimes in a quite unexpected manner. You never know how your data will be used. This is one of the fun things about science. Collective science is very important at primary school level, since there are so many things which can be collected.

A great historical example of someone collecting data is provided by the Dane, Tycho Brahe, who sat up night after freezing night measuring and recording the astronomical coordinates of the planets.

[ST1- 4WS] {ACSHE013, ACSIS011, ACSIS233, ACSHE021, ACSIS039, ACSIS055, ACSIS105}

Descriptive Science

This is where the data is organized, analysed and structured. The main question is, "*What patterns exist in the data?*" Very often this stage involves graphs and equations, which is why maths is so important in science. One branch of maths which is often useful here is statistics. Computers, too, are frequently used in data analysis. The end result of this stage is a well-structured arrangement of the data. Sometimes, however, even trying to organize the data involves some unavoidable assumptions and guesses. In these cases we end up with what is sometimes called a "descriptive theory". More on theories later.

This is also a very important stage of the scientific process. In fact, it is often as far as new scientific investigations can get, since explanations of "why" things are this way are simply not available! We might all agree on what happens but have no idea of the reasons why it is this way. Descriptive science is also very important to primary school students since anyone can see that collections are so much more useful if they are organized and arranged in their natural patterns. Also, some of the basic tools of this process, such as simple graphs, are well within the capabilities of your students.

An excellent illustration of descriptive scientific work is provided by Johannes Kepler, who used the massive data collected by Brahe and reduced them to three simple descriptive statements, the so-called Kepler's three laws of planetary motion. You may have heard of the first of these. It states that all planets follow elliptical paths as they orbit around the sun. In fact Kepler's work provides an excellent example of a descriptive theory.

[ST2 – 4WS] {ACSIS040, ACSIS057, ACSIS061, ACSIS068, ACSIS090, ACSIS107}

Causal Science

This is the attempt to provide explanations for the patterns noted above, to provide understanding and to causally link all the bits and pieces into a coherent picture. The main question is, "*Why is it like this and what is causing it?*" This is widely regarded as the most difficult part of science. Not surprisingly, it is here that the best-known scientific work is done and generally where the most famous and nerdiest scientists work. Einstein, whose work on relativity has been used to explain many different phenomena, is a great example of a causal scientist. The term "theorist" is often used to describe causal scientists and this is where most scientific "theories" arise, although, as we noted, sometimes theories arise at the descriptive level.

Obviously one should not expect that your primary school students will contribute largely to the enterprise of causal science, although they can certainly understand a bit about it.

A good example of a causal theory is Newton's theory of gravity, which completely explained the descriptive relationships which Kepler had noted some 60 years earlier.

[ST3 – 4WS] {ACSIS214, ACSIS216, ACSIS218, ACSIS221}

1.3 Scientific Theories

How Scientific Theories are Initially Developed

The aim of science is to describe and explain more and more aspects of our universe. To this end scientific knowledge in a particular area is generally presented as a *scientific theory*. Let us now take a look at the way in which such theories are developed. We will meet some more important terms along the way, such as *hypothesis*. These can sound a bit daunting but don't be put off. Beginners in science sometimes get the impression that scientists never use a short word when a long one will do! It can seem like that at times.

The development of scientific theories may be represented as shown in Figure 1.1.

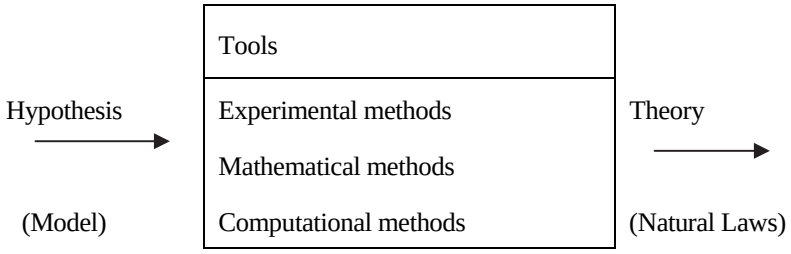


Figure 1.1 The development of scientific theories.

A theoretical scientist working in a given area first suspects that a particular relationship exists. This initial idea is called an **hypothesis**. Basically, this is a guess. At this stage the scientific process is very inductive and very creative, not a bit dull or formulaic. Scientists do a lot of guessing and it takes imagination! Many people do not understand this. Such guesses may be very inspired and astute, guided by long experience in studying a particular topic. They may also be just a spontaneous thought, coming at the unlikeliest moment. A famous British scientist used to talk of the importance of the three "B"s: the bed, the bath and the bus!

Sometimes an hypothesis involves a **model,** which is an association with some more familiar, perhaps every day, object or process. For example, the physicist J.J. Thomson's early hypothesis about the atom was that all the negative charges were spread evenly through the positive medium in the atom, like currents and raisins in a good fruit cake. This soon became known as Thomson's "plum pudding" model. Such models are widely used in science. Sometimes models are more mathematical.

The scientist then uses the tools of science: experimentation, mathematics and computation to test the hypothesis out against the experimental facts. If it turns out as we do our scientific experiments that our hypothesis is wrong or deficient and is not supported by the data, then our "great" idea gets discarded on the very large heap of great scientific ideas that did not work! Back to the drawing board to develop a new hypothesis! As we said earlier, this is a common experience for scientists and one to which they get accustomed. Even Einstein made some mistakes. But good scientists are made of stern stuff and they just press on.

On the other hand, if the experimental data support the hypothesis, then further testing is carried out. Often the initial hypothesis is modified, refined or extended to relate more data. In the meantime, the scientist reports his or her progress at conferences and in the scientific literature and other scientists check it out, to see if they come to the same conclusions. Experimentalists and theorists work together. Gradually there develops out of this process a body of knowledge on which there is wide agreement among the scientists concerned. This becomes known as a scientific **theory**. Examples are: the theory of the heliocentric solar system, Newton's theory of gravitation, Einstein's theories of relativity and the theory of plate tectonics and continental drift. Sometimes such a theory includes a relationship so apparently well supported and so useful as to be called a **natural law**. It needs to be recognized here that so-called natural laws are not in any way absolute, but simply relationships which have been observed to work reliably within a particular context. They may turn out to be convenient fictions, in fact most do. In such cases they may need to be modified or discarded.

It is important to recognise that what scientists call a "theory" only gets that designation after a great deal of scientific work has already been done and many checks made. It should be clear, then, that in science the term "theory" has a very different meaning to the same term when used in everyday conversation. This point is commonly misunderstood. Whenever someone says, "Well, science cannot be taken too seriously – after all, all it has are theories", you can be sure they don't understand the nature of a scientific theory.

{ACSIS024, ACSIS025, ACSIS026, ACSIS027, ACSIS212, ACSHE081, CASHE098, ACSIS232}

How Scientific Theories Change and Mature

Sometimes over a period, observation may so thoroughly support some aspect of a theory that it comes to be regarded as a fact itself. Such an example is the idea that the Earth goes around the Sun. When this was first seriously proposed in 1543 as part of the new heliocentric (Sun-centred) model of the solar system it was very conjectural, but today very few doubt it. Aspects of continental drift and plate tectonics are now also widely regarded as factual, particularly since we can now directly measure the movement of the Earth's plates. It must be said, however, that such cases are comparatively rare in science, requiring huge amounts of consistent data and interpretation over a long time.

Most theories in science are progressive, with each sequential version of the theory explaining and relating more experimental facts. Also, later versions often employ more sophisticated mathematical models. Sometimes changes to a scientific theory emerge from new technologies, which have enabled the collection of data which were previously inaccessible. In most cases the new version of the new theory agrees pretty closely with the old for those situations in which the old version was developed. For example, Einstein's General Theory of Relativity, which effectively replaced Newton's theory of gravitation, gives similar results to Newton's theory in most situations encountered on Earth. Only in the huge gravity encountered, for example, in the interior of dense stars does the older theory come badly unstuck and the new one do much better.

In most instances the development and fine tuning of scientific theories is rather slow, sometimes almost imperceptible. However, in some instances the new ideas are radically different. In such

cases the takeover of the old theory by the new is sometimes referred to as a "paradigm shift" within science. This change can be very rapid, such as in the case of the acceptance of the theory of plate tectonics in the 1960s, which was accomplished within a decade.

The science of cosmology provides perhaps the best illustration of a theory maturing through a series of refinements. Our first cosmological theories were geocentric, i.e. placing our Earth at the centre of everything, with just seven heavenly bodies circling close around it, outside of which rotated all the "fixed stars". Then came Copernicus' heliocentric (Sun-centred) system. Further adjustments were forced by the discovery of more planets orbiting the Sun. Then, within the last 100 years, we discovered galaxies outside our own. In fact, our current cosmological model, with all of its dark matter and energy, is still being refined. [ACSIS060}

Fair Testing and other Principles behind Scientific Experiments

Great care must be taken in the design of experiments, particularly in the identification of all the factors which might affect the outcome. Many experiments have been performed only to have it later discovered that the data were useless because they were corrupted by factors or processes which had been unknown to the experimenters or had been ignored by them. For example, many chemical reactions run faster as the temperature increases. In such cases it is important to keep the temperature constant as one investigates the effect of other factors, such as the concentration of the chemicals reacting, the use of different solvents, the presence or absence of light or the presence of other substances which may impede or accelerate the reaction.

In order to understand what is going on in a given experimental situation it is important first to identify all the factors (variables) which might affect the results. This can be hard. Nature can be very subtle! It is then necessary to keep all these factors constant throughout the experiment except the one you are investigating. This is called conducting a "fair test". This is one of the main challenges of doing good experiments.

Because most hypotheses turn out to be wrong, or at least to need further tuning, experimentation relies very heavily on the principle of falsification. There must be a way of clearly disproving this hypothesis. The form of logic most commonly used goes like this: If proposition A implies experimental result B, then if we don't get result B we know that proposition A must have been false! In the language of logic we say that

If A implies B, then "not B" implies "not A".

Sounds simple doesn't it. Let's try an example. Suppose we are looking at a partially obscured animal. Our hypothesis is that this animal is a dog. On the basis of our experience of dogs we construct the cunning logical statement: "If it is a dog it will have four legs". We then carefully count the legs on the animal under investigation and get two! Implication? Clearly the animal is not a dog. Note that the logic only works this way. If it does have four legs we cannot conclude it was a dog – it might be a heffalump or an armadillo!

[ST3 – 4WS] {ACSIS058, ACSIS069, ACSIS231, ACSIS086, ACSIS103, ACSIS104}

The Role of Mathematics in Scientific Theories

Mathematics is not technically a science. However, as we noted earlier, maths is very important in descriptive and causal science. In fact it was Galileo who first demonstrated the importance of maths to scientific thinking. In Galileo's time maths was not seen as a very important area of study. It was regarded as a lower order occupation. Certainly it was not as important as natural philosophy (what we would call science today), philosophy itself, the classical languages like Greek or Latin, or theology. In fact it was impossible to do a PhD in maths at the universities. Galileo and Newton, among others, elevated the status of maths hugely, demonstrating that God was indeed a mathematician and that maths unlocks many aspects of our universe. [ST3 – 4WS]

1.4 Scientific Units

Units and Standards

You may have already heard about some scientific units. In fact, learning these units may have been one factor which turned you off science in your impressionable youth. But the fact is that they really are of fundamental importance and there is no way around them. We promise, though, not to overdo them and to explain the ones we do use carefully.

It is pretty obvious that if we are going to measure anything at all we need some well-understood, commonly accepted standard. You can't live without having to do this. Travelling, cooking and buying are just three activities which require standard quantities and units. Imagine trying to buy things if there was no agreement over what a certain coin was worth! The measurement of any natural quantity is always in terms of the standard unit for that quantity. This unit must always be given when recording measurements. Certain collections of such quantities and units are referred to as a *measurement system*. A number of such systems have been employed by scientists over the years. For most purposes, however, contemporary scientists observe the *Systeme Internationale* (SI), originally known as the MKS system since the standard length is the **m**eter, the standard mass is the **k**ilogram, and the standard time is the **s**econd. Other systems sometimes encountered are the "centimeter, gram, second", CGS system, another metric-based system; and the "foot, pound, second" (FPS) system, originating in Britain, and still widely used in the USA.

Physical quantities may be divided into two categories, **fundamental** or **base** quantities, and **derived** quantities. The corresponding units for these quantities are called fundamental units and derived units. The smallest number of base quantities which can be used to describe the physical world is just seven. It turns out that all other quantities may be defined in terms of these base quantities. The selection of the base quantities is somewhat arbitrary, and often has to do with the ease of accurate measurement of those quantities. The seven which are currently regarded as base quantities are shown in Table 1.1, with their SI units.

Table 1.1 Base quantities and their SI units.

Quantity	Unit	Symbol
mass	kilogram	kg
length	meter	m

time	second	s
electric current	ampere	A
temperature	kelvin	K
luminosity	candela	cd
amount of subst.	mole	mol

We don't have to worry about all of these. In fact, for this course, we will largely deal with mass, length and time, with a little bit of electric current and temperature thrown in. These base quantities can be combined to give derived quantities. For example, speed is a derived quantity. It is length/time and is measured in m/s.

One problem we encounter very soon is that these units are not always convenient. For example, if we want to measure the thickness of human hairs we will find that they have values such as 0.00004 m. If we are in the wig making business we are going to end up writing an awful lot of zeros! On the other hand, if we are measuring distances in space we will find the zeros on the other side of the numbers of interest. Even the tiny distance from our Earth to the Moon is 384000000 m. To solve this problem we invent smaller and larger units to suit a wide range of measurements. These are usually defined in multiples and divisions of ten from the standard unit. Some common metric prefixes are given in Table 1.2.

Table 1.2 Metric Prefixes.

	Prefix	Abbreviation	Value
Bigger:	giga	G	a thousand million of (10^9), e.g. *giga*byte
	mega	M	a million of (10^6), e.g. *mega*litre
	kilo	k	a thousand of (10^3), e.g. *kilo*gram
Smaller:	centi	c	one hundredth of (10^{-2}), now used only with the meter, i.e.*centi*meter.
	milli	m	one thousandth of (10^{-3}), e.g. *milli*gram
	micro	μ	one millionth of (10^{-6}), e.g. *micro*gram
	nano	n	one thousand millionth of (10-9), e.g. *nano*meter.

1.5 The Different Scientific Disciplines

Modern science is composed of a number of major disciplines. In order of emergence, these are astronomy, biology, physics, chemistry and geology.

Astronomy is usually regarded as one of the sciences in its own right, although it is very closely connected to physics, and sometimes to chemistry. It is the oldest science of all, going back to antiquity. Some of the astronomical work done by the Babylonian, Sumerian, Egyptian, Greek and

Roman astronomers is very impressive indeed. Astronomy is also very important historically to science, since the Copernican Revolution of the 1500s, which radically changed our ideas on the structure of our universe, is generally regarded as the beginning of modern science.

Biology is also an ancient science, going back to the Greeks. However, modern biology did not develop until the great voyages of discovery which heralded the end of the middle ages. Physics is usually regarded as starting off in its modern form with Galileo in the 1600s. Modern chemistry followed soon after, as it grew out of alchemy – the search for the "philosopher's stone", that illusive substance which would transmute all objects into gold! Modern geology was a comparatively late starter. It really only got going after the industrial revolution started shifting lots of rocks, letting us see what was there. Since that time geological discoveries have given us many surprises! Because the other sciences rely heavily on physics, chemistry and biology these are sometimes referred to as the "enabling sciences".

More recent times have seen the development of many derivative sciences and technologies, such as: psychology; medical and paramedical sciences; sociology; information technology; chemical, civil, mechanical and electrical engineering; avionics, photonics and surveying. These represent important dimensions of our modern lives.

1.6 Science and Christian Faith

It is widely accepted that modern science grew out of a solidly Christian world view, incorporating the following elements, among others:

- the idea of a permanent, reliable and consistent God, who was seen as the originator of all physical reality,
- the idea that the creation was separate from the Deity, and in that sense was non-sacred, and that it could be investigated without risk of offence to God,
- the idea that God had endowed humanity with a capacity, even a responsibility to at least partially understand the Creation.

It is also true that many, if not most, of the early scientists, like Galileo (1564-1642), Kepler (1571-1630), Newton (1642-1727) and Boyle (1627-1691), were devoted Christians with a high view of scripture. It is clear from historical records that they saw their work of scientific discovery as bringing glory to the creator. Kepler wrote famously that as an astronomer he was able to "think God's thoughts after Him".

However, this was also the time in which discord struck. In 1543 Copernicus published his now-famous *De Revolutionibus Orbium Coelestium*, or "On the Revolutions of the Heavens", in which he challenged the ruling geocentric (Earth-centred) understanding of the universe which had enjoyed millennia of patronage, including universal acceptance by the Christian Church. Copernicus suggested that the Sun, not the Earth was at the centre of things.

When Galileo began to popularise this idea with great vehemence and passion he attracted the opposition of the Church, as well as that of the classical scholars. Eventually, he was put on trial, shown the instruments of torture, and "invited" to recant. This he did, at least in the public sense, as

most of us would have done, although he continued to believe in, and write privately on, the new cosmology. It is worth noting that the transition from geocentrism to heliocentrism was a lengthy process. This was partly due to the reluctance of Christians, both Catholic and Protestant, who saw the issue as one of loyalty to the Bible. The book which got Galileo into such hot water, and which was banned by the Catholic Church in the early 1600s was not removed from the forbidden list until 1822! By that time the vast majority of Christians were totally unthreatened by the idea of their Earth going around the Sun.

Sadly, there has been a long history of misunderstanding between science and Christianity, with science gradually getting the upper hand in the popular mind as its discoveries were more and more firmly established. A few decades after Galileo's death Newton came under criticism by conservative elements in the Church, this time "for substituting gravitation for providence". In time, however, we Christians came to see formalised rules for gravity and other regular laws of nature not as a threat to Christianity, but as the strongest evidence for a designer.

Not too many years later there were Christians who opposed the introduction of lightning rods, particularly on cathedrals. They felt that it would be foolhardy to attempt to frustrate what they saw as God's judgements. Such a course might easily, they thought, result in a more devastating action by God than simply toppling their steeple with a lightning bolt. Later still, in the 1800s a number of Christian leaders (all men!) opposed the use of anaesthetics in childbirth, since it would certainly violate Genesis 3:16. Christians have changed their minds on many of these issues and now no longer understand the Bible as they once did. Through all these challenges Christianity has proved remarkably flexible and resilient.

This strained relationship is unfortunate, given the Christian heritage of modern science which we noted earlier. Of course, at all times over the last 400 years there have been devout Christian scientists of the very top rank. Even today, despite the publicity given to popularists of atheistic philosophy, such as Richard Dawkins, over 30% of practising scientists in America claim sincere adherence to Christianity, although not necessarily to its most conservative expressions.

And although fifty years ago most non-believing scientists thought that the Christian idea of a God who was behind the design of the Universe was almost dead, this idea has seen an astonishing re-emergence in recent decades. This has largely been due to two main areas of discovery:

- the incredible complexity of the microbiological world, such as the living cell, DNA and the human brain, and
- the exquisite fine-tuning of our universe for life. The laws of physics, chemistry and biology seem to have just those values which are required to hold together a universe in which life can survive. This is sometimes referred to as the "Anthropic Principle".

Professor Paul Davies, himself a non-Christian, has written books such as *The Goldilocks Enigma*, in which he points out that our universe is very much like the little Bear's porridge, in that it is "just right"! Other non-Christians have also written books pointing out these evidences. A huge number of books are also being written by high-profile scientists who are Christians. Many universities are now endowing chairs, departments and research programs in the area of Science and Christianity. While serious scientists should never claim to be able to "prove God", and they don't, it is

comforting to know that in the world of science Christianity is not so much out of vogue as some atheists would urge us to believe. It is important for Christian teachers, at whatever level, to present science as being comfortable within a Christian context, although we must not deny or misrepresent the difficulties science continues to throw up to Christian understanding.

Arthur Holmes, in his book *The Idea of a Christian College*, argues that any form of integration of faith and learning must flow naturally from the content under study and must not be forced. Fortunately, modern science is making this integration easier in many respects, even at the primary school level. The Christian teacher can safely emphasise the importance of science in the following Christian contexts:

- as a responsibility, given God's invitation to study and understand Him through His works,
- as a responsibility, given our charge as stewards of, and carers for, our environment, and
- as a response of gratitude to God for providing such a wonderfully contrived environment for us, along with the rest of his creative entities.

Activities

The following fun activities grow out of this chapter.

1. Write a list of some common quantities and their units which are encountered in life? (money-dollars, time-seconds, length-meters, area-hectares, mass-kilograms, speed-kilometers per hour, temperature-degrees Celcius, etc.).
2. Write a list of things which can be collected: coins, stamps, bottles, matchboxes, rocks and minerals, timber samples, spoons, insects, shells, swap cards, seeds, leaves, etc.
3. Ask class members who have such collections, or parents and other relatives who have them, to bring them to a class and talk about them. Many things about such collections can be discussed: where the samples were found, how difficult they were to find, how they are classified, the rarity and value of some of the items, other similar collections in your town/city, etc.
4. Initiate a class collection of one or more of these items, following careful reporting and classification systems. Establish your own museum!
5. Find out about the Anthropic Principle and the ways in which the Universe is fine-tuned. For example, you may want to find out about the type of radiation produced by our Sun, the type of radiation which our atmosphere allows to reach us without being absorbed, and the type of radiation which helps sustain life on Earth. It turns out that these three are almost identical, although there is no intrinsic reason why they should be. You may also want to explore the various properties of water which sustain life. There are at least six!
6. Do a research project on Dr Ignaz Semmelweis, the Hungarian physician who discovered how to significantly reduce the post-natal death rate of mothers giving birth at the Vienna Hospital in the 1840s. The story of his scientific approach, as he tried to eliminate many of the false hypotheses of the day is now a classic study in scientific method. Be warned, though, this is a tragic story.
7. Do a research study on some of the early scientists, from Greeks, such as Aristotle, Plato and Archimedes, to the recognisably modern scientific pioneers like Galileo and Newton.

Chapter 2

The Earth in Space

2.1 Introduction

In this chapter we encounter the exciting domain of space, with a particular focus on our solar system and the manner in which our Earth moves within it. Space exploration is often in the news, since it is a sure-fire media hit. The way our Earth moves is a great topic to study in upper primary school, since there are so many links with other areas, such as the seasons and weather.

Although humans have been looking up at the heavens since antiquity, only in the last 450 years has our modern understanding of the universe developed. For most of human history we understood that the Earth was the centre of the Universe. The seven heavenly "wanderers" moved around us, as we thought, on seven spheres. These were: the Moon, Mercury, Venus, Mars, the Sun, Jupiter and Saturn. The rest of the "fixed stars" were outside of these, on the eighth sphere, which formed the very edge of the physical universe. This last sphere moved around the Earth once a day. This cosy picture was banished in 1543 when a Polish monk, Nikolas Copernicus published a famous book *De Revolutionibus Orbium Coelestium* (On the Rotations of the Heavens).

This book argued that the Sun was at the centre of the Universe and that the Earth was just one of the planetary bodies rotating around it. This was hard for most people to accept. As we noted in Chapter 1, some Christian groups took 200 years to accept this idea because they initially thought that it contradicted scripture. Over that period of time Christians learned to read the Bible in a slightly different manner. Much later it was realised that our solar system was only a very minor structure within a much vaster universe than had been earlier supposed. It was also hard for us to accept at first that we were not at the very centre of the universe, but now it doesn't seem to worry anyone very much. This is just as well, as there is not much we can do about it.

2.2 Deep Space

Distances in space are so immense that they are often measured in *light years*, i.e. the distance light travels in one year. Since light travels about seven times around the Earth's equator each second, a light year is a huge number. In fact, it is about 9,500,000,000,000 km! Other units used to measure distances in space are the parsec (3.26 light years), or the mega parsec (3,262,000 light years!) These are gigantic units indeed.

The universe is thought by most scientists to be expanding, since most galaxies appear to be moving apart. This produces a change in the light which comes from them. It is shifted towards the lower frequency end of the visible light spectrum, i.e. towards the red end. This "red shift" is similar to

one form of the common Doppler effect, whereby the pitch of sounds appears to be changed as their sources move towards or away from a listener.

We often talk of “empty space” but in fact there are about one million atoms per cubic meter, even out in empty space. There is also a great deal of gas and dust. Gravitational attraction, which is the dominant force in space, pulls these particles together into nebulae, stars and planets. Stars are often mutually attracted into binary pairs. This is where two stars rotate about their mutual centre of mass. In fact, astronomers sometimes jokingly say that three out of every two stars are binary pairs! Planets may be trapped by the gravity of nearby stars, thus forming solar systems, such as our own. Stars, with their associated planetary systems, if any, are in turn pulled by mutual gravitational attraction into galaxies and clusters of galaxies. Thus, space demonstrates a multi-layered order. We briefly examine some of these entities below, in decreasing order of scale. We focus particularly on those closest to us.

Nebulae

These are large clouds of gas or dust as shown in Figure 2.1.

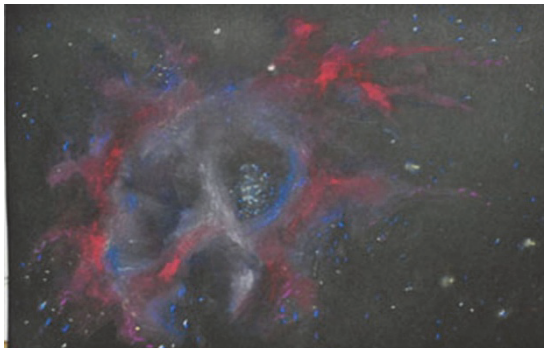


Figure 2.1 Example of a Nebula.

Some of these are spectacular when viewed through a good telescope and have become quite famous. Examples are the Great nebula in Orion, the Horse head Nebula, shown in Figure 2.2, and the Crab Nebula. Such nebulae are quite common in space.



Figure 2.2 Horse Head Nebula.

2.3 Our Galaxy

Initially we thought that all the stars in the night sky were within our own galaxy, the *Milky Way*. About 100 years ago, however, evidence began to suggest that some astronomical objects were outside our galaxy. This question gave rise to one of the most famous debates in science, between astronomers Harlow Shapley and Heber Curtis in 1920. During the next decade the existence of extragalactic objects was conclusively demonstrated. This recognition paved the way for our modern understanding of the structure of the universe.

We now recognise the existence of something like 150 million galaxies. These are huge clusters of up to a trillion (a million million) stars, so far away from Earth that they appear to be point-like stars themselves. Most are only visible though powerful telescopes. In some instances the central gravitational attraction for a galaxy is thought to be a black hole. These are accretions of such large amounts of matter that even light cannot escape from them. This is why they appear black. They also pull any surrounding matter into themselves with an irresistible embrace. We have many reasons to believe in their existence but no one wants to get too close!

Our own galaxy is the *Milky Way*, containing some 200 billion stars. It is a common spiral galaxy about 100,000 light years across. Our Sun and solar system are situated about one half of the distance out from the centre, as shown in Figure 2.3. If we look out from the Earth in any direction *through* the disk of stars we see a great many of them, which is why the Milky Way seems like a line of stars. If we look out in a direction perpendicular to the disk we see far fewer stars.

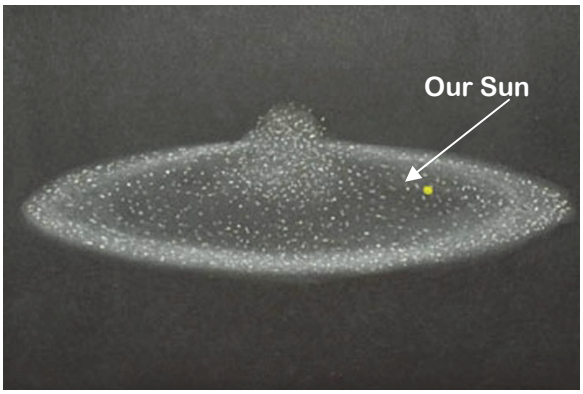


Figure 2.3 Our Sun in the Milky Way galaxy.

2.4 Our Solar System

As noted above, solar systems generally consist of individual stars or binary pairs which have attracted other, smaller, orbiting bodies around them. The last decade has revealed evidence for many such systems, although the only one of which we have intimate knowledge is our own. The principal component of our solar system is the Sun. The next most significant bodies are the eight planets. There are also many smaller bodies, such as comets, asteroids and meteorites. The paths followed by these bodies are called *orbits*. The time taken to traverse an orbit is called the *period* of the orbit.

Our Sun

The Sun is a small medium star, as stars go. Scientists classify our Sun as a G2V yellow star. The "G2" indicates its surface temperature, about 5,500 °C. The "V" indicates that it is an ordinary sort of star, producing energy by a nuclear fusion reaction, which converts hydrogen into helium. (Scientists are still trying to get this happening on earth in a safe way. When we can accomplish it we will be able to produce lots of clean power without disturbing all the carbon!) Much of the energy produced by this fusion reaction is radiated out as light.

The Sun contains the equivalent of about 333,000 Earth masses. This is about 99.9% of all the mass in our solar system. All other bodies within our solar system are held by the gravitational pull produced by this immense mass. The diameter of the Sun is about 1.4 million km, about 109 times that of the Earth. The Sun is not a solid body and its equator rotates more quickly than its polar regions. At its equator the Sun rotates once about every 26 Earth days. The Sun consists of approximately 75% hydrogen and 25% helium. Sometimes there are huge eruptions, or flares, on the solar surface. These appear to us as "sunspots" and can throw flares of helium gas out from the solar surface and up to 1 million km into space. These also produce a lot of radio noise, which we pick up as static on earth. These disturbances on the Sun's surface are actually cooler than the surface elsewhere, which is why they appear as black spots against the Sun's surface. A picture of a solar flare is shown in Figure 2.4. It seems that about every 11 years there is a systematic increase in the number of sunspots. This periodicity is known as the solar sunspot cycle.

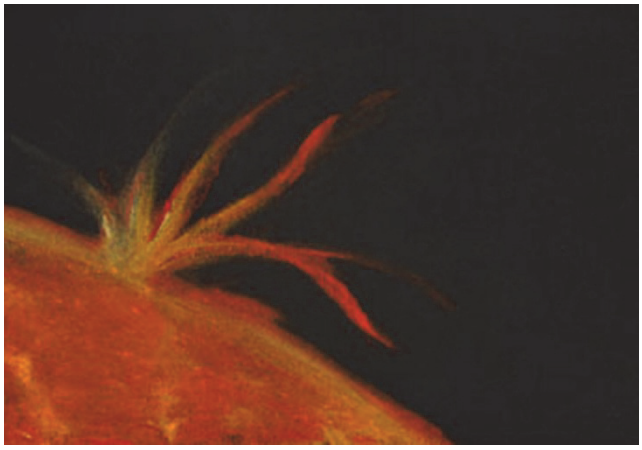


Figure 2.4 Solar flare.

The Planets

All the planets move around the Sun, and so appear to move against the background provided by the distant or "fixed" stars. This gave rise to their name since the word "planet" is derived from the Greek "planetae", which meant "wanderer". The eight planets are shown in Figure 2.5.



Figure 2.5 A composite image showing the planets in our solar system (credit: NASA). Pluto is now classified as a dwarf planet, since it is actually smaller than our moon. There are a number of other dwarfs in our solar system.

The planets circle the sun in the same plane and in the same direction. Six of these: Mercury, Venus, Mars, Jupiter, Saturn and Uranus are visible from Earth without a telescope. The four inner planets: Mercury, Venus, Earth and Mars are called the "dense" or "rocky" planets, because they are mostly solid or liquid. The next two, Jupiter and Saturn, are called gaseous giants because they are large and predominantly composed of gases. The last two, Uranus and Neptune, are called "ice giants" because they are largely comprised of frozen gases. Pluto, now no longer classified as a planet, since it is smaller than our Moon, is once again solid. Only the Earth has conditions which favour life and because it is so important to us we examine it in more detail below and also in later chapters.

Comets

These are chunks of ice and rock which orbit the Sun in very flattened (elliptical) orbits. Most comets appear to have initially come from deep space and to have been captured by the Sun. As comets orbit they are slowly melted by the Sun's rays. These melted particles form the tail of the comet which is pushed away from the comet head by the solar wind (masses of charged particles streaming from the Sun). Thus a comet's tail always points away from the Sun. Perhaps the most famous comet was named after Sir Edmund Halley, a famous contemporary of Sir Isaac Newton. Halley noted in 1705, that two strange objects which had been recorded in the night sky over the previous 100 years were very similar. He suggested that these were successive visits of the same object and correctly predicted its return in 1758. Sadly, he did not live to see this event. Halley's comet, shown in Figure 2.6, visits the vicinity of Earth once every 75 years, and was last observed in 1986. It should return again in about 2061.

A more recent comet event was the spectacular collision of Comet Shoemaker-Levy 9 with the planet Jupiter in July, 1994. This was the first major extra-terrestrial collision between objects within our solar system to have been observed. Another recent comet event was the discovery of Comet Hale-Bopp, one of the brightest comets to have visited Earth in the last 100 years. It was first observed on the night of July 23, 1995, by Hale and Bopp independently and became visible to the naked eye in 1996. It continued to grow in brightness until about April 1997, being visible to

observers in the Northern Hemisphere. By the time it became visible to us in the Southern Hemisphere it was much less spectacular but continued to be visible down under until late 1997.

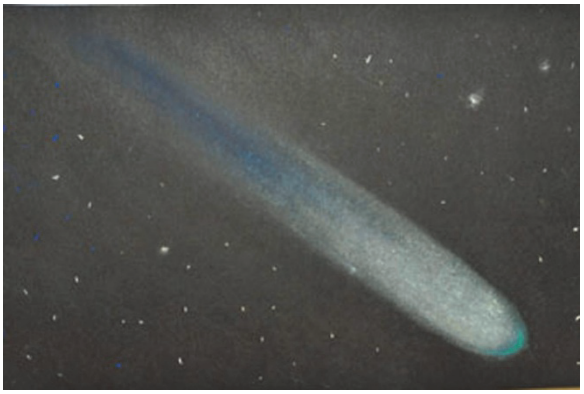


Figure 2.6 Halley's comet.

Asteroids

Asteroids are solid objects circling the Sun but much smaller and more numerous than planets. The biggest concentration of asteroids is between Mars and Jupiter. The biggest asteroid is called Ceres. It is an irregular rock about 950 km in diameter. An asteroid is pictured in Figure 2.7. The small craters, due to collisions with space dust and debris, can be clearly seen.

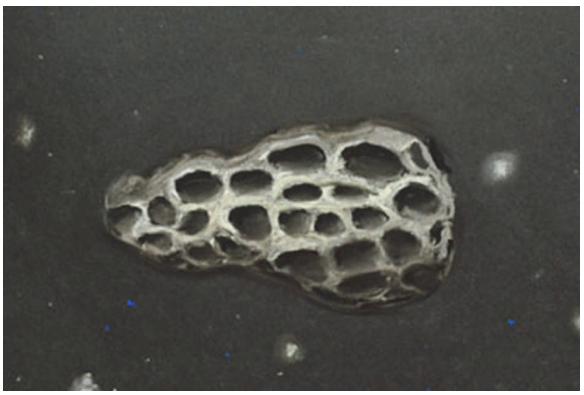


Figure 2.7 An asteroid.

Meteoroids and Meteorites

Meteoroids are small asteroids down to the size of pebbles whose orbits come close to and sometimes intersect that of our Earth. Because of the speeds (up to 70 km/sec) with which they hit the Earth's surface they can cause immense destruction. Fortunately, however, such impacts are rare. The last such event of any magnitude was the Tunguska meteoroid, which is thought to have exploded a few kilometres above a remote and heavily forested area of Siberia on June 30, 1908. It is thought that this meteoroid was some tens of meters across. Its impact had the same effect as the detonation of about 1000 atomic bombs of the type dropped on Japan in WW2. There are more of these out there than many of us would like to think. On March 2, 2009, a similar sized asteroid passed just 60,000 km from Earth.

Smaller particles, sometimes having masses less than one milligram, are usually called meteorites. Earth is intersecting these all the time. Occasionally, however, Earth passes through the path of an ancient comet, where there is a higher concentration of such particles than in the rest of space. This is what typically produces meteor showers, such as the famous Leonid shower of 1833. When these meteorites enter the Earth's atmosphere they are slowed down and heated up by air friction. Most burn away totally in a blaze of glory before reaching the Earth's surface. However, the largest reach the Earth's surface and form craters. Meteorites consist of either metal alloys or rocks. Metallic meteorites have been collected by some cultures, such as the Inuits, and utilised for their metal content. Snow-covered regions are great for collecting meteorites since any rock found on top of snow and ice has a good chance of having come down from the sky!

[ST1-8ES] { ACSSU078}

2.5 The Motion of Our Earth about the Sun

As briefly mentioned in Chapter 1, for millennia humans believed that the Earth was at the very centre of the universe and that everything else, including the Sun, moved around it. This idea was seriously challenged by Copernicus in 1543 and subsequently by Galileo and others. The story of how we changed our minds over 200 years is a fascinating story indeed, particularly for Christians, who had to learn to read their Bibles somewhat differently. It was actually quite hard to infer from the most obvious evidence, such as the sequence of day and night, and the rotation of the night sky, whether the Sun or the Earth was at the centre. Both models provided satisfactory explanations of these phenomena. It was not until Newton provided some powerful mathematical arguments in favour of the new Sun-centred model that this view began to powerfully prevail. However, by the late 1700s all educated folk were persuaded that the Earth did, in fact, travel around the Sun.

From the time of Kepler the path of the Earth around the Sun has been known to be an ellipse, i.e. a flattened circle. But whereas some ellipses can be very flattened, the Earth's orbit is almost circular. The Earth-Sun distance varies only from about 147 to 150 million kms. Thus the distance from the Earth to the Sun is almost constant throughout the year at about 149 million kms. This minor variation in distance is not enough to play any part in producing our seasons, despite what some people think. It takes about 8 minutes for the light from the Sun to reach Earth. So if anything happened to the Sun it would be 8 minutes before we would know! The orbit of the Earth about the Sun is shown in Figure 2.8.

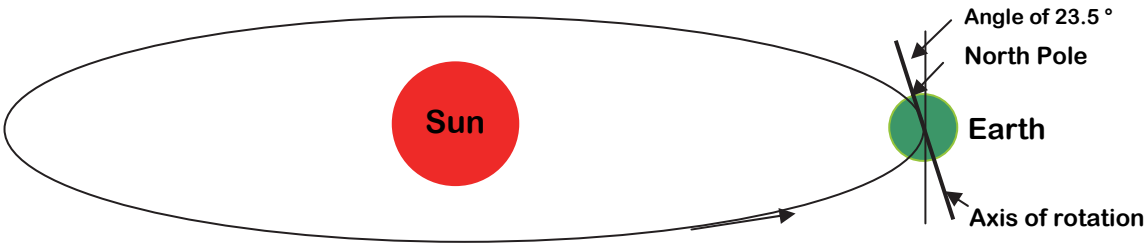


Figure 2.8 Earth's orbit around the Sun.

As can be seen, when looking "down" at the plane of the Earth's orbit from a distant point above the Earth's North Pole, the motion of the Earth about the Sun is anticlockwise. The rotational motion of the Earth about its own axis is also anticlockwise.

By the way, there is something rather interesting about the terms "clockwise" and "anticlockwise" for Australians. Of course, many modern clocks and watches don't have moving hands at all but fortunately enough still do for most kids to still know about "clockwise". However, the origin of this term is rather confusing for those who think about it (i.e. almost nobody!). Most people can readily assert that this term must have somehow come from clocks, and before that, sundials. And sure enough, the hands on a clock do go clockwise. However, a moment's thought will reveal that if one watches an Australian sundial the first shadow of the day will lie somewhere in the west. At noon the shadow will be in the south and at evening, in the east, as shown in Figure 2.9.

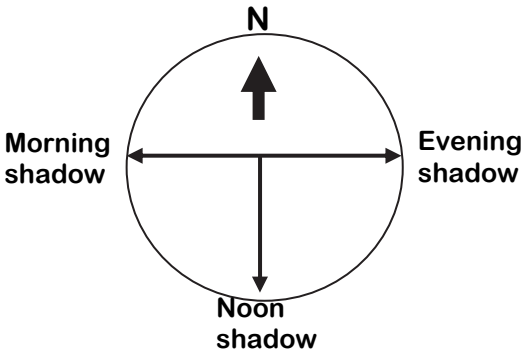


Figure 2.9 Movement of the shadow on an Australian sundial.

One doesn't need to be a rocket scientist to realise that the shadow on this sun-dial clock actually goes in an anticlockwise direction! So what went wrong? How could our forebears have gotten "clockwise" from a sundial? Maybe they didn't after all?

This is an interesting problem and a great way to get primary kids (and their parents, sometimes!) thinking. What is the explanation? It's simple. Clocks of this nature were first developed in the northern hemisphere, where the shadow of the sun goes in the opposite direction than it does for us in the southern hemisphere. In ancient Mesopotamia and Egypt where sundials were first used, the shadow does, in fact, go clockwise, so all is explained!

The Earth goes around the Sun once each year, which is not surprising since it is this motion which produces our year! With respect to the plane of its orbit around the Sun, the Earth's axis of rotation is tilted at an angle of about 23.5 degrees. This angle of tilt remains constant because the angular momentum of the Earth does not change, although we don't need to go too much into that! The undeviating direction of this tilt means that the axis of the Earth's rotation always points to the same region of the stars. It is this unchanging direction of the Earth's axis of rotation which gives us our seasons.

The way in which it does this is not really hard to understand. Imagine that at one position of the Earth's orbit around the Sun the North Pole is tilted *towards* the Sun. This results in the North Pole being lit by the Sun's rays continuously as the Earth rotates. Even for lower latitudes the northern

hemisphere experiences long days, i.e. more than 12 hours of sunlight each day. In other words, the northern hemisphere is in the grip of summer! The day on which the pole is most pointed towards the Sun will be the longest day for the northern hemisphere. This is called the *summer solstice* and occurs on either June 21, 22 or 23. Meanwhile, the poor South Pole, which is tilted *away from* the Sun, is in perpetual shadow and even lower southern latitudes experience short days, i.e. less than 12 hours of sunlight each day. In other words, the southern hemisphere finds out about winter! While the northern hemisphere is celebrating the summer solstice the southern hemisphere is experiencing the *winter solstice*.

It is not difficult to imagine that 6 months later, when the Earth is on the opposite side of the Sun, it is the South Pole which is tilted towards the Sun and the situation reverses entirely. Summer solstice for the southern hemisphere (and winter solstice for the northern hemisphere) is on December 21, 22, or 23. Exactly in between these two solstice positions the Earth's tilt will be "square on" to the Sun and the entire Earth will experience equal-length day and night. These dates are referred to as *equinoxes* and occur on March and September 21, 22 or 23. If your hemisphere is passing from winter to summer this occurrence is called the *vernal equinox*. If your hemisphere is passing from summer to winter it is called the *autumnal equinox*.

The Earth spins through 360 degrees on its axis once every 23 hours and 56 minutes. It takes us an extra 4 minutes to complete a solar day, i.e. for the Earth regain the same position due to the Sun, to due to the distance we have travelled around the Sun during the 23 hours and 56 minutes. Of course, it is this daily rotation of the Earth which makes the sun, moon and stars appear to move in their regular fashion across the sky. The Frenchman Foucault was the first person to unambiguously demonstrate that it was the Earth which rotated when he set up a giant pendulum in one of the towers of Notre Dame Cathedral in Paris in 1851. During the course of a day the pendulum appeared to slowly change the plane of its swing. Actually, such pendulums maintain their original swing plane. The apparent change is due to the Earth rotating about its axis!

In fact, the day is gradually growing longer due to friction of the tidal movement dragged around the Earth by the Moon. The rate of this increase is about 1.5 second every 100,000 years.

[STe-7NE, ST2-9ES], {ACSSU004, ACSSU019, ACSSU048}

2.6 Our Moon

Many of the planets in our solar system have their own moons. Jupiter has the most, 63 moons at latest confirmation. The Earth is comparatively impoverished, with only one. Our Moon orbits Earth at a radius of 384,000 km. It has a diameter of 3,480 km and a mass of 1/81 that of our Earth. Its mass and diameter give it a gravitational attraction at the lunar surface of about 1/6 that of Earth. Astronauts on the lunar surface can then jump about six times higher than on earth. Actually, they don't do much jumping, but they can carry bigger loads.

The Moon takes a period of 27.3 days to orbit Earth. However, during this time the Earth moves some way around the Sun, so the Moon has to travel for about 2 more days to get into the same position with respect to the Sun. This explains why the lunar phases, which depend on the Moon's position with respect to the Earth and Sun, repeat every 29.5 days. Interestingly, the Moon spins just

once about its own axis for each rotation around the Earth. This is called “captured rotation”. One consequence is that the same part of the Moon faces the Earth at all times. In fact, there is a little bit of wobble and about 55% of the Moon’s total surface is visible to us at different times.

A number of theories exist for the formation of the Moon. The most popular of these suggests that the proto Earth was impacted by another planet-like body, with the Moon ultimately being formed from the debris thrown into near space. Certainly we have discovered that Moon rocks are very similar to those on Earth. The lunar surface is covered with craters formed by the impact of meteorites with the lunar surface. The dust from these collisions covers much of the Moon’s surface. Some of these craters are large enough to see from Earth with modest binoculars. They are best observed during a “half Moon”, when the Sun is at a strong angle to the lunar surface facing the Earth, thus producing the best shadows.

The Moon has no atmosphere since it does not have enough gravity to hold one. Because there is no atmosphere there is no weather and very little erosion. There is also no free water, which would also accelerate erosion. (So far as we know the only water is locked up in a small ice lake on the far side of the Moon from Earth.) This means that craters, once formed, last indefinitely. It also means that there are no sedimentary rocks on the Moon’s surface, since these are formed from erosion products. The portion of the Moon’s surface facing the Sun gets hotter than boiling water, (100 ^{o}C). Meanwhile, the shadowed portion gets colder than the temp needed to freeze carbon dioxide at the Earth’s surface, (-78 ^{o}C).

2.7 Space Travel

Humans have always dreamed of escaping from Earth’s confines, particularly once we learned to fly. But it has not been an easy road. Some of the early steps toward the conquest of space are shown in the time line below. All this has happened within the last 100 years.

1926 - first liquid-fuelled rocket launched by inventor-physicist Dr Robert Goddard, one of the fathers of modern rocketry, on March 16.

1944 - first V2 rocket launched towards London on September 7 by the German team led by Dr Werner von Braun. Von Braun would later go to America where he developed the Saturn V rockets which took the Apollo missions to the Moon.

1957 - Sputnik, the first un-manned satellite to go into orbit was launched by Russia.

1961 - The first man, the Russian cosmonaut Yuri Gagarin, was launched into orbit in Vostok 1. He spent less than 1 hour and 48 minutes in orbit. This was mankind’s first experience of orbital weightlessness.

1961 - The first American, Alan Shepard, made a 15-minute sub-orbital space flight.

1962 - John Glenn became the first American to orbit the earth. He completed three orbits. (Glenn also returned to space in 1998, at the age of 77 as part of a Space Shuttle experiment on aging and space travel.

1963 - The Russian Valentina Tereshkova became the first woman in space, orbiting the Earth. It would not be until 1983 that an American woman, Sally Ride) rode into space.

1965 - Alexei Leonov became the first space walker.

1967 - the Russian sent up the first of their Soyuz spacecraft. These were capable of carrying three persons. In 1969 they managed a space docking, transferring cosmonauts from Soyuz 5 to Soyuz 4.

It interesting to note that it was the need to save weight by miniaturising everything which provided the impetus to produce integrated circuits and the silicon chip. There have been many other technological spinoffs from space exploration. There was intense rivalry during the 1960s between the Russians and Americans. The primary interest during this time was the conquest of the Moon. Although the Mercury and Gemini programs yielded valuable data, the Apollo program was the most significant. In all, there have been some 25 trips to the Moon, some just orbiting and a few involving actual landings. Some of the highlights of the Moon program are shown below.

1961 - President John F. Kennedy announces to a joint session of Congress that America will land men on the Moon within a decade.

1968 - Apollo 8 launched, leading to the first human orbit of the Moon.

1969 - Apollo 11 blasts off from Cape Kennedy on the first lunar landing mission on July 16 with three astronauts: Edwin (Buzz) Aldrin, Michael Collins and Neil Armstrong. It took four days to reach the Moon. On July 20 Armstrong became the first human to set foot on the lunar surface as he stepped from the lunar module *Eagle*. After 6 hours on the surface the *Eagle* returned to the mother craft, which was orbiting above the Moon's surface. The three then blasted out of lunar orbit on their return to Earth. About a quarter of the distance back to Earth they passed the gravity transition point where the Moon's gravity is overpowered by that of the Earth. From that point on the space craft gradually accelerated, until by the time it approached the Earth's atmosphere its speed was about 11 km per second. At this speed the task of re-entry is a very difficult one. Hit the atmosphere at too steep an angle and the space craft will heat up too rapidly to be protected by its heat shield. Hit at too narrow an angle and the space craft will bounce off the atmosphere and head off on a journey into space from which there can be no possible return. The angle between these two disasters is only 3 degrees wide!

1970 - Apollo 13 launched on April 11. En route to the moon an explosion on board resulted in the termination of the mission. Only the superb training and skill of the technicians at mission control and the three astronauts aboard brought the latter safely back to Earth. 1995 saw the release of *Apollo 13*, the highly acclaimed film made of this heroic venture.

1972 - Apollo 17 was launched. This would be the last trip to the Moon and the last Moon landing by humans. Dr Harrison Schmitt, a geologist, and later a US senator, was the last person to walk on the Moon's surface.

Following the Moon missions, attention was once again focussed on space exploration nearer the Earth using space stations serviced by shuttles. A number of probes have also been launched with the aim of investigating distant reaches of our solar system.

1962 - The Mariner Spacecraft launched to explore Mars, Venus and Mercury.

1971 - The first Russian space station, *Salyut*, was launched. This was crewed by three people. These were transferred by the Soyuz space craft.

1973 - The first American space station, "*Skylab*", was launched. Skylab eventually dropped out of orbit over the SW tip of Western Australia on July 11, 1979. Although it largely burned up on re-entry, some debris was found. The Shire of Esperance attempted to fine the United States $400 for littering!

1975 - Viking I and Viking II dispatched to Mars.

1977 - The un-manned Voyager I and Voyager II were launched to explore Jupiter and Saturn. Currently Voyager I is the man-made object most distant from the Earth. As of about 9:15 am, August 19, 2013 it was some 18,683,525,000 km from earth and receding at about 40 km/second! This is about 12.5 times the distance from the Earth to the Sun.

1982 - The first operational Space Shuttle mission blasted off on November 11 with *Columbia*.

1984 - The first Australian, Dr Paul Scully-Power blasted into space on the Space Shuttle *Challenger*.

1986 - The Space Shuttle *Challenger* exploded soon after launch on January 28, killing all seven on board, including civilian primary teacher, Christa McAuliffe.

1986 - The Russian space station *Mir* was sent into orbit in 4 separate modules. These were assembled in space. An Australian, Andy Thomas spent time in Mir during 1998.

1999 - Mir was replaced by the *International Space Station.* This was a cooperative venture by America, Russia and the Common Market states. This was completed and became fully functional in 2000. It weighs 520 tonnes and is now the forth brightest object in the night sky.

2003 - On February 1 the Space shuttle *Columbia* broke apart on re-entry and 7 astronauts died. This was thought to be due to damage sustained by the heat shield.

2011 - On July 21 the last Shuttle mission concluded with the safe landing of *Atlantis* at the Kennedy Space Centre.

When venturing outside their heated and pressurised space craft, such as during space walks and lunar landings, astronauts must be protected from the almost zero gas pressures and low temperatures of space. They wear flexible space suits which allow movement but retain air pressure inside. Their eyes must also be protected from the intense solar radiation, since there are no light-absorbing materials in space. Often a thin layer of gold which is very reflective, but which allows some light through, is used on the visors of space helmets.

Man-Made Earth Satellites

Over the last 30 years humans have placed a number of satellites in earth orbit. Many of these are quite small. They are used for global positioning, weather mapping, communications, scientific research and, of course, spying. The period of a satellite turns out to depend only on its distance from the Earth's surface. A satellite in close orbit, just above the atmosphere, orbits in as little as 2.5 hours. By the time we get out to the Moon, at a distance of 384,000 km, the period is about 29 days, as we have seen.

Obviously at some intermediate distance the orbital period will be exactly one day. This occurs at a distance of about 6 Earth radii above the surface of the Earth. If such a satellite is placed in orbit above the Earth's equator an interesting consequence emerges. The satellite goes around once a day and the Earth also goes round once a day. This means that the satellite apparently sits above the same spot on the equator. Such satellites are said to be "geostationary", and are used extensively for communications. This is why communication dishes on homes, pubs and churches can be set in concrete! They only have to point to the same part of the sky. This is also the reason why such dishes in Australia always point in a northerly direction (maybe north east or north west) but never towards the south. Other families of satellites such as the "Iridium" group assist such functions as GPS navigation and satellite phones.

Activities

The following fun activities grow out of this chapter.

1. Build a sundial in the school ground and calibrate it. What are its advantages and disadvantaged over regular watches?
2. Study other ancient means of time keeping: candles (King Alfred the Great of England used them) and hour glasses.
3. Study different types of clocks: pendulum clocks, automatic watches, electric clocks, crystal regulated watches, stopwatches, solar powered watches, water clocks, winding clocks and all sorts of even more unusual clocks. Perhaps some old clocks, including those with pendulums and chimes, may be available for exhibition. You could get the children to research the fascinating story of John Harrison, who made the first clocks accurate enough to determine longitude at sea – see Dava Sobel's Longitude.
4. Make a primitive telescope from two lenses.
5. Locate an astronomical telescope and arrange a viewing session, hopefully with some one who knows the night sky and can point out easily visible objects such as: the binary pair comprising the top pointer on the Southern Cross, the "Jewel Box", the moons of Jupiter, the rings of Saturn and some globular clusters. You may also use the telescope to observe sunspots, although you must take care and get advice. NEVER look through a telescope at the Sun!!
6. Make some model rockets and fire them. Again, take care!
7. Locate and watch footage of some of the Saturn V and Shuttle launches. These are exciting!
8. Locate and watch footage of the first moon landing in 1969.
9. Research the story of the Apollo 13 explosion and watch parts of the video Apollo 13.
10. Make a model of the solar system to hang as a mobile on the classroom ceiling.
11. Get your children to research the origin of the expression "once in a blue Moon". (This refers to the somewhat rare occurrence of two full moons in the same month.)

Chapter 3

Our Dynamic Planet

3.1 The Earth's Atmosphere

The Earth's atmosphere is held to the Earth by gravitational attraction. It extends upwards for approximately 120 km, forming only about 2% of the Earth's diameter of approx 13,000 kms. The atmosphere is most dense at the Earth's surface and gradually gets thinner with altitude. The uppermost layer is called the stratosphere. The weight of the atmosphere pressing down on the Earth gives rise to what we call "atmospheric pressure", which at the Earth's surface is equivalent to the weight of a litre of water on every square centimetre of surface. In fact pressure is measured in many different units and is one of the most confusing quantities in science. Scientists often express atmospheric pressure as 101 kiloPascals (kPa). Atmospheric pressure at the Earth's surface varies slightly and such variations are usually associated with certain weather patterns. We will have more to say about this later in this chapter, in our discussion of weather. Obviously, atmospheric pressure gradually decreases with altitude, becoming zero at the edge of space. Temperatures, too, generally decrease with altitude.

Earth's atmosphere is largely made up of three gases: nitrogen (78%), oxygen (21%) and carbon dioxide (less than 1%). The last two of these gases are very important for animal and plant life respectively. Oxygen also supports combustion. The nitrogen fortunately dilutes the oxygen to a level safe enough for animals to breath and also low enough to prevents things from spontaneously bursting into flame! Carbon dioxide is breathed out by animals and also released by the burning of fossil fuels. Its presence in the atmosphere reduces heat loss from the Earth to space. We will discuss this in more detail later in this chapter in connection with global warming.

Ordinary atmospheric nitrogen consists of molecules, which are pairs of nitrogen atoms, designated N_2. These atoms seem to like to hang around in pairs. Atmospheric oxygen also consists of molecules, in this case two oxygen atoms together, designated O_2. However, at high altitudes in the atmosphere three oxygen atoms can clump together into an O_3 molecule. This form of oxygen is called "ozone". It forms a thin layer in the upper atmosphere, which varies in height from about 20 to 60 km above the Earth's surface. This layer is very important to life on Earth, since it absorbs a great deal of harmful radiation, particularly ultraviolet light, coming in from the Sun and from space. We would get many more skin cancers if it were not for this protective layer. Carbon dioxide consists of one carbon atom and two oxygen atoms, one on each side. It is said to be a linear molecule because all the atoms form a straight line.

In addition to these major components the atmosphere also contains water vapour, dust particles from winds and volcanoes and some other more complex gases, like methane and oxides of sulphur

and nitrogen. Some of these gases are produced by human industrial pollution and can return to the Earth's surface as acid rain.

3.2 The Earth's Surface

About 70% of Earth is covered by water, almost all of it being salt water. This huge amount of liquid water is one of the major factors which enables our Earth to support carbon-base life as we know it. The average depth of the ocean is nearly 4 km, although the deepest part of the ocean, the Mariannas Trench, has a depth of approximately 10.99 km.

Only about 2.5% of the water on Earth is fresh water. Most of this is frozen in icecaps and icefields, found at high latitudes and/or high altitudes. 90% of the world's ice is found in the Antarctic, with about 10% in the Greenland Icecap. All the other icefields on Earth amount to less than 1%. Australia does not have any of these icefields, although the New Zealand Alps certainly do. If all the polar ice were to melt the level of the Earth's oceans would rise by about 70 m. Quite a lot of fresh water is stored worldwide in rocky reservoirs, or aquifers, beneath the surface. This is sometimes called "artesian:" water. Australia is fortunate to have vast reserves of such water although these have been seriously depleted in recent decades. All these bodies of water on our planet: vapour, cloud, sea, lakes, rivers underground (artesian) water and ice are sometimes collectively known as the "hydrosphere".

About 30% of Earth is land mass, with about 40% of this being desert. The highest mountain, Mt Everest is over 8 km above sea level. Interestingly, the Mariannas Trench is deeper than Mt Everest is high. The lowest dry land level is 417 m below sea level and is around the shoreline of the Dead Sea.

3.3 Weather and Climate

Climate

Climate is "what you expect". It has to do with long-term, time-averaged and annual weather patterns. It is affected by such factors as:

- average temperatures, together with range of temperatures experienced and the frequency of these variations,
- average humidity, patterns of cloud cover and average rainfall, also the time distribution of rainfall, and
- patterns of air pressure, wind speed, wind direction and level of storm activity.

Weather

Weather is "what you actually get". Weather is changeable and can alter from day to day and even from hour to hour. In some places, like Tasmania, it is said that it is possible to "get all four seasons in a day"! Weather consists of a range of parameters:

- air temperature,

- humidity level, amount of cloud cover and whether it is raining, and
- air pressure, wind strength and direction.

Temperature

Both instantaneous and average air temperatures are primarily affected by altitude, the amount of heat received from the Sun, wind and cloud cover. Temperatures decrease with increasing altitude, roughly at the rate of 9 ºC per 1000 meter climb. The amount of heat from the Sun is dependent on the angle of the Sun and the proportion of daylight hours, both of which are determined by latitude. Obviously temperatures decrease as one travels further towards the poles, causing the angle from the vertical (zenith) to the Sun to increase as it dips closer to the horizon. Clearly, too, temperatures decrease as the proportion of daylight hours in the day decreases. Interestingly, as one goes further south, for example, both the angle of the Sun and the length of a summer's day increases. The first of these effects will reduce midday temperatures while the second tends to increase midday temperatures. Which effect typically wins? The first! Midday temperatures tend to decrease as one travels further south.

Winds can also affect temperature. During the day, winds from hot inland regions can raise temperatures while cool winds, generally from the south or from the sea, lower temperatures. Cloud cover also tends to reduce temperatures by absorbing some of the Sun's energy. Heavy cloud cover also tends to even out extremes in daily temperature cycles. In many regions heavy cloud cover can reduce the occurrence of damaging frosts, with their effects of agriculture and lifestyle. The presence of volcanic dust can also block out sunlight, thus producing a cooling of temperatures and climate, sometimes drastically. Temperature is also affected by proximity to cool or warm ocean currents, such as the Gulf Stream, which warms the NE United States. The highest temperature ever recorded was 58 ºC in Libya. The lowest temperature ever recorded was -80 ºC in the Antarctic.

The range of temperature variation within a daily and annual cycle is largely determined by proximity to large volumes of water, such as the sea. Water can absorb or give up large quantities of heat energy without changing temperature very much at all, whereas land masses heat up and cool down much more rapidly. As discussed in more detail under "Wind Patterns", this evenness of the sea temperature reduces both hot and cold extremes for coastal land regions.

Humidity, Cloud Cover and Rainfall

The term "humidity" refers to the amount of water vapour mixed in with, and supported by, the air mass. Humidity has a huge effect on vegetation and human lifestyle. The warmer the air mass the greater the amount of water vapour it can support. This means that humidity is generally greatest in now-latitude, equatorial regions. Obviously, humidity will also be greatest in regions close to large bodies of water. For this reason humidity levels tend to be greater along the coast and much lower inland. If warm air is cooled it reaches the point at which it can no longer support the amount of water it contains. This temperature is called the "dew point". Further cooling results in the water vapour condensing out of it, forming the tiny droplets which appear to us as clouds.

There are many different kinds of clouds. High, thin and wispy clouds are called cirrus clouds. Cirrocumulus clouds are tiny, high clumps of shadowless cloud. High, fluffy (usually white) clouds are called cumulus clouds. Big, dark clouds, of the sort which often bring rain, are called

cumulonimbus clouds. Low rain-bearing clouds are called nimbostratus clouds. Clouds associated with thunderstorms may be huge, and go from low level right up to cirrocumulus in one huge cloud body, the top of which can have solid ice crystals. These are cloud types are shown in Figure 3.1.

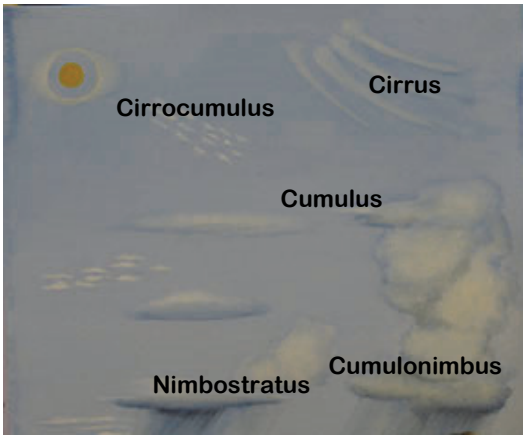


Figure 3.1 Various cloud types.

As well as affecting temperatures cloud cover produces shadier conditions which affect many aspects of existence, such as: vegetation patterns, production of vitamin B12 in animals such as humans, the growth of moulds and the occurrence of skin cancer. Such factors may significantly affect our conception of climate. They may also significantly affect our climatic satisfaction!

Most importantly, of course, clouds bring rain. Most rainclouds form over the oceans, as water is evaporated by the Sun's energy. This water remains in suspension as vapour until the air mass in which it is carried is cooled. This often happens as winds from the sea encounter cool land masses. It also happens when moisture-laden winds are cooled rapidly as they rise over mountain ranges. When these mountain ranges are on coasts facing into strong prevailing winds the effect is spectacular, explaining the 3m annual rainfalls in such regions as the west coast of Tasmania or the Fiordland of South New Zealand. Because most of the rain is precipitated on the windward side of mountain ranges, the other side is generally much drier and is often said to lie in a "rain shadow". This is one reason why the Tasmanian midlands, or the NSW Bathurst plains, have comparatively low rainfall levels.

Clearly, the direction and temperature of the ocean currents from which the clouds evaporate have a significant effect of a region's rainfall. This effect is very noticeable in the rainfall patterns of the landmasses situated on the Pacific rim. The El Niño currents result from colder water welling up from the ocean's depths in the western Pacific, near Australia's east cost, and moving into the eastern Pacific, near South America, as it warms up. The colder water near Australia does not evaporate much moisture whereas the warm air does. Accordingly, the El Niño current brings dry conditions to Eastern Australia and rain to Western South America. The La Nina current does the reverse. It is associated with the monsoonal rainy season in New Guinea, Queensland and northern NSW. These currents normally alternate in an annual cycle. However, sometimes this does not happen. The drought caused by the 2002-4 extended El Niño event was the most severe on record.

Rain also forms when a “cold front” of cooler air pushes in under a layer of warm air. At the boundary the warm air is cooled below its dew point, resulting in condensation and rain.

Snow is formed when the air temperature slowly falls below freezing, causing the air to become supersaturated with vapour. The vapour then passes directly from the gaseous state to the solid state, forming ornate hexagonal crystals around smaller ice crystals or dust particles, as shown in Figure 3.2.

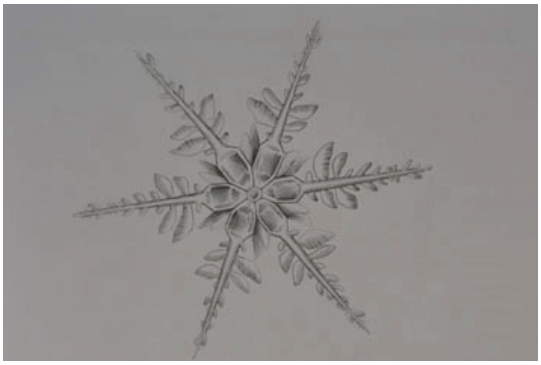


Figure 3.2 A typical snow crystal pattern.

The heat which is released as rain forms from water vapour can sometimes cause violent air movement. The resulting frictions result in the clouds accumulating huge electrical charges, which may spectacularly discharge as lightning. Large drops of water can form in such storms, which can fall as very cold rain or balls of ice, i.e. sleet or hail.

A region having an annual rainfall of less than 250 mm is usually regarded as a desert. Two places vie for the reputation of being the driest place on earth: the Atacama Desert in Chile - where it has never been known to rain, and the Antarctic - where all the moisture is frozen. Fire is actually a huge risk in the Antarctic, since everything is so dry. Scientists going to work in the Antarctic are given specialised fire training for this reason.

Wind Patterns

Winds are air flows caused by variations in atmospheric pressure, generally caused in turn by temperature variations. Sometimes these can be very severe and destructive. The three most significant wind factors are speed, constancy and direction.

The temperature variations causing winds are strongly influenced by the varying patterns of warming as the Earth rotates on its axis. When air heats it expands and rises, reducing air pressure. Colder air, at higher pressure pushes air mass into the region of low pressure. This is why, during daylight hours, there is generally a wind from the sea onto the land, since the land is hotter. At night, however, when the land is colder, the wind changes direction.

Also, the air over the equator is much warmer than the air over the poles. Accordingly, there is generally wind movement at the Earth’s surface down from the poles towards the equator and in the reverse direction at high altitudes. The Earth’s spin also creates a drag effect which influences the direction of such major wind patterns. This is a significant factor in the formation of the prevailing

westerly winds which influence Australia. These winds are sometimes known as the “Roaring forties”, since they centre around the 40s in latitude.

Some wind patterns are quite complex, very destructive and not uncommon. The two best known of these are cyclones (hurricanes) and tornados.

Cyclones form over warm oceans, generally in tropical regions. Updrafts carry warm, humid air high into the sky, forming towering cloud masses. As this vapour condenses into water droplets a great deal of heat energy is released. It is this energy which drives the strong winds which begin to rotate about the centre, or “eye” of the cyclone. This rotation is anti-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. These strong winds result in even more moisture uptake, feeding off the warm sea, forming a positive feedback loop. Winds at the base of the cyclone can reach 200 km/hr, with the area of wind disturbance exceeding 100 km in diameter. Cyclones typically cover large areas, which enables their frequent detection from orbiting satellites.

An interesting feature of cyclones is the formation of very low pressure in the centre, or “eye”, in which air actually descends to sea level, in contrast to the upward tending, circular airflow elsewhere in the system. The eye of the cyclone can be relatively placid. When a cyclone runs over land the supply of warm, humid air is shut off and the cyclone degenerates into a rain storm. If the rotation of the Earth was more rapid, i.e. if the day was shorter, the destructive effects of cyclonic winds would be significantly increased. As it is, scientists estimate that a large tropical cyclone releases energy equivalent to exploding a 10 megaton nuclear bomb every 20 minutes. Cyclones are usually given human first names. Hurricane Katrina, which struck Louisiana and Mississippi in 2005, is generally regarded as the most destructive cyclone of modern times, with a death toll of some 1,800 people and a damage bill of $100 billion US dollars. From space a cyclone often has an appearance similar to the picture shown in Figure 3.3.



Figure 3.3 A cyclone viewed from space.

Tornados, or twisters, are similar to cyclones in some ways but much more localised in effect and form in a different way. Tornados are associated with thunder storms and generally form over dry land after hot summer days. However, tornados can form over water or cross bodies of water in their path. Moist air is lifted rapidly by updrafts. Again, condensation releases heat energy, providing the energy to produce violent circular air currents, sucking more air in at the base. This begins to spiral upwards rapidly and as the radius of rotation reduces the air speeds up, like a spinning ice skater pulling in his/her arms. Wind speeds can reach 300 km/hr, with the diameter of

the rotating air column being as small as a few meters. Typically, the bottom of this column of spiralling air descends down from the covering cloud. When it touches the Earth it darkens as dust and debris hurtle skyward, as shown in Figure 3.4. Although tornados have been known on all continents except Antarctica their most common occurrence is within the “tornado alley” region of the United States.



Figure 3.4 A tornado.

Weather Maps

Important features of weather may be shown on a weather map, such as the ones shown in Figure 3.5 and Figure 3.6. Similar maps are displayed on every television weather coverage, along with satellite pictures and forecasts.

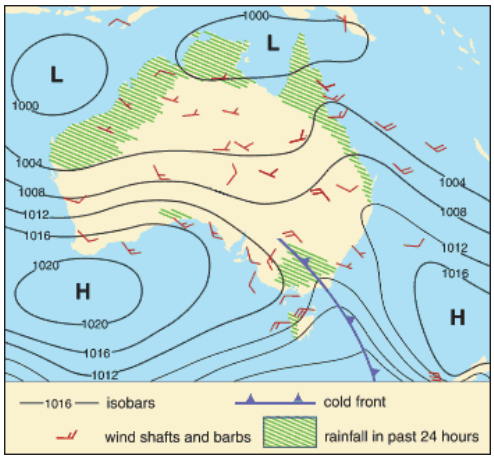


Figure 3.5 A typical weather report map.

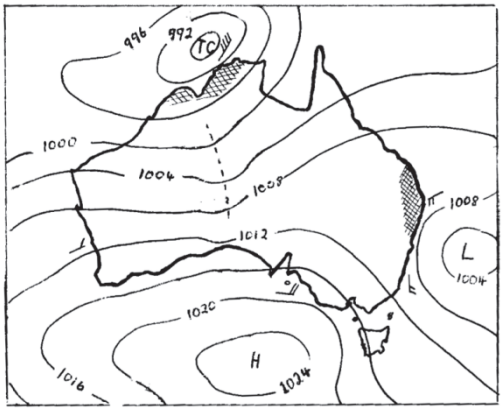


Figure 3.6 Another weather report map.

Isobars

The main features of weather maps are the "isobars" – the wavy lines showing regions where the air pressure is equal. The pressure in millibar units is usually given for each isobar and the spacing between isobars is usually 4 millibars. The average atmospheric pressure is 1000 millibars. Air pressure usually varies between 980 and 1020 millibars. Sometimes the isobars form circles around high or low pressure cells, indicated by an "H" or a "L", as shown in the Figures. A low pressure system associated with a tropical cyclone is designated "TC", as shown off Darwin in Figure 3.6.

Ridges and Troughs

A ridge is formed when air from a high pressure area bulges out to one side, as may be seen in the region of the Great Australian Bight on the map shown in Figure 3.5. Such ridges usually indicate fine weather. In contrast, a trough is formed where low pressures bulge out. These are usually indicated by "U" shaped fluctuations in the isobars, as also shown in both Figures 3.5 and 3.6 over the region of central Australia. A dashed line is often drawn through the central line of such a trough, which is usually associated with unsettled weather and sometimes rain.

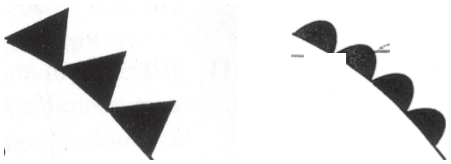
Winds

Wind direction and speed for any region can be inferred directly from the isobars. In the Southern Hemisphere the winds circulate clockwise around a low pressure cell and anticlockwise around a high pressure cell. The closer the isobars are together the faster the wind speed! Using this information it can be seen that in Figure 3.6 the wind in Perth will be easterly, i.e. off the land. In addition, wind directions and speeds are often given explicitly by the inclusion of "wind arrows". The direction of the arrow indicates the wind direction and the number of barbs shows the wind speed. Each full-length barb indicates 10 knots. Half-length barbs indicate 5 knots. Thus the north easterly wind associated with the tropical cyclone off Darwin, as shown in Figure 3.6, is 40 knots.

Fronts

A cold front often forms out of a low pressure cell or trough, where a cold mass of air moves towards and underneath a warm air mass. In Australia they generally bring southerly winds and a lowering of temperature. This temperature decrease can be very sudden, taking place in minutes. A warm front is a mass of warm air which blows across the land and rides up over a cold air mass. This can produce rain if the warm air mass is carrying moisture. These two types of front are

denoted by the symbols shown in Figure 3.7. A cold front can be seen in Figure 3.5 east of Tasmania and heading north east.



Cold Front Warm Front

Figure 3.7 Symbols for cold (left) and warm (right) fronts.

Rainfall

Rainfall is generally indicated by a pattern of diagonal lines or cross hashing. It may also be inferred from some isobar patterns. For example, low pressure cells coming off the ocean generally bring rain to coastal regions.

3.4 Global Warming and Climate Change

As we have seen, climate is the aggregate effect of a number of factors such as: average temperature, range of temperatures, rainfall and rainfall patterns, wind directions and speeds, and levels of storm activity. Climate very directly affects our lifestyle and even small climate changes may have complex effects on that lifestyle. The global picture shows a temperature increase of some 0.75°C since pre-industrial times with about 0.4°C of this increase occurring over the last 25 years. Projections indicate that the next century will see a further increase of between 2°C and 6°C. Anything like the latter figure will be very grim indeed! Almost certainly, current primary school students will see an increase of 2°C within their lifetime. The increase in the atmosphere of "greenhouse" gases, such as carbon dioxide, is thought by most scientists to be a significant factor in retaining heat in the Earth's surface, just as glass retains heat in a greenhouse.

Evidence for Global Warming and Climate Change

Even the Antarctic is warming, which has been a significant factor in rising sea levels. These have risen about 3 cm over the last 12 years and are now rising 3.5 mm per year, with 0.5 mm of this coming from melting Antarctic ice. A great reduction in the extent of summer ice, particularly in the Arctic, has also been noticed. In 1999 the largest iceberg in recorded history broke free from Antarctica. It is thought that the formation of this large berg was due to global warming. Careful measurements also indicate that oceans have also become more acidic, as they have absorbed atmospheric carbon dioxide ($CO_{2)}$. In addition to these effects temperature extremes are widening, more storm surges are evident and wind and snowfall patterns are changing.

In Australia

The National Climate Centre has collected data in Australia since 1908, with rainfall records going back to the 1870s. Total rainfall has increased by 10% over the last century, with the biggest increases occurring in the north and centre. Generally, rain in the south has decreased, particularly in the SW and SE. The recent 9-year drought in many southern areas was on a par with those of

1937-46 and 1895-1903. For Victoria and the southern Murray-Darling basin the recent drought was the worst on record.

Since 1950, average year-round temperatures in Australia have increased by 0.9°C. The year 2009 was the second hottest on record, after 2005. Additionally, more sites across the country recorded a highest temp in 2009 than in any previous year. The strongest warming has been observed in our red centre, with coastal regions and Tasmania least affected. There have also been changes in both temperature extremes, although record highs have outstripped record lows by at least 2:1. Maximum annual temperatures have risen approximately 1 degree over the last 13 years. There has been little corresponding change in minimum temperatures. Both the higher mean temperatures and the increase in variability are significant features of Australia's climate change.

The total number of tropical cyclones over 1960-2009 has declined, which is consistent with the global picture. Claims that cyclone intensity has increased are unproved at this point. Australia has records of cyclone intensity going back only to the 1980s.

Ecological Effects

Australia has been assessed to be one of the countries most at risk due to climate change, particularly due to our precarious water resources. There have already been many observed changes in Australia. These include:

- Changes in the life cycles of plants and animals. This is particularly poorly understood in Australia where 86% of plants and 45% birds are endemic to Australia. We have records of the first day of flowering of some species in Victoria since 1900. Eight of these species are now flowering 40 days earlier in Victoria than was the case 100 years ago. Similarly for birds: the Grey Fantail now arrives 2 days later as it flees the Tasmanian winter and leaves earlier to return to Tassie. There have also been changes in the cycle of the common brown butterfly. Butterflies are particularly good indicators of climate change.
- Changes to the Great Barrier Reef. The reef has seen an increase in temperature of 0.8 °C over the last 100 years. Such temperature increases cause stress on corals. First comes "bleaching", then the death of the coral plant. There has also been a decrease of 0.1 pH units as acidity has increased. At about 450 ppm (parts per million) of atmospheric CO_2 ocean acidity becomes too great for coral reef ecosystems to persist. Our current levels are about 380 ppm. We need to bring CO_2 to less than 350 ppm for the reef to survive in any recognisable form. Current conditions are outside those experienced by the reef over a very considerable period. The reef is already changing in consequence. Calcification and growth has dropped by 15%, just since 1990. Coral populations are only about 50% of those present in the 1800s and are dwindling by 2% each year.
- The increase in the number and severity of major fires has a major effect on terrestrial species distributions.

Effects on Human Society

Climate has a number of direct and indirect effects on human lifestyle, in areas such as agriculture, economics, population demographics, both physical and mental health and engineering. Some of these are discussed below.

i) **Agriculture and Economics**. Australian farmers are already being forced to adapt to climate change.

- Temperature increases: The wine grape industry is a good "canary". In most locations the annual vintage has moved forward at approximately a day/year since 1980. People are planting and harvesting other crops earlier and later.
- Frosts: These are another extreme event which directly affects agriculture. Clearer skies and dryer soils can give rise later frosts, with devastating effects on production.
- Crop types and crop cycles are also changing in response to water availability and other climate changes. Rice production in the Griffith Riverina area has dropped from 1,000,000 tons to just 5,000 tons, i.e. virtually disappeared, over the last 15 years. Olive cultivation may take over from citrus in some locations. The peanut industry has largely moved from Kingaroy to Catherine. The Sunraysia district around Mildura has seen drastically reduced areas under fruit cultivation due to with reduced water allocations from the Murray-Darling. Such changes have huge social and infrastructure effects.

ii) **Population Demographics**

- For example, the Great Barrier Reef is worth 6.5 billion dollars annually in tourism revenue. The loss of the reef would reorganise the population of North Queensland.
- As agricultural industries shift locations, town planning and government infrastructure in areas such as transport, health, and education must also make adjustments.
- According to projections there could be a rise in sea level of up to 90 cm by the end of this century. Large areas of NSW's Central Coast are less than 1 m above sea level. Studies suggest that such a rise in water level would require the re-routing of some 72 km roads, to say nothing of many homes, schools and even towns.

iii) **Health**

- High temperatures, particularly prolonged high temperatures have a significant effect on mortality and well being. The fact is that climate change kills people. During 2009, three days of very hot weather in Victoria, with temperatures up to 15°C above the expected average, resulted in 88 extra deaths and five times more ambulance callouts than usual. This reflects the situation in Europe where in 2003 France experienced a "heatquake", the worst heatwave ever recorded, with temperatures over 35 degrees for many days. This caused some 15000 deaths in France. Remember, it is the highs and lows which test us, not so much the average. Higher temperatures also increase the risk of food poisoning, as harmful bacteria can grow more easily in unrefrigerated food.
- Pollens directly influence conditions such as hay fevers. Changes in the timing of plant breeding cycles can, and have, extended hay fever periods in some locations.

- The incidence of mosquito-borne diseases, such as malaria (not currently endemic in Australia), Dengue fever (also not currently endemic in Australia) and Ross River virus (currently endemic) may also change. It is currently feared that for Dengue fever, the range of the mosquitoes responsible may extend by up to 800 km down the coast in the medium future.
- The effects of fire have been demonstrated in recent years by those in South Australia, Victoria and Tasmania.
- From the time of Banjo Paterson the image has predominated of emotionally tough Australian country dwellers over against the palsied and stressed urbanites. This picture has now substantially changed, as country stresses have driven many to uncertainty and insecurity, even to suicide. Those in rural communities are now less mentally robust than those in urban Australia. This is a very significant change. Young and female farmers are particularly at risk. Agriculturalists are aging – fewer young farmers are taking the farming risk. Some 16% are saying that they cannot cope with any more change and are uncertain how they should adapt. Climate looks to be one of the straws breaking the rural camel's back.

Strategies for Coping with Climate Change

- Improved Efficiency. It is generally agreed that efficiency is where the low hanging food lies. We must reduce heat losses, unnecessary petrol usage, inefficiencies with our transport system, etc. Correspondingly, we must increase recycling to a very great extent, conserving our natural resources.
- The Use of Alternative Energy Sources. Alternative energy sources include: solar photovoltaic, solar thermal, wind, geothermal, waves and tide, as well as nuclear fission and fusion.
- Compensation. An example of such compensation is provided by the recent long, dry period in Victoria which, after 2002, led to a new Melbourne water policy, resulting in over 100 different strategies. An unexpected 25% reduction in water usage was achieved where the aim had been just 15%. This extra achievement was most timely since the drought was actually worse than had been expected. Another 120 policy actions are pending, including de-salinisation investigations. Thus, although no grand plan has emerged, a lot of small contributing strategies have certainly helped. This reflects an adaptive approach to policy making.
- A number of engineering considerations arise. We may need higher heat tolerances for power transmission lines, more concrete sleepers to prevent the buckling of railway lines, higher bridges to allow for more severe storms and higher water levels and stronger buildings to cope with higher wind speeds.
- A modest benefit of the design, implementation and management of these climate change strategies will be an increase in employment opportunities, perhaps the emergence of entirely new industries.
- Adaption. Significant adaptions will be required, particularly within agriculture. It has been noted that an increase of 2 degrees/century is probably within the power of agriculture to manage adaptively. However, 6 degrees/century is a very different scenario.

[STe-7NE, ST1-8ES, ST1-9ES] {ACSSU004, ACSSU019, ACSHE022, ACSSU032, ACSSU075, ACSSU096}

3.5 The Structure of the Earth

In fact, the Earth is not perfectly spherical but is slightly bulged out at the equator, mainly due to its rotation about its axis. Thus it is called an “oblate spheroid”. This spheroid is not uniform in cross-section but has a definite structure. It does sound rather complicated, but the various components of the Earth can be described in two somewhat different ways. The first is in terms of the materials from which various parts of the Earth are made. According to this criterion there are of five main parts: crust, upper mantle, lower mantle, outer core and inner core.

The crust is the outer rocky skin, approximately 8 - 40 km thick. It is thinnest under the oceans. The crust is comprised of about 30 tectonic plates, which are mostly made of solid basalt rock. The discontinuity between the crust and the upper mantle is called the Mohorovicic discontinuity (Moho).

The upper and lower mantles are layers of hot, plastic (pliable) rock about 3,000 km thick. The temperature of the mantle is from 800ºC at the Moho, to 4,400ºC as it approaches the outer core.

The outer core is understood to be molten rock, about 2200 km thick and thought to be very rich in iron and nickel. The inner core is thought to be a ball of radius 1200 km. It is thought to be solid, due to the huge pressure. It is also thought to be largely comprised of iron and nickel. This view of the structure of the Earth is shown in Figure 3.8. Six types of atoms are thought to make up about 98% of the whole Earth. These are: iron, oxygen, magnesium, silicon, sulphur and nickel. The relative abundances of these elements varies throughout the Earth’s cross section. It is generally accepted by scientists that the most abundant element in the crust is oxygen while the most abundant element in the core is iron.

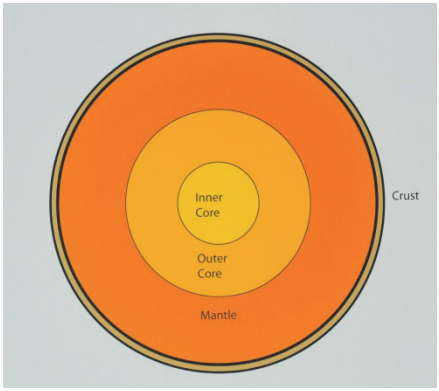


Figure 3.8 Cross section through Earth.

The second way to differentiate constituent layers of the Earth is on the basis of their mechanical properties. According to this criterion there are also five main parts: lithosphere, asthenosphere, mesosphere, outer core and inner core. The lithosphere (sphere of rock) is used to denote the crust and the upper mantle, where a great deal of convective flow takers place. The asthenosphere and mesosphere correspond to the rest of the mantle, which appears to be much more static, and the inner and outer core correspond exactly to the descriptions given above. As can be seen, these two classification systems are actually rather similar.

The Earth has a magnetic field, thought to be due to movement of electrically charged particles in the molten outer core. Magnetic compasses respond to this field, as do some migrating animals and birds. The so-called North pole is actually a field north-seeking (magnetic south) pole, since it attracts the north poles of magnets. The strength of Earth's magnetic field appears to change over long periods of time. It is now in decline. It is thought by scientists to have changed many times over geological history. The Earth's magnetic field extends far into space and acts as a shield from many dangerous charged particles travelling through space, particularly those coming from the Sun. The magnetic field "catches" such particles so that they do not enter the atmosphere so readily.

Plate Tectonics and Continental Drift

The molten lithosphere is in continual motion. As molten rock from the lithosphere wells up convectively towards the surface in some places, new basaltic crust material is created, pushing up in ridges. This largely occurs in the middle of the oceans, for example at the Atlantic mid-oceanic ridge, and is referred to as an instance of a "divergent" boundary. Where it occurs on land it forms what is called a "rift valley". Obviously, since the Earth's surface area is not increasing, crustal material must be disappearing in other parts of the planet's surface. This happens in two main ways which are not hard to understand or visualise.

In some places the two crustal plates push against each other with the result that rock is distorted and uplifted in a "convergent" boundary. The Andes Mountains in South America are thought to have formed in this way. Also the Himalayas, which have resulted from the northerly movement of the Indian subcontinent under the North Asian plate. In fact, this process is still happening, which is why the Everest summit is rising steadily at the rate of about 3 mm per year!

In other places one plate slips below the other and is gradually subsumed or "subducted" into the lithosphere below. Not surprisingly, this results in trenches. The deepest part of the ocean, the Marianas Trench is thought to have formed in this way. Commonly, the huge friction between the sliding rock plates produces enough heat to melt the rock above, often producing volcanoes.

This gradual upwelling and subduction are thought to be the mechanisms by which the Earth's 30 or so tectonic plates were formed. The continental land masses are composed of rocks of lower density than the basalt plates and so "float" on top of them, being carried along as they move. This produces what is known as "continental drift". For example, Australia is currently drifting north at approximately 6 cm per year. This regeneration of plate material also brings minerals to the Earth's surface which ultimately weather into plant nutrients, giving rise to long-term productivity. It is now thought that the movement of the tectonic plates is one of the major factors shaping the Earth's surface. Some of these processes are shown in Figure 3.9.

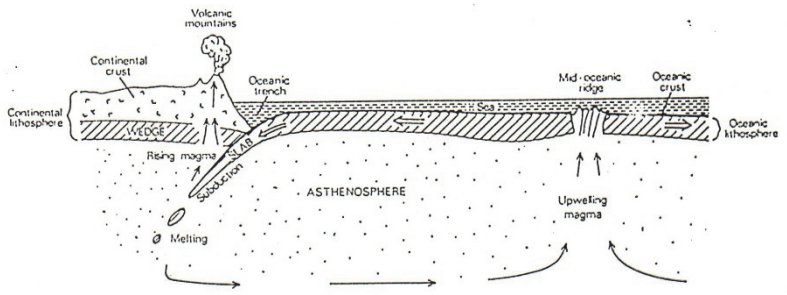


Figure 3.9 Upwelling and subduction zones.

Earthquakes, Tsunamis and Volcanos

Earthquakes

Plate boundaries can also slip against each other in a "transform" boundary. Again, due to the huge friction, such slippage is not gradual. The forces build up until they are sufficient to break rocky obstructions to movement. The plates then relieve the tectonic pressure by sudden movements i.e. earthquakes. The fact that the majority of volcanoes and earthquakes occur on plate boundaries lends huge support to the theory of tectonics. Where continental land masses sit over such a plate boundary, as is the case in New Zealand and California, these sudden subterranean slippages can cause fractures of, and movement within, these continents. If these disturbances occur near population centres great devastation can result, as in the 2011 Christchurch quake. Slippages of the famous San Andreas fault in southern California were responsible for the devastating San Francisco quakes of 1906 and 1989. The heat resulting from the friction of moving plates also causes volcanos, geysers and thermal pools.

Sometimes plate movement produces buckling or twisting of the plates. This can create disturbances at great distances from the plate boundaries, as happened in the 1989 Newcastle earthquake.

As we have noted, earthquakes usually occur as a result of plate slippage. Such movement produces three types of shockwaves which propagate through the Earth's crust from the point of movement, or "epicentre". Two of these travel through the body of the Earth. These are the "p" or primary wave and the "s" or secondary wave.

The "p" wave is a compressional wave, causing vibration or oscillation parallel to the Earth's surface. This results in objects moving back and forwards. This wave, which is generally the first to strike, is like a punch. Such waves can travel through any part of the Earth's interior. The "s" wave is a transverse wave, like a water wave, and causes objects on the surface to move up and down, producing a shaking action. The "s" waves can only travel through solid portions of the Earth's interior. The total absence of "s" waves in regions on the other side of the Earth from where the disturbance occurred provides strong evidence for a molten core within the Earth. The combined effect of the "p" and "s" waves can cause huge damage. The third type of shockwave is the "surface wave", which, unsurprisingly, travels along the Earth's surface, causing a swaying action. The surface wave typically does little damage compared to the other two wave types.

The destructive strength of an earthquake is measured on the "Richter" scale from 0 to 10. This is a logarithmic scale, where to increase by one unit requires something like a doubling of destructive power. Thus a quake which registers 8 on the Richter scale is hugely more destructive than the 1989 Newcastle earthquake, which registered 5.6 on this scale and killed 11 people. The most powerful recent quake ever recorded was the 1960 Chile event, which registered 9.5! The recent Haiti earthquake registered 7.0 on the Richter scale. The March 2011, earthquake off the Japanese coast registered 9.0. Earthquakes can break sewerage, gas and water pipes, bring down and sever electrical lines as well as bringing down buildings, bridges and roads. Earthquakes are detected by sensitive instruments called seismographs, where the disturbance of a delicately mounted cylinder is measured and recorded.

Tsunamis

Earthquakes which occur under the ocean can cause high-energy ocean waves, which can travel at hundreds of km/hr across the surface of the sea. As these near land and encounter the rising sea floor, their height is vastly increased and their speed slowed to tens of km/hr. However, this is still much faster than ordinary beach waves and these speeds provide little opportunity for escape. Such waves, called "tsunamis", can apparently rise from the sea and overwhelm coastal regions, causing immense destruction and loss of life. In 2006 a 7.7 magnitude quake off Java triggered a tsunami which killed almost 600 people, injuring many more and destroying the homes of over 60,000. Much of the huge death toll from the 2011 Japanese earthquake was due to the accompanying tsunami.

Volcanos

Volcanos are caused when molten rock, or "magma" reaches the Earth's surface. Generally this molten rock results from the huge friction of plate slippage or subduction, as may be seen in Figure 3.9. It should come as no surprise that most volcanoes occur along plate boundaries. However, in some other cases this molten rock appears to rise from the asthenosphere, producing so called persistent "hotspots" in the mantle, which seem to erupt at intervals. As the crustal plates move over these hotspots a series of volcanic cones result, as evident in the Hawaiian island chain, as shown in Figure 3.10, and also on the east coast of Australia. Mt Canobolas at Orange (NSW), the Warrumbungles (NSW), Mt Warning (NSW) and the Glasshouse Mountains above Brisbane (Qld) are included in this chain.

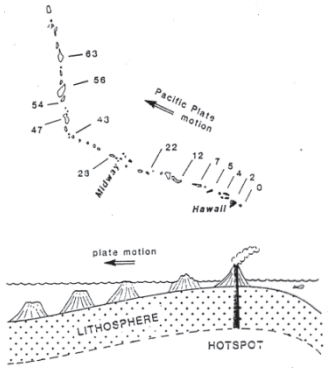


Figure 3.10 The Formation of the Hawaiian Island chain by movement of the pacific plate over a "hotspot".

There are three kinds of material produced by volcanos: lava, tephra and gas.

Lava is molten rock, sometimes so hot that it flows easily, like a liquid. Such lava cools into smooth, sometimes folded sheets of rock. This hot lava can also form lava tubes, where solidification takes place around the flow, forming an under-surface conduit of flowing lava, which gradually reduces. Such "lava tubes" may be 2-3 km in length. Other lava flows are cooler and more sticky, and solidify into rough, broken surfaces.

Tephra is the name given to broken rock fragments often thrown up from the throat of a volcano. Such material, from huge rocks weighing hundreds of tonnes to fine dust, may be thrown thousands of meters into the air. It is estimated that the AD 180 Hatepe eruption of Mt Taupo in NZ ejected some 100 cubic km of material. The material from such eruptions covers large proportions of countries such as New Zealand. Different eruptions, even of the same volcano, generally have different metallic "fingerprints, i.e. different proportions of the various natural elements, which enables their extent to be traced. As these tephra break down and erode, they produce rich soils. The recent Icelandic volcanic eruptions spewed huge amounts of such material into the atmosphere, severely hampering international air travel. Volcanic dust is not good for jet engines, as was decisively demonstrated by the 1982 eruption of Mt Galunggung, Java, which almost caused the crash of Flight BA 009, a 747 airliner which inadvertently flew through it at night!

Volcanos also produce large amounts of gas: carbon dioxide, nitrogen dioxide and sulphur dioxide. Some of these gas cocktails are extremely toxic to humans, as was evidenced when the AD 79 eruption of Mt Vesuvius wiped out life in the Roman cities of Pompei and Herculaneum.

There are four kinds of volcanic activity. These are named after past or present volcanoes. The first is the Hawaiian type, which is slow and predictable. The second is the Strombolian type, named after Mt Stromboli, near Sicily. Such volcanos give rise to a continual explosive eruptions of gas and tephra. Mt Stromboli itself has been in constant, steady eruption since the beginning of recorded history. The third type is the Vulcanian, named after Mt Vulcano, also near Sicily. These volcanos exude sticky lava, sometimes on a large scale. This sticky lava forms plugs in the vents, resulting in explosions which cast forth rocks and dust. The fourth type is the Peléean, named after Mt Pelée, in Martinique. These are the most destructive type, in which whole mountains can be blown skyward. In 1902 Mt Pelée blew apart, killing 38,000 people. Earlier, in 1883, Mt Krakatoa in Indonesia blew up, producing the loudest sound ever heard in recent centuries (it was heard in Perth, Australia, over 3,000 km away) and tsunamis up to 40 m high, which killed some 36,000 people on nearby islands. The 1980 Mt St Helens eruption in the USA was also a Peléean volcano. With the exception of the Strombolian category, volcanos can lie dormant for many years.

Earth is not the only planet to display volcanic activity. The largest volcano in our solar system is "Olympus Mons", on the planet Mars. It is three times the height of Mt Everest and at least four or five times the height of the largest volcano on Earth. It is thought to have been caused by a "hotspot" on Mars.

Erosion

The surface of the Earth is also shaped by erosion, which begins by weathering. Rock may be broken down in a number of ways.

It may be worn away and transported by flowing water. Rivers shape mountains and valleys and transport huge amounts of sediment. Rivers range from fast flowing and quickly falling torrents in narrow "V" shaped valleys, carrying pebbles and stones, to slower flows across wide plains, transporting fine sediment. Flood events can dramatically speed up such transports. The ocean is also a major force in erosion since wave action can collapse seaside rock faces and shift vast quantities of sand. These forces can produce islands by cutting off headlands, such as happens regularly on Victoria's Great Ocean Road and sometimes along the NSW coast near Cooranbong.

Rock may also be abraded by grinding rivers of ice, or glaciers. Glacial valleys are usually "U" shaped. Glaciers carry large amounts of the rocky debris carved from the sides of the valley. This rock also assists the abrasive action of the ice. The rock is ultimately deposited in the glacial lakes and moraines as the glacier terminates.

Erosion is also caused by wind, which is very effective at shifting soil and sand, even to the point of carrying quantities of Australian soil to New Zealand, as happened during September, 2009. Australian farming practice over past decades has increased the rate of such topsoil loss. Fortunately, improved agricultural methods can reduce these losses.

Chemical reactions also assist erosion. The chemical constituency and thus the hardness and toughness of rock may also be reduced by oxidation and other chemical processes. Such rocks are then more easily worn away. Acid rains caused by human pollution can accelerate these processes.

Further, the expansion of water as it freezes also erodes rock. In cold conditions the water trapped in rocky fissures and cracks freezes, expanding as it does so and cracking the rock apart, thus accelerating weathering. Many of the dolerite and granite tors and spalls of Australian mountain country have been shaped this way.

Temperature changes also tend to break down rock. As parts of rocks heat and cool at different rates the resultant expansions and contractions produce internal stresses, resulting in fractures and cracks. Finally, tectonic disturbances can also accelerate weathering, causing rock to be physically shattered and crushed. Further, the opening of fissures allows water to penetrate more easily.

The average rate of erosion due to all these factors working together has been estimated to be around 137 tonne of rock per square kilometre per year. This erosion rate would result in the lowering of an average land surface by 1 meter every 22,000 years.

[ST2-8ES, ST3-9ES] {ACSSU075, ACSSU096}

3.6 Rocks and Minerals

Rocks

All rocks are made up of minerals, most of which are rather simple chemical structures. However, before examining the minerals (which are generally much better looking) it makes sense to discuss rocks, since these are mostly what we see. The branch of science which studies of rocks and minerals is called Geology. There are three main classes of rocks on Earth: igneous, sedimentary and metamorphic.

Igneous Rocks

The word “igneous” means “fire formed”. These rocks have crystalised from molten magma. There are three types of igneous rocks: volcanic, plutonic and porphyritic. Volcanic rocks form on the surface and thus cool very quickly, due to heat loss into the atmosphere. Because the rock crystals form rapidly they form in great numbers and are small in size. Often a microscope is needed to observe these. Basalt and dolerite are examples of a volcanic rock. Sometimes, if the rate of cooling is very rapid, some combinations of minerals can form a dark volcanic glass, called obsidian.

In contrast, plutonic igneous rocks form deep in the crust. The much slower cooling rates result in much larger crystals. Granite is the most common example of a plutonic rock. Porphyritic rocks are something of a compromise. They contain large crystals (those which crystalised deep down) embedded in masses of smaller crystals, formed when the remaining liquid rock reached the surface. In fact, most such rocks are simply called Porphyry.

Molten lava may carry dissolved gases, which become air bubbles as the lava reaches the surface and pressure is reduced. Thus, many of the volcanic rocks formed as this lava cools contain air bubbles. In extreme cases, some basalts contain so many air spaces that the rock actually floats. Such rocks are called pumice.

Basalt rocks weather to form rich, red soils, such as those observed in the Lismore area or on Tasmania’s north west coast. Granite, dolerite and basalt are very hard rocks which bear weight well and are very resistant to weathering. For these reasons they are commonly used for architecture. Figure 3.11 shows some grey and red granite. These are the two most common forms.



Figure 3.11 Grey and Red Granite.

Sedimentary Rocks

These are ultimately erosion products of their igneous forbears. As igneous rocks are broken down by water, ice, chemical attack and wind, they form easily transported smaller rocks, sand and mud. These are transported by water or wind and relayed as sediment, generally under a quiet body of water. Eventually this sediment hardens or chemically binds into new rock. Shale, mudstone, sandstone, conglomerate and limestone are common examples of sedimentary rock.

Shale and mudstone are formed from fine clay particles which precipitate slowly out of still water. Shales often exhibit "varving" or layering, where, for example, summer and winter deposits may be of different colours, due to different inclusions, such as pollens. Summer deposits have pollens whereas winter deposits do not. Sandstone is formed by the consolidation of sand deposits. Sometimes such stone is poorly formed and very soft. In other locations, such as in the Sydney and Gosford area, sandstone is hard, durable and of great architectural value. These sandstones are thought to have been laid down under oceans. Conglomerate is formed when gravel is deposited by fast-flowing streams and rivers.

Limestone is a slightly different type of sedimentary rock, rather uniquely composed of just one chemical compound, calcium carbonate. It can sometimes be deposited as this chemical precipitates out of evaporating sea water. It can also be produced from the consolidated remains of organisms such as shells and corals, whose rigid structures are made of calcium carbonate.

Sometimes the remains of living organisms get trapped in forming sedimentary deposits. Under the right conditions these may form fossils, about which we will have more to say. Generally, only sedimentary rocks contain fossils, although some types of fossil remains have been identified in basalt. For example, the last volcanic flow in Samoa, in 1910, pushed over a number of coconut trees, which fell into lava. While the trees quickly burned away the lava cooled sufficiently to retain imprints of the trees, even of the bark pattern. However, this is rare. One common type of sedimentary rock almost entirely composed of fossil remains is coal, formed by the burial and compression of plant material. In most cases coal is formed not from the remains of trees, as some think, but from large, fern-like plants.

Metamorphic Rocks

Metamorphic rocks are formed when existing igneous or sedimentary rocks are subjected to intense heat and pressure over long periods of time. This causes alterations to the minerals and crystal structures in these rocks, changing their form and appearance. The conditions which produce metamorphic rocks are often associated with volcanos. These conditions turn shale into slate, which may, under certain conditions, change to schist. Limestone is converted to marble. Sandstone may be changed to quartzite, a rock type often associated with gold reefs. The rock cycle is shown in Figure 3.12.

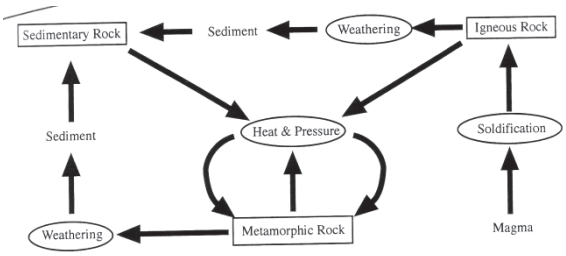


Figure 3.12 The rock cycle.

Interestingly, the moon appears to have no metamorphic rock. It has volcanic and plutonic igneous rock, as on Earth. It also has rock powder, mostly caused by meteoric impacts, which, although unconsolidated, may be considered to be sedimentary.

Minerals

Minerals are the relatively pure chemical substances of which rocks are comprised. For example, all granites consist of the minerals mica (the shiny black bits), **feldspar** (which may be white, grey or pink) and **quartz** (the clear glassy bits). Minerals may also occur naturally in isolated deposits. Some of these are of huge commercial value, like the metallic minerals from which we smelt iron, copper, lead, zinc, aluminium and other metals. Some of them are most attractive, exhibiting brilliant colours and magnificent crystals, like **amethyst** and crocoite. Sometimes a mineral may be both pretty and valuable, such as in the case of **diamonds** and **rubies**. Make no mistake – minerals are where it's at! Perhaps with the exception of those like diamonds, minerals are easy and cheap to collect and make great school displays. Almost certainly someone in your class will already have a collection or know of one. Figure 3.13 shows some common minerals.



Figure 3.13 Some common minerals.

There are about 3000 different minerals found in the Earth's crust. Some of these are pure chemical elements, such as diamond, which is 100% carbon, or natural gold. Others are simple compounds of just two chemical elements, such as **gypsum**, from which we make plaster sheeting (calcium sulphate), **quartz** (silicon dioxide), crocoite (lead chromate) or **salt** (sodium chloride). Other minerals contain many elements in quite complex structures. Interestingly, the minerals found in Moon rocks have been found to be similar to those found on Earth.

As earlier noted, one group of minerals which is of particular commercial interest is that containing the metallic ores. These are often of striking appearance. **Calcopyrites**, from which we smelt copper, appears shiny and metallic, and has such a range of colours it is sometimes called "peacock ore". **Galena**, from which we get lead, is lead coloured, with shiny cubic crystals. **Sphalerite**, from which we derive zinc, and **cassiterite**, from which we obtain tin, form shiny metallic crystals. **Iron pyrites**, or fools gold, forms cubic, gold-coloured crystals. In contrast to some of the above, commercial iron ore is not very spectacular. It is normally found in the form of **magnetite** or **hematite**. These are iron oxides and are usually grey, black or red depending on the chemical form. Iron ores, of course, are of enormous economic value. The gravitational attraction at the Earth's surface is slightly altered by the different densities of rocks and minerals. This effect is often used to detect large ore bodies comprised of minerals such as those discussed above. The mining of such minerals and the development of technology to extract the metals has been one of the major factors shaping human civilisation.

Some minerals are easy to identify. Others can be quite tricky. There are six properties which are commonly used to identify minerals. These are: colour, lustre, crystal shape, streak, hardness and cleavage.

Colour is rather obvious. **Olivine**, **Jade** and **Malachite** are deep green. Natural **sulphur** is yellow. Crocoite and ruby are bright red. Other minerals, such as **quartz** can have a large variety of colours

Lustre is a little more tricky. The term describes the interaction of light with the surface of the mineral. How much is absorbed? How much is reflected? Diamond is said to have an "adamantine" lustre, whereas iron pyrites and many other metallic minerals are said to have a "metallic" lustre. Other minerals may be said to have a "dull", "pearly" or "greasy" lustre.

Crystal shape is, again, rather obvious. Of course, some minerals are not obviously crystalline, so this criterion is of little value in identification. Such material is said to be in "massive" form. However, other minerals, such as quartz, have a well defined and easily identified crystal shape. Quartz occurs as hexagonal crystals, with well defined angles between all surfaces. Irrespective of the colour: amethyst, smoky quartz, rose quartz or clear, this mineral is easily identified by crystal shape. Some minerals, such as **mica**, are flat and flaky. A considerable variety of crystal types are found.

Streak is the colour of the powdered mineral, i.e. of the composite constituent chemicals. It is observed by rubbing the material across a hard, abrasive surface. Sometimes this colour is quite different from the colour of the undisturbed mineral surface. For example, **hornblend**e is usually dark green but has a grey streak. **Olivine** is also dark green but has a white streak.

Hardness is reasonably self explanatory. The hardness of all minerals is defined by reference to Moh's scale, from "1", corresponding to talc, the softest mineral known, to 10, corresponding to diamond, the hardest material known. This scale is shown below in Table 3.1.

Table 3.1 Moh's scale of Hardness.

Hardness	Mineral	Guide
1	Talc	Can be crushed between fingers

2	Gypsum	Can be scratched by fingernail
3	Calcite	Can be scratched by coin
4	Fluorite	
5	Apatite	
6	Feldspar	Can be scratched by knife blade
7	Quartz	
8	Topaz	
9	Corundam	
10	Diamond	Cannot be scratched by anything!

Cleavage refers to the number of planes or flat surfaces along which the mineral crystal will break if struck with a small hammer. Because the mica crystal is thin and flat it has only one plane of cleavage. **Calcite**, which forms rhombohedral crystals, has three cleavage planes, as do the cubic crystals of rock salt.

Fossils

Fossils were not widely known until the steam shovels of the industrial revolution started biting deeply into the rocky layers of Europe. When first brought to public attention there were many theories about their origin. Some felt that they were the remains of animals which had not made it to the surface, so to speak, during the creation. Others thought that they had been deliberately planted by the devil, for the confusion and consternation of good Christians. Others recognised them as the remains of once living organisms, although this view took some time to prevail. Now everyone accepts this view, although there are differing opinions over the age of many fossils. It is thought that most fossils were laid down under water, mostly salt water.

Fossil remains are very common indeed and widely spread over the world generally and in Australia. One of the biggest fossil beds in the world, found in the Karoo River area in Africa, is estimated to contain many millions of fossils. One of Australia's biggest fossil beds is found in the remote Riversleigh region in north western Queensland. It has been estimated that there are thousands of fossils in over 250 sites.

Fossils may include actual organic remains, such as shell, wood, ash, bone, teeth, skin or hair. Sometimes they include no such remains but simply outlines and impressions, such a body outlines, skeletal outlines, burrows, nests, footprints or drag marks. The condition and details from some fossils enable scientists to identify the cause of death, for example in the case of crushed or punctured skulls resulting from the predations of carnivora.

Fossil impressions of past life may be recorded in both casts and moulds. A cast is formed when soft sedimentary material forms around the dead organism, taking its shape. Long after the organism has decayed, its shape and form remain in the rock. In contrast, a mould forms when an organism, such as a shell, admits soft sedimentary material and traps it inside. The shell disappears over time but the rocky casting remains.

It should be noted that rock fossils are not the only form in which the remains of living organisms are found. In fact, there is quite a range of other means of preservation. These include:

- Peat bogs. Many mammoths, among other species, have been found in the frozen peat bogs of the northern Europe and Asia. For much of the nineteenth century a considerable proportion of the ivory circulating in Europe was from this source.
- Ice. Victims of sacrifice have been found in the frozen peaks of South America and presumably lost travellers have been found in Europe.
- Desiccation. The dried out remains of plants and animals are sometimes found in a well-preserved state in dry regions. For example, the remains of Thylacines, (Tasmanian Tigers) have been found in a South Australian cave.
- Amber. Pollen, leaves, and even small animals have also been found preserved in fossil tree sap, called amber.
- Petrification. This occurs when the living tissues, both plant and animal, are slowly replaced by rock as mineralised water seeps into the cavity. The water evaporates, leaving mineral deposits which eventually completely displace the organism and taking its form. Petrified wood is a common example of this process. Often the detail is excellent enabling, for example, the counting of tree rings. Petrified fossils in Australia usually involve either iron oxide or silicon dioxide, the latter producing a glassy appearance.

The fossil record shows evidence of many changes over time. For example, Australia's fossil beds show evidence of very much larger marsupials than we now find in the Australian bush. It also indicates a larger time scale than that with which some Christians are comfortable, although other Christians are unconcerned by the prospect of longer time periods. In many ways the fossil record, which is very incomplete, poses some problems to almost every model of origins, which makes it both frustrating and exciting for scientists.

Activities

The following fun activities grow out of this chapter.

1. Learn about nitrogen and how certain crops "fix" it into the soil so that we can grow food.
2. Record weather maps over a few days and map the movement of cold fronts, rain depressions, wind directions etc.
3. Research some of the strategies which have been implemented by farmers to cope with climate change. You may want to look particularly at: forestry, grains such as wheat and rice, grazing, viticulture, cotton, fisheries and water resources.
4. Measure maximum and minimum temperatures for a fortnight, or a school term. You may need to buy some thermometers which record such data. Graph this data and display it. You may be able to do it in both summer and winter to observe the differences.
5. Set up a rain gauge and record rainfall for a period of time. Graph this data and display it. It may be possible to contact a teacher in a school which has vastly different rainfall. Data sets could then be swapped.
6. Make and install a weather cock to indicate wind direction at your school.
7. Research Giles Meteorological Station, Australia's most remote weather station, in our red centre.
8. Research the Life story of Len Beadell, who surveyed Giles Station, Woomera rocket range, the Gunbarrel Highway, Maralinga and many other features of the Australian outback.
9. Obtain a barometer and record air pressure. Can you determine any patterns corresponding to the weather?
10. Demonstrate atmospheric pressure by "sticking" a plumber's suction pad to some smooth surface and pulling against it. Note that it is the pressure of the outside air which provides the force which "sticks" the pad to the surface.
11. Find out the location of your closest Bureau of Meteorology (BOM) weather station. You could then regularly inspect its readings using the BOM website.
12. Research some of the endemic species (only found in Australia) which are under threat due to climate change.
13. Study the effects of ships barging through coral reefs, such as happened with the Chinese ship, the Shen Neng, in April, 2010.
14. Research the effect climate change is having on our great artesian basin.
15. Research some of the stories of famous earthquakes, tsunamis and volcanic eruptions worldwide. Some examples are the San Francisco earthquakes, Krakatoa, Mt St Helens, Mt Vesuvius and Pompeii, Mt Pelée and Mt Taupo.
16. Find out in which directions and with what speeds the major continents are currently drifting. Discover the methods by which these rates are measured.
17. Research Australian volcanic history.

18. Research the 1989 Newcastle Earthquake in Australia.
19. Start a collection of rocks and minerals.
20. Do a project on the things we use which are made out of rocks and minerals.
21. Do a project on erosion. Are there any stark examples of erosion in your district?
22. Collect and identify some fossils.

Chapter 4

Matter and Motion
Physics: How Things Work

4.1 Introduction

Physics is the branch of science which addresses many of our most common every-day experiences and our most familiar gadgets. Physics tells us how they all work. In some ways we are all physicists, whether we realise it or not. For example, we all have to go places and so we need to know a bit about distances and how to measure them, times and how to measure them, and speeds and how they are measured. We know that pushing and pulling forces have something to do with motion and that friction forces slow motion down. Our eyes are light sensitive devices and we love colour, so the study of light is obviously right up there. We listen 24/7 to our iPod – so sound is something worth knowing about. We like to feel warm in winter and cool in summer and we don't want to die of hypothermia, so heat is useful as well. We can't stand it when the power goes off because everything we need to use just stops! Electricity is that important. But a bit dangerous if you do the wrong thing! All this stuff is physics.

4.2 Quantities and Units

Back in Chapter 1 we talked about the seven basic units and about how we can combine them in hundreds of exciting ways to get other units. The most common units about which we need to know are mass, length and time. We quickly revise them below.

Mass

The commonly used units are the gram (g) and the kilogram (kg), where

$$1\text{kg} = 1000\text{ g}.$$

Length

The most commonly used units are the centimetre (cm), the meter (m) and the kilometre (km), where

$$1\text{ m} = 100\text{ cm, and}$$
$$1\text{ km} = 1000\text{ m}.$$

Area is simply obtained by multiplying one length by another length. For example, the area of a rectangle of side lengths 5 cm and 10 cm is 50 square cm, or 50 $cm^{2.}$

Similarly, **volume** is obtained by multiplying three lengths together. For example, the volume of a cube of side length 10 cm is 1000 cubic cm (1000 cm^3), often more simply written as 1000 cc.

In fact, a volume of 1000 cc has a common name, the litre (L), i.e.

$$1\ \text{L} = 1000\ \text{cm}^3 = 1000\ \text{cc}.$$

Time

The commonly used unit of time is the second, s.

Other units will be introduced when we need them but we can do a great deal of physics, and unlock many of the common mysteries of life just with these. These units were originally defined with respect to something thought to be rather obvious. The meter, for example was defined to be one ten millionth of the distance from the equator to the North Pole. One trouble was that it was kind of tricky to fix, since few of us get to the North Pole! We now do it in a much more complicated but more easily reproduced way. However, one important definition which remains is the gram. One gram is the mass of 1 cc of water. This brings us to density.

4.3 Density

A very useful concept with which to start is density. Everyone knows that some materials are "heavier" than others. Of course, if you get a whole lot of the "light" stuff it can weigh as much as a bit of the heavy stuff. The way we sort this out is to take a standard volume of some substance. Physicists often use a cubic centimetre (cc), and measure its mass in grams. We define the density of that substance as the number of grams per cubic centimetre, or g/cc. If we don't have a volume of the material equal to 1 cc we can still determine the density in g/cc by using the formula

$$\text{Density (in g/cc)} = \text{mass/volume} \qquad \text{-4.1}$$

where mass is in g and volume is in cc.

Example 4.1
For example, a 2.0 cc piece of a particular aluminium alloy is found to have a mass of 7.0 g. Determine its density.

Solution:

$$\text{Density} = \text{mass/volume} = 7.0/2.0 = 3.5\ \text{g/cc}.$$

Densities vary a lot. A list of the densities of some common substances is shown in Table 4.1.

Table 4.1 Densities of some common materials.

Substance	**Density in g/cc**
Coolite foam	0.05 - 0.10
Wood	0.2 – 1.8
Fresh Water	1.000
Plastic	1.2-1.8
Aluminium	2.7
Steel	6.9
Mercury	13.6
Gold	19.1

Obviously if a substance has a density less than 1g/cc it will float in water. If its density is greater than 1g/cc it will sink. {ACSSU074}

4.4 Forces and Motion

Force

Most of us have a pretty reasonable idea of what we mean by a force. We normally experience these as “pushes” or “pulls” and it is these terms which are commonly used in the syllabi, particularly in connection with younger children. It does not matter whether a force is applied as a push or pull, it does the same thing! Often forces are applied by physical objects such as ropes, chains, poles or wind. At other times they may be applied by force fields, such as magnetism, without any physical contact at all. The Greeks thought that forces were required to produce and sustain motion. This understanding certainly seems to match our experience and in fact was the view until the time of Galileo, in the 1600s. He agreed that a force is necessary to get something moving. However, he realised that the only reason why we need to keep applying a pulling or pushing force to *keep* something moving is because there is always a friction force acting to slow it down. In other words, if there was no friction we would not need a force to keep something travelling in a straight line. This was a most important breakthrough. We can demonstrate conditions of very low friction in a science lab on a linear air track, where a small puck rides on a cushion of air. A few decades after Galileo these ideas on the way forces cause motion were described in a very impressive fashion by Sir Isaac Newton, who was quite disgustingly brilliant. His first two laws of motion are given below.

- Newton’s First Law: Everything continues in its state of rest (no motion) or at a constant speed in a straight line, unless some force acts on it.
- Newton’s Second Law: If some force does act, then the speed of the object will change. In fact, for a given size force, the acceleration will be bigger if the object has a small mass and will be smaller if the body has a large mass.

These laws do make common sense. For example, we often use the term inertia in connection with the second law. We say that the reason a heavy object accelerates slowly when we push it is because of its inertia. Inertia tends to resist force. Some forces are very big, as shown in Figure 4.1.



Figure 4.1 Tugboat at work, with a huge force exerted by the cable.

Speed and Acceleration

This all brings us to think more closely about the quantities of speed and acceleration. Obviously speed is the rate at which we cover distance, i.e. the number of meters we go each second. We might say that the speed of a cyclist is 15 meters/second, or 15 m/s. When we are in cars we generally use kilometres/hour, or km/hr.

There is a good reason why Newton's first law lumps both rest (speed of zero) and constant speed in together. In fact, human bodies (and every other object as well) cannot distinguish rest from a state of constant speed. We cannot "feel" speed. This is obvious to us when flying in a jet. We look around the plane and everything seems to be pretty stationary, apart from a few hostesses walking about. It feels as if we are at rest in a some closely spaced armchairs. Only in our minds can we realise that we are actually doing 800 km/hour *with respect to the Earth*. And it turns out that the last part of the last sentence is the most important. "With respect to the Earth" gives us the **reference frame**. If we took the reference frame of the jet, we would be at rest. Of course, our usual reference frame is the Earth, and when it is, we don't often think about it. But physicists always need to note which reference frame is being specified or implied.

Often in everyday life we use the concept of average speed. This is defined as shown below.

$$\text{average speed} = \frac{\text{distance travelled}}{\text{time taken}} \qquad -4.2$$

If we measure distance in meters and time in seconds our average speed will be in m/s. If we measure distance in kilometers and time in hours our average speed will be in km/hr.

Example 4.2

If we travel from Cooranbong to Dubbo, a distance of 400 km, in a total time of 5 hour, then our average speed is given by:

Solution:

$$speed_{av} = \frac{400\ km}{5\ hour}$$

i.e.

$$speed_{av} = 80\ km/hr\ .$$

Notice that we may have speeded up and slowed down along the way. We probably stopped for petrol. None of this matters. All that is important is the total distance and total time. Sound simple? It is, but you can get caught by cunning physicists, so beware!

Example 4.3

I travel from down the Freeway from just north of Cooranbong to Hornsby, a distance of 100 km, at a constant speed of 100 km/hr. I return pulling a heavy load, at a constant speed of 50 km/hr (not a good idea on the freeway). What is my average speed?

Solution: Clearly, the trip down will take 1 hour and the trip back will take two hours, so the total time taken will be 3 hours. The total distance travelled is 200 km.

$$speed_{av} = \frac{200\ km}{3\ hour}$$

$$speed_{av} = 67\ km/hr\ .$$

Notice that this average speed is less than the mean of 50 and 100! This is always the case and explains why it sometimes takes longer to do a road trip than we estimated. Any slowing down, especially stops, decimates our average speed. It is easy to show that if we travel at 30 km/hr to some destination and return at 120 km/hr the average speed is only 48 km/hr. You can't fool physics!

[STe-6NE, ST1-7PW, ST2-7PW,] {ACSSU033, ACSSU076}

4.5 Light

Light is a very tricky phenomenon and took science over 300 years to figure out with any real success. Only in the mid 1900s did we develop anything like a comprehensive model. At times light appears to travel as waves, with a specific wavelength between crests, similar to those at the beach. At other times is seems to travel as a series of small, energetic particles, called photons. To make it even harder to study it goes ferociously fast, in fact at a speed of 300,000 km/s. This about one million times faster than sound and corresponds to just over seven times around the Earth's equator each second. Einstein suggested that the speed of light was a sort of upper limit to the speed of any physical objects. This seems to have been true so far, at least.

As we know, visible light is actually composed of a spectrum of colours, from red, having the longest wavelength, to purple, having the shortest wavelength. What is not so widely known is that this visible light is only a small part of the whole "light" spectrum, more correctly called the **electromagnetic spectrum**, since all light is actually electromagnetic. On the longer wavelength side of visible light we have infrared radiation, microwaves, and radio waves. On the shorter wavelength side of visible light we have ultraviolet rays, x rays and gamma rays, which are very harmful to humans. The whole spectrum is shown below, from long wavelength (low energy) to short wavelength (high energy).

Radio waves, microwaves, infrared, visible light, ultraviolet, X rays, gamma rays

Our eyes are sensitive to a very large range of light intensities, which is very useful. Wartime has demonstrated that a keen-eyed bomber pilot can detect a glowing cigarette butt on a dark night at a distance of 10 km. On the opposite end of the brightness scale, our eyes can cope with light intensities many millions of times greater, such as those encountered on a hot sunny day at the beach.

Colour

One fascinating aspect of our perception of light is colour. This is actually quite a complex topic. Ordinary white light is made up of coloured light and can be split up into its colours, for example, using a prism in the well-known manner, as shown in Figure 4.2.

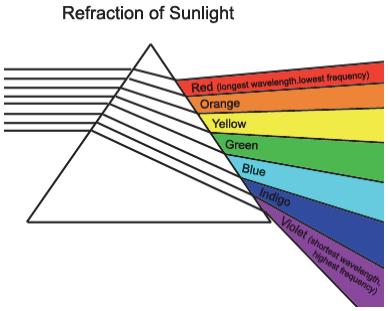


Figure 4.2 Prism splitting the colours.

It turns out that there are three primary colours for light: red, blue and green. If light of these three colours is mixed together our eyes detect this mixture as white light. If we mix any two of the primary colours for light we get the following:

red light + blue light	=	magenta light ,
blue light + green light	=	cyan light (sort of aqua blue) ,
green light + red light	=	yellow light (this is true!) , and
red + blue + green	=	white.

Of course, this is not the case if we mix red, blue and green paint. We would be more likely to get brown instead! And in any case, the three primary colours for paint are red, blue and *yellow*. How ever does this work?

Well, firstly, it should be pointed out that the primary red for light is not the same red as for paint. The same is true of the two blues. So really, all three colours in the “light” primaries are different from those of the “paint” primaries. Put your thinking caps on and follow carefully. Let’s take some cyan paint, i.e. an aqua blue. From the above we can see that this paint obviously has pigments which, when illuminated with white light, absorb red light and reflect blue light and green light, giving our eye the “cyan” impression, i.e.

Cyan paint has pigments which absorb red light, reflecting blue and green light.

Now let's take some yellow paint. This paint obviously has pigments which, when illuminated with white light, absorb blue light and reflect green light and red light, giving our eyes a "yellow" impression, i.e.

Yellow paint has pigments which absorb blue light, reflecting green and red light.

If we now mix these two paints together we obtain a brew which absorbs both red and blue light. The only colour left, which is the colour reflected off the surface, is green. Thus cyan paint + yellow paint = green paint! Simple!! In fact colour can get very complex, and this is without the even more complex psychology of colour which interior decorators need to keep in mind.

Forming images with lenses

Optical instruments like cameras are very similar in their essential operation to our eyes, having aperture control, lenses and light detection devices. The essential way in which these instruments work is not difficult to understand and you may wish to investigate some of this basic optics with your classes.

The main principle involves using a convex lens (one which is fatter in the middle) to form an image of some object, which is what happens in our eyes. This is illustrated in Figure 4.3.

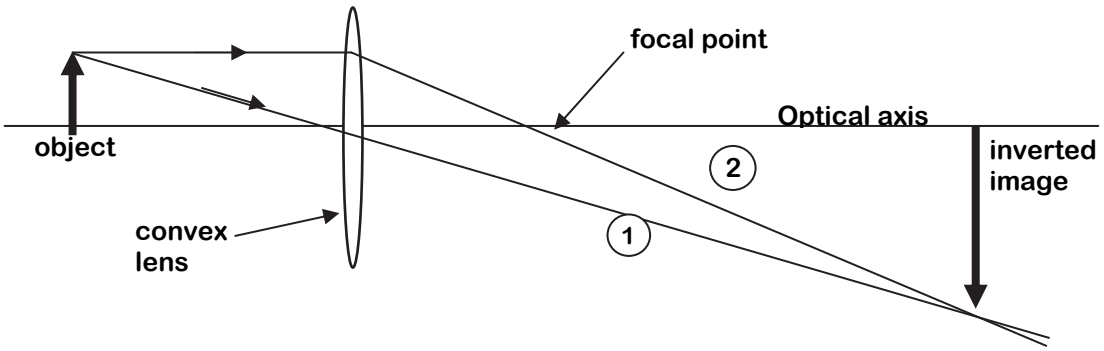


Figure 4.3 The formation of an image by a convex lens.

Many light beams reflect off the point of the object, going in all directions. Our diagram shows just two of them, in fact, the two most useful for telling where the image will be located. Light ray 1, which passes through the middle of the lens, is not bent at all. This is always the case for light rays which pass through the centre of lenses. Light ray 2, which travels parallel to the main horizontal axis (sometimes called the optical axis) and then passes through the lens, is bent so it passes through the focal point on the far side of the lens. Where the two light rays cross behind the lens is where the head of the image is located, as shown.

[ST1-6PW, ST3-7PW] {ACSSU020, ACSSU080}

4.6 Sound

Sound is much easier to understand than light. It is also very important to humans. Sound is also a wave and is carried by our atmosphere, although it can also be carried by liquids and solids. No sound can travel through a vacuum. As sound waves travel through the air the gas particles move

somewhat back and forth along the same line as that along which the **wave** is travelling. This is called a **longitudinal** wave. The particles do not move back and forwards in the sideways direction, like a water wave, which is called a **transverse wave**. Many different vibrating objects produce sounds.

Sound waves travel much slower than light rays. In air sound travels at about 340 m/s, which is about a million times slower than light. Since about the 1940s, we have been able to build aeroplanes which can travel faster than sound. These are called supersonic planes. The speed of sound actually varies a bit with air temperature and pressure.

Sound waves may be represented by the air particles shown in Figure 4.4.

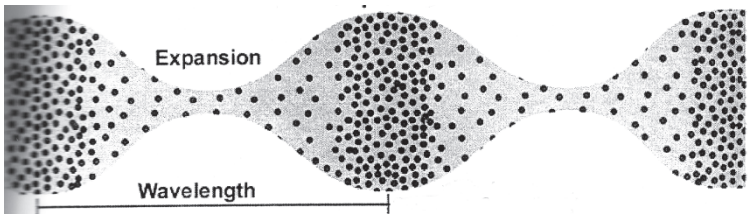


Figure 4.4 Sound waves travelling through air.

The distance between two consecutive "bunches" of air particles is called the wavelength of the sound and the number of bunches which move past any point is called the frequency of the sound wave. There is a simple relationship between the wavelength, the frequency and the speed of any wave, including sound waves, i.e.

$$\text{wave speed} = \text{frequency} \times \text{wavelength} \qquad -4.3$$

Interestingly, sound waves of all frequencies travel at the same speed, so wavelength automatically adjusts to fit this formula. Frequency is measured in vibrations /second, or Hertz (Hz), and wavelength is simply measured in meters. In fact, there are only two ways in which a pure sound wave can vary. The frequency can change, (automatically changing the wavelength, as we noted), or the amplitude of vibration of the particles in the air through which the wave is passing can change.

If the frequency changes we hear a change of pitch. The higher the frequency, the higher the pitch. For example, a frequency of 440 vibrations per second corresponds to the musical pitch of the first "A" above "Middle C". Every octave we go higher the frequency doubles and every octave we go lower the frequency halves.

If the amplitude of vibration of the particles changes we hear a different loudness. The more widely the particles move back and forward, the louder the sound. If the amplitude of vibration of the particles is reduced we hear a quieter sound.

The normal hearing range for a young person is from 20 to 20,000 Hz. At frequencies lower than about 20 Hz the wave form is heard more as individual pulses than as a continuous pitch. Frequencies higher than about 20,000 Hz are simply inaudible. This normal hearing response is represented by the dark oval on the frequency-loudness curve shown in Figure 4.5. However, as one ages hearing acuity diminishes, as shown by the irregular shape shown on the graph in light outline. The highest frequency which can be heard drops considerably, as shown, often to less than 10,000

Hz. Also, a higher volume is required in order to hear sounds at any frequency, which is represented by the bottom line being raised. Sometimes this bottom line can have irregularities. For example, at the frequency corresponding to point "A" in the figure sound must be even louder in order to be heard at all. Such a condition may be caused, for example, by industrial noise over many years. Sometimes there are chimneys in this curve, indicating that certain frequencies simply cannot be heard at any volume! Also, higher volumes can cause irritation, thus are not regarded as being within the acceptable hearing range. This is represented by the lowering of the top line, as shown.

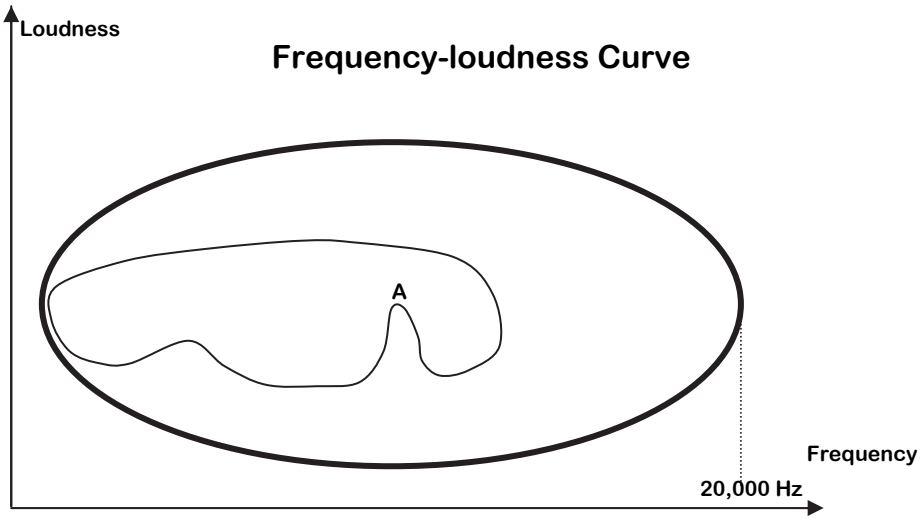


Figure 4.5 Changes to human hearing responses with aging.

In fact we do not generally hear pure sounds of just a single frequency. Even a musical instrument playing just a single note produces many frequencies at once, besides the main pitch we assign to the note. This may be demonstrated by reference to a vibrating string, as shown in Figure 4.6, although a vibrating air column, such as in an organ pipe or clarinet, behaves similarly. The simplest mode in which the string can vibrate is with a single maximum amplitude in the middle, as shown in the top figure. This frequency is said to be the "fundamental" frequency, or the "first harmonic".

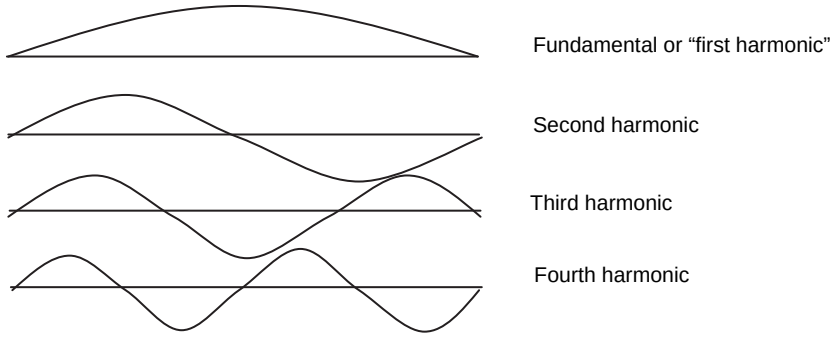


Figure 4.6 Harmonic series.

The next simplest mode in which the string can vibrate has two regions of maximum amplitude, as shown in the second figure. This produces a frequency of 2x the fundamental frequency (i.e. one octave above the fundamental). This is called the second harmonic. The next most simple mode, as

shown in the third figure, has three regions of maximum amplitude, corresponding to a frequency of 3x the fundamental frequency (i.e. one octave and a fifth above the fundamental). This is the third harmonic. And so it goes on. The fourth harmonic has a frequency of two octaves above the fundamental. In fact, any vibrating string is likely to be vibrating simultaneously with some combination of at least the first eight harmonics! The pressure with which it is bowed or struck, as well as the position on the string at which this bowing or striking takes place will affect the amount of each harmonic produced.

Wind instruments produce different amounts of each harmonic, depending on their size, shape, the material from which they are constructed, as well as the manner in which they are blown. This is why a flute and a clarinet, for example, can both play "Middle C" and yet sound a bit different. If this was not the case we would only need one type of instrument, which would be a bit dull! In fact flutes have predominantly first and second harmonics. Clarinets have much more third and fifth harmonics. An oboe has even more of the 3rd, 5th and 7th harmonics. In general, the more the upper odd harmonics are strengthened, the more nasal the sound of the instrument. The various harmonics, with other sounds, all add together as they travel through the same air space, producing very complex vibrations indeed.

[ST1-6PW] {ACSSU020}.

4.7 Heat

Heat is another topic in physics which relates closely to our everyday lives. For example, when we apply heat energy to a metal bar or a tub of water a number of interesting things happen, such as a rise in temperature, an increase in length and volume, and the transfer of the heat energy through the material. If we heat a solid material a lot it might even change to a liquid, i.e. melt. If we do the same to a liquid it may change to a gas, i.e. boil. Let's examine these consequences of applying heat energy.

Temperature Increase

As you might expect, it turns out that all materials get hotter, i.e. experience a rise in temperature as we apply heat energy. But what you might not expect is that if we apply the same amount of heat energy to the same mass of material, let's say one minute on a gas stove, each type of material will show a different increase in temperature. Some materials get hot very quickly and lose heat very quickly. Most metals do this. On the other hand, water requires a huge amount of energy in order to increase its temperature. It takes about 11 times as much energy to heat 1 kg of water by 10 ºC as it does to heat I kg of copper by the same amount. The fact that water takes a lot of energy to heat up is actually very convenient. Our bodies are about 75% water and it is this water which regulates our temperature. We can absorb or lose heat in quite large quantities without overheating or overcooling. We also use water in our car engines for the same purpose. In fact water has one of the highest heat absorbing values of any known substance.

Expansion

When we heat a solid body its length and volume increase. When we heat a liquid or gas its volume also increases. Since its weight stays the same this means that the density of a body decreases as its

temperature goes up. The fact that things expand when they are heated gives all sorts of problems to structural engineers. Large concrete slabs, buildings and bridges all have to be made with expansion joints, as shown in Figure 4.7, which allow different parts to get bigger and smaller without breaking the whole thing down! If you walk over the Sydney Harbour Bridge you can easily see the expansion joints at each end.



Figure 4.7 Expansion joints on Hexham Bridge.

Heat Transfer

Some materials allow heat to travel very quickly. For example, if you place one end of a metal rod in a fire the other end soon gets hot and you have to drop it. These materials make good heat conductors. Copper is one of the best such materials which is why we use it on the bottom of good quality cooking pots. (Interestingly, the best heat conductor we know is diamond, which conducts heat five times better than any metal!) However, if you placed one end of a rod made of granite in a fire it would take a very long time for the other end to feel hot. Some materials, such as asbestos, allow even less heat flow. Such materials make excellent heat insulators. Of course, we no longer use asbestos due to other health risks. When we build homes we place pink or yellow bats, like those shown in Figure 4.8, in the walls, to reduce the heat flow. This saves us money in heating and cooling costs and also uses less energy, so is better for the environment.

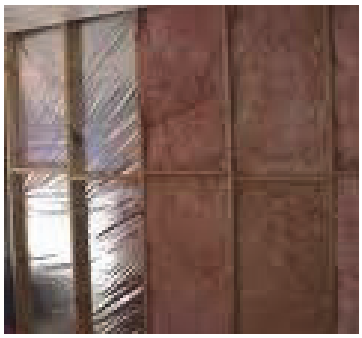


Figure 4.8 Insulation in the walls of a home under construction.

Reducing heat flow is an important engineering challenge in our society. It is also an important thing to understand when outdoors in cold weather. It can be easily shown that your rate of heat loss if you get wet through can be up to 100 times greater than if you had stayed dry. This is because water conducts heat much more effectively than dry clothes. This may mean that your body is losing heat at a much faster rate than it can produce heat, no matter how hard you run on the spot or shiver. In such a case you will soon be suffering from hypothermia, which can prove fatal if not treated rapidly. Bushwalkers need to understand the early signs of hypothermia, such as poor concentration, blurred speech and lack of interest.

Melting and Boiling

Every type of material has a melting point temperature and a boiling point temperature. These temperatures very hugely between different materials. For example, the boiling point of helium is -268.9 ºC, which is why we *always* experience it as a gas, whereas the boiling point of the metal tungsten is 5660 ºC. This is the highest boiling point of all the elements. For water, the melting point is 0 ºC and the boiling point is 100 ºC.

In fact it takes a considerable amount of energy to melt a given mass of material and a huge amount of heat to boil it away. The actual amount of heat energy required for these tasks varies according to the substance. For example, the energy required to melt 1 kg of ice at 0 ºC into water at 0 ºC is almost as much as it takes to heat the same amount of water from 0 ºC all the way to 100 ºC. The amount of heat energy required to then turn this water at 100 ºC into steam at 100 ºC is more than six times the amount of energy required to melt it! This can easily be demonstrated by seeing how long it takes to boil away a pot of water. Don't hold your breath!

The fact that water requires such a huge amount of energy to melt or boil is very useful to life on Earth. For example, when we get hot we perspire. This water evaporates from our skin (unless we are in the tropics, where evaporation is slow because the air is so moist). In order for this water to evaporate it must absorb a huge amount of heat energy which, of course, is the whole idea. We are cooled down as it does so.

[ST2-6PW] {ACSSU046}

4.8 Electricity

Introduction

Electrical phenomena are very common. We get out of the car on a hot day and get a small shock. Lightening forks across the sky during a thunderstorm. These are all phenomena involving the build up of static electric charges which then jump across some gap. However, the electrical equipment we use does not use static electric charges but a steady flow of electric charge, which we call an electric current.

The Basic Electrical Circuit

All matter is made up of electrical charges, both positive and negative, although it may not look like it. In some materials, like rubber and plastic, these charges are hard to get moving. These substances are called **electrical insulators**. In other materials the charges can be moved, but resist

strongly. These materials are called **electrical resistors**. In yet other materials, particularly metals, the charges are very easy to get moving indeed. Such materials are called **electrical conductors**.

For electric charges to flow as a continuous electric current we must have a **power supply**, i.e. a source of electrical energy which can push the charges around. We can use small batteries for this, or if we need a lot of energy we may need to plug into the wall socket. The amount of energy imparted to these charges as they pass through this energy source is sometimes called the **voltage** of the circuit. Typically a small torch battery has a voltage of 1.5 volt (V), whereas a wall socket provides 240 volt. Obviously, the higher the voltage (i.e. the more energy carried by the circulating charges) the more dangerous the electric current.

We also need some device, like a light globe, a heater, or a computer which is wanting to use the energy being carried around by the electric charges. Such devices are sometimes called electrical loads. Then we need to connect these two essential elements together with conducting metal to make a complete "**circuit**". Only when the circuit is complete can the charges circulate in what we call an **electric current**, which is measured in **amps** (A). Sometimes we put a switch in the circuit so we can turn it on and off when we want. A switch simply breaks the circuit. This arrangement is shown in Figure 4.9.

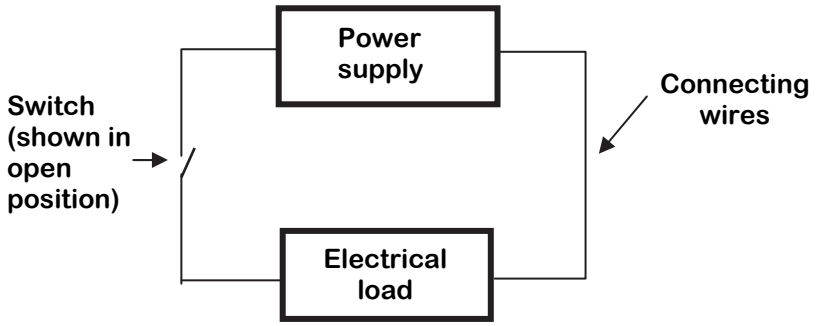


Figure 4.9 A simple electrical circuit.

As the electric charges pass through the load the energy they carry is dumped, which makes the light glow, the heater get hot, or the computer work. The power used by any such device indicates simply the amount of energy it uses each second. Power is measured in watts (W). Typical power levels for common devices are shown in Table 4.2.

Table 4.2 Power consumption of typical electrical devices.

Electrical Device	Power, (wattage)
Small torch	6
Car headlight	60
Electrical hotplate	600
Hair dryer	600 - 1,000
100 W light globe	100
Blow heater on full	2,400
hot water cylinder	3,600
Car starter motor	3,000

Direct and Alternating Current

As we have noted, all the electrical appliances to which we are totally addicted operate off electric current. Depending on the type of power supply, this electric current may flow consistently in one direction (direct current or dc), or may change directions in a regular, and often rapid fashion (alternating current or ac). Alternating current results when the voltage changes rapidly back and forward from (+) to (-). Whenever we store electrical energy in chemical form, such as in torch batteries, or lead-acid car batteries, we always get the energy back in dc. When we generate the electrical energy by mechanical means, generally by turning a generator shaft, it is much easier to get it in ac. This is why our cars operate on dc while our household electricity is ac.

Some electrical appliances, such as light globes will work on both dc and ac. Motors can be made to suit both dc and ac (but not both with the same motor!) Other appliances, such as computers, are real electrical gourmets and ***must*** have dc, and not just any dc but dc at a very particular and exact voltage.

All alternating currents much change back and forward through a certain number of complete cycles each second. For example, our household ac changes 50 times each second. We call this a frequency of 50 Hertz (Hz). You may have heard of this "mains frequency". You can sometimes hear this frequency as a quiet hum near electrical appliances, sometimes through PA systems, particularly if they are not high quality.

Our Australian Domestic Electricity Supply

It turns out that low voltages are much safer but hard to use if you want a lot of power. High voltages deliver lots of power but electrocute people and cause fires. As you might expect, the voltage level of 240 volts has been chosen to give us access to adequate amounts of power without being too dangerous. Some countries, like the USA use 110 volts. The frequency of 50 Hz was also chosen as the best compromise. Fast frequencies work best in transformers, when we want to change the voltage level, which we often want to do. For example, we do not want small boys playing with a 240 V electric train or LEGO set, so we transform the electricity down to 12 V. However, ac electrical currents with really high frequencies also leak badly off connecting wires and cause radio interference and we don't want that! A frequency of 50 Hz turns out to be a good compromise, although the USA uses 60 Hz.

Electric Current and the Human Body

Fortunately the electrical resistance of skin is very high, so high in fact that many people survive accidental contact with electric potentials of hundreds of volts. Skin resistance is higher when the skin is cold and dry. For warm, moist skin this resistance may drop to less than one thousandth of the "dry" value. This can be fatal.

A small current through the skin in the order of just 10 mA may place the heart in fibrillation. However, currents as low as 60 microamp can damage the heart under some circumstances. These may be easily introduced through a trans-venous pacemaker, or a monitoring device which bypasses the skin, such as a saline-filled catheter, or a drainage catheter. For this reason doctors and nurses must observe careful protocols in order to avoid electrocuting their patients!

[ST3-6PW] {ACSSU097}

4.9 Alternative Energy Sources

At the current rate of consumption and taking into account projected demand increases, particularly in developing countries such as China, it is estimated that the world's currently known reserves of coal and oil will run out in about 50 years time. As mentioned earlier in connection with global warming, our first responsibility is to reduce energy usage by such technological innovations and lifestyle changes as: better home insulation, smaller cars, more efficient heating and cooling and increased utilisation of public transport. Many of these changes are well within our reach and represent the first line of defence against a local or global energy shortage. But these measures will not solve the energy problem in the long term.

So it is not surprising that these days we hear a great deal about alternative energy sources. Both the Federal Government and most Australian states now offer incentives aimed at encouraging consumers to satisfy at least some of their energy needs from alternative sources. Such initiatives include subsidies for the replacement of old hot water heaters with solar alternatives and electrical power buy-back schemes to encourage households to cover their roofs with solar panels. As the cost of these panels comes down and their efficiency goes up these will become more and more attractive.

As well as measures which may be implemented by end users, such as ourselves, huge research is being put into alternative energy technologies which can replace our large coal-burning power stations and produce industrial-strength power. The main alternative options to coal and petroleum are natural gas, solar, wind, tides, hydro, bio-fuel and nuclear. We briefly examine these alternatives below.

Natural gas

While some natural gas is brought to the surface on land, most of the world's natural gas reservoirs are off-shore. Australia's main natural gas resources are located in Bass Strait and off the coast of Western Australia and the Northern Territory. This gas is then brought to land via undersea pipes. There are also gas reserves under parts of New South Wales and Queensland.

Advantages

This is a cheap, clean and convenient source of power and may well provide for interim needs whilst more technologically complex and expensive renewable methods are further developed.

Disadvantages

Natural gas is not a renewable resource. Our current world-wide reserves are estimated to be 400,000,000,000,000 cubic meters. This sounds like a lot but it won't last forever! It has been estimated that our known Australian reserves will last about 100 years. Also, the burning of natural gas does produce both heat and carbon dioxide and so contributes to global warming.

Solar

Solar electricity is most commonly produced by the action of the Sun on flat, low- voltage solar cells, generally located on the rooves of buildings. This electricity is then electronically converted to the ac grid voltage.

Advantages

Obviously, solar power is an attractive alternative for Australia, since we have such a large sunlit area. Once the cells are constructed it is non-polluting, quiet and obviously renewable.

Disadvantages

The obvious problem is that such cells can only generate power when the sun is shining. This means on average, only 50% of the time at best. In fact, cloud cover further reduces the effective solar exposure. In most regions solar cells are estimated to produce useful power for only 30% of the total time. In order to supply power 24/7 storage cells are needed.

In addition, there are a number of problems with obtaining industrial quantities of electricity. One is that the sunniest and least obstructed areas of Australia are those most distant from our cities. It is both inefficient and expensive to transport power over long distances. One way to solve this problem would be to relocate power-hungry industry to inland regions. The problem is that this introduces distribution and transport problems of its own.

Unfortunately, also, both the solar cells and storage batteries are expensive to produce and involve some environmental pollution in their manufacturing process, since they involve the use of a large range of unfriendly chemicals. Disposal of worn out cells must also be considered. If we can discover how to produce organic solar cells these factors may change.

Wind

Wind power is produced by huge, fine-bladed windmills geared to generators and grouped in what are called “wind farms”. Australia now has 767 wind farms, mostly in South Australia and Western Australia. An experimental 600 W wind turbine was commissioned at Kooragang Island, near Newcastle, in 1997. This was the first wind turbine commissioned in NSW. The best districts for wind farming in this state are the Glen Innes and Goulburn regions.

Advantages

Obviously wind power is quiet and renewable.

Disadvantages

Some regions of the world, and indeed of Australia, are eminently suitable for wind power. Tasmania’s west coast is an excellent example. Steady winds of more than adequate speed consistently lash this region. However, some regions do not have enough wind or wind which is unpredictable. In addition, the presence of extensive wind farms significantly modify the land and sky scapes, which is seen by many as detrimental.

Tides

Electrical power may be obtained from large tidal flows and current movements. The water flow is used to turn high-volume, low pressure turbines, which in turn spin electrical generators.

Advantages

This power source is low-tech and renewable. Tides are also more predictable than wind and sunshine.

Disadvantages

Large water flows and fast currents are needed for cost-effective electricity generation. These are very dependent of shoreline and island placement, among other factors. There are few places in the world where these conditions occur and none in Australia. However, Cook Strait and Kaipara Harbour in New Zealand are better prospects. Other places are England, Wales and Scotland, California and Canada.

Hydro

Hydro power is obtained when water, collected in high-altitude locations like highland lakes, is fed down huge penstocks (pipes) to lower levels where high pressure turbines run generators. The gravitational energy stored in the water is thus converted to electrical energy while the waste water can be used for agriculture and many other purposes.

Advantages

While the construction of hydro schemes may involve expensive roads, dams and pipelines, this infrastructure lasts for many decades and requires minimal human resources to operate. The operation of the system is totally non-polluting and absolutely quiet. Further, the turbines can be easily turned on and off, enabling the generation system to match the electrical load on the power grid. In Tasmania, for example, some of the generators are typically turned off during the day and switched in again as household demand rises in the late afternoon.

Disadvantages

The main disadvantage is that the natural features of the landscape are inevitably permanently disturbed. This often produces conflict between power generation initiatives and green interests. The 1983 decision by the new Hawke labour government to abort the damming of the Lower Gordon River on Tasmania's west coast is an example of such conflict.

Biofuel

Bio-fuel, principally ethanol and bio-diesel, is produced by the fermentation of plant and some waste materials. This fuel can be used in internal combustion engines instead of petroleum-based fuels or mixed with them.

Advantages

These fuels are low-tech and effective.

Disadvantages

Bio-fuels use up large tracts of land which could be used for other agricultural or farming purpose.

Nuclear

Nuclear power is obtained by splitting heavy atoms, such as uranium and plutonium. This process takes place in large power stations and produces huge amounts of energy.

Advantages

The main advantage of nuclear power is that it can produce very large amounts of energy. It also uses completely renewable resources. Although world stocks or uranium are limited, “breeder” nuclear reactor can be made which produce more fuel material (in the form of plutonium) than they consume. This excess fuel can then be chemically separated out and used in the production of more fuel rods.

Disadvantages

The main disadvantage of nuclear power is that it inevitably produces radioactive by-products which require safe disposal. This is both inconvenient and expensive. Further, since some of these waste products will remain as biohazards for hundreds of years, secure disposal is technologically difficult. If scientists succeed in producing energy by the fusion of hydrogen into helium, these problems will be solved. Even larger amounts of electricity are produced and the only by-product of this process is helium gas. We can always use more party balloons!

[ST1-9ES, ST2-8ES] {ACSHE035, ACSSU219}

Activities

The following fun activities grow out of this chapter.

1. Collect a whole lot of 1 cc blocks of different substances, even of different woods and measure their masses. You may even wish to build a display showing them from least dense to most dense. Keep a careful eye on your 1cc gold cube!
2. Investigate the relationship between density and floatation. Get a glass beaker and put in some oil and some water. The oil will float on the water. Drop in a coin, which will fall to the bottom of the water. Drop in a bit of light wood, like pine. It will float on the oil. Now get a similar bit of wood and drive in a few small nails. With a bit of experimentation on the number of nails you can get this third object to float between the water and the oil.
3. Make a pin-hole camera. You may even be able to make a big one by blocking up a window in a small room with a piece of cardboard having a small hole in the middle. The image then appears on the opposite wall, if you get the room really dark.
4. Investigate the colour wheel. What is it about colours opposite each other on the colour wheel which somehow go together?
5. Further investigate the primary colours, both for light and for paint.
6. Investigate colour blindness. What colours are usually involved?
7. Investigate the human eye and identify the main functional components. You may even wish to buy some bovine eyes from a butcher and dissect them to get the lens. Kids will be impressed but you will need to wash up and disinfect carefully as these things can carry infections and can also stink a bit if they are not fresh.
8. Research the story of Helen Keller and the way in which she was taught to speak by Ann Sullivan.
9. Get a winbeck whistle, which sounds ultrasonically, and excite all the dogs around the place.
10. Make a bottle organ (playing a single octave) with eight similar soft drink bottles, all filled with water to different heights. You may need to tune this instrument using a piano before blowing across the bottle tops to make a tune.
11. Prepare a poster showing loudness - the softest sounds to the loudest sounds. Show the typical loudness of each sound in decibels (dB). Where do you hear each of these sounds?
12. Make a string telephone using two tin cans and a 5 m string pulled tight between them.
13. Make a Mexican wave movement with a whole lot of students, like they do at football matches.
14. Listen to the unique sounds of different musical instrument. Different students or their parents might play some of these instruments.
15. Investigate sonic booms. The best way to hear these is to crack a whip in the school ground. The actual whip crack is a small sonic boom. Be careful, however.

16. If you have access to a vacuum pump and can remove the air from a container you may wish to might like to place a small bell into a glass flask and slowly remove the air. The students will hear the sound of the bell gradually disappear as the air is removed.
17. Collect materials which are used to stop heat movement: wool, cotton, pink fibre-glass batts, rock wool, down from sleeping bags, etc.
18. Investigate how a thermos flask works.

Chapter 5

The Chemical Nature of Matter

5.1 Introduction

The world of chemistry

People usually think of chemistry as the study of chemicals and reactions in laboratories. While that is true, the definition is actually much broader than that. Chemistry is the study of matter. Matter is anything that has mass and takes up space. Matter is all around us and makes up the substances that surround us: food, animals, the earth, stars and planets, the entire universe. That means that chemistry is the study of everything around us.

Sometimes people label chemistry and chemicals as dangerous but we ourselves are actually made up of chemicals and we rely on chemical reactions for every breath we take. Sometimes chemistry is easy to see, for example when you dissolve sugar in water, but even when it is less obvious it is still an integral part of our world. For example, the sugar you dissolved in water originally came from plants and was produced via a chemical reaction. Green plants use sunlight to make sugar in their leaves from water and carbon dioxide in a process called photosynthesis (see Figure 5.1).

The study of chemistry focuses on what substances are made up of (their composition), how they behave (their properties) and how they change (their reactions).

Scientific Models

A very useful tool in science is the concept of a scientific model. Scientific models are used to describe concepts that are much larger and more complex than the model itself. They are built up by combining data from many experiments. As more information becomes available they are refined making them a better reflection of reality. The models are tested against experiments to make sure that they are reliable.

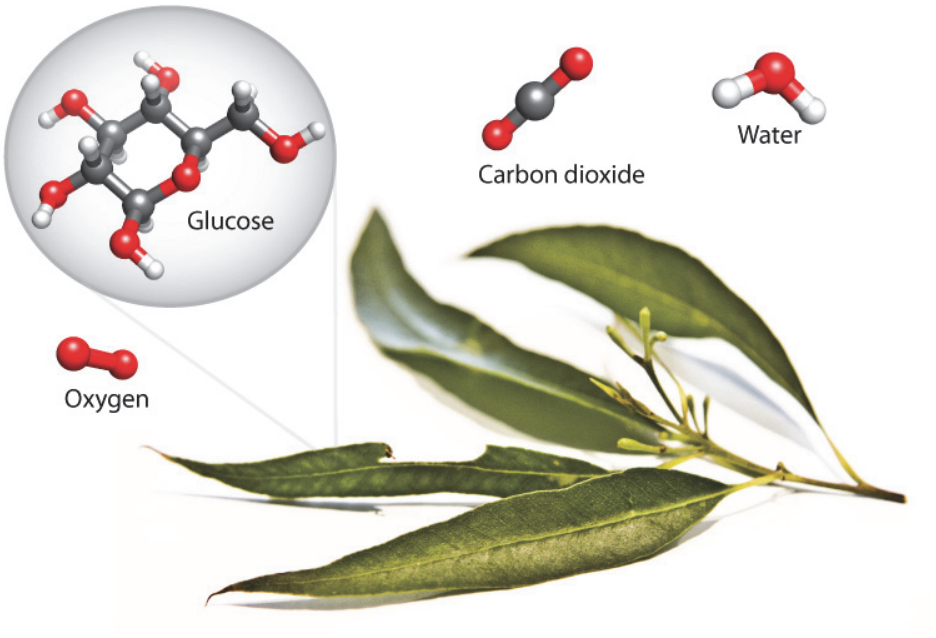


Figure 5.1 Glucose is made via photosynthesis in leaves from carbon dioxide and water.

One example of models in our day-to-day life is making maps. In the days of the great explorers, maps were drawn of the coastline of Australia but none were complete because the explorers had not made the journey all the way around. That meant that the explorers' concept of Australia was very different from ours today. For instance they didn't realise that Tasmania was not part of the mainland. Just like a scientific model, the map of Australia was modified as more information from new explorations became available, like a jigsaw puzzle being put together, until the current shape of Australia was established.

One very important thing to remember is that a model is a good approximation but it is not an exact representation of reality. For example, depending on the map you choose you can locate a street but the houses may not be marked. The map will probably not tell you anything about the climate or the type of soil in the street either. That doesn't mean that it is not a good map. It is very well suited to describing the characteristics it was designed to include but it is not a perfect representation of Australia.

In chemistry we use different models to describe matter. Some are relatively simple (like an atlas map of Australia) and others are far more complex and give detailed explanations of what is observed. Just as you wouldn't choose a city map to plan a hiking trip, it is important to choose an appropriate model for the concept you want to study.



Figure 5.2 As well as its usual liquid form water exists as ice (solid) and steam (gas).

The Particle Model of Matter

As we discussed in the introduction, chemistry is the study of matter. For a long time humans have tried to understand what matter was and what makes it up. The ancient Greek philosophers believed that matter was made up of five elements: fire, water, earth, air and ether. Other Greek philosophers argued that if you take matter and divide it into smaller and smaller pieces that eventually you reach indivisible particles which they called atomos (atoms).

Now we know that matter is not made up of five elements but the ancients were right in a way. If you take a substance and keep dividing it into smaller and smaller pieces eventually you will get down to the elements that make it up. These elements are the smallest pieces which still have distinct properties of that type of matter. For example the smallest part of gold which is still gold. This takes us right down to the level of the atom.

All matter exists in three states: **solids**, **liquids** and **gases**. These three states (or phases) all behave differently and the differences can be explained by considering the particles that make them up. This is sometimes called the particle model of matter. This model assumes that everything is composed of tiny indivisible particles that move around and interact with each other. The particles may be considered to be molecules or atoms.

Water is a good example. The tiny particles (molecules) that make up water behave differently when water is a solid (ice), a liquid, or a gas (steam or water vapour). When water is a solid (ice) the molecules of water are not free to move around, in liquid water they slip and slide over each other very freely and when water is a gas (steam) the molecules move around quickly and have large spaces between them.

It can seem strange that everything around us is made up of tiny particles when it all seems very solid and smooth to us. That is because the particles are extremely tiny and it is impossible to see them individually. Atoms are so small that you could fit about 1,500,000 carbon atoms across a pinhead 0.1mm wide! That means that when you look at a substance it appears to be smooth. You

can compare it to looking at a lawn. If you are close enough you can see the individual blades of grass but if you stand on top of a building the lawn looks like a smooth green surface.

[SC4-16CW] {ACSSU151}



Figure 5.3 These are all examples of solids which have fixed shapes.

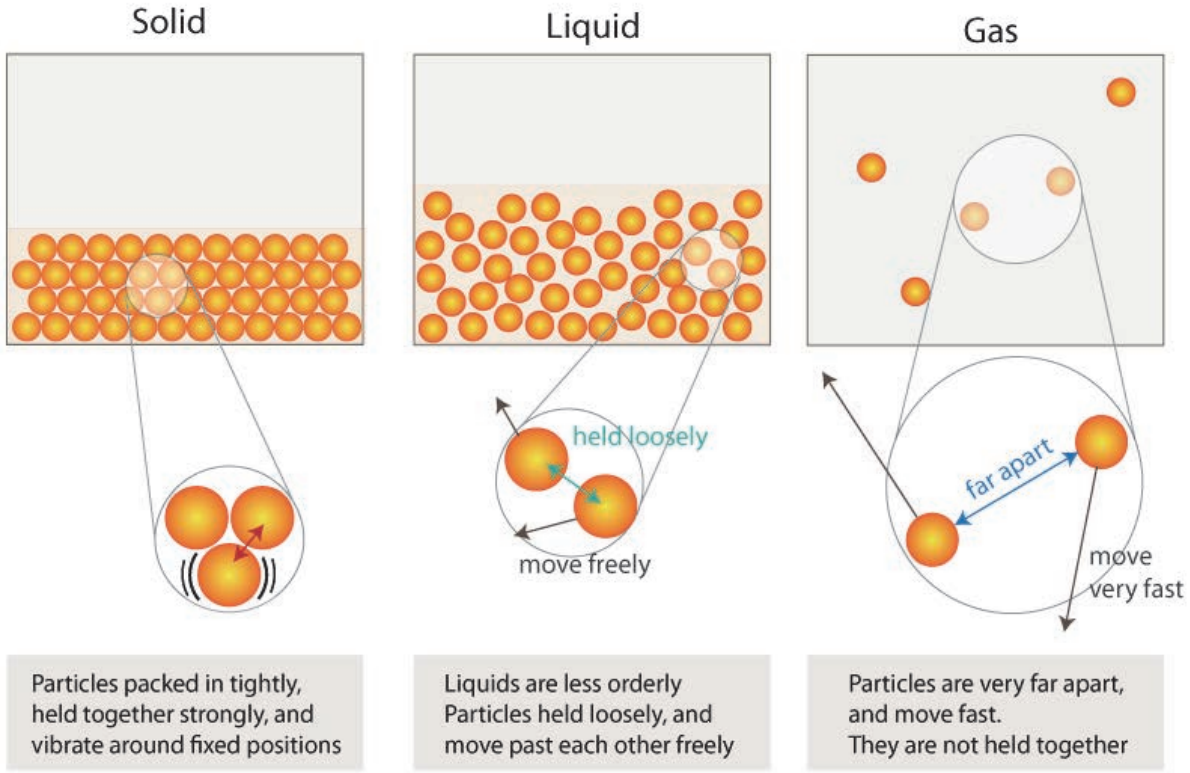


Figure 5.4 The particle model explains the differences between solids, liquids and gases and their properties.

5.2 Solids, Liquids and Gases

Solids

Solids are the hard firm substances in our world. Solids have many different shapes and types and can seem very different from each other but despite the variation, all solids share some important

properties. Solids are 1) hard, 2) have a fixed shape, and 3) cannot be compressed. We can understand why solids have these properties when we look at the particle model shown in Figure 5.4.

In a solid the particles (molecules or atoms) are packed in closely and bonded firmly together. The particles are able to vibrate but they cannot move from their positions. Since the particles can't move it means that solids are hard and have a definite shape. They are not able to flow. Since the particles are already packed in tightly, solids can't be compressed. Solids may expand and contract as they heat up and cool down. This happens because when the temperature increases the particles vibrate more quickly and push each other apart slightly. When the temperature decreases the particles vibrate less vigorously and the bonds between them pull them in closer.

Liquids

Liquids are the second state of matter. Liquids are very different from solids. They are not hard and can flow and change shape to fit the container they are poured into. The particle model states that liquids are not as ordered as solids. The particles in liquids are loosely bonded together (unlike the strongly bonded particles in solids). That means that the particles still stay together but aren't held in fixed positions. The particles are constantly moving and tumbling past each other in random ways. That explains why a liquid will take on the shape of the container it is placed in.

Liquids can vary from fluids that flow very readily (like liquid water) to highly viscous substances like honey that don't flow all that well, particularly when they are cold. The particles move around much faster as the liquid is heated and slow down as the liquid is cooled. As they move around faster, the liquid becomes less viscous and can flow better (honey straight from the refrigerator flows very slowly but becomes more runny as you warm it up). However, while free to move, the particles in liquids are still very close together and this means that it is not possible to compress liquids. Most liquids expand when heated and contract when cooled as the speed of movement of the particles increases or decreases.

Brownian motion

The movement of water molecules cannot be seen directly as they are much too small to be seen by even powerful microscopes. The effect of their movement can be seen if carbon particles or dilute ink is placed in water on a glass microscope slide. When viewed with a microscope, the carbon or ink aggregates are seen to jostle around. This jostling type motion is the result of bombardment by fast randomly moving water molecules. So while the movement of the water molecules cannot be seen, their effect on much larger objects is evident. Such an effect seen under the microscope is called Brownian motion. It is named after the Scottish botanist Robert Brown who noticed the phenomena in 1827 while observing pollen grains in water under his microscope.

Gases

Gases are the third state of matter. Gases are the only state which can't really be touched or held and often can't even be seen but they are just as important in our lives. Our air is made up of gases, mostly nitrogen and oxygen. We need to breath in oxygen gas and we breath out carbon dioxide gas.

In a gas, the particles move fast in random directions and are not bonded together. Each particle moves in a straight line until it hits a surface or another molecule. Since they are not held together they spread out to fill the space they occupy. This means that a gas has no fixed shape and like

liquids, will still take the shape of their container. Since the particles are so small and spread out they are often invisible to us.

When a gas is held in a container, the particles constantly hit and bounce off the walls of the container. Each time they hit the walls they exert a force on them. The combination of the forces of all the particles hitting in the inside of the container is called pressure. Pressure can be increased by heating (the particles move more quickly and hit harder) or decreased by cooling (the particles move more slowly).

The particles in a gas are spread very far apart compared to solids and liquids. That means that it is possible to compress a gas, making the particles move closer together. If a gas is compressed in a sealed container, the pressure increases. You may have experienced this by compressing a sealed syringe full of air. It is easy to push down the plunger at first but it becomes more and more difficult the further you push it. That is because the pressure increases as the volume decreases.

Diffusion

Gas particles diffuse very easily. If someone walks into a room wearing perfume or after-shave, the smell begins to waft through the room.

Those closest to that person will smell it first, then after a while people on the other side of the room will also be able to smell it. The gas particles move (or diffuse) from an area of high concentration to an area of lower concentration until they are spread evenly throughout the room. This is the result of the random movements of the gas molecules. Liquids can also diffuse in other liquids for the same reasons. Try dropping a drop of food colouring into a glass of water and watch what happens over a short period of time.

[ST3-12MW] {ACSSU077}

Changes of State

Solids, liquids and gases can be converted from one state to another. For example, solids may melt and become liquids, liquids may boil and become gases, and liquids may freeze and become solids. These transformations from one state to another are called changes of state and can be explained using the particle model of matter.

[SC4-16CW] {ACSSU151} {ACSSU095}



Figure 5.5 Diffusion of food dye in a glass of water.

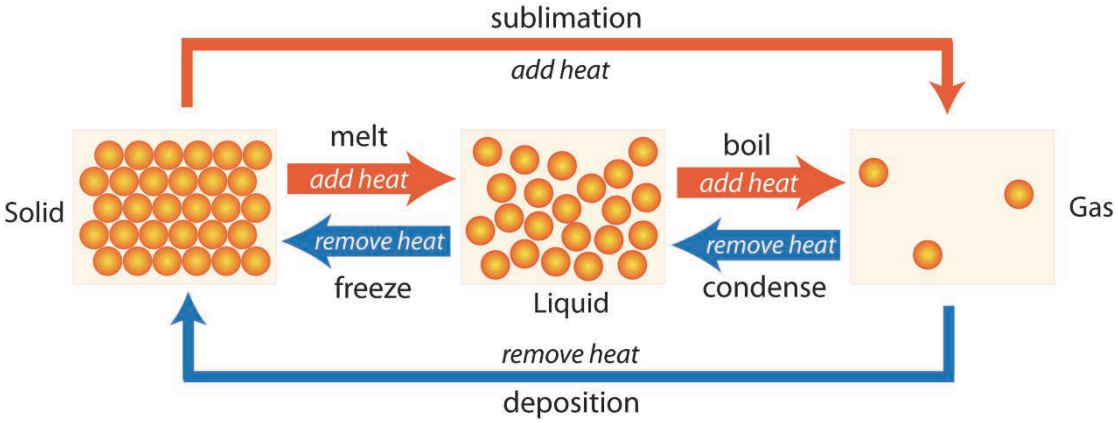


Figure 5.6 Changes in state between solid, liquid and gas.



Figure 5.7 Breathing on a cold mirror forms condensation.

Melting

When a solid is heated, energy is added. This makes the particles vibrate more vigorously. The particles move apart from each other causing the solid to expand. Eventually the particles have enough energy to break the bonds with their neighbours and start to move more freely. The solid is melting and making the transition to a liquid state. The ***melting point*** is the temperature at which the solid becomes liquid and varies greatly for different solids (for example, solid water or ice melts at 0°C, candle wax melts at about 60°C and diamonds melt at 3,550°C). The opposite of melting is ***freezing*** or ***solidification***. In this case a liquid becomes a solid because as energy is lost the particles no longer have enough energy to overcome the attraction between them and they bond together to form a solid. The point at which the liquid becomes a solid again is the ***freezing point***. The freezing point and the melting point of a solid occur at the same temperature.

[ST2-12MW] {ACSS046}

Vaporisation

Is the change in state from a liquid to a gas. For example when water is boiled, more energy is given to the water molecules and they move so quickly that they are able to escape the liquid and enter the gas phase known as steam. This happens at 100°C.

Condensation

Of course the molecules of water in the steam can lose energy and then form water droplets again, and this is known as condensation. A great deal of energy is lost as steam condenses to water droplets. When steam condenses on human tissues like the skin, thermal energy (heat) is transmitted straight into the skin and underlying tissues during the rapid condensation process causing a burn.

Evaporation

Liquids don’t have to boil to enter the gas phase, they may simply evaporate over a period of time. The temperature at which this occurs is usually below the boiling point. Not all the particles move at the same rate. Some of the particles move very slowly and others move fast enough to escape from

the liquid's surface and become a gas. This happens gradually until all the liquid has moved into the gas state and we say that the liquid has dried up.

Sublimation

If the particles of a solid move directly into a gas phase, this is called sublimation. A good example of this can be seen with frozen carbon dioxide (CO_2) otherwise known as dry ice. The dry ice is referred to as being dry because it does not melt and become liquid, it ***sublimates*** directly to the gas phase. Other solids such as naphthalene (moth balls) will do the same thing. They have a very distinct odour (particles in the gas phase reaching the nose by diffusion) but leave no liquid as the solid under goes sublimation. Iodine is another example of a solid that will sublimate.

Water (H_2O) – a unique molecule

Water is one of the most common molecules on the planet and is found in all cells making up the medium in which the biochemical reactions of life take place. Without the water molecule there would be no life on earth and it has some very unique properties that make life possible.

One of these important properties is the amount of heat required to convert it from a liquid to a gas. Water needs to absorb a large quantity of energy to become steam. That makes it excellent for cooling. For example when you sweat it takes a lot of energy for the sweat to evaporate. The heat to evaporate sweat comes from your body, cooling you down. That means that water stores large amounts of energy that can be used to do work (consider the steam engine).

When water freezes it expands (unlike other liquids which contract) and so ice floats rather than becoming more dense and sinking. If ice did sink, so much fresh water would be locked up at the bottom of the oceans and the world would be a much drier and colder place probably making life impossible.

Water molecules are attracted to each other and hold together strongly. This attraction is what holds water droplets in their round shape and pulls water up to great heights in trees. These forces of attraction between water molecules can form the 'skin' on top of water, a phenomenon known as surface tension. The upper water molecules at the surface are pulled down into the solution. Surface tension is strong enough to allow insects to be supported on the surface and you can even float razor blades or paper clips on water.

[CW4]



Figure 5.8 Droplets on this leaf are formed by surface tension.

5.3 Atoms and Elements

Building Blocks of Matter – the Atom

In the particle model, we described matter as a collection of very tiny particles. The particle model, however, didn't tell us anything about the particles themselves.

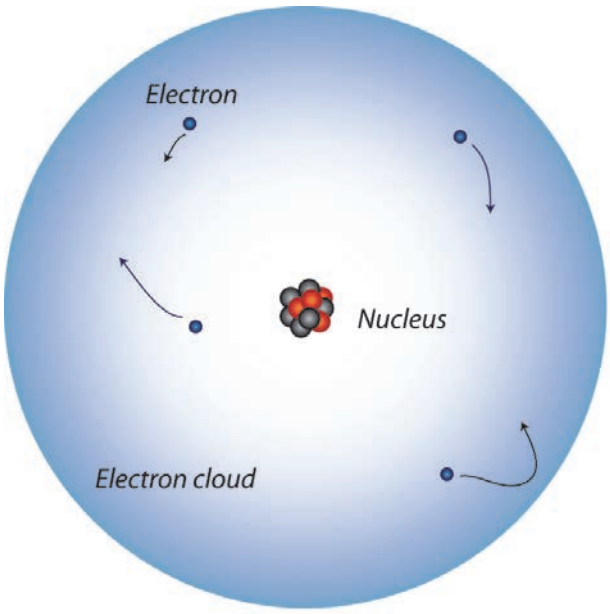
Ancient Greek philosophers (around 400 BC) reasoned that all matter was made up of minute particles called *atomos*. John Dalton (1766 -1844) proposed the first modern concept of atomic theory in 1808. This theory basically states:

1. All matter is composed of tiny particles called atoms.
2. All atoms of a given element are the same.
3. All atoms of a particular element are different from all the atoms making up another element.
4. Atoms cannot be created nor destroyed.
5. Atoms can combine with different atoms to form different compounds (such combinations involve chemical reactions and the atoms in small whole number ratios).

That means that the smallest basic particles in chemistry are atoms, and all matter in the universe is made up of these tiny particles. They can combine in many different ways to make more complex molecules. Matter that is made up of only one type of atom is called an **element**.

Structure of the Atom

Almost 100 years after John Dalton, in 1909, Ernest Rutherford demonstrated that the atom is made up of a very small positively charged nucleus surrounded by negatively charged electrons. The nucleus has more than 99% of the atom's mass. To give an idea of relative sizes, if an atom were about the size of a sports field, the nucleus would be smaller than the ball. Since electrons are even smaller than the nucleus that means that an atom is actually mostly just empty space!



Important note: This diagram is not to scale! If it was drawn to scale the nucleus would be so tiny that it would be invisible! Electrons are even smaller again.



The **nucleus** is made of:
Protons (red): positive
Neutrons (black): neutral

In a neutral atom there are the same number of electrons as protons.

In this diagram the **electrons** are shown as moving dots. However we can't know exactly where they are at any time. Instead we say they form an **electron cloud** around the nucleus.

Figure 5.9 The structure of the atom showing the nucleus and electron cloud.

The nucleus of the atom is made up of **protons** which are positively charged and **neutrons** which are not charged and therefore electrically neutral. They are similar in size. In comparison the electrons are very tiny, about 2000 times smaller than a neutron. Electrons move around the nucleus very quickly in random rather than fixed paths. That means that we cannot know exactly where they are at any point in time but we know where they spend the most time on average. Since they are moving so fast and are so tiny, we can think of them as an electron mist or cloud. Just like a cloud is made up of tiny moving droplets of water within a certain area, we define the **electron cloud** as the space where the electrons spend 99% of their time. Another way of thinking of the way electrons move is to compare them to a swarm of bees. They all move in random ways but overall they form a group that you can see even though it is hard to locate the individual bees.

An atom has the same number of electrons as it has protons. That means that the positive and negative charges balance out and the atom is electrically neutral. It is possible for an atom to loose or gain an electron. If an atom has lost or gained an electron we call it an **ion**. It will be either positive or negative in charge depending on whether it lost or gained an electron. Understanding how electrons are organised and how they move between atoms is one of the most important parts of chemistry.



Figure 5.10 Zinc (left), sulfur (middle), and copper (right) are examples of common elements.

Elements

Elements are composed of only one type of atom. There are 118 different types of atoms, so there are 118 different elements. Only 92 of these elements occur naturally. The important difference between elements is the number of protons in the nucleus. For example, carbon has 6 protons in the nucleus and oxygen has 7. That means that the atoms of different elements are of different sizes. The number of protons in the nucleus is important and is called the **atomic number**. Each element is assigned an individual symbol (for example; hydrogen - H, oxygen - O, carbon - C and calcium - Ca).

Elements are listed in the **Periodic Table.** The periodic table organises elements into groups with similar properties. The elements are listed in order of increasing atomic number. On the left hand side of the periodic table you find **metals** (shown in blue) and on the right hand side, **non-metals** (shown in orange and red). In between there are elements called **metalloids**. These elements have properties in between metals and non-metals. There is another important group of elements called **noble gases**. They are a special type of non-metal and are shown in red.

[SC4-17CW] {ACSSU152}

Metals

Most of us are familiar with metals in every day life. Much of a car is made of metal, coins are made of metals, cutlery is often metal and we even wear metals as decoration (jewelry). We are used to using metals all the time but what actually do we mean when we say that something is a metal?

Metals are found on the left hand side and middle of the periodic table. Metals are shiny solids at room temperature (25°C) with the exception of the metal mercury (Hg) which is a liquid. They are good **conductors** of heat and electricity so you often find them as wires in electrical equipment. They are **malleable** and **ductile** which means they can be hammered and bent into different shapes. That makes them useful for making structural elements for large structures, or even small parts for machines. They melt at high temperatures and are dense. Some common metals are aluminium (Al), lead (Pb), copper (Cu), sodium (Na) and iron (Fe).

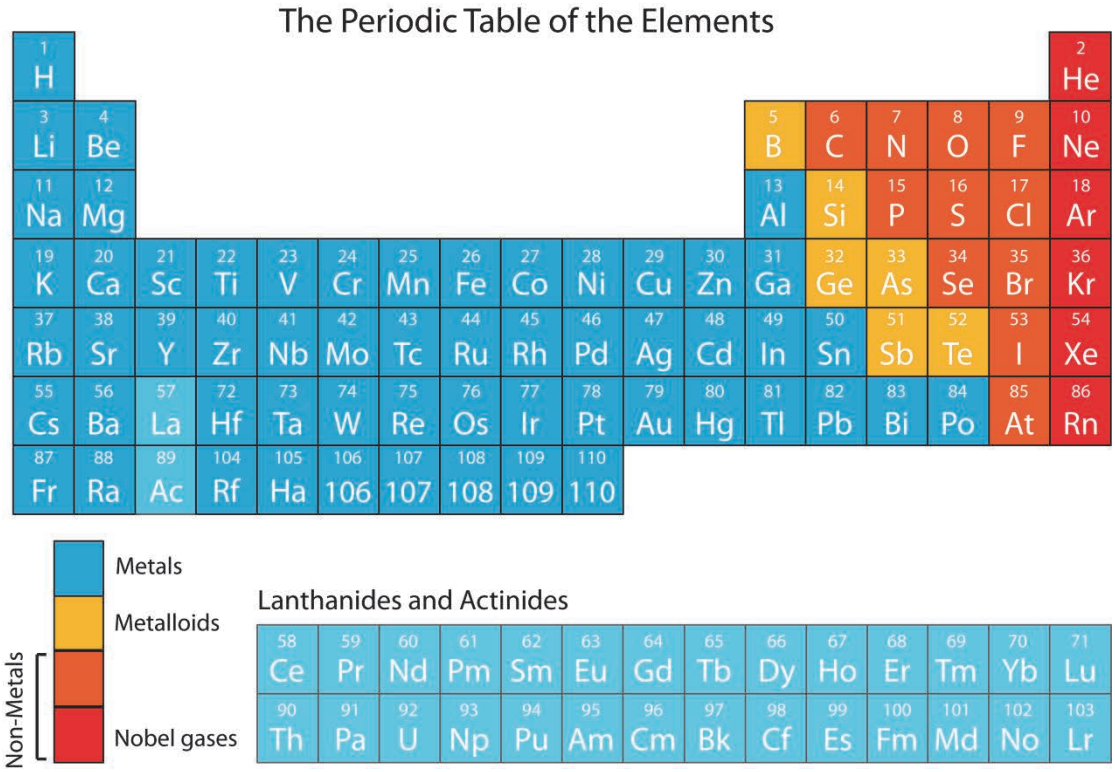


Figure 5.11 The periodic table of elements lists elements according to increasing atomic number. It can also be divided into metals and non-metals. There are some elements which have properties in between metals and non-metals and these are called metalloids.

Non-metals

Non-metals are all the elements that are not metals. If you think about our world that means that non-metals can be solids, liquids or gases at room temperature. They are poor conductors of electricity and heat (they are good insulators). In general they melt at low temperatures and have low densities.

Some common non-metals are chlorine (Cl), iodine (I), neon (Ne), nitrogen (N), oxygen (O) and carbon (C).

Metalloids

Metalloids are elements that don't easily fall into the definition of a metal or a non-metal. That's because they have properties that are in between a metal and non-metal. In general they look metallic and are brittle. They have intermediate electrical conductivity.

Noble gases

Noble gases are found in the far right column of the periodic table. They are special because they have very little attraction between the atoms and are very unreactive. Since they aren't attracted to other atoms they exist as individual atoms and are colourless, odourless gases. They are used in situations where it is important that no reaction happens. For example noble gases are often used as the gases in light bulbs since they won't burn or explode.

5.4 Chemical Bonds

Atoms sometimes exist on their own but they are most often found connected to other atoms. The forces which hold the atoms together are called **bonds**. For example, water is made up of two hydrogen atoms bonded to an oxygen atom, H_2O. There are two very important types of chemical bonds: ionic bonds and covalent bonds.

Ionic bonds are formed when two oppositely charged ions come together.

Ions form when an electron is transferred from one atom to another. The atom which lost an electron becomes a positively charged ion and the atom which gains an electron becomes a negatively charged ion. If two ions have opposite charges they are attracted to each other and can form an ionic bond. This is shown in Figure **5.12** 5.12. This type of bond usually occurs between metal ions and non-metal ions. For example, a positively charged sodium ion (Na^+) is electrically attracted to the negatively charged chloride (Cl^-) ion producing the very inert substance sodium chloride (NaCl) otherwise known as common table salt.

Ionic compounds are made from many ions packed in together. They make a three dimensional structure where each positively charged ion is surrounded by negative ions and vice versa. The attraction between all the different ions holds everything together.

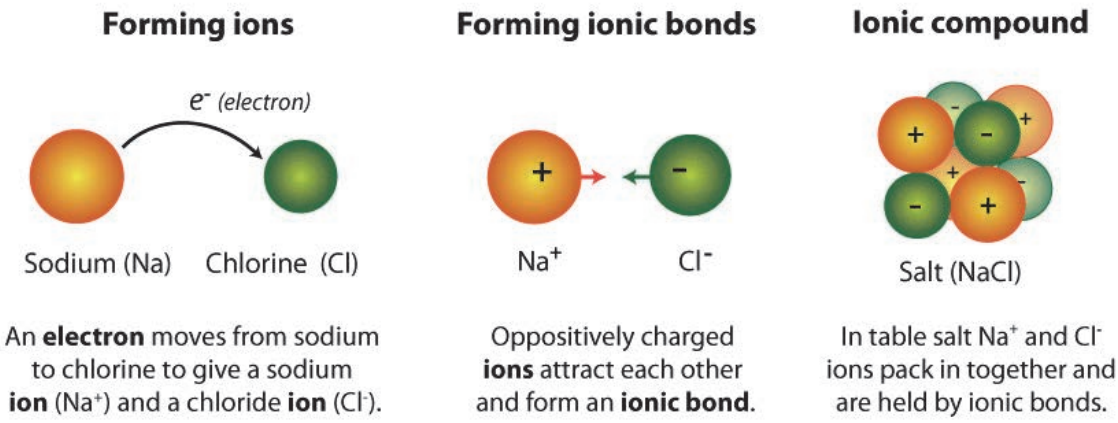


Figure 5.12 Ionic bonds form between oppositely charged ions.

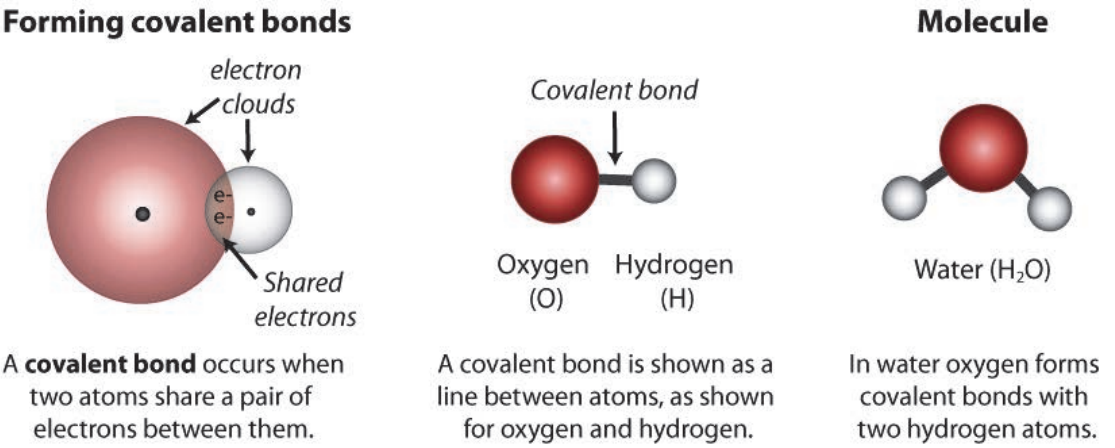


Figure 5.13 Covalent bonding occurs when atoms share electrons between them.

Covalent bonds occur between non-metals. A covalent bond is created when two atoms share a pair of electrons between them. When atoms are covalently bonded they form a **molecule**. These are the kind of bonds that are found in a molecule of water, sugar or even the organic molecules that make up the structure of cells.

Hydrogen bonds are weak transient bonds that are formed between very small opposite charges atoms in certain molecules. For example, in water (H_2O), the hydrogen (H) atoms have a very small positive charge compared to the oxygen (O) atom which has a very small negative charge. This means that the H atoms of one water molecule are attracted to the O atom of another water molecule if the two molecules are close enough. Thus the water molecules make hydrogen bonds with each other, but the bonds are not fixed. Instead they are continuously breaking and reforming. This attraction accounts for the surface tension of water and the ability of water to be “pulled” up a tree trunk. It is a very important physical property of water upon which all life on this planet depends.

5.5 Compounds and molecules

As mentioned earlier, there are 118 different types of elements. When the atoms of elements combine chemically with other atoms they can form literally millions of different types of substances. Substances that are made up of two or more elements together are called **compounds**. Compounds will have very different chemical and physical properties when compared to the individual atoms from which they are composed.

Consider water. Water is made of two atoms of hydrogen and one atom of oxygen. Oxygen (O_2) and hydrogen (H_2) are both gasses and unless mixed with other more stable gases like nitrogen (N_2) are very reactive. They will burn and even explode easily when ignited. But when they are chemically combined as water (H_2O) this resulting compound has very different properties. Water is no longer a gas but rather a liquid at room temperature. It is quite unreactive compared to individual atoms that make it up.

Each compounds is given a **chemical formula** that list all the elements in it. For example, carbon dioxide is made up of one carbon atom and two oxygen atoms so it has the formula CO_2. The subscript after O means that there are two oxygen atoms. Water has the formula H_2O which means that it is made up of two hydrogen atoms and one water atom. The subscripts are very important. For example CO is not the same as CO_2. The chemical CO is called carbon monoxide and is toxic to humans. Carbon dioxide, CO_2, however, is not.

Compounds can't easily be separated back into their respective elemental atoms. They may undergo further chemical reactions with other atoms or more commonly with other compounds to form other substances. This happens all the time in chemistry laboratories, industry, the environment and in the cells of living organisms. When this takes place in living organisms the breaking and reforming of compounds is known as **metabolism**.

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Molecules and Macromolecules

If the atoms in a compound are covalently bonded together the compound can be called a **molecule**. Water (H_2O) and carbon dioxide are compounds which are also molecules, however the compound NaCl (salt) is not a molecule since it has ionic not covalent bonds. Glucose ($C_6H_{12}O_6$) is another example of a molecule.

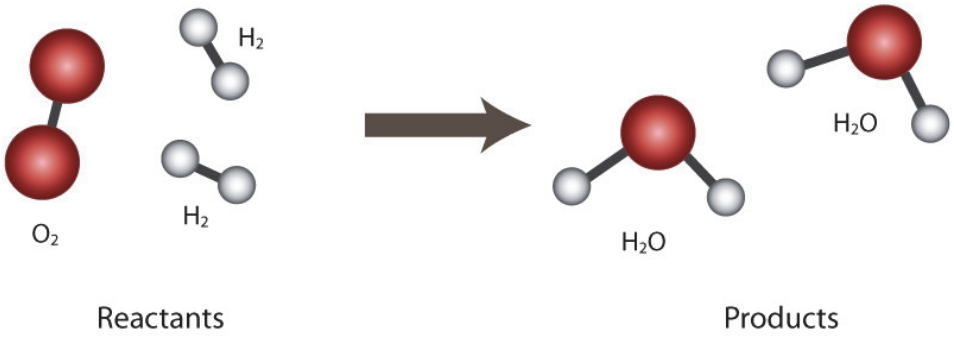


Figure 5.14 In this chemical reaction the bonds in one molecule of O_2 (two oxygen atoms joined together) and in two molecule of H_2 are broken and new bonds are formed to give two molecules of water (H_2O).

5.6 Chemical reactions

Chemistry becomes really exciting when substances react and change from on thing to another. Chemical reactions can be slow and seem gentle, for example when iron rusts, or they can be very fast and release a lot of energy, for example a burning fire (combustion) or explosive fireworks. Chemical reactions take place all around us including in the cells of our bodies. Chemical reactions are changes at the level of atoms. That means that a physical change like boiling water or grating a carrot isn't a chemical reaction.

In a chemical reaction we convert the substances we start with (the **reactants**) to different substances (the **products)**. That means that some of the bonds in the reactants are broken (atoms are disconnected) and new bonds are formed to give new substances. This is shown in Figure 5. for the formation of water from molecular oxygen (O_2) and molecular hydrogen (H_2). In a chemical reaction the number of atoms stays the same and the atoms are just rearranged to new molecules with different properties. If you count the number of hydrogen and oxygen atoms in the reactants and products in you will see that there are the same number on both sides.

Chemical reactions also involve energy exchanges; either energy is used in the chemical reaction, or energy may be produced in the chemical reaction. Energy produced by a chemical reaction is often obvious as light or heat. If energy is used up in the reaction the reaction is said to be **endothermic** and the final reaction solution will feel cold. If energy is released during the chemical reaction, the reaction is said to be **exothermic** and the final reaction solution will feel hot. An example of an exothermic reaction is the combustion (burning) of wood.

Chemical equations: describe what is happening in a chemical reaction:

Reactants → Products



Figure 5.15 Addition of vinegar to baking soda causes a vigorous reaction.

Chemical equations tell us what is happening to the atoms in the reaction. It lists the chemical makeup of the reactants before the reaction and the makeup of the products after the reaction. Chemical equations tell us where the actual atoms that participate in the chemical reaction end up.

Chemical reactions may be written as word equations (the reactants are on the left of the arrow, the products are on the right of the arrow):

sodium carbonate + hydrochloric acid → sodium chloride + water + carbon dioxide

Chemical reactions may also be written as chemical symbols in the form of chemical formulas (the following means the same as the word formula above):

$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$$

In addition to the energy either used up or generated by a chemical reaction, there other tell tale signs that a reaction has occurred. For example a gas may be given off and the mixture of chemicals may form bubbles. An insoluble substance, known as a precipitate may form or there may be a colour change in the solution containing the reactants as new products form.

[SC4-17CW] {ACSSU152} {ACSSU225}

Mixtures

Mixtures are commonly found in the environment and we encounter them often in daily life. Mixtures are made of different compounds literally mixed together. The compounds in a mixture are not chemically bonded together, there has been no chemical reactions taking place either making or breaking chemical bonds. An example of a mixture on a large scale is a cup of M&M's and smarties together. They are evenly spread through each other but are not joined to each other. Mixtures of molecules have far smaller particles but the basic principle is still very similar. This means that mixtures can be separated into the compounds that make them up. This is different from compounds, which can't easily be separated back into their elements or atoms. There are three important types of mixtures; **solutions**, **suspensions** and **colloids**.

Solutions are formed when one substance is dissolved in another. The substance being dissolved is called the **solute** and the substance doing the dissolving is called the **solvent**, as shown in Figure

5.16. When sugar is added to a cup of coffee the sugar is regarded as the solute and the hot coffee is the solvent. The sugar molecules are spread evenly throughout the hot coffee after it is stirred. Thus the cup of coffee is a solution of sugar molecules, hot water and coffee. The molecules are all dispersed between each other but do not chemically react to form new compounds. Solutions can also be made by dissolving a liquid in a liquid or even a gas in a liquid – for example carbon dioxide can be dissolved in water. If a solute can be dissolved it is **soluble**, if it cannot be dissolved it is **insoluble**.

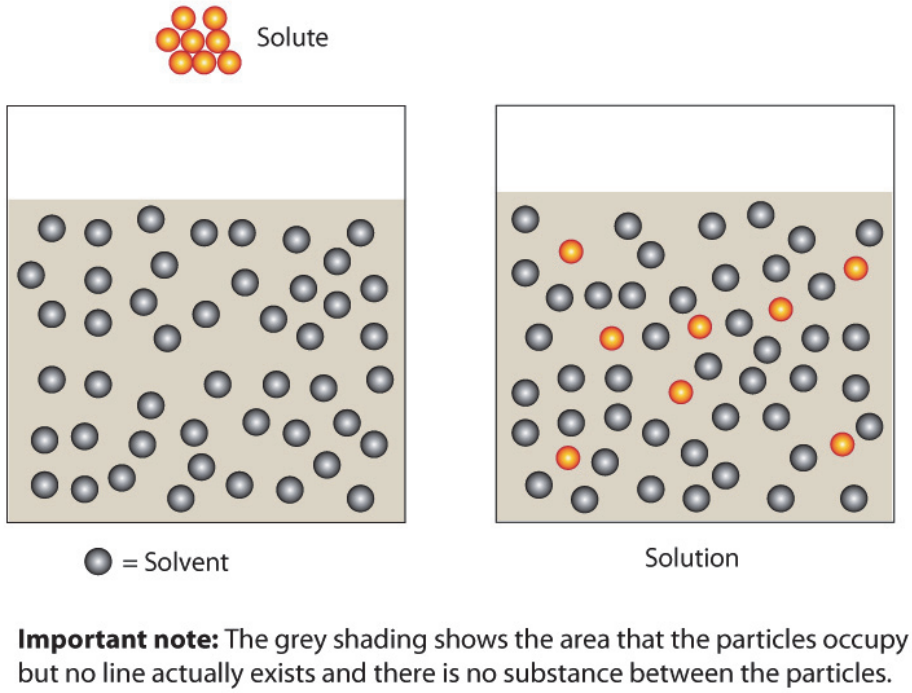


Figure 5.16 In a solution the solute dissolves and is dispersed evenly through the solution. Note that the size of the particles is greatly exaggerated in these diagrams.

If a solution has a lot of solute in it compared to solvent, it is a **concentrated** solution. If there is very little solute then it is **dilute**. You can make a solution more concentrated by adding more solute. In the same way you can dilute a solution by adding more solvent. We do this whenever we make up a glass of cordial and water. If we don't add enough cordial the drink is very weak (dilute) but we can make it nicer to drink by adding more cordial. That is, we increase the **concentration** of cordial in the drink.

Suspensions are formed when substances are added to liquids but do not dissolve. A good example is the addition of sand or soil to a bucket of water. The mixture can be stirred very thoroughly, but the sand or soil will not dissolve in the water. When left to stand for a period of time the sand or soil will settle out forming a **sediment** on the bottom of the bucket. The water can be carefully poured off or **decanted** leaving the sediment behind. Generally the particles that make up the substance being added (soil or sand) are much larger than the molecules making up the solvent (in this case water molecules).



Figure 5.17 Muddy water is an example of a mixture of soil and water.

Colloids are mixtures that are somewhere between a solution and a suspension. The particles being added to the liquid still do not dissolve, but they are not large enough to quickly settle out like the soil and sand in the suspension mentioned above. Colloids really consist of two **phases**, a dispersed phase (the particles) and a continuous phase otherwise known as a **dispersion medium** (sort of like the solvent). The two phases can be solids, liquids or gases and can form **sols**, **emulsions**, **foams**, **gels** and **aerosols**.

Foams and **gels** are maybe the names that you are most familiar with. **Foams** are formed when a gas is mixed with a liquid. An example of a foam is shaving cream. **Gels** are liquids mixed in a solid, for example hair gel. A **sol** is where solids are dispersed in a liquid (for example ink particles in liquid to make ink for pens). **Aerosols** are liquids or solids mixed with gases. An **emulsion** is produced when one liquid is dispersed in another liquid without being dissolved. A good example of an emulsion is where droplets of oil are dispersed in a liquid as in the case of salad dressings. The oil droplets do not dissolve in the water phase of the salad dressing and produce a cloudy liquid. If left to stand the two phases separate with the oil floating on top of the watery phase. The salad dressing bottle has to be shaken up to remix the two phases. Milk is also an emulsion, as are face creams and even mayonnaise.

Colloids can be very difficult to distinguish from a solution because the two phases don’t separate. However if a colloid is made of a solid mixed into a liquid you can tell the difference by filtering it. All the particles in a solution will pass through the filter but in a colloid the solid particles will not. Alternatively you can tell the difference between a colloid and a solution by taking advantage of the Tyndall effect. When a light beam is passed through a colloid the light beam will be scattered by the colloid particles, making it possible to see the path of the beam as it passes through, just as it is possible to see light beams passing through smoke. However, the path of the light beam will not be visible when passed through a solution.

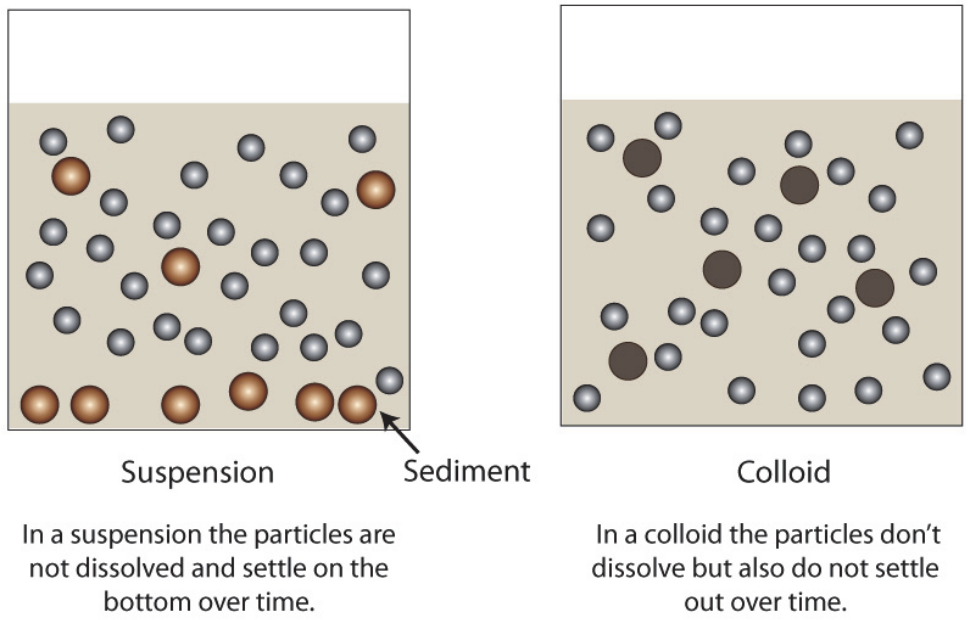


Figure 5.18 Suspensions and Colloids.

Separation of substances

It is often very important to be able to separate mixtures and solutions into the various components that make them up (whether they are soluble or insoluble). Such techniques may be applied in the laboratory, industry or even the kitchen. Very often separation techniques are used to purify something by separating the different components. Separation procedures will depend on the type of mixture or solution and will also depend on the chemical and physical properties of the different substances. {ACSSU113}

Insoluble Substances

If you have a mixture of insoluble components it is usually possible to separate them using a physical method. The insoluble particles are usually relatively large and can be separated by techniques such as **decanting**, **filtration** and **sieving**, and **centrifugation**.

Decanting is a very simple and ancient method of separation. The mixture is allowed to stand so that the insoluble component settles out under the force of gravity and the liquid portion is slowly and carefully poured off. This technique is often used for clarification of old wines or home made ginger beer.

Filtration and sieving are very common methods where the insoluble component of the mixture is removed by a filter or a sieve. The filter or sieve has holes or pores which allow liquids or small particles to go through but not the insoluble particles. Filters with different size are used for different purposes depending on the size of the particles. For example you would not use a kitchen colander to sieve out sugar. Some examples of filters in our day-to-day lives are vacuum cleaner bags, tea bags, pool filters and fuel filters in cars.

Soluble Substances

Soluble particles or molecules are very small, much smaller than the particles that make up insoluble substances. Methods such as decanting and filtration used for the separation of insoluble substances do not work well with solute molecules in solution. The solute molecules are dispersed between the solvent molecules of the solution and do not settle out, nor do they exist as separate phases as in the case of colloids. Instead completely different techniques are used to separate out solutions.

Evaporation and Crystallisation: Everyone has seen the ring of sea salt that is left around the rim of rock pools at the beach as the seawater evaporates. Standing in the sun, the water heats up and water molecules change from a liquid to a gas and escape. This phenomenon is called **evaporation**. The solvent (water) escapes the rock pool leaving the solute (salt) behind. As the rock pool dries out, the salt forms crystals, a process called **crystallisation**. The processes of evaporation and crystallisation can be accelerated by heating the liquid to temperatures that approach the boiling point of the solvent.

Distillation is a separation technique related to the principle of evaporation. Distillation is used in chemistry laboratories and industry to separate solvents and solutes even when they are two liquids. Distillation relies on the fact that different substances have different boiling points.

In distillation the solution is heated until it begins to boil but instead of allowing the gas to escape it is captured and cooled down by passing it through a glass tube cooled with flowing water. As the gas cools it **condenses** back to a liquid and is collected. Since different substances have different boiling points the substance with the lowest boiling point boils off first leaving the other substances behind. The liquid collected in this manner is called a **distillate**.

Chromatography is another technique that can be used for separating substances in solution. Often some form of paper chromatography is used. A spot of the solution to be separated is applied to the bottom of the chromatography paper and allowed to dry. The bottom of the chromatography paper is placed in a suitable solvent and the components of the solution applied to the spot will separate as the solvent moves up the paper and carries them along. The solution separates because substances move at different speeds through the paper because of their chemical composition. Various applications of this technique are used in chemical analysis and medical research.

5.7 Acids & Bases

One very important part of chemistry is the study of acids and bases. Acids and bases are an intrinsic part of our lives. We find them in many places in our homes and work places, and even in our foods. For example acids are found in many foods, in batteries, and unfortunately in acid rain. Bases are found in many cleaning products. Sodium bicarbonate is a common base. However the uses and importance of acids and bases don't stop there. Many of the reactions in our bodies are acid-base reactions and their balance in our body is very carefully maintained.

In this section we define an acid and a base and talk about their properties but before we start there are two very important ions we need to talk about: hydrogen ions and hydroxide ions. A hydrogen ion, H^+, is formed when an electron is taken away from a hydrogen atom. This gives it a positive charge. A hydroxide ion, OH^-, is made of oxygen and hydrogen bonded together with a negative

charge on the whole molecule. If you add a hydroxide ion to a hydrogen ion you get water! You can write the reaction as: $H^+ + OH^- \rightarrow H_2O$. The reaction can also go in the reverse direction. That is, water can split into H^+ and OH^- but it only happens to a very small extent. In pure water there are exactly the same number of H^+ as OH^- ions.

Acids

The simplest way to define an as **acid** is a substance that gives up hydrogen ions (H^+) when it is added to water. A good example is hydrochloric acid, HCl. When you add it to water it separates into H^+ and Cl^-. That means that more hydrogen ions are present and therefore HCl is an acid. If a solution has a high concentration of H^+ ions then we say that it is **acidic**.

We find many acids in cooking and in food. Lemon juice and vinegar are acidic and tartaric acid is also used for cooking. Vitamin C is acidic which is more obvious from its other name, ascorbic acid. Citric acid is found in lemons and oranges. Many fizzy drinks are acidic.

In general acids are sour tasting. If they are strong acids they are corrosive, that is they can burn your skin. Two common strong acids are hydrochloric acid, HCl, and sulphuric acid, H_2SO_4. Both of these are dangerous when they are concentrated.

Bases

Bases can be defined as substances that release hydroxide ions when they are added to water. One example is sodium hydroxide, NaOH. When added to water it separates into Na^+ and OH^-. Because it increases the concentration of hydroxide ions NaOH is a base. If a solution has more OH^- ions than H^+ ions then we say it is basic. Substances that are basic are sometimes also called alkaline.

Like acids, bases are also often found in the kitchen. However they are usually under the kitchen sink! Many cleaning products are basic including soaps, bleaches and ammonia. In comparison to acids, there are few fewer basic foods. Bases taste bitter. Bases usually feel soapy or slimy on your fingers because they react with the fats in your skin. Finally, bases can be corrosive and should be treated with care. Sodium hydroxide is an example of a strong base.

The pH scale

One way of comparing solutions of acids and bases is to measure **pH**. The pH scale runs from 0 to 14 and measures how many hydrogen and hydroxide ions there are in a solution. Acids are found at the low end of the scale (<7) and bases are found at the high end (>7). The lower the pH, the more acidic the solution. High pH, for example pH = 11, indicates a basic solution.

Right in the middle are solutions that are **neutral** and have a pH of 7. These are substances that are neither acids nor bases. In acid/base terms that means that there are exactly the same number of H^+ and OH^- ions and the solution is neither acidic or basic. The pH in our bodies is usually between 7.3 and 7.4, which is very close to neutral and our bodies have complex systems to keep it close to that value. If your body pH changes by even 0.3 it could kill you. The pH of soils is also important for plants. In basic soils nutrients are not as available, and if soils are too acidic some toxic compounds can be released. The pH of a substance can be measured using a special electrical probe.

Indicators

One way of checking whether something is acidic or basic is to use an **indicator**. Indicators are special substances that change colour depending on pH. Litmus indicator is maybe the most commonly known. It changes from red in acidic solution to blue in basic solution. There are many types of indicators with different colours. For example, bromothymol blue is yellow in acidic solution and dark blue in basic solution. The colour changes of indicators make it possible to test whether something is are acidic or basic with just one or two drops.



Figure 5.19. The colour changes of two indicators: **Left two flasks:** Methyl Orange is **yellow** when pH is above 4.4 and **red** when pH is below 3 and **Right two flasks:** Bromophenol Blue is **purple** when the pH is above 4.6 and **yellow** when the pH is below 3.

Indicators are also present in nature. Have you ever noticed what happens when you try to wash out a fresh cherry stain with laundry detergent? Fresh cherry juice turns from its natural colour of reddish purple to blue in the presence of the basic detergent. If you then put lemon juice or vinegar in the blue solution, it will turn red again. Some flowers even change colour depending on the pH of the soil. When hydrangeas are planted in acidic soil the flowers are blue but in basic soil they are pink. Red cabbage juice also makes an excellent indicator. It is naturally purple in colour but can change to red, blue, yellow or green as you can see in Figure 5.20. It turns red with a couple of drops of acid, blue with ammonia (basic) or yellow with NaOH (more basic than ammonia). The natural colour of cabbage juice is the second from the right. The active ingredients in the cabbage juice are anthocyanins. They are found in many different plants.



Figure 5.20 Cabbage juice indicator from acidic on the right to basic on the left.

Neutralisation

Acids and bases have a very important property. When an acid is added to a base it makes a salt and water. If you take hydrochloric acid, HCl, and sodium hydroxide, NaOH and add them together they form NaCl, which is just table salt, and water. Both hydrochloric acid and sodium hydroxide are very corrosive substances but when we add them together we get something completely harmless! Not only that, the pH of the salty water formed is 7. Because a neutral solution is formed, adding an acid and base in this way is called **neutralisation**.

Activities

The following fun activities grow out of this chapter.

1. Make a scale model of a hydrogen atom on a sports field. What would the diameter of a hydrogen atom be if the nucleus were the size of a ball bearing about 0.5 cm in diameter? The radius of a hydrogen atom is about 1.70×10^{-10} m and the radius of the nucleus is about 1.0×10^{-15} m. (*Hint: That means that the atom is about 170,000 times larger than the nucleus.)* How large would the diameter be if the nucleus were the size of a ball about 7 cm across? Remember that electrons are about 2000 times smaller than a proton.
2. Do a research project on the development of atomic theory and the importance of the experiments carried out by the New Zealand born scientist Ernest Rutherford.
3. Drop a drop of food colouring into a glass of water and watch it diffuse. Try using drops of two different colours and watch as they mix. Try it with hot and cold water. Is there any difference?
4. Using the periodic table find the chemical symbols for carbon, oxygen, lead, gold and silver. Look up the origin of the symbols and names of these elements.
5. Grow your own sugar crystals from sugar dissolved in hot water. There are many instructions on the internet.
6. Make an indicator out of cabbage juice. Chop up a red cabbage into pieces about 1 cm wide and between 5 and 10 cm long. Pour boiling water over it and leave for about 10 minutes until the colour has leached into the water. Sieve the mixture to remove the pieces of cabbage and keep the liquid. If the mixture is cloudy pass it through a coffee filter. Collect household solutions. Pour out the indicator into small clean cups. Test to see whether the household solutions are acidic or basic by placing a few drops of the solutions in the cups with the indicator.
7. Test other foods with strong colours to see if they can act as indicators. Squeeze out a drop of juice or soak the food in boiling water (as for activity 6). Then test with a drop of lemon juice or some washing detergent. For example you could start with cherries. The ingredients that change colour with pH are anthocyanins. Do some research to find out which other plants have high anthocyanin content. Which other plants could be good indicators? Test your hypothesis.

Chapter 6

The Chemistry of Life

6.1 Introduction

All living things (from the smallest bacteria to the great blue whale) are composed of essentially the same types of molecules. In this chapter we introduce the chemicals of life and the chemistry of many of the products we use every day. These molecules fall into an area called **organic chemistry**. It is called organic chemistry because many of them come from living organisms, *i.e.* organic matter. In fact people used to think that it would be impossible to make the chemicals of life and that they had a special life force in them. However scientists discovered it is possible to make these chemicals and that they are made up of exactly the same building blocks as "regular" chemicals, that is they are made up of atoms. There is still something special about organic compounds - they all contain large amounts of carbon as their basis. So modern day organic chemistry can be defined as the chemistry of carbon. Organic compounds also usually contain atoms of oxygen (O), hydrogen (H) and nitrogen (N). These atoms are used to construct biomolecules that may be either small or very large (macromolecules). The terms used here 'small' and 'large' are relative terms describing molecular sizes that are all very, very small on the scale of everyday things. These molecules may also contain smaller amounts of sulphur (S), iron (Fe), magnesium (Mg) and other trace elements.

6.2 Organic Chemistry

Most molecules in our bodies are made up mainly of carbon (C), hydrogen (H), oxygen (O) and nitrogen (N). Of these elements carbon is the most important because it is very good at bonding to itself or to other atoms. You can think of the carbon structure as the "frame-work" of the molecules. There are millions of ways of combining carbon with itself and with other elements and the molecules can be anything from very small, for example methane with just four atoms, to extremely large and complicated, for example proteins with thousands of atoms.

When the molecules become extremely large in chemical terms (thousands of atoms) they are called **macromolecules** (Macro as a prefix means large). The molecules making up cells such as protein, DNA and lipids are classed as macromolecules.

There are many different types of organic molecules. Hydrocarbons are made up of just carbon and hydrogen. There are also alcohols, ketones, aldehydes, esters, and ethers just to name a few. All of these different groups of chemicals have special properties. For example alcohols can be dissolved in water but hydrocarbons can't. These properties come about because of the type of molecules that make them up.

If there are strong attractions between molecules they tend to be solids, if the attractions are not quite as strong they will probably be liquids and if the attraction between molecules is extremely weak they will be gases. For example there is very little attraction between molecules of methane and as consequence methane is a gas. Ethanol and methanol are two small alcohols and have reasonably strong attractions between the molecules. Therefore they are both liquids. Very large hydrocarbons are held together by lots of small forces. All together these small forces are significant and they hold the molecules together strongly enough so that large hydrocarbons tend to be waxy solids.

6.3 Polymers

Polymers are very special organic molecules. They are made up by linking together small molecules to make very long chains. They are very large molecules and can contain hundreds or thousands of atoms.

The individual molecules or repeating units that make up a polymer are called **monomers**. That means one "–mer". *Poly* means many so polymer means many "-mers". Polymers occur in nature and are also made in industry. Some of the most important biomolecules are polymers. In industry, plastics are mainly made up of polymers. When a polymer is made artificially it is called a **synthetic polymer**.

Synthetic polymers are named after the monomers that make them up. So polyethylene is made up of lots of ethylene molecules joined together, poly vinyl chloride is made up of vinyl chloride molecules, etc.

Polymers have different properties depending on the monomers that make them up. For example if a monomer forms hydrogen bonds then the polymer will also form hydrogen bonds. The properties of a polymer also depend on the way the monomer units are joined together. Polymers can be made up just of long straight chains but they can also be branched or linked together or even make star patterns as shown in Figure 6.1.

The stronger the attraction is between the chains, and the closer they pack in, the stronger the plastic made out of that polymer will be. Polymers made up of straight chains can pack close together. If the chains are packed in closely the plastic tends to be stronger and more rigid. If chains are linked together then a polymer will be even stronger. Glues and resins are made up of polymers with chains linked together.

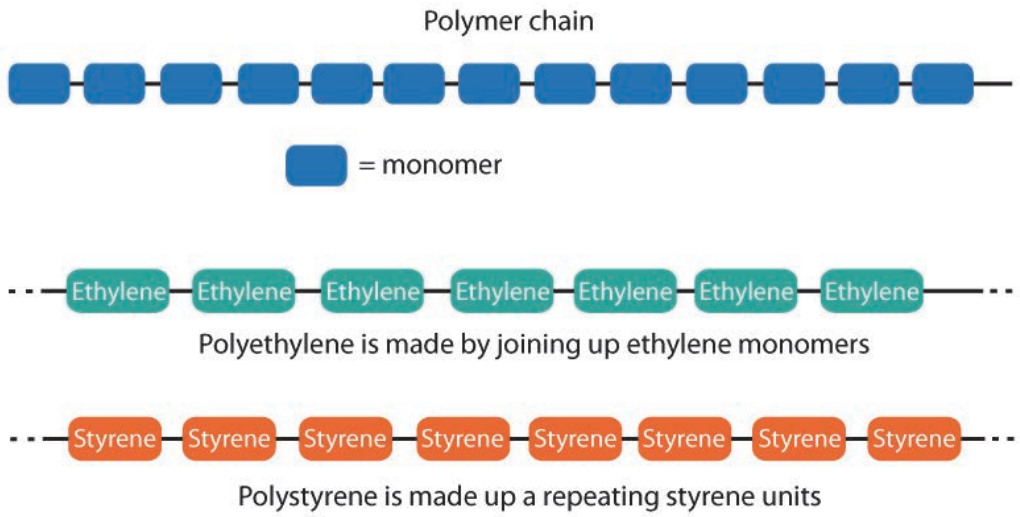


Figure 6.1 Polymers are long chains of repeating units called monomers.

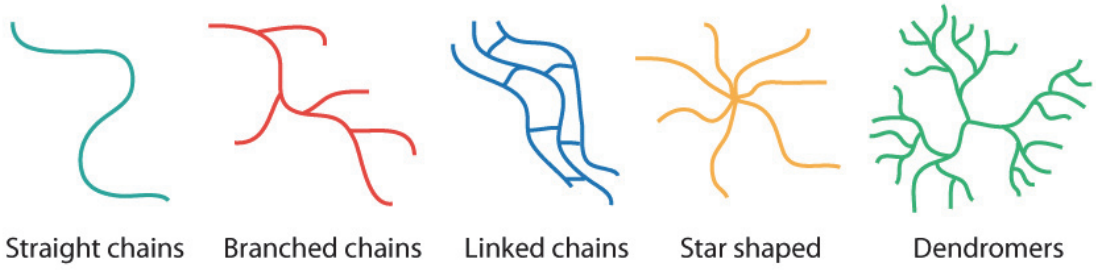


Figure 6.2 Monomers can be linked together in many different ways to make polymers.

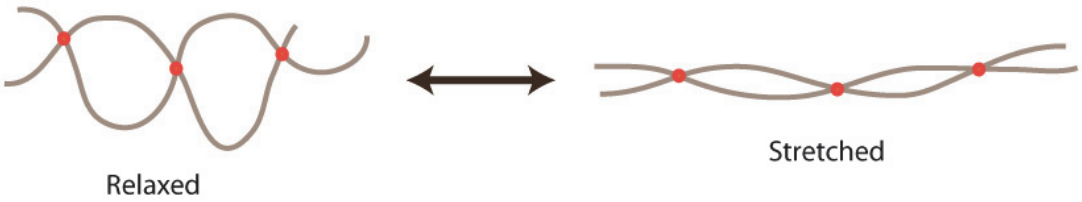


Figure 6.3 The polymer chains in an elastomer lie in random ways when they are relaxed but line up when the polymer is stretched. The links between the chains help them go back to their original shape.

If a polymer has lots of branches then the chains can't pack together as easily and the plastic will not be as strong or stiff. If the attraction between the chains is weak then the polymer can actually form

something between a liquid and a solid. An example of a polymer of this type is silly putty. If you bounce it off the floor it acts like a solid but if you pull it slowly it will flow like a liquid.

Elastomers are made from polymer chains that have weak attraction between them but also have some links between the chains. That means that the chains tend to be arranged in random ways but if you stretch them out the chains line up. They spring back because the links between the chains help the polymer go back to its original shape. Rubber is a naturally forming polymer. The elasticity of rubber is improved by adding links between the chains in a process called vulcanisation.

6.4 Biomolecules

Just like synthetic polymers many biomolecules are made up of small organic molecules like amino acids, glucose and fatty acids are used to produce larger macromolecules such as proteins, polysaccharides (carbohydrate) and lipids (fats). These macromolecules are used to make structures in cells which then make up whole cells. Collections of cells are assembled to form tissues that make up organs such as the stomach, brain or liver, etc. Organ subsets combine to form organ systems; for example, the oesophagus, stomach, small and large intestines, the pancreas and the liver all form the digestive system. Bodily systems coordinate and combine to form the whole organism. It is incredible to think of how organisms are built up in this way.

All the molecular construction and coordination follows a blueprint of chemical information. The information in every cell that determines its structure and function and how it behaves with respect to the rest of the body is stored in a molecule called **deoxyribonucleic acid** or **DNA**. This remarkable macromolecule governs the day to day running of the cell, the replication of the cell and makes sure that each cell makes a positive contribution to the function of the entire organism.

The study of these molecules and macromolecules of life comes under the scientific disciplines of **biochemistry** and **molecular biology**. The study of the structure of the body is **anatomy**, the study of the normal functioning of body systems is **physiology** and the study of disease and its effects on the body is **pathology** and **pathophysiology**. Of course, as would be expected, these biomedical disciplines all overlap and inform each other continuously.

We will now turn our attention to the some of the important characteristics of these incredible biomolecules.

The Three Major Food Groups

The three major food groups are **carbohydrates**, **lipids** and **proteins**. It is not surprising that the components of these three major food groups make up the structure of our bodies because the food we eat is digested down into the molecules that make them up. These molecules are then absorbed by the digestive system and distributed to the body cells by the blood. In the cells they are built into the structure of the body.

6.5 Carbohydrates

Structure of Carbohydrates

Carbohydrates are widely distributed in nature and make up most of the organic molecules on the planet. They are called carbohydrates because they are made up of carbon, hydrogen and oxygen. They are synthesised by green plants from carbon dioxide and water in a process called **photosynthesis**.

The carbohydrates are then stored as starches.

Starches are **polymers** made from glucose molecules joined together into long chains. Just a short part of a starch chain is shown in Figure 6.4. The starch molecules tend to be stored in plant cells as long coils. Starches or other long chain of sugars are also called polysaccharides, where the prefix poly means many.

Digestion of Carbohydrates

Carbohydrates are found in bread, pasta and rice, etc. They are digested or broken down in the mouth into the molecules which make them up. For most of the carbohydrates this is the molecule glucose. Carbohydrates are broken down by a special class of protein molecule called **enzymes** (enzymes are like molecular tools or machines for processing other biomolecules). In this case, the specific enzyme is salivary amylase. Carbohydrates not fully digested in the mouth will be digested in the upper part of the small intestine (called the **duodenum**) by a similar enzyme called pancreatic amylase.

Digestion of the carbohydrates breaks them down into glucose, which is absorbed into the blood stream from the small intestine and distributed to the cells of the body.

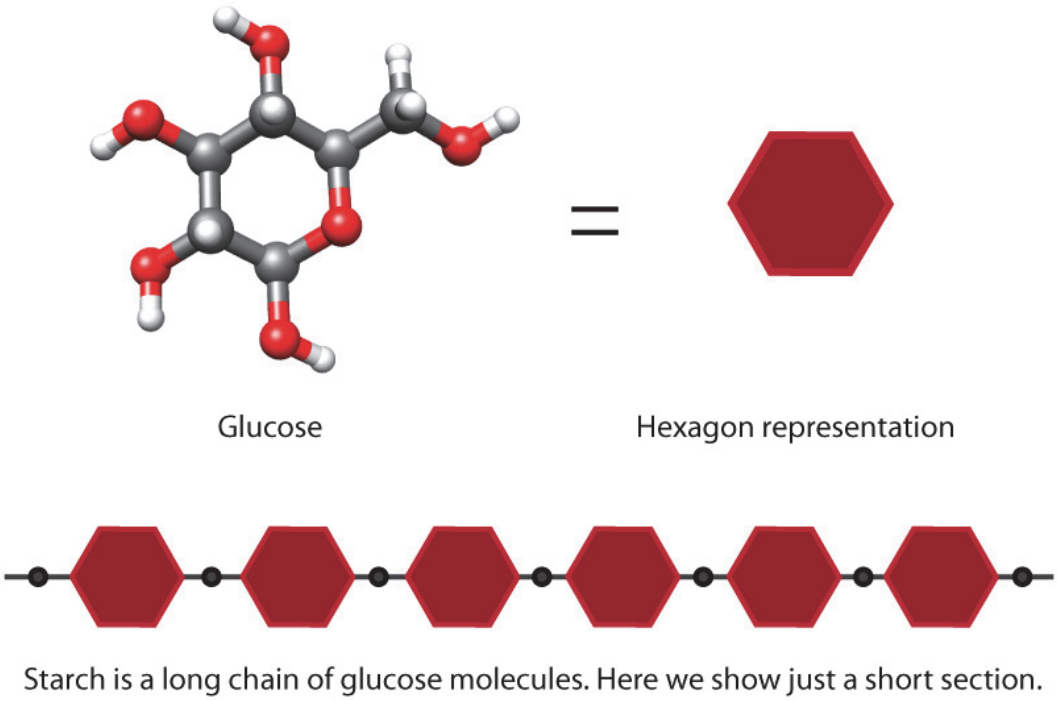


Figure 6.4 Starch is made up of a long chain of glucose molecules.

Side note:
Did you notice: **Glucose** is a fuel for our cells. But remember! Glucose is made from carbon dioxide and water using the energy from the sun. **Photosynthesis** catches the energy of sunlight and stores it in the chemical bonds of glucose. Then we can "burn" glucose to get energy for our bodies when we need it. That means that we're powered by sunlight!

Biological Functions of Carbohydrates

Carbohydrates have some very important functions in living organisms.

1. They are very important as fuel molecules. The 'burning' of carbohydrates like glucose provide the cells of the body with energy (this process is called **cellular respiration** and chemically it is known as **glucose oxidation**). Glucose is the major metabolic fuel of the body.
2. Glucose may be stored for later use. It is stored as **starch** in plants and as **glycogen** in animals. Glycogen is stored in the liver and skeletal muscle. The liver uses its glycogen store to maintain blood glucose levels, while skeletal muscle use its glycogen to supply glucose for its great energy generation needs.
3. Glucose makes up another very important molecule in the plant kingdom – **cellulose**. Cellulose fibres are tough and stringy and help give plants their strong structure. When we eat plant foods we eat cellulose but we cannot digest it (it has a different molecular configuration to starch), passing through our digestive system undigested and it is known as dietary fibre.

4. Modified carbohydrate molecules are an important component of animal connective tissue.
5. Special carbohydrates known as **mucopolysacchrides** are found as lubricating fluids in the joints between bones.
6. Very specialised carbohydrates can be bonded to certain protein or lipid molecules found on the membranes of cells. These complex molecules are involved cell communication and recognition.

6.6 Lipids

Structure of Lipids

The next important group of biomolecules is lipids, also known as fats. Lipids are widespread in the food we eat and essential for life. However eating large amounts of lipids is associated with various health problems such as obesity, diabetes and heart disease.

Lipids are chemically diverse but all are insoluble in water. The most common form of lipid is the **triglyceride** and is made from smaller fatty acid molecules. Fatty acid molecules have a water-loving (**hydrophilic**) end and a water-hating or water-avoiding (**hydrophobic**) tail as shown in Figure 6.5. The combination of these two properties in these molecules give lipids some very interesting properties.

For example, salts of fatty acids are used in soaps and detergents. The water hating tail of the molecule is attracted to the grease or oil (it allows it to escape the water). The head of the molecule is attracted to the water so the molecules arrange themselves so that their tails stick into the grease with the heads on the outside facing the water just as shown in Figure 6.5. The oil droplets are then solubilised and can be removed. The same thing happens to oils on your skin when using a bar of soap.

Lipids may exist as **saturated** (contain the maximum possible number of H atoms) or **unsaturated** (less than the maximum number of H atoms) molecules. Saturated fats such as those found in butter and meat can pack tightly together as all the fatty acid tails of the lipid molecules line up nicely. This means they are usually solids at room temperature. Unsaturated or polyunsaturated fats cannot pack tightly together because their fatty acid tails have kinks in them caused by double bonds in their structure. These bent tails won’t line up very well as the temperature drops and the fat starts to solidify. Polyunsaturated fats like vegetable oils and margarine stay liquid at lower temperatures.

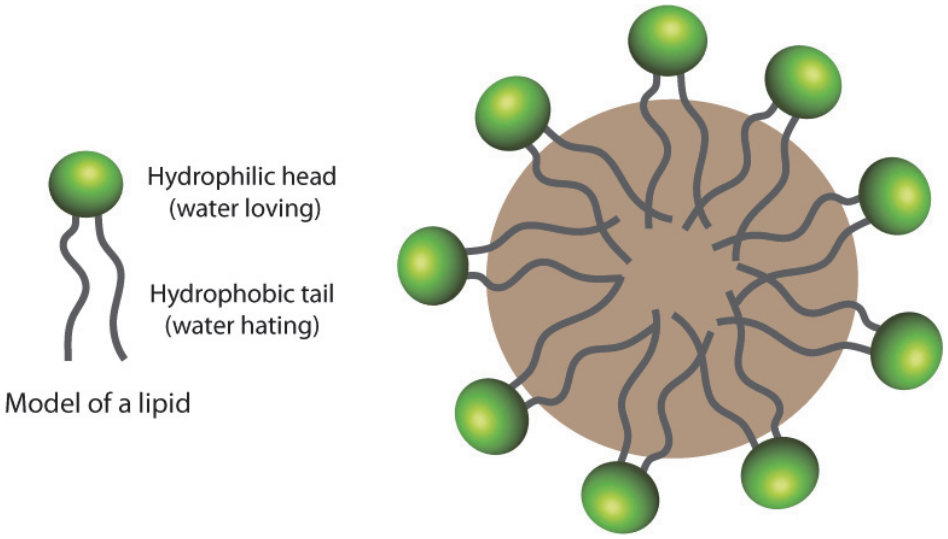


Figure 6.5 Lipids consist of a hydrophilic head and a hydrophobic table. Lipids are able to dissolve oils and grease.



Figure 6.6 Butter is a saturated fat so it remains solid at room temperature but vegetable oil is an unsaturated fat so it remains as a liquid.

Digestion of Lipids

Lipid digestion occurs in the upper part of the duodenum. Lipids are turned into tiny fat droplets by **bile salts**. Bile salts are like an organic detergent. They are produced in the liver and stored in the gall bladder until needed in the small intestine. These tiny fat droplets of lipid are then digested by an enzyme called pancreatic lipase. The breaking down of lipids into tiny droplets by bile salts is called **emulsification**. This process greatly increases the surface area of the lipid allowing for more efficient digestion by pancreatic lipase. The resulting fatty acids are absorbed by the small intestine.

Biological Functions of Lipids

Lipids also have some very important functions in living organisms.

1. Special lipid molecules called **phospholipids** are made from fatty acid molecules. They make up the bulk of the structure of cell membranes.
2. The triglyceride molecule acts as an excellent source of metabolic fuel and is stored in large quantities in adipose tissue.
3. Adipose tissue can act as insulation under the skin and is also found packed around some internal organs for protection.
4. Certain special lipids known as **steroids** are used to produce **cholesterol** (found in the membranes of animal cells and in the blood where elevated levels are one of the important risk factors for heart disease) and **steroid hormones**. Steroid hormones, including the sex hormones such as **testosterone** and **estrogen**, are involved in sexual development. Other steroid hormones include the **anabolic steroids** involved in the growth and repair of the body. Such steroid hormones are sometimes used by athletes to enhance muscle development and performance. Such activities are not endorsed by sporting bodies and there are specific analytical tests to detect these hormones in the blood and urine of athletes.

Formation of cell membranes

Membranes, the barrier around cells, are made up of special lipid molecules called phospholipids. The heads of these molecules are water loving (hydrophilic) and point outwards, while the tails of these molecules are water hating (hydrophobic) and point into the membrane just as shown in Figure 6.7. Sometimes the membrane is referred to as a **phospholipid bilayer** because it is made up of two rows of phospholipids orientated in two different directions. The lipid molecules are not fixed in place but act a little bit like a sea with other special protein molecules floating in it. The membrane is held together by the attraction between the hydrophobic tails and their aversion for water.

6.7 Proteins

Structure of Proteins

Proteins, also known as **polypeptides**, and are made from just twenty different kinds of much smaller molecules called **amino acids**. The amino acids are chemically linked by **peptide bonds** into long unbranched polypeptide chains. These chains automatically fold into specific three-dimensional shapes that determine the function of the protein. The order of the amino acids in the protein molecule is determined by the genetic information contained in the DNA molecules of the cell.

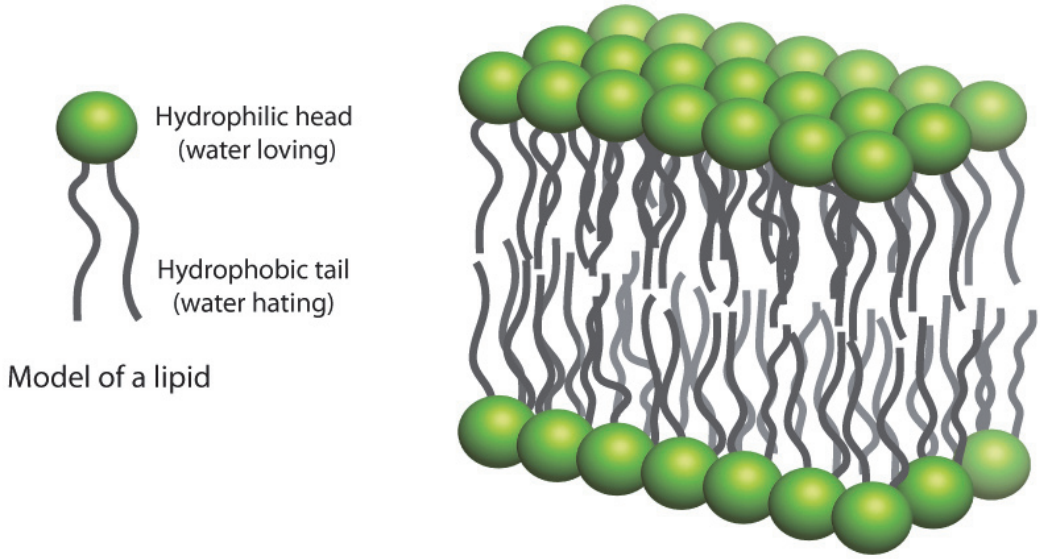


Figure 6.7 Phospholipids form cell membranes. The membranes are organised so that the hydrophobic tails are on the inside of the membrane with the hydrophilic heads on the outside.

Digestion of Protein

Proteins are found in most foods but particularly in meats, cheese, fish and legumes (beans). Proteins are digested in the stomach by hydrochloric acid and special acid resistant enzymes such a pepsin. Proteins are also broken down in the small intestine by a cocktail of **proteolytic** (‘able to breakdown proteins’) enzymes produced in the pancreas**.** Proteins are broken down to smaller peptide molecules which in turn are broken down to their constituent amino acids. Amino acids are then absorbed into the bloodstream from the small intestine and distributed to the cells of the body.

Biological Functions of Proteins

The range of functions of proteins in biological systems is much broader than that of either carbohydrates or lipids. For example, proteins can be used for things as different as the structure of cells all the way to the coordinating and controlling metabolism.

1. **Structure**: Proteins involved in body structure are fibrous and insoluble. **Collagen** is found in connective tissue and bone. It provides great strength to connective tissue and can be compared to steel reinforcing rods in concrete (but much more flexible). The **keratins** are found in skin, hair, nails, hoofs and horns. Keratins give flexibility, resilience and protection.
2. **Catalysts: Enzymes** are special biological catalysts that speed up and control the biochemical reactions of the cell. Collectively these reactions are referred to as **metabolism**.

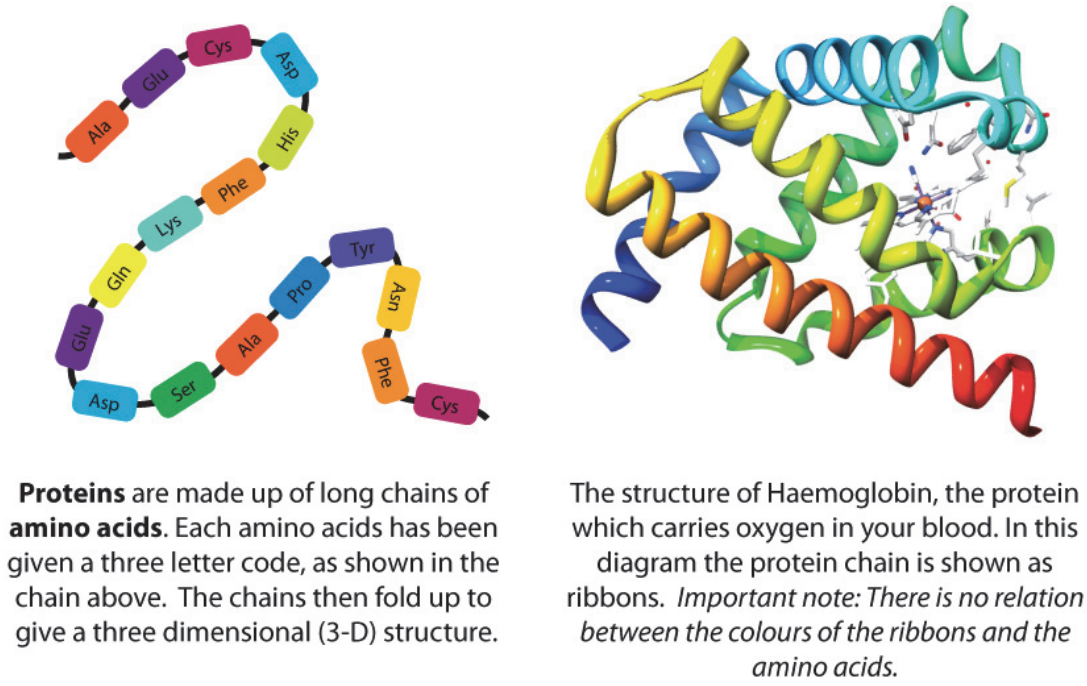


Figure 6.8 Proteins are long chains of amino acids that fold up into three dimensional shapes.

3. **Transport**: Proteins can be involved in transporting other molecules. A good example is **haemoglobin** which is found in red blood cells. Haemoglobin binds oxygen in the lungs and transports it to the tissues of the body. The structure of haemoglobin is shown in Figure 6.8. On a much smaller scale, transport proteins can be found embedded in the membrane of cells and are responsible for moving molecules into and out of cells across the cell membrane.
4. **Movement**: Proteins can allow cells to contract and move. **Actin** and **myosin** proteins in muscles are responsible for muscle contraction. **Cilia** and **flagella** found on different cell types allow for movement of the cells.
5. **Storage: Casein** is a nutrient storage protein found in milk. **Ovalbumin** is a nutrient storage protein found in egg white. But it's important to note that protein is not stored in the body for energy needs like carbohydrate or lipid. Casein and ovalbumin are really for the benefit of offspring.
6. **Defense**: Proteins are also involved in defending an organism. Animals produce **antibodies** that protect us against foreign toxins and invading **viruses** and **bacteria**. Spiders, snakes, jellyfish, blue-ringed octopus, certain bacteria and other venomous creatures produce venoms and toxins which are made of protein.

The Interesting Case of Botox

In general protein toxins can be quite dangerous and we try our best to avoid them. They can cause everything from food poisoning, tissue damage to muscle paralysis and even death. However one very dangerous **neurotoxin** (a toxin that affects the nervous system) is used by the cosmetic industry. It is produced by a bacterium called *Clostridium botulinum*. This organism causes the fatal food poisoning **botulism**. The botulinum type A toxin produced by these bacteria is one of the most toxic substances we know. It causes muscle paralysis by blocking nerve signals to muscles and can cause paralysis of the respiratory muscles leading to death. This same toxin is injected into tissues of the face to relax smooth muscles under the skin to reduce wrinkles.

6.8 Deoxyribonucleic Acid (DNA)

DNA carries all the genetic information of an organism. This information not only governs the day to day running of the cell, but is also passed on to offspring and determines all the characteristics of the organism from height to eye colour, from hair type to body shape, from biochemistry to behaviour. This genetic information is stored as a written chemical language along the DNA molecule, each section of information is referred to as a **gene**. In a way you can think of DNA as the library of the cell. **Human Genome Project** (which has sequenced the entire human genetic material or **genome**) suggests there are about 30 000 different genes in human DNA.

The structure of DNA was worked out in 1953 by Francis Crick and James Watson. The structural detail they described has become known as the Watson and Crick model of DNA structure. In this model, DNA is made up of two long unbranched chains of special molecules called **nucleotides**. Two chains twist around each other almost like a spiral staircase, as shown in Figure 6.9. This shape is called a double helix. The sides of the "staircase" are made up from ribose and phosphate and the steps are made up of four different **nucleotide bases – adenine (A), guanine (G), thymine (T) and cytosine (C)**. The nucleotide bases link up in pairs, joining the two chains together. The order of the repeating bases A, G, T and C carries the genetic code. Adenine usually binds to thymine, and guanine to cytosine.

The structure of DNA is the same in all living organisms (including viruses). The only difference is the order or sequence of bases and the amount of DNA that an organism's cells may contain. The information stored in this chemical language of bases determines what that organism will be and to an extent how it will behave. There are approximately three billion base pairs in the human genome (all the DNA in a cell).

The information in DNA is accessed continually by the cell to make protein molecules (the molecular tools of the cell). Also, the entire amount of DNA can be replicated every time a cell divides or whenever special reproductive gametes (sperm and ova) are produced. Thus sexual reproduction with the fusing of a sperm cell and ova ensures the passing on of DNA from one generation to another.

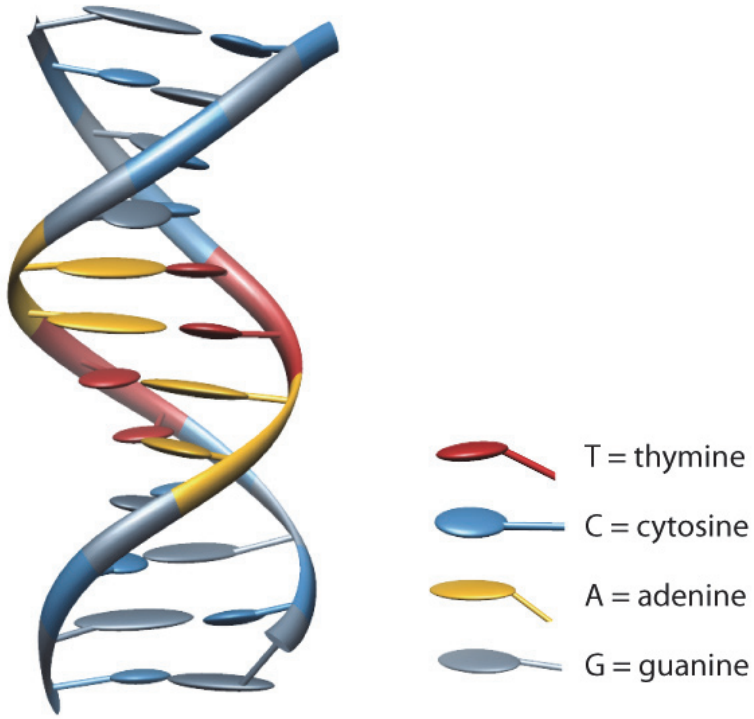


Figure 6.9 DNA is made of two chains twisted together into a double helix.

Activities

The following fun activities grow out of this chapter.

1. Make a polymer, silly putty, at home. There are many great websites with recipes.
2. Identify the polymers in your life. What polymers do you find around your home? Your clothes? In your car? If their name is listed look up their monomers and properties. For example teflon is the common name for polytetrafluoroethylene. Other plastic products have a number on them. For example you can see them on the bottom of plastic containers. Look up the type of plastic the numbers correspond to.
3. Test different foods for starch. You need iodine, water and some food samples. Put the food samples in small jars and drop in some iodine. If the sample turns dark brown or purple then starch is present.
4. Spell your name in DNA. Amino acids have a one letter code that helps us label them in long chains. Look up the one letter symbols and the genetic sequences (DNA) that code for different amino acids. Can you spell your name using the one-letter amino acid symbols? If so, can you write the genetic sequence that would code for your name? It is even possible to buy silver necklaces with words or names spelled out in amino acids.
5. Do a research project on the discovery of DNA and the scientists who worked out its structure.

Chapter 7

Living Things

7.1 Biology: The Study of Life

Biology is the study of life. What is life? To some, life is anything that has a heartbeat. Whilst many living things do have a heartbeat many, such as plants, do not! What about growth? Living things do grow but so do crystals, which are certainly not life forms. Clearly, there is no simple definition of what a life form is, instead, living things must satisfy several characteristics to be considered a life form.




Figure 7.1 Animals and plants are, without question, life forms but what does it mean to be living?

Two of the major characteristics of life are that living things are made up of cells and they are capable of reproduction. However, these are only two of at least *seven* characteristics of life that biologists recognise. For something to be classified as a living thing it must satisfy all the characteristics of life. These living things are termed **organisms** by biologists.





Figure 7.2 Each of these life forms are called organisms.

Organisms are composed of cells

Cells are the building blocks of all organisms. Some organisms are composed of only one cell, whilst others have many cells. **Unicellular organisms** are small and consist of only a single cell but **multicellular organisms** are often very large and have numerous cells. Multicellular organisms also have cell specialisation to form tissues, organs and organ systems which work together to carry out a specific function for the organism. For example, muscle tissue allows movement, the heart is an organ that pumps blood around the body, and the skeletal system is an organ system that provides structural support to the body and protection to many vital organs.

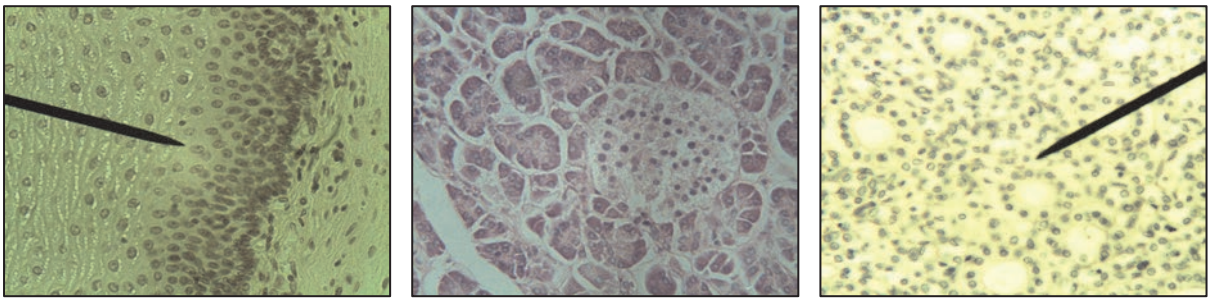


Figure 7.3 If you magnify the tissues of our body you will find that they consist of cells.

Organisms are able to reproduce

Reproduction is the process of creating new 'daughter' individuals that are similar to the 'parents'. **Sexual reproduction** requires the uniting of genetic material from two parents in an act of **fertilisation**. Many organisms produce only one type of reproductive material so they are termed male or female. These species are called **separate sex species**. Other species, termed **hermaphrodites** or bisexuals, have both male and female reproductive structures (see Figure 7.4). Even plants engage in sexual reproduction. In fact, most plants are bisexual as they have both male and female parts on the some flower. This discovery proved difficult for the Church as it was believed that God would never have created individuals that were bisexuals.



Figure 7.4 The fish on the left and the plant on the right are both bisexual species.

The genetic material of organisms is packaged in many different ways including as eggs and sperm in animals, and pollen and ovules in plants.

Asexual reproduction is useful for organisms that want to rapidly reproduce without wasting time searching for a mate. The major disadvantage of asexual reproduction is that the offspring are

genetic clones of their parent (see Figure 7.5). Therefore, if conditions become unfavourable to the parent, for example the environment gets too cold or the parent succumbs to a disease, then the offspring are also likely to be affected. In sexual reproduction, there is mixing of genetic material from two different parents to create genetically unique offspring that may survive environmental conditions that are unfavourable to their parents. Mixing of genetic information is a requirement of all life forms to survive in variable environments so most organisms will engage in sexual reproduction at some stage in their life cycle, including those that engage mostly in asexual reproduction.



Figure 7.5 We thankfully do not produce genetic clones of ourselves!

Organisms take in energy and manipulate it for their own use

Heterotrophic organisms, also known as **heterotrophs** or **consumers**, obtain their energy from food. Nutrients in the food are ingested (eaten), digested (broken down), absorbed into the body, and converted to a type of sugar called **glucose**. Glucose is transported around the body in the blood and, after reacting with oxygen in a process called **cellular respiration**, is used to create **adenosine triphosphate**, better known as **ATP**. ATP stores the energy needed by the body for movement, reproduction, growth and maintenance.

Some heterotrophs, including most animals, ingest their food before starting digestion so they are called **ingestive heterotrophs**. Other heterotrophs digest their food outside their body and then absorb the nutrients released from the food. These organisms, which include fungi and even sea stars, are called **absorptive heterotrophs** (Figure 7.6).



Figure 7.6 Giraffes are ingestive heterotrophs but a seastar and fungi are absorptive heterotrophs.

Plants capture energy from sunlight to combine carbon dioxide and water to produce glucose and oxygen.

carbon dioxide + water + *energy (sunlight)* → sugars (glucose) + oxygen

This chemical reaction is called **photosynthesis**. As plants are able to make their own food (i.e. sugars) they are called **autotrophs**, or **producers**. Algae is another example of an autotroph (Figure 7.7).

In **cellular respiration**, the opposite reaction to photosynthesis occurs where glucose is broken down in the presence of oxygen to produce carbon dioxide, water and energy (stored in ATP).

glucose + oxygen → carbon dioxide + water + *energy (stored in ATP)*

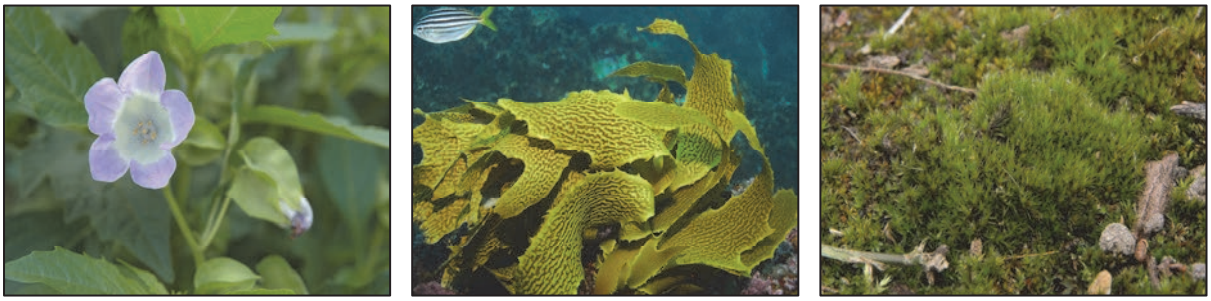


Figure 7.7 Plants, seaweeds and mosses are examples of autotrophs.

NB: Both heterotrophs and autotrophs engage in cellular respiration so even though plants produce oxygen, they also use oxygen for reproduction, growth and maintenance.

Organisms use air

Atmospheric air consists of approximately 79% nitrogen, 21% oxygen and 0.03% carbon dioxide. During photosynthesis, autotrophs use carbon dioxide to produce glucose and oxygen and, during cellular respiration, both autotrophs and heterotrophs use oxygen to break down glucose to release energy and produce carbon dioxide.

Atmospheric gases are taken into autotrophs through tiny holes in their leaves called **stomates**. Surrounding each stomate are two **guard cells** that regulate gas entry into, and water loss from, the leaf. Air breathing animals usually have special structures to take air, and the oxygen that it contains, into the body. **Lungs** are one type of structure found in animals but other structures include the skin surface and even the stomach (Figure 7.8).



Figure 7.8 Unlike chimpanzees, a land snail is able to obtain some oxygen across its skin surface.

The composition of gases in the atmosphere is relatively stable over the Earth but the amount of oxygen and carbon dioxide varies considerably in water. In the turbulent aerated waters of mountain streams the oxygen levels can be very high but in muddy sediments and stagnant water there may be no oxygen at all. This is due to heterotrophs engaging in high rates of cellular respiration, which uses oxygen, and there are no autotrophs to replenish the used oxygen. Many aquatic organisms simply diffuse gases across their body surface but others have specialised structures, such as **gills** (Figure 7.9).



Figure 7.9 Gas exchange occurs across the body surface of anemones but crabs and fish use gills.

Organisms respond to stimuli

Obvious stimuli include sounds, light, taste, smell and touch but some organisms have extrasensory abilities including the ability to hear ultrasound (frequencies >20,000 Hz) and infrasound (frequencies <20 Hz), to see ultraviolet light (wavelengths 10-400 nm) and infrared light (wavelengths 700-10000 nm), or even detect electricity or magnetism (Figure 7.10).



Figure 7.10 Bats are able to hear ultrasound and elephants are able to hear infrasound.

Even plants respond to stimuli although their responses are not as obvious as those of animals. For example, plants grow toward sunlight, grow quicker if they are eaten/cut, grow against gravity after they germinate, and the flowers of plants often follow the sun's position throughout the day. Plants also monitor day lengths, or night lengths, to determine whether it is the season to flower.

Organisms move

It is obvious that animals move, even a slow-moving snail or sea star, but even plants and fungi move when they grow or respond to light.

Organisms are able to regulate their internal environment

On a cold day, humans will shiver as a means of warming up and they will often be pale as blood is directed away from the extremities as a means of keeping the body's heat at its core where the organs are located. This is one way that we regulate our internal environment - in this instance, the regulation of our body temperature. This is termed **thermoregulation** (temperature regulation).

All organisms, whether they be unicellular or multicellular, are able to regulate their internal environment. For example, paramecia (singular: paramecium) are small unicellular organisms found in freshwater ponds. These organisms are faced with the continual problem of water rushing into their bodies so, to ensure they do not explode, they have contractile vacuoles to expel this excess water. Similarly, pelicans eat salty fish and drink salt water so they require salt glands to eliminate excess salt from their body (Figure 7.11). The salty fluid produced by the salt glands drips out of the nostrils. This is an example of **osmoregulation** (salt regulation).

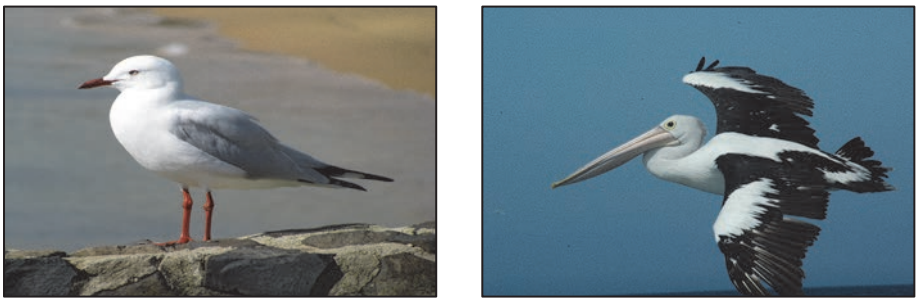


Figure 7.11 Seagulls and pelicans use salt glands to eliminate excess salt from their body.

Animals that use a lot of the energy in their food to maintain a high body temperature are called **endotherms** (internal temperature) as they are heated from within. Examples include mammals and birds. **Exotherms** (outside temperature) are animals that use external sources, such as the sun, to warm their bodies. Exotherms include reptiles and insects (Figure 7.12). Endotherms are commonly called 'warm blooded' animals and ectotherms are commonly called 'cold blooded' animals but these terms are inappropriate as on a warm day reptiles can have a body temperature far higher than many mammals.



Figure 7.12 Mammals heat themselves using their metabolism but reptiles heat up using the sun.

[Ste-8NE, ST2-10LW, ST2-11LW], {ACSSU002, ACSSU044, ASCCU073}

7.2 Cells

In the previous chapter, we looked at the macromolecules (proteins, carbohydrates and lipids) that make up living things. DNA contains the genetic information needed to not only build the macromolecules but also gives an organism its overall physical characteristics. The expression 'the whole is more than the sum of its parts' is particularly true when we think about how molecules are organised into macromolecules which are then in turn organised into cells. Cells form the basis of living things. Cells are ultimately organised into tissues, organs and organ systems producing a complete functioning organism. To traverse the path from simple chemicals to organic molecules and macromolecules all the way to a thinking, self-aware human being is an extraordinary journey.

Cell Structure

Cell theory states that all organisms are composed of cells and that these cells come from other existing cells by cell replication. Cells are the basic functioning self-replicating unit of an organism. In an adult human there are 10^{13} cells. (10^{13} is 1 followed by thirteen 0's. It is approximately 2000 times the number of *millimetres* it takes to go around the earth). Cells are generally very small. For example a human red blood cell is around 7μm in diameter. That is really small, $7x10^{-6}$ m; or 0.000007 m. Cells are so small they can only be seen with a microscope. It is no surprise then that cells were not discovered until microscopes were invented.

In 1673, Anton van Leeuwenhoek used a simple hand-held microscope with just one small ground glass lens. This crude contraption allowed him to visualise cells and even see bacteria "swimming" in droplets of water. In 1665, using a newly invented compound microscope (a microscope with several glasses lenses) Robert Hooke examined thin pieces of cork and observed the regular spaces that represented dried out cells. To Hooke these looked like the small rooms (or cells, as they were known) in monasteries where monks lived; so he coined the term 'cells'.

Today scientists use powerful versions of the compound microscope to examine the minute detail of cells. These microscopes rely on the focussing of light rays to penetrate the specimen. More powerful than these light microscopes are electron microscopes. Electron microscopes use a beam of electrons instead of a beam of light.

Cells come in many shapes and sizes. Muscle and nerve cells can be very long and thin (Figure 7.13). Cells that make up the skin and mucus membranes of the body are flattened and known as epithelial cells. Cells that make up tissues such as the liver are cuboidal. In nearly all cases, shape and function of cells are closely related.



Figure 7.13 Cells can be branched, elongated or cube-like.

Types of Cells

All cells can be divided into two classifications:

1. ***Prokaryotes***: cells that do not have a membrane "package" around their DNA, in other words they do not have a nucleus (Figure 7.14). This group includes all the bacteria and will be discussed in a later section.
2. ***Eukaryotes:*** all the other types of cells whether protist, animal, fungi or plant. The important feature is that they have a nucleus which consists of a nuclear membrane surrounding their DNA. Eukaryotes are also much larger than prokaryotes.



Figure 7.14 These spore-containing bacterial cells do not have a nucleus.

Cells Have Four Important Parts

Calls can be divided into four basic components, each with essential structural features.

1. **Plasma (cell) membrane:** All cells, whether they are eukaryotes or prokaryotes, have a membrane that separates the cell from its environment.
2. **Cytosol:** The cytosol is the fluid part of the cell. It makes up most of its volume and is the liquid that the molecules and macromolecules of the cell are dissolved in.
3. **Organelles:** The organelles of the cell are literally 'little organs'. These structures are found in the cytosol and have characteristic shapes and specialised functions. The cytosol together with the organelles are referred to as the **cytoplasm**.
4. **Inclusions:** The inclusions are the temporary secretions and storage products of the cell. Such products include glycogen (or starch in the case of a plant cell), lipids (in the case of a fat cell) or the pigment melanin (which is stored in the cells of the skin, hair and eyes).

Plasma (cell) membrane

The cell membrane surrounds the cell and separates it from other cells and the external environment. It controls what enters and leaves the cytoplasm, a little bit like a fence around a yard.

Membranes are made up of special lipid molecules called phospholipids. The heads of these molecules are 'water-loving' (hydrophilic) and point outwards, while the tails of these molecules are 'water-avoiding' (hydrophobic) and point into the membrane (see previous chapter **Figure 6.7)**. This membrane is referred to as a **phospholipid bilayer** because it is made up of two rows of phospholipids orientated in two different directions. The lipid molecules are not fixed in place but act a little bit like a sea. In this sea there are other special protein molecules that float around controlling which molecules can get into or out of the cell. These molecules are like gates in the

"fence" around the cell. They are also involved in other activities such as cell recognition and receptors for cell communication.

Cytoplasm

The cytoplasm is the contents of a cell between the nucleus and the cell membrane. The nucleus is usually (but not always) in the centre of the cell. The fluid part of the cytoplasm that contains inclusions and dissolved substances is called the **cytosol** or intracellular fluid. This fluid is mostly water with dissolved salts, proteins, carbohydrates and lipids. The cytosol is where many of the metabolic reactions of the cell take place.

Organelles in a "typical" eukaryotic cell

Organelles are permanent, specialised structures that have characteristic appearances and perform unique functions. These structures include the **nucleus**, **ribosomes**, **rough** and **smooth endoplasmic reticulum**, **Golgi apparatus**, **mitochondria**, **vacuoles** and **cytoskeleton**.

Nucleus: The nucleus is the largest organelle in the cell. It contains the DNA of the cell, which directs all the cellular activities. Whilst most cells have one nucleus, some have more than one. For example, skeletal muscle cells are very long and have many nuclei, while red blood cells have none. The nucleus has a membrane similar to the cell membrane with the DNA inside. The long DNA molecules are arranged in **chromosomes**. You can think of the chromosomes as a DNA packaging structure. Each chromosome is made up of one DNA molecule. A human has 46 chromosomes. If we lined up the DNA from all the chromosomes found in one human cell, the total length would be two metres. Since there are 10^{13} cells in an adult human, this would mean that in one person there is $2x10^{13}$ metres (or $2x10^{10}$ kilometres) of DNA. The circumference of the earth at the equator is about 40 000 km, this means that the DNA of one human would wrap around the earth 500 000 times!

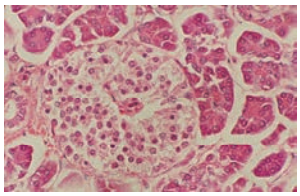


Figure 7.15 The nuclei of these pancreatic cells (stained purple) all contain DNA.

Ribosomes: The ribosome is where proteins are made. Messenger RNA (mRNA – a molecule similar to DNA, but much shorter) carries the genetic information from the nucleus to the ribosome. It then directs the construction of proteins. Ribosomes may be found floating free in the cytoplasm or attached to a membranous structure called the **endoplasmic reticulum**.

Endoplasmic Reticulum: The endoplasmic reticulum is a network of membrane-enclosed channels continuous with the nuclear membrane. There are two types. The rough endoplasmic reticulum is studded with ribosomes and is involved in the processing of proteins after synthesis. The smooth endoplasmic reticulum doesn't have ribosomes. Proteins synthesised in the rough endoplasmic reticulum may be modified in the smooth endoplasmic reticulum.

Golgi complex or Golgi apparatus: The Golgi complex is made up of 4 to 6 flattened sacs called **cisterns**. Proteins from the endoplasmic reticulum are received here and may be changed chemically before being sent to the rest of the cell or to the cell membrane for transport outside the cell.

Mitochondria: The mitochondria is the power-house of the cell. This is where chemical energy is extracted from certain molecules and converted into a form that can be used by the cell. These molecules are sometimes called **metabolites** – for example, the breakdown products of glucose and lipids. The energy molecule formed is called **ATP** (adenosine triphosphate). The mitochondria are surrounded by a membrane similar to the cell membrane. Mitochondria also have a folded inner membrane where special biochemical reactions related to energy generation take place. Interestingly, mitochondria also contain their own DNA and ribosomes, and can also replicate themselves.

Vacuoles: Vacuoles are membrane-bound bodies filled with water and dissolved substances. Vacuoles have many different functions depending on the type of cell. These functions include storing waste, maintaining the cell pressure and even controlling the pH of the cell.

Movement Structures: Some (but not all) cells have specialised structures allowing movement.

Cilia are short, stiff hair-like projections from the cell membrane. They are usually present in great numbers on the cell surface and beat in one direction only. They may allow a cell to swim along (such as a paramecium in pond water) or they may work together to move substances like mucus across their surface (such as the cells that line the windpipe).

Flagella are another movement structure found on some cells such as bacteria, protists and sperm cells. They are much longer than cilia and are found singly, in pairs or tufts. They revolve (bacteria) or undulate like snakes (sperm cells) to drive a cell forward.

The Animal Cell

All animal cells are eukaryotic. That means that they have a membrane-bound nucleus. The nucleus contains the genetic information (DNA).

Animal cells also have a cytoplasm containing a variety of organelles including ribosomes and mitochondria. Surrounding the cell is the cell membrane. Internally the structure of the cell is supported by the cytoskeleton. Unlike the plant cell, there is no strong cell wall outside the cell membrane.

The Plant Cell

Plant cells are very similar to animal cells in terms of basic structure and types of organelles. There are, however, a few very important differences. In addition to the plasma (cell) membrane, plant cells also have a rigid **cell wall** outside the cell membrane (Figure 7.17). The cell wall is made of tough fibrous cellulose (an indigestible polysaccharide of glucose molecules) that gives structural support to not only the cell but to the whole plant.

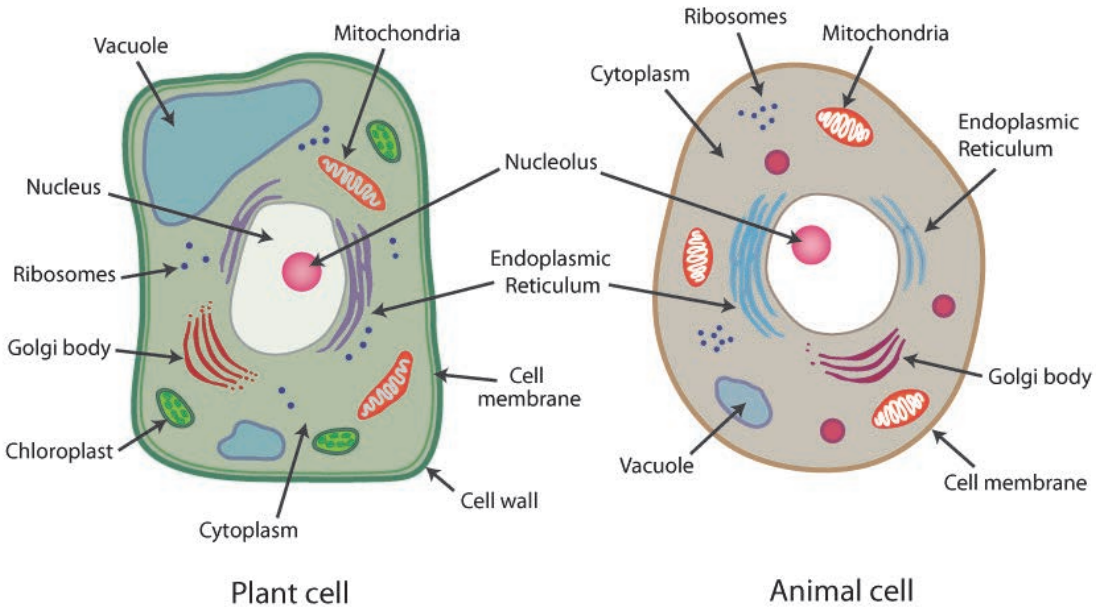


Figure 7.16 Plant and animal cells showing their organelles.

The other significant addition to plant cells is the **chloroplast**. Chloroplasts are very important to plants as they allow them to convert atmospheric carbon dioxide (CO_2) to glucose, which can then be stored as starch. This process is called **photosynthesis**. Chloroplasts are found in the cytoplasm of the plant cell and have an internal membranous structure that is packed with **chlorophyll**. Chlorophyll is green pigment that is involved in trapping light energy required for the process of photosynthesis.

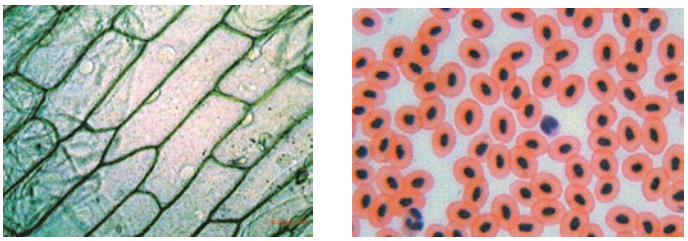


Figure 7.17 Plant cells (left) have a rigid cell wall but animal cells (right) only have a flexible cell membrane.

Diffusion and Osmosis

All cells, whether eukaryotic or prokaryotic, depend upon the diffusion of molecules into and out of their cytoplasm. This is seen when waste leaves cells or when nutrient molecules enter. Water molecules and gases like oxygen and carbon dioxide also diffuse across membranes.

Diffusion: as mentioned earlier, diffusion is the movement of molecules from an area of high concentration to low concentration until **equilibrium** is reached (the molecules are spread evenly everywhere). Molecules in liquids and gases move in random ways. In diffusion, over time molecules move through the holes in the membrane. They can move through the membrane in either direction. At first they move mainly from the area of high concentration to low concentration. That

is because there are more molecules on one side so it is more likely that a molecule on that side will move in the right direction and pass through a hole in the membrane. After a time the concentration is the same on both sides of the membrane and molecules move through the membrane in both directions. To us it seems that nothing is changing because the concentrations don't change but at the level of the particle molecules are still moving through the membrane.

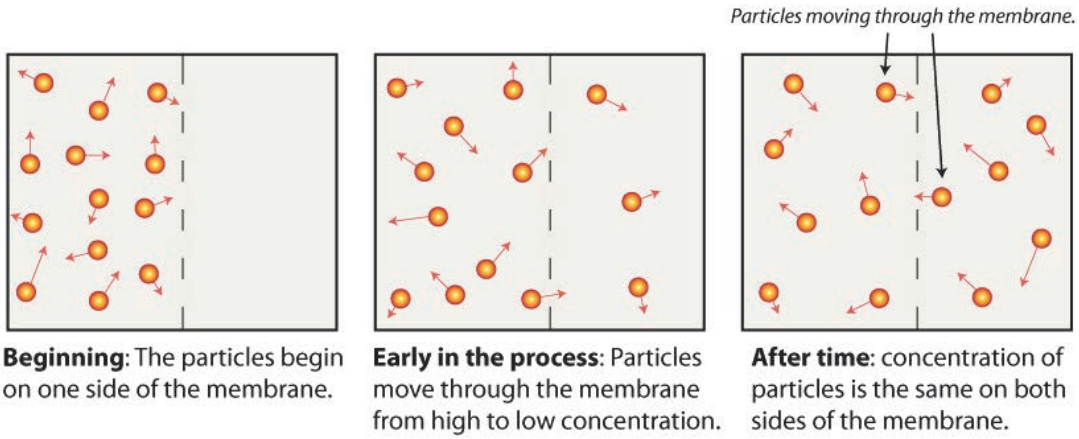


Figure 7.18 Diffusion of particles or molecules through a membrane.

Osmosis: Osmosis is a special case of diffusion. By definition, osmosis is the diffusion of water molecules across a semi-permeable membrane. In the case of the cell, the semi-permeable membrane is the cell membrane itself. It is semi-permeable because it doesn't allow all molecules to cross it. Water will move across such a membrane so as to dilute higher concentrations of solute molecules.

7.3 Classification of Life Forms

Classification is used by biologists to group organisms with similar characteristics and to separate organisms with dissimilar characteristics. Classification infiltrates into our lives every day. If you are wanting to buy a 1 kg box of Sanitarium Weet-Bix at a supermarket you would first find the cereal aisle, then the wheat biscuit section of that isle, the Sanitarium Weet-Bix boxes, and finally you would select the box of Weet-Bix of the appropriate size. Imagine trying to find something in a supermarket if the stocked items were randomly placed on the shelves anywhere in the store!

Classification and grouping of items certainly makes it easier to find what you are looking for in a supermarket. If you understand how the classification system works then it is a lot easier to find your grocery item. I'm sure we have all wandered aimlessly in a supermarket trying to find a grocery item that we are not sure to what aisle it belongs! Likewise, clothing shops, libraries etc. all group similar things together to help people find the items they are looking for. Classification is particularly important in biology because biologists have to deal with over 13 million different organisms (see Figure 7.19).



Figure 7.19 All of these organisms are classified by biologists into various groups.

Biologists use a key to make classification easier. Keys work by starting with a group of organisms and splitting this group into smaller and smaller groups until no more splitting can occur. At this stage, individual organisms are recognised. The most common type of key is a **branching dichotomous key**, which has two choices at each branch. An example of a branching dichotomous key is provided in Figure 7.20.

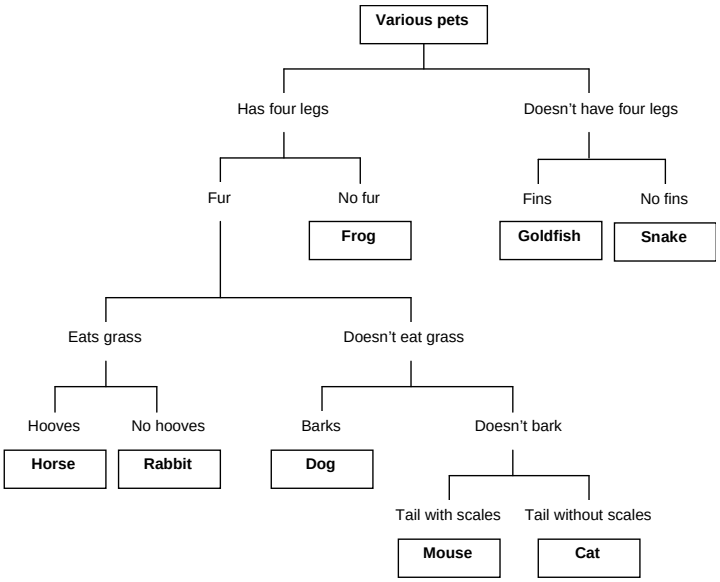


Figure 7.20 An example of a branching dichotomous key.

If you have ever played the game *Guess Who* then you will be familiar with this style of dichotomous key for classification. Another type of key is a **tabular dichotomous key** where you start from the top of the table and work your way down the table, answer questions, get directed to other parts of the table, and continue until the organism is identified. An example of a tabular dichotomous key is provided in Table 7.1.

Table 7.1 An example of a tabular dichotomous key.

1.	Has four legs	…..	go to 2
	Doesn't have four legs	…..	go to 7
2.	Has fur	…..	go to 3
	Doesn't have fur	…..	**Frog**
3.	Eats grass	…..	go to 4
	Doesn't eat grass	…..	go to 5
4.	Has hooves	…..	**Horse**
	Doesn't have hooves	…..	**Rabbit**
5.	Barks	…..	**Dog**
	Doesn't bark	…..	go to 6
6.	Tail with scales	…..	**Mouse**
	Tails without scales	…..	**Cat**
7.	Has fins	…..	**Goldfish**
	Doesn't have fins	…..	**Snake**

Tabular dichotomous keys are also known as 'GO TO' keys for obvious reasons. Those who grew up reading *Choose Your Own Adventure* books will be familiar with this type of key.

7.4 Taxonomy

Taxonomy is the process of sorting all living things with similar characteristics into groups. Clearly, a rose bush and apple tree share similar characteristics so they can be clearly distinguished as plants and, similarly, a cheetah and shark are clearly animals. Animals (Animalia) and plants (Plantae) are just two of the five main groupings, or **kingdoms**, of life forms recognised by biologists. In addition to large groupings, biologists also recognise smaller groupings such as mammals (Mammalia), dogs (Canidae), birds (Aves) etc (Figure 7.21).



Figure 7.21 Different fishes but biologists recognise the two on the left belong to the wrasse family.

All living things are first organised into broad groupings, as kingdoms, and then organised into smaller and more specific groupings called **phylum**, **class**, **order**, **family**, **genus** and **specific epithet**. This sequence is often remembered by the saying 'King Phillip Classified Ordinary Families as Generous and Special'. The further down the taxonomic hierarchy, the more similar organisms are. The highest level in the taxonomic hierarchy is the kingdom level, which includes **Animalia** and **Plantae** (Figure 7.22). The other kingdoms are **Fungi** (these were once considered plants), **Protista** (the seaweeds and unicellular organisms), and **Monera** (all the bacteria).

Higher level ↑	**KINGDOM**	Animalia	Animals
	PHYLUM	Chordata	Backboned animals
	CLASS	Mammalia	Milk producers
	ORDER	Carnivora	Meat eaters
	FAMILY	Canidae	Dogs
	GENERA	*Canis*	
Lower level	**SPECIFIC EPITHET**	*familiaris*	Species



Figure 7.22 Three of the five kingdoms of life – Animalia, Plantae and Fungi.

A **genus** is a group of organisms that share many features in common. An example of a genus is *Canis* which includes wolves, coyotes, jackals, dingos and domestic dogs – all of which are clearly dog-like. Other examples include the genus *Rattus*, which includes black rats and brown rats of Europe, and native bush rats in Australia, and *Panthera*, which includes the lion, tiger, leopard and jaguar.

The most definable group in the classification scheme is a **species**. A species is a unique type of life form. Individuals belonging to the some species are able to mate with each other and produce fertile offspring. All species are given a unique, two-part scientific name that is shared with no other species. This name is composed of the genus to which the organism belongs followed by the specific epithet. Examples of scientific names include:

Homo sapiens	(modern humans)
Eucalyptus robusta	(swamp mahogany)
Canis familiaris	(domestic dog)
Austrocochlea concamerata	(zebra periwinkle)

There are several **rules** that need to be followed when names are assigned to species. These rules are:

- The genus is always capitalised.
- The specific epithet is never capitalised.
- The two-part species name is always italicised or, if handwritten, it must be underlined.
- The name is always Latinised.

Whilst the names of organisms may seem very hard to pronounce and confusing, after you have become familiar with some Latin names it is a lot easier to understand how the names of many organisms are derived. Some interesting examples are shown in Table 7.2.

Table 7.2 Latin species names often make more sense when you know what they mean.

Common name	Scientific name	Meaning
Red Kangaroo	*Macropus rufus*	*Red big foot*
Eastern Grey Kangaroo	*Macropus giganteus*	*Giant big foot*
Cat	*Felis catus*	*Cat cat*
Platypus	*Ornithorhynchus anatinus*	*Duck-like bird-nose*
Echidna	*Tachyglossus aculeatus*	*Sticky-tongue sharp point*
Tiger	*Panthera tigris*	*Cat tiger*
Llama	*Llama glama*	*Llama ????*
Hippopotamus	*Hippopotamus amphibius*	*Land and water river horse*
Black rat	*Rattus rattus*	*Rat rat*
Brown antechinus	*Antechinus stuartii*	*Stuart's hedgehog*

7.5 Animals

When asked to name different types of living things most people will list various animals as these are the most familiar of living things – humans and pets are of cause animals. When asked to list different types of animals, people will also focus on the approximately 5400 species of mammals and forget about the millions of other types of animals Figure 7.23).

Although people are familiar with animals they often find it hard to actually define the characteristics of an animal. In fact, I find myself continually informing people that animals are not just elephants, frogs, snakes and cats, but that fish, insects, worms, jellyfish, sea stars and even sea sponges are also animals. So what are animals? Some of the characteristics of animals include:

- They are heterotrophic.
- They are multicellular.
- They are capable of locomotion at some stage in their life cycle.



Figure 7.23 Frogs, snails and moths are all types of animals.

Broadly speaking, animals are divided into two major groups – vertebrates and invertebrates – based on whether they have a spinal cord enclosed in a bony structure known as a spine or **vertebral column**.

The Vertebrates

The **vertebrates**, which belong to the phylum **Chordata**, are the most familiar of the animals. There are six major classes of vertebrates.

Mammals

The only real unifying feature of all mammals (class **Mammalia**) is they feed their young milk but most also have hair, are endotherms and give birth to live young. Mammals are split into three major groups based largely on their mode of reproduction. In monotremes, which include echidnas and the platypus, eggs are laid then the hatchling emerges after a few days. The young feed on milk that oozes from the skin surface in the mother's pouch. In marsupials, the young are born at a very undeveloped stage. The young move to a pouch where they are nourished by the mother's milk provided by a teat. Placental mammals give birth to a more developed young after a relatively long gestation period. The young feed on the mother's milk but the teats or nipples are not contained within a pouch. Australian and New Guinea are the only places on Earth where all three groups of mammals are native.

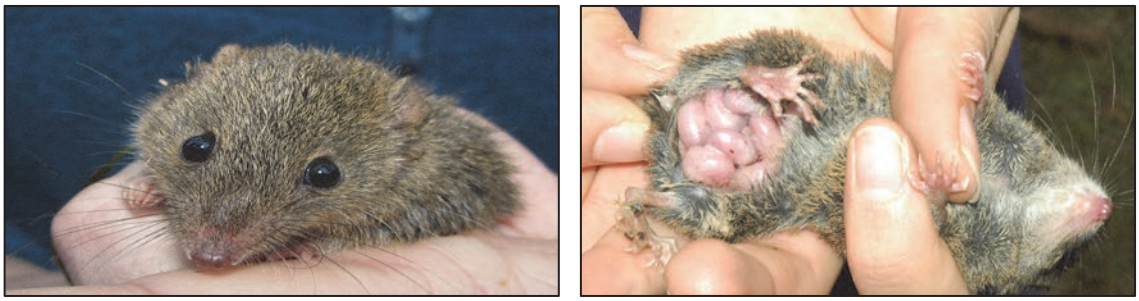


Figure 7.24 This may look like a mouse but it is a marsupial mouse complete with babies in a pouch!

Birds

Birds (class **Aves**) are endothermic animals that have feathers and wings but not all are able to fly (e.g. emus, kiwis, ostriches, penguins). Birds lay hard-shelled eggs which hatch after a relatively long incubation period. The legs of birds are not covered in feathers but, unusually, are covered in scales.

Reptiles

Reptiles (class **Reptilia**) are ectothermic animals with dry scales and soft, leathery eggs. Reptiles are represented by turtles, snakes, lizards and crocodiles with many species being deadly to humans Figure 7.25). Being ectotherms, reptiles are most active on warm days or are restricted to warm climates.



Figure 7.25 Crocodiles and lizards are both reptiles.

Amphibians

Amphibians (class **Amphibia**) have two stages to their lives with a complete body transformation, called **metamorphosis**, occurring between the stages. In frogs and toads, the first stage begins as a legless tadpole which uses gills to breathe underwater, followed by a four-legged, hopping individual which uses its lungs and skin to breath in air. A frog will drown if held underwater!

All amphibians must keep their skin wet so most remain near water bodies such as lakes and ponds. Their eggs are also easily dried out so most species place their eggs in water.

Bony fishes

All fishes are ectotherms that have fins and use gills for breathing underwater. The bony fishes (class **Actinoterygii**) are those fishes with a skeleton composed of bone and have scales over their body. If you have ever found the hard skeleton of a fish on the beach then it would be from a bony fish. Most fish including goldfish, leatherjackets, clownfish, barramundi, groupers, bream, snapper etc. are bony fishes (Figure 7.26). Bony fishes have external fertilisation and produce soft eggs like amphibians, although a few species have live births.

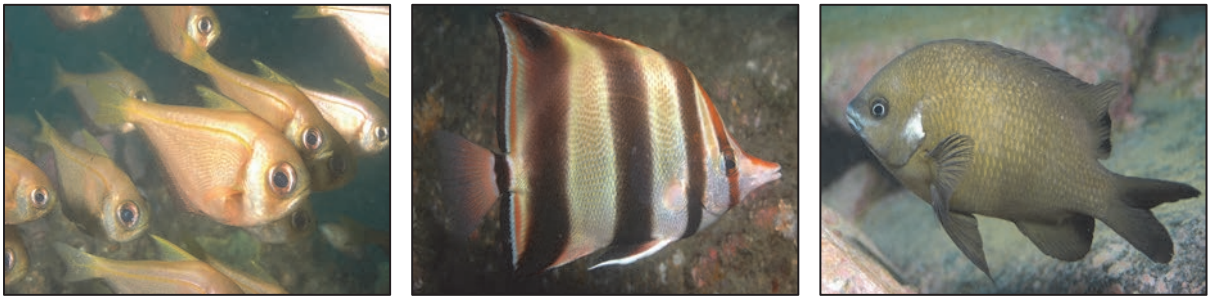


Figure 7.26 Bony fishes come in all shapes, colours and sizes.

Cartilaginous fishes

Cartilaginous fishes (class **Chondrichthyes**), which includes sharks and rays, have a skeleton composed of cartilage (Figure 7.27). Cartilaginous fishes have internal fertilisation and can produce eggs or have live births. The skeleton of cartilaginous fishes do not preserve well so is very hard to find shark or ray skeletons. Unique to cartilaginous fishes is a skin covered not by scales but by small tooth-like structures called **denticles**. The denticles are very hard and make the skin of sharks and rays feel like sandpaper. Many swimmers have thought they have been attacked by a shark but their skin has only been grazed by the shark's skin!

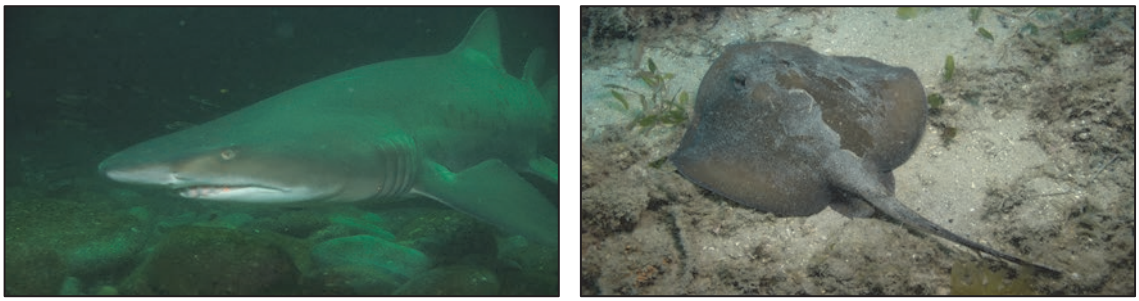


Figure 7.27 Sharks and rays have a skeleton made of cartilage, not bone like other fishes.

NOTE: This is a good place to clear up a long-held misconception that *fishes* is not a word. *Fish* is a generic term for lots of individual fish, whether they are of the same or different species. The term *fishes* is used to describe several different species of fish. For example, if you were talking about clownfishes, groupers, eels, barracouta etc. you would be talking about fishes.

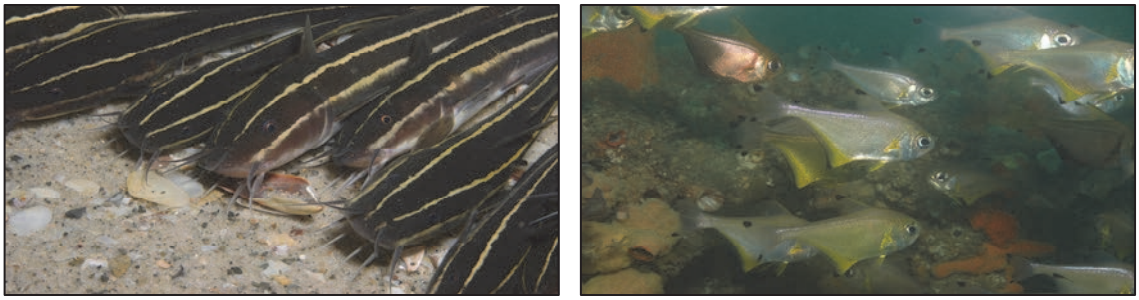


Figure 7.28 The picture on the left shows many fish as they are all the same species but the one on the right shows many fishes as there are several species.

Invertebrates

The vast majority of animals on Earth do not have a backbone so they are called **invertebrates**. The invertebrates are represented by many different phyla and, within each phyla, many different classes. The phylum with the most number of species – about 75% of all animal species - is Arthropoda, which includes the insects, but other common phyla include Mollusca (e.g. snails), Annelida (e.g. earthworms) and Echinodermata (e.g. sea stars).

Arthropods (phylum Arthropoda)

Arthropods are found in the air, in the oceans, in ponds, on land, in trees and in the soil. They have a segmented body plan with paired, jointed legs and an outer body covering called an **exoskeleton**. There are five main classes of arthropods – **insects**, **arachnids**, **crustaceans**, **centipedes** and **millipedes**.

Insects

- One pair of antennae
- Body has three sections – head, thorax and abdomen
- Three pairs of legs
- e.g. fly, beetle, butterfly, grasshopper

Arachnids
- No antennae
- Body has two sections – cephalothorax and abdomen
- Four pairs of legs
- No jaws
- e.g. spider, scorpion, tick, mite

Crustaceans
- Two pair of antennae
- Body has several sections – cephalothorax and several abdominal sections
- e.g. crab, shrimp, lobster, barnacle

Centipedes
- One pair of antennae
- Body has many sections
- Flattened body
- One pair of legs per body segment

Millipedes
- Two pair of antennae
- Body has many sections
- Rounded body
- Two pair of legs per body segment





Figure 7.29 Arachnids, insects and crustaceans are all examples of arthropods.

Molluscs (phylum Mollusca)

Molluscs are soft-bodied, unsegmented animals that often possess a shell into which they are able to retreat. Most have a muscular foot that they use for movement and a body mass which sits above the foot. There are four main classes of molluscs – **gastropods**, **bivalves**, **cephalopods** and **chitons** (Figure 7.30).

Gastropods
- Marine, freshwater and terrestrial
- Single twisted shell (if present)
- Eye stalks
- e.g. snail, slug, limpet, periwinkle

Bivalves
- Marine or freshwater
- Two hinged shells
- Foot used for burrowing
- e.g. clam, scallop, oyster, mussel

Cephalopods
- Marine
- Tentacles with suckers rather than a muscular foot
- No external shell but some have an internal shell
- e.g. octopus, squid, cuttlefish

Chitons
- Marine
- Covered in eight protective plates



Figure 7.30 Cuttlefish, oysters, snails and chitons are all examples of molluscs.

Cnidarians (phylum Cnidaria)

Cnidarians have a sac-like body with tentacles that are armed with stinging cells. These tentacles are used to capture their prey from the watery environment in which they live. Cnidarians have a free-living medusa form where their tentacles and mouth face downward (e.g. jellyfish) or a stationary polyp form where the tentacles and mouth face upward (e.g. coral polyps, anemones, hydra) (Figure 7.31).



Figure 7.31 Anemones and jellyfish are examples of cnidarians.

The coral reef structures created by coral polyps are the largest structures created by organisms and the only ones, other than those created by humans, that can be seen from space. Some cnidarians, such as the box jellyfish, are among the most dangerous animals on Earth.

Segmented worms (phylum Annelida)

Annelids are worms with notable repeating body segments – for this reason they are called **segmented worms**. Segmented worms are found in the oceans, in fresh water and on land. Examples include leeches, earthworms and beachworms. Some, such as leeches, feed on blood and have suckers on both ends of their body whilst others, such as beachworms, are active predators with strong jaws that can cause a painful bite if incorrectly handled.

Flatworms (phylum Platyhelminthes)

Flatworms are unsegmented worms that have a flattened body. Some are free-living (e.g. planarians, Spanish dancers) with many of the marine species being wonderfully colourful. Other flatworms are internal parasites. These parasites include flukes and tapeworms.

Roundworms (phylum Nematoda)

Like flatworms, **roundworms** are also unsegmented and can be internal parasites but they have a tubular body shape that is tapered at both ends. Roundworms are also found in their millions in soil, sand and mud where they play an important role in the environment by decomposing dead matter such as leaves and wood of plants, and the dead bodies and waste of animals.

Sponges (Phylum Porifera)

Sponges are also known as **poriferans** as they have numerous pores which are used to draw water, including the oxygen and food it contains, throughout their body (Figure 7.32). Sponges are the simplest of all animals but they do possess all of the characteristics needed to be classified as animals. Sponges are common on any hard structure in the marine environment, whether it be a rock or pylon, if algae does not cover the surface.

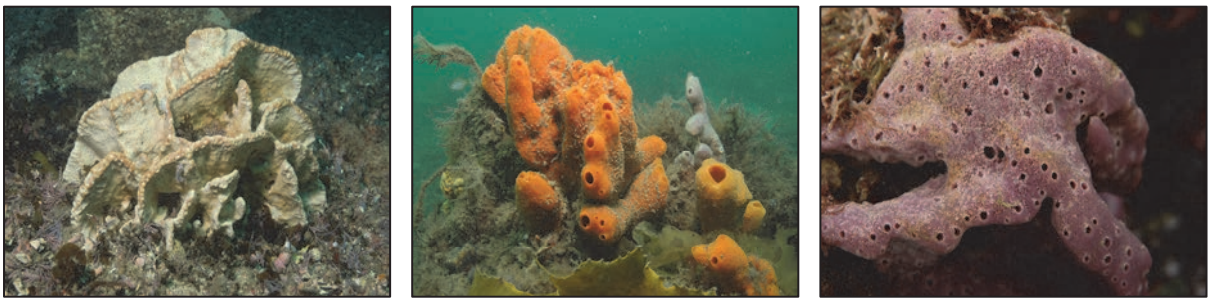


Figure 7.32 Sponges are very simple animals.

Echinoderms (phylum Echinodermata)

Echinoderms are spiny-skinned marine animals with tiny tube-feet that are used for movement. Echinoderms have radial symmetry where their body is arranged in a circular body plan with the organs in the centre and the arms and spines projecting outward. Examples of echinoderms include **sea stars**, **sea urchins** and **brittlestars** (Figure 7.33).

Sea stars
- Flattened star-shaped body
- Arms do not move
- Tube feet used for movement

Sea urchins
- Round body shape

Brittlestars

- Spines extend from the body
- Tube feet and spines used for movement
- Flattened star-shaped body
- Arms extend from a central disc
- Arms used for movement



Figure 7.33 Sea stars, sea urchins and brittlestars are all spiny-skinned echinoderms.

There are few places where each of the phyla and classes outlined above are easily observed. The best place to see them is on an intertidal rocky shore as this is a favoured habitat of many of these organisms and it is very easy to see them as they are attached to the rock surface (Figure 7.34). It is for this reason that rocky shores are great places to visit to show the diversity of animals to students. However, always remember that rocky shores can be dangerous places so take all safety precautions seriously and never undertake a rocky shore walk if there is a risk of wave inundation.



Figure 7.34 Rocky shores are wonderful places to see animal life but be very careful.

7.6 Plants

Plants are multicellular organisms that engage in photosynthesis to convert carbon dioxide and water into sugars and oxygen. These sugars are stored in the plant and used to provide the energy for plant growth. The tissues of plants provide food to other organisms to power their energy demands. The oxygen that plants produce is used by themselves and other organisms for cellular respiration (i.e. the breakdown of glucose to produce energy).



Figure 7.35 Plants make their own food much of which is eaten by other organisms.

The kingdom **Plantae** is split into two main groups – vascular plants and the nonvascular plants known as bryophytes. **Vascular plants** have specialised, cylindrical structures that transport water and nutrients around the plant. These transporting structures are either **xylem**, which carries water and its dissolved minerals from the roots to the leaves, or **phloem** which carries foods such as sugars from the leaves to other parts of the plant. When a plant is ringbarked, its vascular tissues are removed and the transport of water and nutrients cannot occur resulting in the death of the plant.

There are three main types of vascular plants (flowering plants, cone-bearing plants and ferns) and one main type of nonvascular plant (bryophytes).

Flowering plants (Angiosperms)

Flowering plants, or angiosperms, produce flowers ranging from large, brightly coloured blooms (e.g. tulips, roses, banksias, sunflowers, dandelions) to small, dull-looking flowers (e.g. those of grasses and seagrasses) (Figure 7.36). Flowers use their **petals** to attract pollinators, such as insects and bats, to a source of sugary nectar and, as a payment for the snack, the plant dusts the pollinator with small, sticky **pollen grains**. These pollen grains carry the male 'sperm' of the plant. Pollen grains are produced from the male structures of plants called **anthers**. Anthers are at the top of a stalk with the anther and stalk collectively called a **stamen** or the male parts of the flower.



Figure 7.36 Flowers are often very colourful but those of the grasses on the right are not.

When the pollinator visits another flower the pollen grains stick to the female **stigma** which is an aerial structure supported by a long **style** and an **ovary** at its base which contains the **ovules** (i.e. eggs). The stigma, style and ovary are collectively called the **carpel**, or the female parts of the flower.

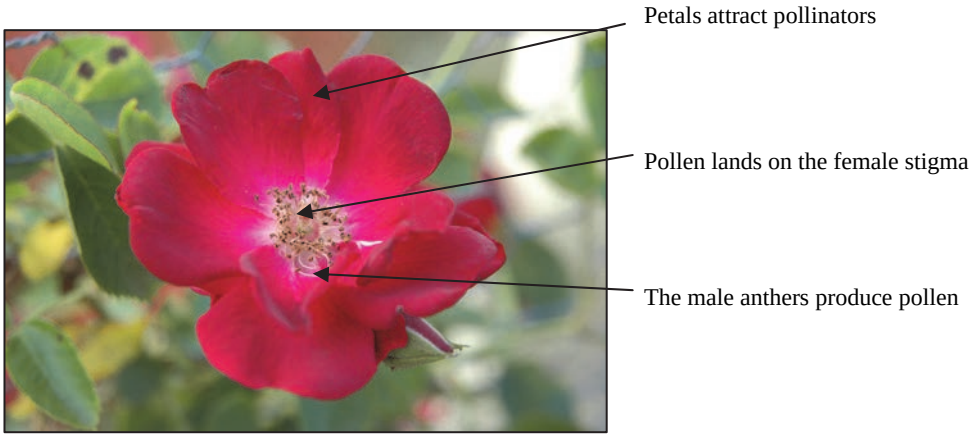


Figure 7.37 Flowers are the reproductive organs of angiosperms.

The pollen grain germinates on the stigma to produce a **pollen tube** which digests its way through the style to the ovules. The male sperm travel down the pollen tube to fertilise the ovules.

After fertilisation, the ovules form **seeds**, which are tiny embryonic plants surrounded by nutritional tissue and packaged in a protective seed coating. The ovary of the flower swells around the seeds to become a fruit. The flesh of apples, bananas, oranges, nectarines, watermelons etc. is formed from the flower's swollen ovary (Figure 7.38). The purpose of this fruit is to attract an animal to feed on it and transport the seeds it contains away from the parent plant. As the seeds are contained within a fruit, the angiosperms are also known as *plants with enclosed seeds*.



Figure 7.38 Flowering plants produce seed-containing fruits to disperse their offspring.

Cone-bearing plants (Gymnosperms)

Cone-bearing plants, known also as conifers or gymnosperm, are nonflowering plants that produce male and female **cone**s rather than flowers. The male cones are smaller than the female cones and produce pollen seasonally (Figure 7.39). We don't often recognise the male cones as they are produced for only a few months and are often higher in the trees. Pollen is released from the male cones and this pollen drifts in the wind to land on the scale-like bracts of the female cones. Like angiosperms, a pollen tube is formed after the pollen grain germinates and the male sperm travels down this tube to fertilise the ovules. The formation of the pollen tube can take over nine months so female cones are present on the plant all year.



Figure 7.39 Pollen-producing male cones (left) are a lot smaller than the seed-producing female cones.

After fertilisation, a seed is formed but this seed is not surrounded by a fleshy fruit. Instead, the seed rests on the bract and, if not eaten by an animal, it drops to the ground after the cone opens to then germinate into a new individual. As the seeds are not contained within a fleshy fruit, the gymnosperms are often referred to as *naked seed-bearing plants*.

Ferns

Ferns have a complex life cycle that does not involve the production of seeds for dispersal away from the parent plant but, instead, the production of microscopic, light-weight spores. **Spores** are released from spore cases that grow on fern fronds (Figure 7.40). These spores are transported away from the parent plant by the wind and germinate into a heart-shaped, leafy structure which remains in the soil. This microscopic structure produces eggs or sperm, or both. Within the soil the sperm swim to the eggs for fertilisation to occur.



Figure 7.40 Spores are produced from numerous brown cases on the underside of the fronds.

After fertilisation, a young fern plant emerges from the soil. This fern will then produce spores to repeat the cycle. As ferns do not produce seeds at any stage in their life cycle, they are often referred to as seedless vascular plants.

Bryophytes

The other major group of plants are the **bryophytes** or nonvascular plants. These plants, which include mosses and liverworts, have life cycles very similar to ferns where **spores** are produced instead of seeds for transport away from the parent plant. As bryophytes do not have the ability to transport water and nutrients they are restricted to being short plant forms that must live in damp areas where water and nutrients can easily be transported by diffusion (Figure 7.41).



Figure 7.41 Mosses do not have transporting tissues so they are small and must live where it is damp.

Moss illustrates the typical life cycle of a bryophyte. The green, leafy moss found on the ground in damp areas has male and female structures located on the top of the aerial leafy projections. Sperm swim from the male structures to the female structures. After the egg is fertilised, a thin stalk grows upward. Spores are produced in, and released from, a capsule at the top of this stalk (Figure 7.42). These spores drift in the air to germinate into another moss plant in soil away from the parent plant.



Figure 7.42 Mosses produce spores from aerial capsules at the top of stalks.

7.7 Fungi

Fungi, which includes mushrooms, toadstools and moulds, were once considered plants but they are clearly not plants as they are not capable of photosynthesis and so cannot produce their own food (Figure 7.43). They may also exist in the form of microscopic single cells as in the case of yeasts. All fungi are eukaryotic organisms.

Rather than photosynthesising, fungi release digestive enzymes over rotting vegetation and then **absorb** the nutrients – they are absorptive heterotrophs. By decomposing the wastes and bodies of dead organisms, fungi play an important role in recycling nutrients in the environment.

Some fungi are the cause of infections in humans, such as tinea, ringworm and thrush.

Yeasts are very important to the food industry. Baker's yeast is an important fungus and there are large industrial process producing these types of yeasts for this market. Moulds are used to produce certain foods such as soy sauce and certain cheese.

Bacteria-killing antibiotics are derived from a type of mould (eg. penicillin).



Figure 7.43 Mushrooms, toadstools and puff balls are all examples of fungi.

Fungi are similar to animals in that they are heterotrophs and similar to ferns and mosses in that they disperse using spores. The spores of fungi are around us everywhere. If these spores settle in a favourable spot (e.g. a piece of bread or other food), they germinate and form multicellular strands called **hyphae** that make up a cobweb-like mesh called a **mycelium**. The fuzzy mould found on food or damp walls is the mycelium of fungi. The mycelium spreads throughout food and absorbs the nutrients. The mycelium of mushrooms and toadstools is hidden within soil so they are not noticed unless you go out looking for them.

Two mycelia unite beneath the soil to form a specialised fruiting body which protrudes above the soil. These aerial **fruiting bodies** are the mushrooms and toadstools we are most familiar with when we think of fungi. The fruiting bodies of mushrooms and toadstools produce spores on the **gills**, which are found on the underside of the **cap**, but in bread moulds the spores are produced in round capsules (Figure 7.44). The purpose of the aerial fruiting body is evident – the spores would not easily disperse if released within the soil but they are easily carried away by the wind from an aerial structure.

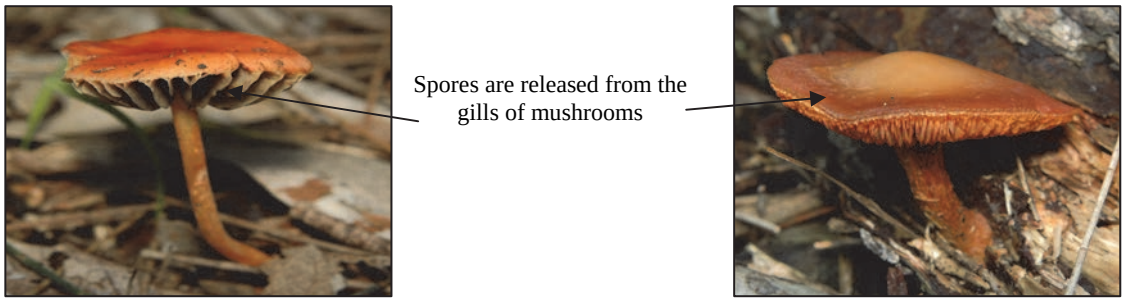


Figure 7.44 Spores are very light so they easily float in the wind.

7.8 Protists

The kingdom **Protista** is a mixed-bag of organisms that do not fit easily into the other kingdoms of life. Most protists are single-celled organisms but many, including seaweeds, are multicellular. Protists are called **algae**, or ‘plant-like’ protists, if they are able to photosynthesise to produce their own food, and they are called **protozoans**, or ‘animal-like’ protists, if they are unable to photosynthesise. Another group are similar to fungi so they are called ‘mould-like’ protists.

Protists are found in almost all environments including the oceans, lakes and ponds, soils and even within the bodies of animals. Some play a very important role in the environment by producing oxygen and being food for other organisms, whilst others cause diseases such as malaria and African sleeping sickness.

Algae ("plant-like" protists)

The 'plant-like' protists can be classified as either red algae, brown algae or green algae. Red algae and brown algae are multicellular organisms found on rocky shores in the marine environment so they are commonly called **seaweeds**. Some multicellular green algae are also called seaweeds as they too are found on rocky shores in the marine environment (Figure 7.45). Other multicellular green algae are found in freshwater, such as spirogyra or pond slime.



Figure 7.45 Brown, green and red seaweeds are all examples of algae.

The majority of green algae are unicellular and are capable of movement. Examples include **dinoflagellates** and **diatoms** which produce an outer casing and are important algae in marine waters. These protists are microscopic but if you have ever been to the beach at night and seen the waves glowing then you have witnessed the bioluminescence (i.e. light) produced by millions and millions of dinoflagellates.

Another common, unicellular green algae are **euglena** which are found in freshwater ponds. Euglena are quite unique in that they photosynthesise like plants if they are in sunlight but they feed like animals if they are in the dark. Euglena are therefore mixotrophs. In addition they posses a flagellum, allowing them to move.

Some algae will overgrow streams or lakes resulting in an algal bloom that can contribute toxins to the water. When algal blooms die and decompose, oxygen is removed from the water leading to the death of fish and other marine life. Such events can have significant consequences for the health of effected waterways.

Protozoa ("animal-like" protists)

Protozoans are all unicellular and are capable of movement. They ingest particulate food by phagocytosis. They may posses either flagella or cilia for movement. **Paramecium** move rapidly by beating the cilia that surrounds their body. Paramecium move so fast that they are called the "cheetahs of the protist world" as under a microscope they pass very quickly in and out of view. Because of this, if you are wanting to view them in detail they need to be slowed with a thick, viscous solution.

Other protozoans move more slowly by bending and flexing. The protozoans that do this are often internal parasites such as those that infect the blood and cause malaria and African sleeping sickness.

Amoebas are protozoans that creep around by flowing their inner fluids in different directions producing temporary pseudopodia ("false foot") and continually change shape. Some amoeba-like protozoans produce a shell casing similar to the diatoms and dinoflagellates. Examples include **radiolarians** and **foraminiferans**. These protozoans have spine-like projections from their shell casings which they use to capture food. The shells of radiolarians and foraminiferans are often beautifully patterned. Cryptosporidium and Giardia are protists that can cause vomiting and diarrhoea. They are found in contaminated water courses and are one of the main reasons why all water from rivers and streams should be boiled or otherwise treated before drinking.

"Mould-like" protists

The mould-like protists are similar to fungi in that they release digestive enzymes over food and then absorb the nutrients. Most people are not familiar with the mould-like protists but if you have ever seen a white, cobweb-like fuzz around a dead fish in a fish tank then you have seen a mould-like protist - in this instance, a water mould.

Another mould-like protist is slime mould which is a bright yellow, jelly-like mass found on rotting vegetation. Although slime moulds do not appear to move, if they are viewed under a microscope, it can be seen that their inner substances are continually flowing.

[St1-10LW, St2-10LW], {ACSSU017, ACSSU044, ACSSU072}

7.9 Monera

This kingdom consists of ***prokaryotes*** – unicellular organisms that lack a nuclear membrane. Bacteria are limited to a very small size by the very short distance over which molecules can diffuse in and out of these cells. Bacteria have a cell wall (very different to the cell wall of plant cells) to maintain shape and offer some protection from the environment. The bacterial cell wall surrounds the cell membrane and this cell membrane is very similar to that found in eukaryotes (this is the greatest similarity between prokaryotes and eukaryotes). Further, they do not contain organelles as eukaryotic cells do. However they do contain ribosomes for protein synthesis and some inclusion bodies for storage of materials. They come in only a few basic shapes: **cocci** (singular – **coccus**) are spherical, **bacilli** (singular **bacillus**) are rod shaped, and **spirilla** are rods that are twisted into spirals. Sometimes cocci and bacilli may grow in short chains. Some bacteria, particularly the bacilli, have **flagella** that can be rotated very quickly to propel the bacteria through its watery environment. Bacteria may have only one flagellum or many flagella, either at the ends of the bacterial cell, or all over it.

Some bacteria are photoautotrophs i.e. they can produce food from light. Some have the ability to fix nitrogen from the atmosphere making it available to the roots of plants. Others play an important role in the decomposition of dead organisms.

Monera are found in an extraordinary range of places and can be isolated from deep ocean trenches, the upper atmosphere, volcanic pools and the human body. Some can exist in extremely hostile environments such as hot sulphur springs and extremely salty water. While many cause disease,

most are beneficial to other organisms. In the human body, about 90% of the cells associated with our bodies are bacteria; this means we are only about 10% human by cell number (bacterial cells are so small compared to our cells we normally don't notice them). Most of the bacterial cells associated with the human body live on the skin and mucous membranes associated with the mouth, nose, upper respiratory system, gastrointestinal tract and vagina. The large intestine contains most of the bacterial cells associated with our bodies and they are important in producing vitamins and processing undigested foods. The bacteria that grow on and in us are referred to as the normal **microbiota** of the body and are necessary to help us maintain our health.



Figure 7.46 The mouth provides an excellent environment for the growth of many types of bacteria.

7.10 Microbiology

Introduction

Microbiology is the study of organisms that are too small to be seen with the naked eye. These organisms are collectively known as microorganisms. In general terms objects smaller than 1 mm are not clearly distinguishable without some form of magnification and the microscope is a fundamental tool used by the microbiologist. Microorganisms include four distinct groups all having unique characteristics: **bacteria**, **fungi**, **protists** and **viruses**.

Microorganisms are found throughout the environment and we ourselves carry enormous numbers of bacteria in and on our bodies. Microorganisms are important medically as they can cause infectious diseases and have to be carefully controlled in hospital environments. Microorganisms are of considerable concern to the food industry. They easily find their way into the foods we eat and may cause food poisoning. Interestingly, microorganisms are also important to the food industry for other reasons. Certain microorganisms may modify foods and we depend upon them to produce foods such as bread, certain cheeses and other fermented products and beverages such as sauerkraut, beer and wines. Microorganisms are an integral part of the environment as they are responsible for cycling organic molecules through the environment by breaking down the bodies of organisms after they have died. We also depend on microorganisms for the treatment of sewerage and waste water.



Figure 7.47 Yeast cause bread to rise and mould gives blue-vein chees much of its flavour.

Size Range of Microorganisms recognised by Microbiologists

While we have mentioned that microorganisms require a microscope to see them, this is not always the case. Many microorganisms exist as single cells (unicellular) that are much smaller than animal and plant cells. However some microorganisms exist as multicellular complexes that can form quite specialised structures.

The smallest of the microorganisms are viruses which do not have a cellular structure and cannot be seen using a light microscope. An electron microscope is required to view them. See Table 7.1 for sizes of the other microorganisms.

Table 7.1 Microorganism size ranges.

Microorganism	***Size units***	***Size range***	***Seen by***
Viruses	nanometres (10^{-9} m)	40 – 100 nm	Electron microscope
Bacteria	micrometres (10^{-6} m)	1 – 4 m	Light microscope
Protozoa	micrometres (10^{-6} m)	200 – 400 m	Light microscope
Algae (single cell)	micrometres (10^{-6} m)	a few m	Light microscope
Algae (multicellular)	metres	up to 50 m	Naked eye
Fungi	Centimetres (10^{-2} m)	1 – 10 cm	Naked eye

Viruses

There has been much debate about whether viruses are living organisms or not. They do not have a cell-like structure. They are very simple consisting of a protein coat called the capsid that encloses the viral nucleic acid (either DNA or RNA). They can only replicate inside the host cell they infect. They take over the molecular machinery of the host cell in order to replicate their nucleic acid and assemble more protein coats before lysing the host cell and leaving. As they cannot self-replicate without being inside another cell, there is a dilemma as to whether viruses are living or non-living. They do not have the molecular machinery to replicate on their own, which is an important characteristic of living organisms.

Some viruses are a little more complex in structure and have a membrane around the capsid. These are called the enveloped viruses. The envelope looks like a typical cell membrane consisting of a phospholipid bilayer. The virus does not make this membrane but instead wraps itself in part of the membrane of the host cell it has just destroyed. Good examples of enveloped viruses are the human

influenza virus and HIV (human immunodeficiency virus) that causes AIDS (acquired human immunodeficiency syndrome).

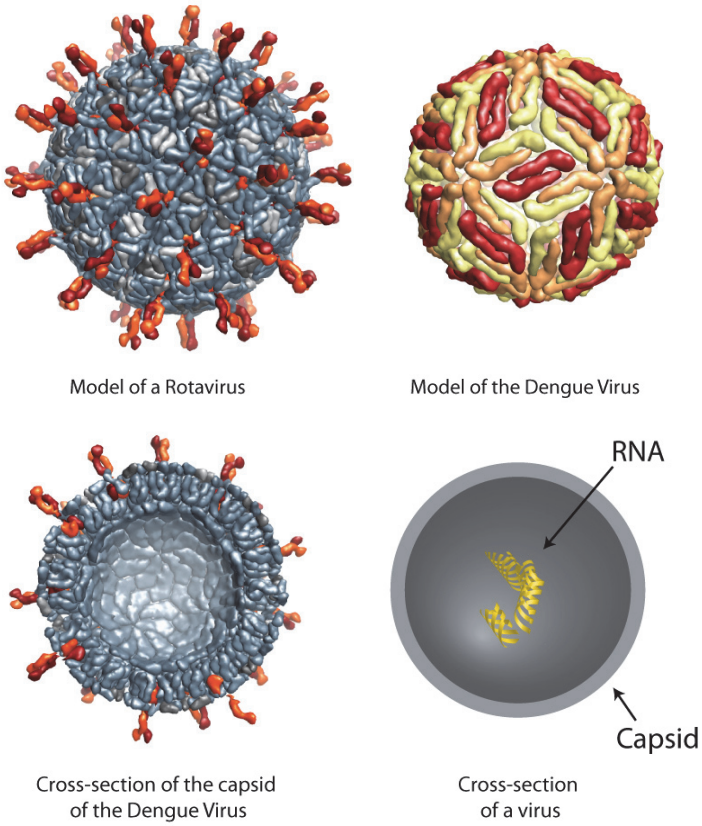


Figure 7.48 Models of virus capsids, the protein coat surrounding nucleic acid.

Viruses may cause diseases in either animals or plants. They are highly specific for both the species they infect and also the exact cell type they then target in the host. For example, flu viruses are species specific; there are human flu viruses, bird flu viruses, cat flu viruses, etc. However flu viruses always target cells that line the upper respiratory passages and do not generally infect other cell types. Some viruses will only infect bacterial cells and these are called bacteriophages or phages.

Something important to remember!!

Bacteria and viruses are very different types of microorganisms. For example, bacteria have a metabolically functioning cell structure while viruses do not. That means that drugs designed to target bacteria do not work for viral infections. Since influenza (the flu) is caused by a virus, it won't help to take an anti-bacterial drug (such as antibiotics), even though many people do.

Activities

The following fun activities grow out of this chapter.

1. Based on the characteristics of living things, consider whether a seed, a freshly picked tomato or an unfertilized egg would be considered living or non-living. You could construct a table to list the various arguments for and against.
2. Research the development of the microscope from the 1600s until today.
3. Make an edible model of a cell showing the various organelles.
4. Observe osmosis in action with "shell-less eggs". You can find the instructions on the internet (e.g. http://www.exploratorium.edu/ and search for 'naked eggs').
5. Research the changes that have occurred at the kingdom level of classification over the past 50 years.
6. Read about some animal hybrids that have resulted from cross-species reproduction e.g. liger/tigon, zonkey/donkra, cama, leopon, zorse etc.
7. Collect a bag of 'leaf litter'. Spread it onto a tray and using a magnifying glass, see how many types of animals (phylum & class where appropriate) you can identify and tally how many of each are present. Construct a branching dichotomous key which would allow someone to identify the various animals you have found.
8. Visit a rocky shore at low tide and see how many invertebrates you can identify. See how many different types of algae you can find.
9. Dissect a number of flowers from various angiosperm species. View the parts with a magnifying glass. Compare the key structures.
10. Find out the difference between a fruit and a vegetable.
11. Draw a series of diagrams to show the stages of fruit development from the flower.
12. Make a seed collection from the food that can be found around the home.
13. Germinate a broad bean seed and document the stages until it is a seedling. (Find some guidelines on the internet.)
14. Investigate whether the orientation of the seed makes any difference to the germination process.
15. View some David Attenborough DVDs (BBC Worldwide Ltd) e.g. The private life of plants.
16. Create a plant press of native Australian plants.
17. Research some of the uses of native plants by Indigenous people.
18. Look for interactive web-based activities which give practice in sorting animals or plants based on physical features.
19. Research how different indigenous communities might classify various living things.
20. Make a collection of different types of fungi.

21. Read about the discovery of penicillin.
22. Research the range of diseases caused by protozoans (e.g. malaria, African sleeping sickness, trichomoniasis).

Chapter 8

Ecology and the Environment

8.1 An Introduction to Ecology

As a teacher, you will often talk about the home environment of your students. This environment includes the people your student interacts with and the types of relationships they have with these people, as well as their pets, the nutrition they receive, the cleanliness of the home, the amount of time they spend in front of the television, home safety etc. In short, anything that influences the student, or that the student influences, is part of their environment. It is not just humans - all organisms live in an environment that they interact with.

Ecology is the study of the interactions between an organism and its environment. The environment of an organism includes biological components and physical components. The **biological**, or living, **components** of an organism's environment includes all life forms they interact with including their prey, predators, competitors and parasites (Figure 8.1). If you were to describe the biological components of a kangaroo's environment you would need to mention the grass that it feeds on, the worms in its intestines, the ticks on its skin, the dingos that prey on them, the birds that swoop them when they feed near their nests, and other kangaroos they interact with including their mates and joeys.



Figure 8.1: Kangaroos and lions interact with their living and non-living environment.

The **physical**, or non-living, **components** of a kangaroo's environment includes the outside temperature (if it gets too hot it will seek shade), rainfall (finding water to drink would be hard without it and the grass may not grow), the air it breaths, and fire (this will cause them to move away from the area until plants regrow).

Ecologists are interested in understanding interactions that occur in the environment as, if altered, these may have disastrous consequences for many organisms, including humans. For example, in northern California, sea otters were hunted to near extinction and, in response, the giant kelp forests

were also lost from many areas. These giant kelp forests provided homes for numerous fishes that supported a large fishing industry but this industry was near collapse due to their being no homes for the fishes that they wanted to catch.

So what was the connection between sea otters and giant kelp forests? Sea otters feed on sea urchins which feed on the giant kelps. When the sea otter numbers were reduced by fur hunters, there was an explosion in the population of urchins as they did not have any predators. These urchins then fed on all of the available kelp. The natural balance of sea urchin numbers being kept in check by sea otters had therefore been upset. Since fur hunting has stopped the sea otters have returned to many areas as has the giant kelp forests and the fish that live in these forests.

A similar situation is occurring in Tasmania where lobsters, a natural predator of sea urchins, is removed from kelp forests by fisherman. Where this has occurred there is an increase in the number of sea urchins, which in turn eat the kelp forests leaving bare rock (Figure 8.2). This situation can be reversed by increasing lobster numbers by preventing fishermen from catching them.

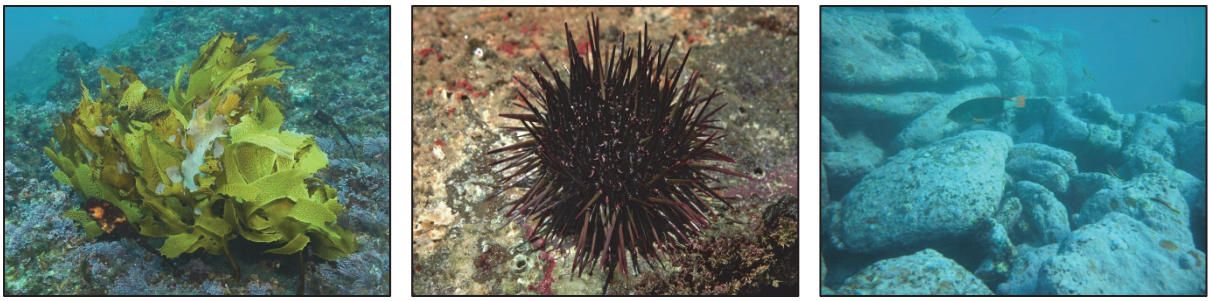


Figure 8.2: Kelp forests are converted to barren rocky areas by sea urchins.

In many ways, ecologists act like detectives either trying to piece together information to determine how an environmental problem has occurred or to investigate relationships in the environment to predict the implications if interactions were to change. Understanding the interactions between organisms and their environment has become something of urgency as people try to predict the effect of global warming on the environment and our place in it.

8.2 The Study of Ecology

People who study ecology are called **ecologists**. Ecology is studied at many levels from individuals, to populations, to communities. An ecologist studying **individuals** may be interested in the way that individuals are *adapted* to their environment, including strategies for survival in desert and frozen environments. A **population** is a group of individuals of the same species interacting with one another. A population ecologist is often interested in *where* species' are found and *reproductive strategies* used by different species. A **community** consists of all the organisms of various species living in a particular area (Figure 8.3). For example, a community on an African grassland would include the grass, trees, lions, hyenas, elephants, zebras, oxpeckers, giraffes, snakes, dung beetles, worms, termites etc. The previously discussed interactions between sea otters, urchins, kelp forests and fishes would be an example of community ecology.



Figure 8.3: These barnacles belong to a rocky shore community, which includes various species of snails, limpets, anemones, seaweeds, crabs etc.

8.3 Interactions Between Individuals and Their Environment

The distribution of organisms is related to how well they are able to cope with environmental hardships and their suitability to the environment. For example, a red kangaroo may be well suited to the hardships of the desert but will not survive in cold, alpine areas. On the other hand, small pygmy possums survive well in the snowy mountains but quickly die if exposed to a hot day in the desert. One way individuals may cope with the stresses placed on them by their environment is to modify their behaviour (e.g. burrow underground to get away from cold winds). Another is to acclimatize.

Acclimatization is a short-term, reversible response where the physiology of your body changes to make the environment less stressful for it. For example, if you climb at high altitude your body responds to the stress of minimal oxygen by increasing the number of red blood cells to improve your blood's ability to transport oxygen. When you return to lower altitudes the number of red blood cells returns to normal. Acclimatization takes time to allow the body's physiology to change so mountain climbers must spend time at base camps to provide time for acclimatization to occur just as it takes time for us to adjust to the cold temperatures of winter and hot temperatures of summer or for goldfish to acclimatise to the water temperature of their new fish tank.

Unlike acclimatization, an **adaptation** is a permanent, genetic trait that has been passed on from the parents which helps an organism cope with environmental stress. Adaptations can be morphological (i.e. structural), physiological (i.e. functional) or behavioural. For example, the Australian pelican has salt glands near its nose which removes excess salt from its body's tissues and drips this fluid out of its nostrils down grooves in its beak (Figure 8.4). Salt glands are an example of a morphological and physiological adaptation that pelicans have received from their parents through their genes. Individuals can be *adapted* to the environment but as they cannot change their genes they are unable to *adapt* to the environment. Groups of individuals, called a population, are able to adapt to the environment as their gene pools are able to change over time. It is therefore said that populations adapt, but individuals acclimatize.

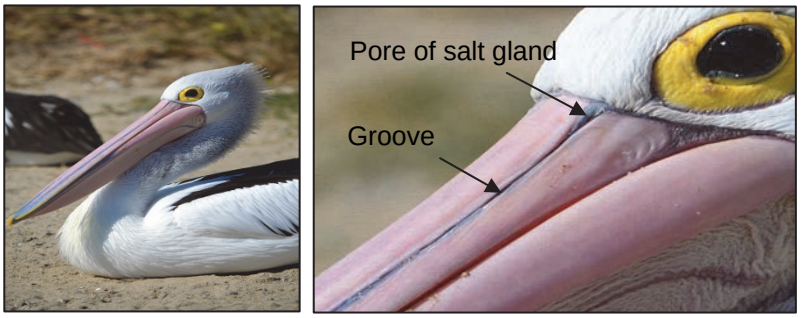


Figure 8.4: Salt glands remove excess salt from the body. In a pelican this salt travels down a groove at the top of the bill.

In the previous chapter the term ecology was introduced as the study of interactions between an organism and its environment – both biological and physical. Physical environments can be severe and adaptations are a must for survival. The rest of Section 8.3 explores various animal and plant adaptations which enable organisms to survive in environments that:

- are very hot, very cold or even frozen
- provide very little fresh water, are salty or are flooded.

Temperature - Hot, Cold and Frozen

Temperature is critical for an organism as the enzymes in their body are temperature-sensitive. These enzymes control physiological processes so if they do not exist in an environment which is optimal for their functioning then they do not function effectively. Consider the human body as an example. Our enzymes work most effectively at our body temperature of approx. 37°C but a change in body temperature by as little as 2-3°C can be life-threatening.

Aquatic organisms typically have a low tolerance to temperature change as they live in an environment that is rather stable given water neither heats up nor cools down very quickly (Figure 8.5). Terrestrial organisms on the other hand experience extreme temperature fluctuations so require various adaptations to allow them to survive.

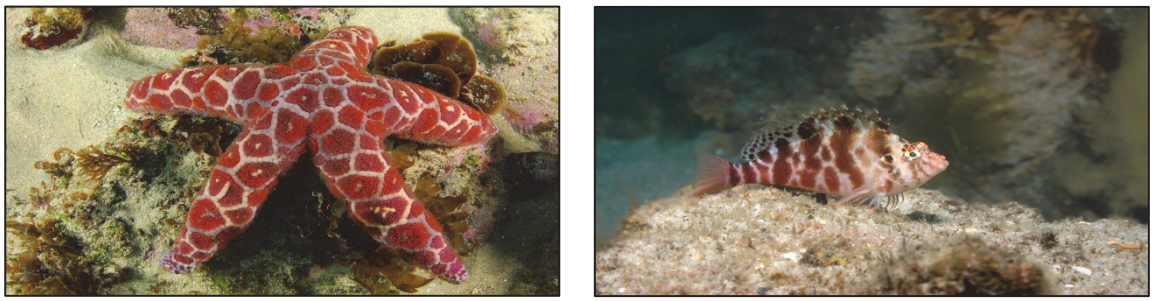


Figure 8.5: This seastar and hawkfish live in a relatively stable environment.

Animals

In hot environments, such as the deserts of Australia, many animal adaptations are behavioural. For example, most of Australia's native mammals are nocturnal choosing to sleep underground or beneath vegetation during the day or to avoid the heat and then emerge in the cool of night to forage (Figure 8.6). Even on the Avondale College campus there are typically no native mammals to be

seen during the day but at night you able to spot brushtail possums, feathertail gliders, native mice and bandicoots. Behavioural adaptations also include wallowing in water, migration to cooler areas and, in the case of the red kangaroo, promoting evaporative heat loss from the body by licking the forearms where blood vessels are close to the skin surface.



Figure 8.6: Many of Australia's mammals, including kangaroos and bandicoots, are nocturnal to avoid the daytime heat. Bandicoots are common on the walking tracks on the Avondale College campus.

Another adaptation for survival in hot environments is to have a **thermal window**. A thermal window is an area of the body that allows heat to escape easily and in doing so acts like the radiator of a car. Thermal windows often project from the body as is the case in the ears of elephants and the Australian bilby. Blood passing through the ears loses heat and returns to the body a little cooler than it left. Unlike humans, some animals are not bothered if their body temperature increases (**hyperthermia**) as their enzymes are not so temperature-sensitive.

Behavioural adaptations are equally important for allowing animals to survive cold environments. For example, male Emperor penguins survive the severe Antarctica winter incubating their eggs on their feet by huddling together as do many other animals in cool climates (Figure 8.7). If the environment is intolerably cool then some animals will migrate to warmer regions. Southern humpback whales do this along the east coast of Australia every year migrating approx. 5000 km north to escape the Antarctic winter. Other adaptations include having different or more hair or feathers in winter to provide better insulation. This hair is usually moulted after winter so the 'winter coat' of our pets usually ends up over our furniture!



Figure 8.7: Lizards choose to hide underground to escape the cold temperatures of winter but emperor penguins chose this time to reproduce.

Another adaptation used in very cold environments is **torpor** whereby the body essentially shuts down by lowering its body temperature to conserve energy it would otherwise have to waste on keeping its body temperature up. Torpor is especially important for mammals and birds as, being endotherms, they are particularly wasteful of energy. Torpor can be short-term also known as **daily torpor**, or long-term also known as **hibernation**. Small endotherms are particularly wasteful of energy as they have high surface area to volume ratios which increase heat loss. It is therefore not surprising that mountain pygmy possums and many other small Australian marsupials experience torpor.

More extreme survival strategies are needed for animals living in environments with temperatures below freezing. These animals have two main strategies. The first is to remain active by having antifreeze in their body to lower the freezing point of their body tissues. This allows them to remain active even though the environment around them may be lower than $0^{O}C$. This is the strategy employed by most of the aquatic organisms in the Antarctic, including fishes and invertebrates, as they remain unfrozen and active despite the surrounding water being approximately $2^{o}C$ below zero.

In terrestrial environments which freeze, some organisms are actually able to freeze and thaw. They do this by allowing the fluid outside their cells to freeze but keeping the insides of their cells liquid using antifreeze. Freezing within the cells would cause irreversible damage. Animals that can freeze are rare. An exception is the wood frog of the northern hemisphere which survives winter frozen beneath leaves and snow then thaws ready for reproducing when the snow melts (Figure 8.8).



Figure 8.8: Some frogs, lizards, snakes and invertebrates are able to survive freezing but this common garden frog does not have this adaptation. Therefore, its distribution is limited to areas experiencing warmer temperatures.

Plants

Unlike animals, plants are less able to use behaviour as a survival strategy so they must rely more on morphological and physiological adaptations. Whilst plants are unable to sweat, they do use evaporative cooling to lower their temperature when they heat up. They do this by opening the stomata in their leaves and in doing so allow water to evaporate from the leaves - known as **evapotranspiration**. Evapotranspiration occurs whenever most plants are photosynthesising but it can be increased if the stomata are open wide. The extent of evaporation cannot be underestimated. If you have ever been to the Amazon or other tropical rainforests you would be familiar with afternoon storms. The rain that falls in these storms has come largely from moisture lost by trees and other plants through evaporation during the day. Evapotranspiration is also the reason why your plants wilt on a hot day – they have lost a lot of water through their leaves so the plant has lost its water pressure.

Increasing evapotranspiration is a good strategy for plants with an endless supply of water but plants experiencing hot temperatures, such as in deserts, are also often suffering from lack of water. These plants have adaptations to reduce heating up in the first place such as shedding of leaves, orientating the leaves away from the sun (Figure 8.9), having small leaves or, in the case of cacti, no leaves at all. These strategies are useful in reducing the surface area to intercept sunlight. In the case of many eucalypt trees, the leaves hang vertically so they do not intercept the hot midday sun. Other plants reflect the sun's rays using waxy leaf coats or, like many cacti, having lots of reflective white hairs over their surface. Like animals, some plants are simply able to tolerate hyperthermia.



Figure 8.9: While the leaves of most plants are oriented horizontally or slightly upward (left), those of eucalypts (right) hang vertically so they do not intercept the midday sun.

In addition to having to tolerate high temperatures, many plants are found in very cold environments. Some survive by forming their own blanket either using hairs over their surface or by folding their leaves or other structures over their trunk. If you have ever hiked in the Cradle Mountain region of Tasmania or the Snowy Mountains in NSW/Victoria you would have observed another strategy to survive the cold. Most of the plants in these regions are very short and clustered together. Like the Emperor penguins, clustering insulates individual plants from the cold winds they would otherwise experience. In temperatures below freezing, some plants are able to store antifreeze or freeze the outside of their cells similar to some animals.

Water: Limited, Marine and Flooded

Water is essential for life yet maintaining the content of water in the body is a challenge for animals and plants particularly those in terrestrial and marine environments. Those living in terrestrial environments, especially those that have limited rainfall, must have adaptations to minimise water loss whilst those in marine environments must minimise water loss as well as expel excess salts that come from the environment.

Animals

For both animals and plants the adaptations that aid survival in hot environments will also be useful in dry environments. For example, being nocturnal means less water is wasted as they do not have to sweat as much as they would if they were active during the day. Similarly, plant adaptations of waxy leaf coats, no leaves, vertical leaves, reflective hairs etc. keep the temperature of the plant lower but this also means that less water is needed to be lost through cooling by evapotranspiration.

For many animals, migration is an important strategy for surviving dry conditions. The Australian deserts are known to explode with life in years of rain as many birds arrive from many thousands of kilometres away to feed and breed. These birds do not remain once the water dries. However, many of the animals they feed on do. The remaining animals often survive by having a waxy or scaly covering that is impervious to water and producing a white uric acid paste instead of liquid urine (Figure 8.10). This allows many arthropods and reptiles to conserve water and survive in the driest of deserts. The conserving of water in desert mammals includes the production of urine that is very concentrated, producing faeces as very dry pellets or even tolerating dehydration without causing cell damage.



Figure 8.10: Unlike frogs and earthworms, a praying mantis and water dragon both have an integument that is rather impervious to water loss.

For some animals the hardships of insufficient water is too much so they must survive underground in an inactive state waiting for the return of the rains. Not surprisingly, frogs are unable to survive the dryness of deserts but when rain falls many species of frogs can be found in the ponds and lakes that are formed. Where do they come from? Many of these frogs, including the burrowing frogs of central Australia, have survived buried beneath dried lake beds waiting for the rains to return.

For other animals, the hardships of survival in the dry times are too great so their survival strategy is to reproduce as much as possible when there is sufficient water then leave behind eggs that can survive years and even decades of dryness. Within a week of rains these eggs hatch creating an explosion of life which includes many crustaceans and insects. Some of these crustaceans, called fairy shrimps, can be purchased from pet shops as *sea monkeys*. These sea monkeys are purchased as eggs, water is added and they soon hatch – just as though it has rained in the desert!

For animals living in the marine environment, adaptations such as producing highly concentrated urine or a uric acid paste are similarly useful for conserving water. Another important adaptation found in vertebrates is to have a salt gland for removing salts from the body which they have acquired from their food and the water around them (Figure 8.11). Salt glands are found near the eyes of turtles, the nose of birds and the mouth of crocodiles and sea snakes. If you are ever asked the question “Where does a sea turtle or seabird get its drinking water from?” you can confidently answer that they get their drinking water from drinking seawater. If humans were to drink seawater we would dehydrate ourselves as our kidneys would need to remove the salts in the seawater with more water than we drank. Salt glands allow the animal to drink seawater and eliminate the salts as a highly salty solution effectively leaving behind the freshwater component of the salt water.



Figure 8.11: Salt glands are found in many marine vertebrates including seabirds, saltwater crocodiles, sea snakes and marine turtles.

Plants

Terrestrial plants take up water from the soil to replace the water they are losing through evapotranspiration. This water is taken up by the roots. However water uptake is helped by a relationship plants have with root fungi called **mycorrhizae**. Mycorrhizae consist of very fine, branching filaments that provide a greater surface area for absorption of water and nutrients than the plant would otherwise receive from their roots. The plant shares some of its sugars with the fungi therefore this is a shared mutual beneficial relationship, termed **mutualism**.

Despite this mutualistic relationship, many plants still have problems either with water uptake or water loss. Adaptations are particularly important for these plants, especially those found in deserts (Figure 8.12). Some plants are especially adapted for accessing water that lies deep underground. If you have ever travelled in inland Australia and have been surprised at seeing trees in very arid land you are likely to be witnessing trees with root systems that may be extracting water from supplies 10s of metres underground. These plants can be somewhat wasteful of water provided they are accessing a plentiful water supply. Other plants rely more on conserving the limited water they do have access to.



Figure 8.12: Plants surviving in the Australian outback require special adaptations to cope with high temperatures and limited water.

As evapotranspiration is a major source of water loss in plants, any method of reducing water loss in this way is an important adaptation (Figure 8.13). Loss of leaves, small leaves or no leaves are all ways of reducing the number of stomata and hence the number of places water can escape. This is an excellent strategy if water is scarce but the problem with not having many stomata is that the plant cannot exchange gases as effectively with the atmosphere so they tend to grow slowly. Cacti do not have any leaves at all but photosynthesise with their trunk (that is why the trunk is green!) and it is

on the trunk that the stomata are found. Cacti have an additional adaptation in that they are able to store the water that their roots collect from the infrequent rain events. Animals like to gain access to this stored water for their own needs so many cacti must protect themselves with spines. Other plants are covered in hairs or have their stomata located in sunken cavities to keep a layer of still air above the stomata rather than allowing the wind to strip moisture from the plant.



Figure 8.13: This elkhorn fern grows high off the ground on the outside of other plants. This gives them better access to light but it means they must have adaptations to reduce water loss as their roots are not in soil.

For other plants, partial closure of stomata is the compromise between water loss and gas exchange but the problem with the closure of stomata is the plants must be able to withstand heating up, which they can! The most extreme strategy for regulation of the stomata belongs to the various plants, including cacti, which engage in **Crassulacean Acid Metabolism** (CAM) photosynthesis. These plants open their stomata during the night when it is cool to avoid water loss then close their stomata during the day where they use the CO_2 captured during the night to make sugars via photosynthesis.

Like animals that are unable to survive without water, many plants grow and reproduce as quickly as possible for the purpose of producing seeds. The seeds can remain dormant in the soil for years or decades awaiting the return of the rains. Desert flowers in South Australia and Western Australia are known for the magnificent displays of colour to otherwise arid areas.

Water loss is also a problem for marine plants as is the uptake of salts they receive from the environment. Like many animals, many of these plants have salt glands so they are able to take in salt water and separate the freshwater component from it by removing the salt. In mangroves, these salt glands are located on the underside of the leaves and can often be easily seen. Other mangroves concentrate the salt into leaves they are soon to shed.

It may be easy to conclude that plants would be best looked after if they were given lots and lots of water. However, plants need just the right amount as too little will cause them to wilt and will not be sufficient for the needs of their cells but too much is equally harmful. For example, watering newly planted photinia seedlings twice a day would result in death by drowning within a couple of weeks! Why do plants drown? Plants use their roots to obtain water but they also require air spaces within the soil from which they obtain oxygen. (Remember, plants make oxygen but they also need it!) When the soil is saturated there are no air spaces in the soil so the roots suffocate (as we do) without oxygen. Plants living permanently in saturated soils require special adaptations. For mangroves, special aerial roots called **pneumatophores** act as snorkels out of the mud to obtain oxygen from the air and deliver it to the roots in the oxygen-depleted mud (Figure 8.14). Other plants living permanently in water, including lilies, transport some of the oxygen they make via photosynthesis down to the roots.



Figure 8.14: Mangroves are only able to survive in waterlogged and oxygen-depleted mud as their roots have special ‘snorkels’ to extract oxygen from the air.

Other Adaptations

So far, Section 8.3 has explored various adaptations that allow animals and plants to survive in environments in which they experience temperature or water stress. It is important to reemphasise that the environment in which an organism lives includes all of the biological and physical components it interacts with. Therefore, any genetic trait that an organism has which helps it survive and reproduce in the environment in which it is found is considered an adaptation whether these are desert environments, a woodland adjacent to your school, a local pond, the rocky shore etc (Figure 8.15). These include traits such as large leaves to allow plants in the lower parts of the rainforest to capture light, dandelion seeds with their fluffy projections to allow them to float in the air to find a good place to germinate or mutualistic relationships such as those that occur between anemone fish and their anemone host.



Figure 8.15: Adaptations are found everywhere. The amazing tail feathers of a peacock are an adaptation to improve the reproductive success of males and the pointed nose of an echidna is an adaptation to allow them to feed more effectively on termites.

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8.4 Population Ecology - Life History Strategies

Life history strategies are strategies used by organisms to most optimally produce offspring. Life history strategies include how individuals select and acquire a mate, the mode of reproduction (e.g.

asexual or sexual reproduction), the number of young produced, how often young are produced, and the amount of parental care offered to the young (Figure 8.16).



Figure 8.16: The planktonic larvae of mussels and seeds of eucalypt trees suffer very high mortality so they are produced in their hundreds of thousands to ensure at least some survive to adulthood.

Although there are differences among individuals due to genetic variation or environmental conditions, generalizations about life history traits of a species can still be made. Consider the traditional life history strategy of humans in a western culture. We typically have two to three children each separated by approximately two years, with the first child born when their monogamous parents are in their mid-twenties. The parents provide lots of parental care until the age of at least 18 years. The children are most likely to leave home anywhere between 21 and 30 years of age. This life history strategy is in contrast to most other animals including marsupial mice which have 6-8 joeys at the age of 11 months. After looking after the babies for several months, the mother leaves them to fend for themselves – that is if she hasn't killed them first, which she may well choose to do! The mother may live to 2 years of age therefore potentially raising two litters in her lifetime. The fathers live only 11 months and all die before the joeys are born. Why would marsupial mice have such a weird life history strategy? It is thought that the joeys are given the best possible chance of survival if they do not have their fathers around to compete with them for food and mates.

Mating Systems

Some organisms do not even waste their time finding a mate but instead produce identical clones by **asexual reproduction**. Examples include many single-celled organisms, such as amoebas and paramecia, but many larger organisms, including anemones and insects, opt for a similar strategy (Figure 8.17). If you have roses or citrus trees growing in your garden, you would be aware of how fast aphids can infest your plants. They do this by the females producing numerous clones of themselves. Remarkably, many lizards can do the same including rare instances where captive female komodo dragons have produced clones from unfertilized eggs.

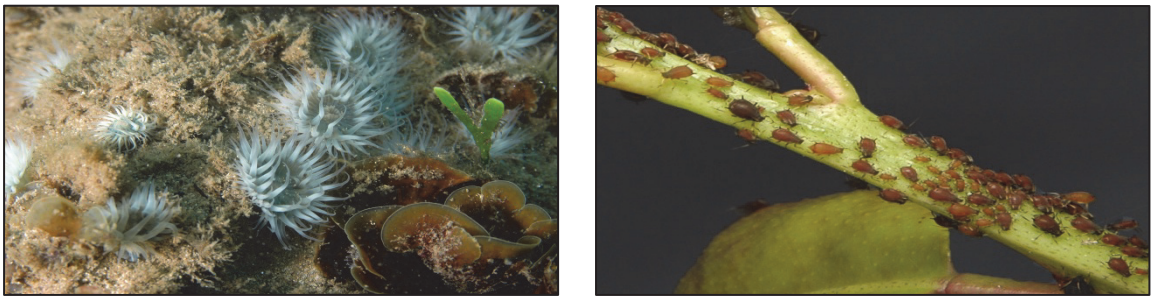


Figure 8.17: These anemones and aphids have been asexually produced so are clones of an original parent.

Other organisms rely on **sexual reproduction** which has the advantage over asexual reproduction in that it requires genetic material from two individuals to unite to create offspring that are different to the parents. These offspring may have advantageous traits that the parents do not have which, in the case of a disease outbreak, may provide them with protection not available to the parents. A major disadvantage of sexual reproduction is that an individual transmits only half of its genetic material to its offspring so it makes sense that each individual should seek the best possible mate to contribute toward the other half of the genes! It is for this reason that most species are selective of their mates, especially females, as they usually have a greater involvement in the rearing of offspring through carrying of eggs, provision of milk, care of the young etc.

How organisms find their mates for sexual reproduction is highly variable among organisms. **Monogamy**, involving the formation of a pair-bond between one male and one female, may be considered normal for most humans but this type of mating system is rare in the animal kingdom. Monogamy occurs in species in which parental cooperation is needed to successfully rear offspring, especially in birds (Figure 8.18). Consider the effort birds must put into incubating the eggs and then feeding the ever-hungry hatchlings. It is estimated that 90% of all bird species are at least seasonally monogamous but many monogamous bird species are now known to cheat on their partners. This means an individual may have young in several nests. Of course this also means that not all the eggs a bird is incubating may necessarily belong to it but rather to their cheating partner and neighbour.



Figure 8.18: Lapwing plovers and rainbow lorikeets are monogamous so the males and females of the species look similar.

The typical mating system for most animals is **polygamy** where an individual, usually a male, mates with several individuals of the opposite sex who have not mated with other individuals. A typical

example would be a mob of kangaroos which have a top ranking male who mates with numerous females who will not allow a male other than the top ranking male to mate with them. Competition for the right to mate often results in **sexual dimorphism**, whereby the males and females of a species look different. For example, males of polygamous species are often larger and stronger than the females, or have horns that are lacking in the females, as the males must compete to win the right to mate (Figure 8.19). Those males that are better equipped to fight are therefore more likely to mate. These genetic traits are then passed on to the next generation of males whilst those of less capable fighters are not. Selective mating therefore promotes males to be different to the females – sexual dimorphism. Similarly, female birds typically select their mates based on the plumage of the males so many bird species have females that are a drab colour but the males have extravagant plumage to win the affections of the females. Remember, sexual dimorphism is common for polygamous species so male and female parrots, penguins, albatrosses etc. are typically the same colour as they are generally monogamous (Figure 8.18).



Figure 8.19: Crimson-banded wrasse males (left) are brightly coloured and much larger than the females (right) as they can compete with other males for mating rights.

Care of Young

Caring for young is a major reproductive expenditure for many organisms. At least one of the parents must provide their offspring with food, shelter, protection from predators etc. In animals, the degree of development at hatching or birth roughly translates into the amount of parental care required after birth or hatching. For example, mice are born blind, naked and helpless so they require a large amount of parental care. Compare this with turtles which hatch as miniature versions of the adults and rapidly scuttle across the sand to the relative safety of the sea – all without support from their parents.

Whilst it is true that most mammals provide a large amount of parental care to their young, we would be mistaken to think that this is not the case for other animals. For example, most birds spend large amounts of time incubating their eggs then feeding their young. Consider the level of parental care that Emperor penguins provide to their young with individuals braving the Antarctic winter to incubate their single egg. Whilst reptiles, amphibians and fish are not known for providing high levels of parental care to their young, many actually do. For example, female crocodiles will defend their eggs then carry the hatchlings in their mouth to the safety of the water. Some amphibians are known to carry their eggs on their backs until they are ready to hatch, whilst the Australian gastric-brooding frog retains up to 26 eggs in its mouth until they are ready to emerge as tiny frogs.

Unfortunately this species became extinct in the mid-1980s. Similarly, many fish retain their eggs in their mouth to protect them from predators but will continue to look after their young after hatching, even allowing hundreds of their young to seek refuge in their mouth if a predator is around.

Surprisingly, many invertebrates provide high levels of parental care to either their eggs or their offspring. It is true that many insects simply place their eggs in favourable habitat then have no more dealings with their offspring, but other organisms such as octopi, crabs and even spiders will provide high levels of parental care (Figure 8.20). In the case of spiders, many will protect their eggs or young in their web or on their backs. Redback spiders do this but it is the female that protects the young as the males are usually eaten during mating in an act called *sexual cannibalism*. Invertebrates providing the most parental care are the social insects which include ants and bees. Workers of these insects clean and feed the young, even transporting them to higher ground when rains are due. The young then provide a life-time of service to the nest.



Figure 8.20: Parental care for cartrut shells ends after they have laid their eggs, but cuttlefish defend their eggs until they hatch and many spiders carry their white egg sac around with them. Some spiders even carry the hatched spiderlings around on their back!

Metamorphosis

Most vertebrates have simple life cycles but complex life cycles are common in animals such as insects, marine invertebrates, amphibians, many fishes and parasitic worms. These complex life cycles often involve an organism passing through at least two distinct stages that may have different body forms and live in different habitats. When there is an abrupt change from one stage to the next it is known as **metamorphosis**. Metamorphosis is not unusual in the animal kingdom with about 80% of all animal species undergoing metamorphosis at some time in their life cycle. Metamorphosis is important to many species to allow their offspring to mature away from the adults to reduce competition and avoid predators. Most people are familiar with the transition of caterpillars to butterflies and tadpoles to frogs, but they do not realize metamorphosis occurs all around them (Figure 8.21).

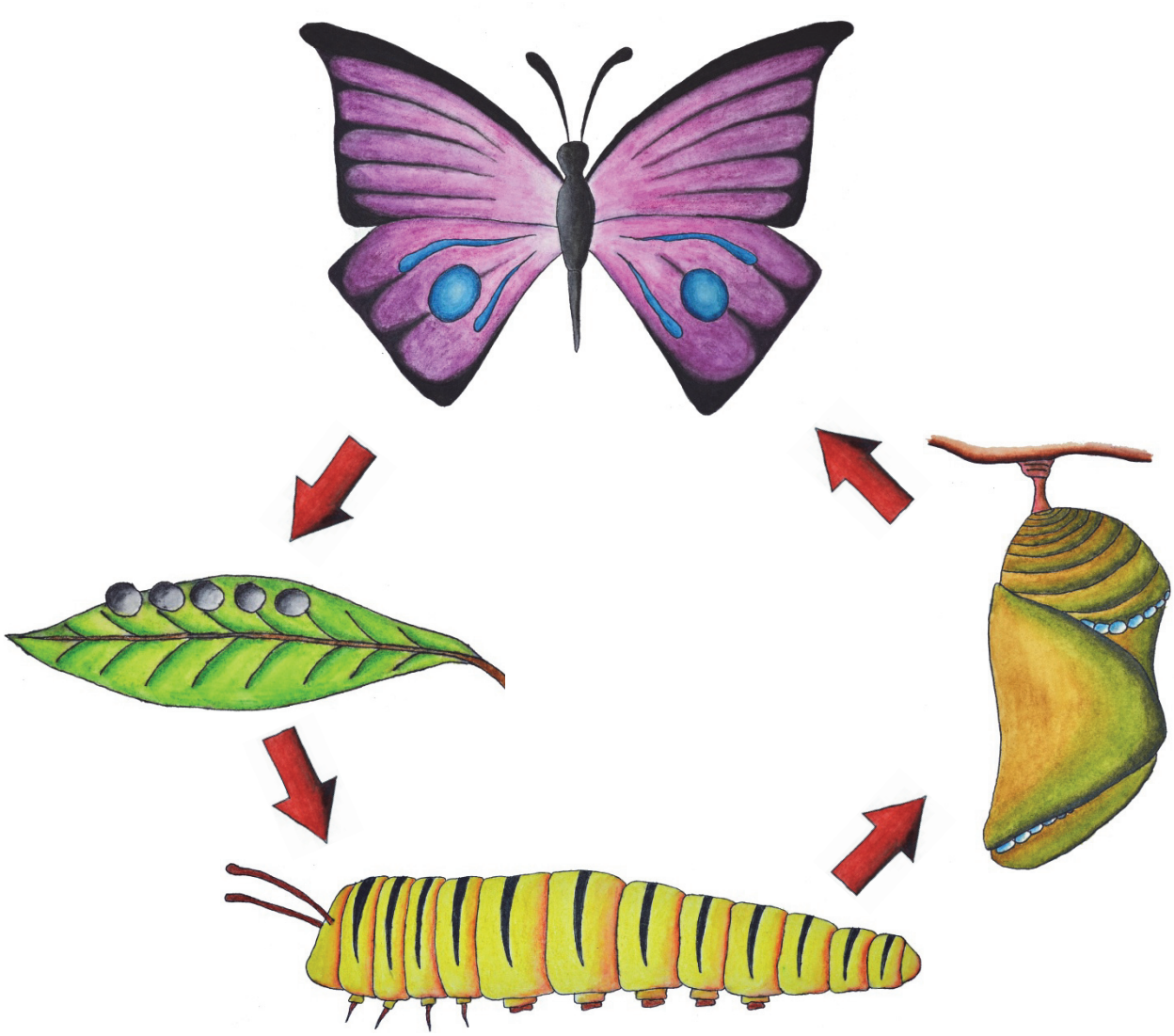


Figure 8.21: The life cycle of a butterfly. After mating, the female butterfly selects a favourable plant to deposit eggs that later hatch into a caterpillar. The caterpillar becomes a pupa, called a *chrysalis* in butterflies, which is the stage that metamorphosis into a butterfly occurs.

Flying insects provide many examples of the less recognized but very common examples of metamorphosis. For example, mosquitoes deposit their eggs in still water bodies which then hatch into wriggling larvae. These larvae become pupae at which time they metamorphose at the water surface into the flying mosquito form which commonly annoy us. This whole process from egg to flying adult lasts as little as a week or two. Similarly, dragonflies and mayflies deposit eggs in water bodies which hatch into crawling larval nymphs before metamorphosing into flying adults. Flies on the other hand lay their eggs in food and other wastes so the hatched maggots can feed before developing the wings of adults. Some flying insects, including many beetles, lay their eggs near the ground so their hatched young can feed on the roots of trees and grasses within the soil - these nymphs are commonly called ‘grubs’. In the case of cicadas, their nymphs can remain underground

for many years before developing legs and climbing fence posts, trees etc. to metamorphose into adults (Figure 8.22). In summer you may have seen numerous cases of cicada pupae on wooden structures around your home or in parks.

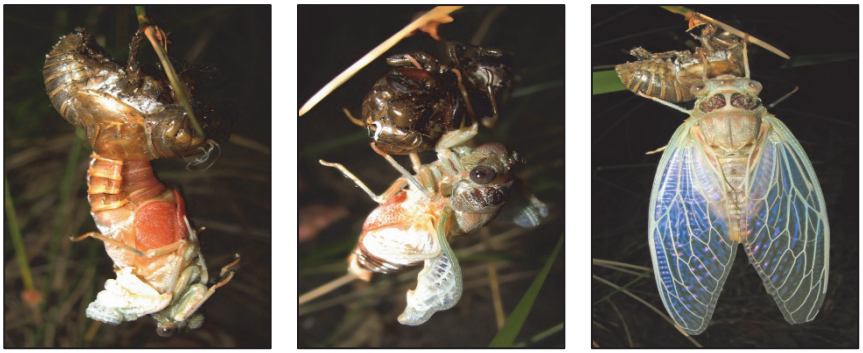


Figure 8.22: This cicada is emerging upside down from its pupa encasement. Most flying insects emerge with shrivelled wings that require fluid to be pumped into the wing veins before they can be expanded for flight.

Most marine organisms, including barnacles, crabs, snails, bivalves, sea stars, octopuses, worms and fishes, start their life in the zooplankton. **Zooplankton** are larval animals that drift with the currents so they can disperse away from the adults and colonize distant areas. This allows many species to colonize distant islands and is also the reason many tropical fish species arrive in coastal waters of Sydney having spent weeks drifting south with the currents. These larvae often do not resemble the adults at all until they metamorphose after finding a favorable place to settle (Figure 8.23). This zooplankton provides a feast for many of the animals living on rocky shores including adult anemones and barnacles.

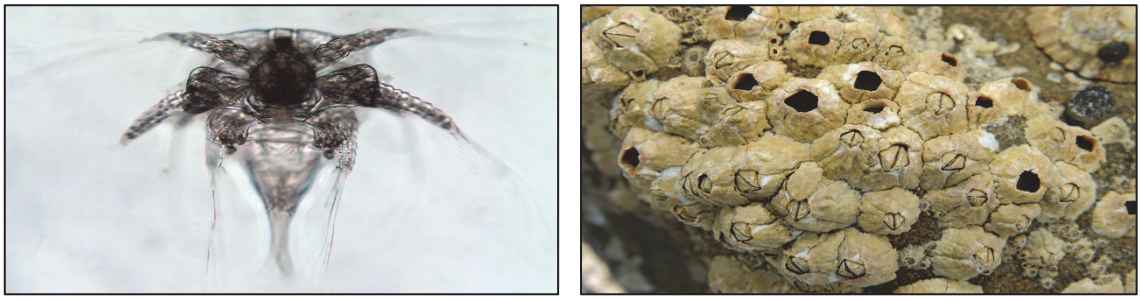


Figure 8.23: Larval barnacles (left) look nothing like adult barnacles (right). These larvae, called *nauplii*, drift in the ocean before metamorphosing into the sessile adult form.

[ST1-10LW, ST2-10LW] {ACSSU030, ACSSU072}

8.5 Community Ecology

There are **three** core themes in the study of community ecology which help ecologists understand interactions among species: feeding relationships, energy flow and nutrient cycling.

Feeding relationships

In any community there is a typical sequence of food transitions. Firstly, food is made by **autotrophs,** such as grasses, trees and algae. As they have produced their own food through photosynthesis, these organisms are also known as **primary producers**. These primary producers are fed upon by **primary consumers**, which are commonly known as **herbivores**. Examples of herbivores include cows, rabbits, caterpillars and koalas.

Herbivores are then fed on by **secondary consumers**, which are also known as **carnivores**. Lions, sparrows and dingos are examples of secondary consumers. The carnivores are often fed upon by other carnivores, known as **tertiary consumers**, and these can then be fed upon by **quaternary consumers**. These feeding links form what is known as a **food chain**. A typical food chain is represented in Figure 8.24.

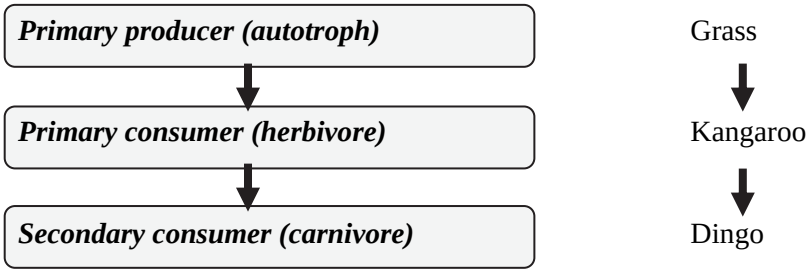


Figure 8.24: An example of a simple food chain.

Food chains can be short with only three links, as the one above illustrates, but sometimes they can have more links (Figure 8.25). However, rarely do they have more than five links.

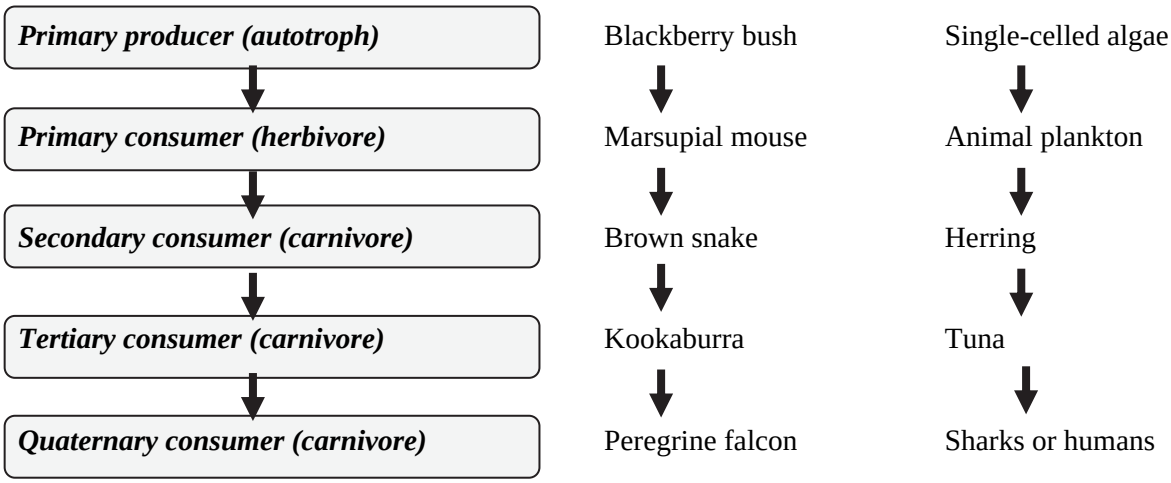


Figure 8.25: An example of a more complex food chain.

Although food chains are useful, it is obvious that they are not isolated from other food chains. For example, the blackberries on a blackberry bush provide food to many different species of birds and insects, each with their own food chain. Similarly, marsupial mice are fed on by many snake species, not just brown snakes, and they eat many types of insects and grubs in addition to blackberries. These branching food chains, with arrows linking species according to who eats whom, are known as **food webs** (Figure 8.26).



Figure 8.26: Lions feed not only on zebras but all sorts of herbivores, including buffalo, giraffes and various antelopes.

Food webs can be very complicated with numerous linkages between species. Therefore, these food webs are often simplified by grouping similar species together (e.g. all snakes could be grouped together if they are eating similar things) or leaving in only the most important species.

Species which have a pivotal role in a food web are known as **keystone species**. If these 'key' species are removed from a food web then there is often a considerable impact on the entire community. Sea otters in northern California and lobsters in Tasmania are examples of keystone species. Bees are also considered keystone species as, without them, pollination of many plants would not occur and therefore these plants would be unable to reproduce (Figure 8.27). Many orchards therefore have beehives in them to ensure that flowers are pollinated and fruits are produced.



Figure 8.27: Bees are very important in communities - without them many plants would not reproduce.

Another very important group in food webs are the **decomposers**. Decomposers break down the bodies of dead organisms and the wastes of living organisms. Examples include fungi, bacteria, earthworms, millipedes and roundworms (Figure 8.28). This feeding group is very important in communities as they break down food into simpler compounds making these nutrients available for

primary producers to use. The decomposers are therefore nutrient recyclers. They are important at every level of a food chain as shown in Figure 8.28.



Figure 8.28: Nutrient Recyclers.

Energy flow

If someone is doing something that is not worth doing, we often tell them not to waste their energy. This statement implies that once we use energy we do not get it back – unless of course we eat again. This is indeed the case for all organisms as the energy that gets used is lost from the organism. In fact, even though some of the energy in our food goes into building our body mass, most of it is wasted as heat, used to move or to repair the body.

Energy enters most communities as sunlight. This energy is captured by autotrophs and converted to food - the energy is stored in the chemical bonds of food. Some of this energy is stored in the leaves, trunk, roots etc. of the plant as food for herbivores. Herbivores use the energy in their food to maintain their bodies and some of the energy is stored in their tissues. Their tissues are then fed on by carnivores, which use the stored energy for their own purposes. Energy is lost at each step of the way though movement, heat production etc. so it is said that energy flows through communities (Figure 8.29).



Figure 8.29: All mammals are energy wasters as they lose a lot of the energy in their food as heat.

Of all the energy in sunlight captured by autotrophs, only a small fraction is passed to herbivores and carnivores. As energy is always being lost, communities must therefore be powered by a continuous supply of energy from an external source – thankfully the sun keeps doing this for us!

Nutrient cycling

Autotrophs, such as plants, take nutrients from the air, water and soil and incorporate these nutrients into their own tissues. For example, the carbon in carbon dioxide is taken from the air by plants and stored by autotrophs as nutritious carbohydrates (Figure 8.30). Herbivores eat these nutrients and

some are incorporated into their own bodies for carnivores to feed on. Those nutrients not incorporated into their own bodies are released back into the environment as waste. The nutrients in this waste are then recycled back into the community by the action of decomposers. Because of this, nutrients are said to cycle through communities.

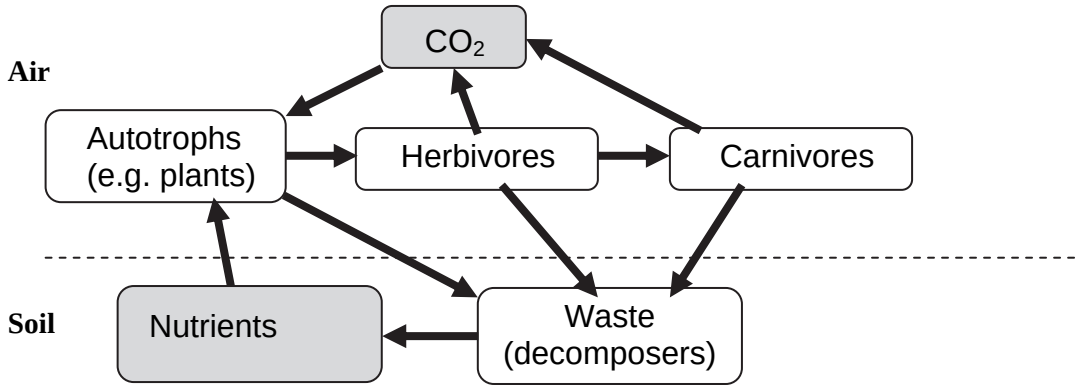


Figure 8.30: Carbon dioxide and nutrients are used by some organisms and produced by others. They therefore cycle through an ecosystem.

The importance of decomposers cannot be emphasised enough in the above diagram. Without them, all life on this Earth would cease to exist as waste would pile up and the supply of nutrients would not be recycled back into the community – the nutrient supply would therefore dry up!

[ST2-11LW] {ACSSU073}

Activities

The following fun activities grow out of this chapter.

1. Research the environmental impact of species introduced into Australia, such as the rabbit, cane toad, fox, camel and prickly pear.
2. See how many interactive web-based resources you can find where students could explore various environmental issues e.g. the environmental impact on an introduced species; food chain/web simulations.
3. Research the adaptations of several native desert Australian animals and plants e.g. greater bilby, thorny devil, spinifex hopping mouse, shield shrimps, spinifex grass, Sturt's desert pea, old man saltbush. Categorise the key adaptations based on water and temperature survival.
4. Obtain meal worm eggs, silkworm eggs or frog eggs. Keep a daily diary (e.g. photographs and measurement data) to show the development of the organisms from egg to adult stages. Use the photographs to create a life-cycle diagram.
5. Go outside and take photos of plants and animals that have a feeding relationship. Create food chains using the photos. Can you create a food web using your food chains? Dig into the soil and see if you can find a decomposer to add to your web.
6. Research the role of the native bee in the pollination of Australian native plants.
7. Build an ant farm.
8. Conduct an investigation to see what factors affect seed germination (e.g. wheat, grass seed).
9. Conduct a number of investigations (broad bean seedlings or grass shoots work well) to see how various environment factors affect plant growth (e.g. light, temperature, water, soil type such as soil salinity etc). You can also do this investigation (e.g. using moldy bread) to see if the factors are similar for fungi.
10. Research the role of Indigenous fire management practices.
11. Learn how to make a compost bin or a worm farm.



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