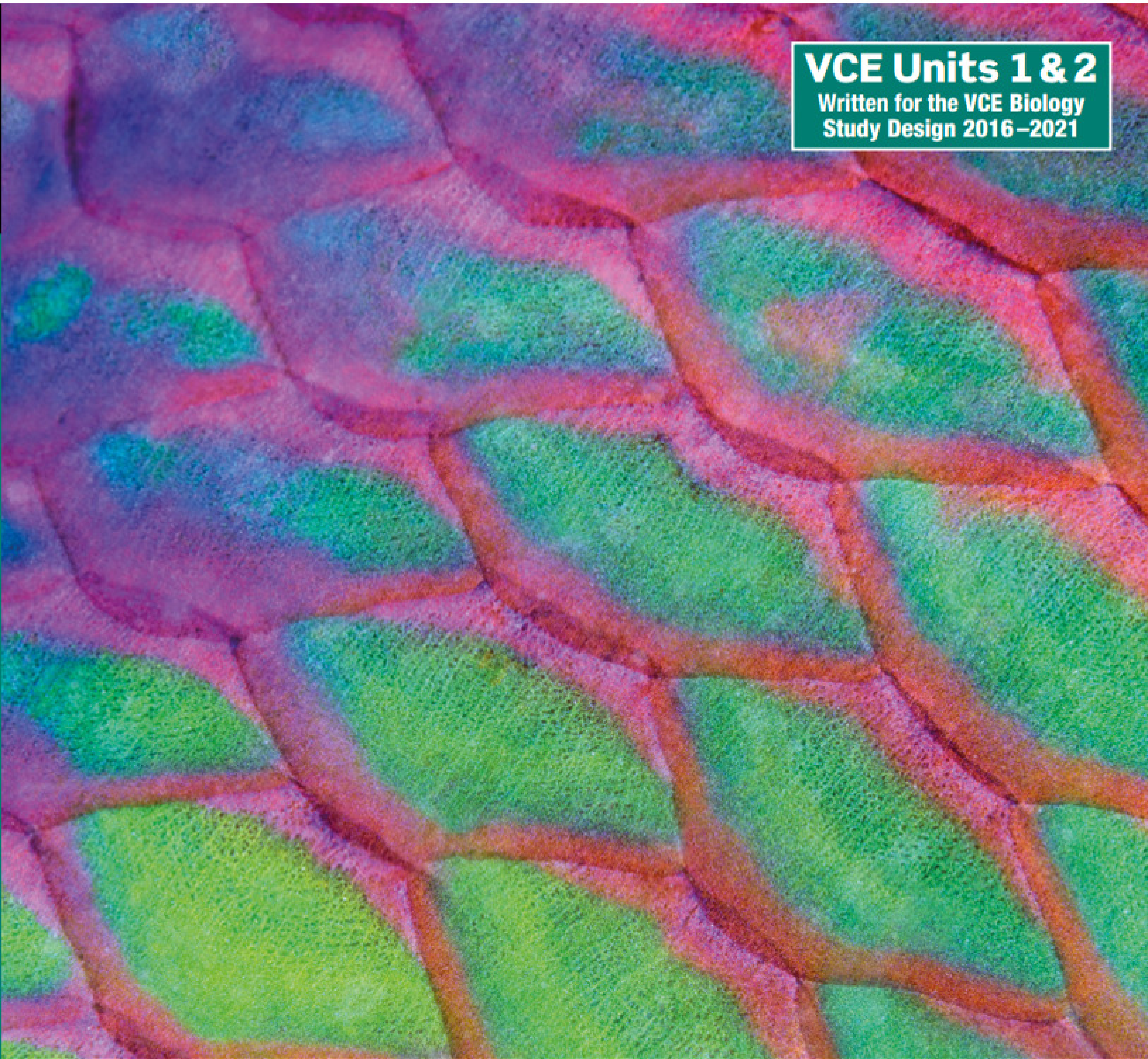
Heinemann

# BIOLOGY 1

5TH EDITION



VCE Units 1 & 2
Written for the VCE Biology Study Design 2016–2021

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ALWAYS LEARNING
PEARSON

CHAPTER 01

# Biology keystones — Foundation concepts and skills

The development of a set of key science skills is a core component of the study of VCE Biology and applies across Units 1 to 4 in all areas of study. Chapter 1 scaffolds the development of these skills. The opportunity to develop, use and demonstrate these skills in a variety of contexts is important ahead of undertaking investigations and when evaluating the research of others.

Although this chapter can be done as a whole, it is best to refer to it and use it when the need arises as you work through other chapters. For example, you may need a refresher on the structure of organic molecules or the process of the scientific method. It also contains useful checklists to assist when drawing scientific diagrams, graphing and completing aspects of your report. Similarly, when performing a first-hand investigation, refer to this chapter to make sure your investigation is valid, reliable and accurate.

## Key skills

**Develop aims and questions, formulate hypotheses and make predictions**

- determine aims, hypotheses, questions and predictions that can be tested
- identify independent, dependent and controlled variables

**Plan and undertake investigations**

- determine appropriate type of investigation: conduct experiments (including use of controls); solve a scientific or technological problem; use of databases; simulations; access secondary data, including data sourced through the internet that would otherwise be difficult to source as raw or primary data through fieldwork, a laboratory or a classroom
- select and use equipment, materials and procedures appropriate to the investigation, taking into account potential sources of error and uncertainty

**Comply with safety and ethical guidelines**

- apply ethical principles when undertaking and reporting investigations
- apply relevant occupational health and safety guidelines while undertaking practical investigations, including following relevant bioethical guidelines when handling live materials

**Conduct investigations to collect and record data**

- work independently and collaboratively as appropriate and within identified research constraints
- systematically generate, collect, record and summarise both qualitative and quantitative data

## KEY SKILLS CONTINUED

**Analyse and evaluate data, methods and scientific models**

- process quantitative data using appropriate mathematical relationships and units
- organise, present and interpret data using schematic diagrams and flow charts, tables, bar charts, line graphs, ratios, percentages and calculations of mean
- take a qualitative approach when identifying and analysing experimental data with reference to accuracy, precision, reliability, validity, uncertainty and errors (random and systematic)
- explain the merit of replicating procedures and the effects of sample sizes in obtaining reliable data
- evaluate investigative procedures and possible sources of bias, and suggest improvements
- explain how models are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of the models

**Draw evidence-based conclusions**

- determine to what extent evidence from an investigation supports the purpose of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation
- draw conclusions consistent with evidence and relevant to the question under investigation
- identify, describe and explain the limitations of conclusions, including identification of further evidence required
- critically evaluate various types of information related to biology from journal articles, mass media and opinions presented in the public domain
- discuss the implications of research findings and proposals

**Communicate and explain scientific ideas**

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- discuss relevant biological information, ideas, concepts, theories and models and the connections between them
- identify and explain formal biological terminology about investigations and concepts
- use clear, coherent and concise expression
- acknowledge sources of information and use standard scientific referencing conventions

# 1.1 Important principles in biology

Biology is a science, and our current understanding of life is based on the results of careful observations and experiments. In biology, some ideas or theories are supported by overwhelming amounts of evidence from such a wide variety of sources that it seems very unlikely they will be found to be untrue in the future. They are accepted as biological principles. Other theories are less strongly supported. Many are being modified or overturned even as you read this book.

Some biological principles and processes are relevant to the ways that almost all living **organisms** function. For example, living organisms are composed of cells, organisms have common characteristics and requirements, evolution explains the diversity of organisms, and organisms are adapted to their environments.

FIGURE 1.1.1 An example of living organisms: a common wombat (*Vombatus ursinus*) mother with her young joey.

**BIOFILE**

### Popular theories overturned

Scientific theories often change or are discarded when new information is obtained. Some popular theories that have been recently modified or overturned include:

- sugar causes tooth decay (bacteria are the real cause; they use the sugar and release acid which attacks teeth)
- stress causes ulcers (the bacterium *Helicobacter pylori* is the cause)
- fibre in the diet reduces the risk of colon cancer (a huge study showed no correlation).

## ORGANISMS ARE LIVING THINGS

There are usually obvious differences between a living organism and a non-living object, such as a wombat and a rock. A wombat (Figure 1.1.1) is able to move, eat and respond to sounds; the young animal in the picture is evidence that the wombat is able to reproduce. A tree cannot move about, but we can observe it grow new leaves and reproduce at a certain time of the year by flowering and producing seeds, which can germinate and develop into new plants. We can observe that a tree obtains materials and energy from its surroundings, since without sunlight, soil, nutrients and water a tree will cease to grow.

We can also see when an organism is no longer living. In a tree the signs of death may be yellowing and loss of leaves, and branches that become dry and brittle. It is perhaps more difficult to tell whether or not mould on rotting fruit or vegetables is living (Figure 1.1.2). But if we carefully observe a patch of mould over a few days we can see it grow in size and eventually produce dark spores that disperse in air currents.

We can also apply the terms 'living' and 'dead' to parts of organisms, but this is not always straightforward. A fruit that has dropped from an apple tree encloses seeds, each of which contains and protects a living embryonic plant. In contrast, the outer corky part of the bark of the tree consists of dead tissue, just as the outer layer of your skin is dead. An organ such as a kidney that has been removed from a donor must be kept alive artificially if it is to be transplanted successfully into a recipient patient. If the organ died it could not maintain its structure and functions.

FIGURE 1.1.2 Moulds are also living organisms. This image shows mould (pale grey) growing in a compost bin on decaying fruit and vegetables.

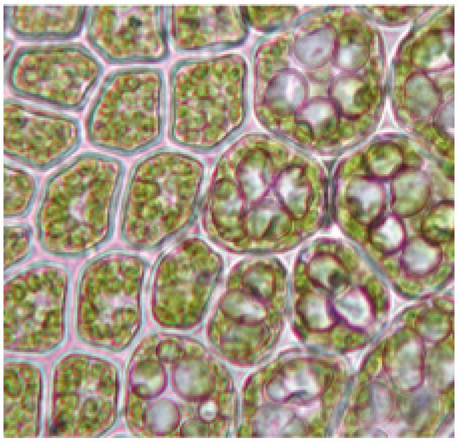


**FIGURE 1.1.3** Living cells of the leafy liverwort *Bazzania subtilis*, which grows in rainforests from Borneo to northern Queensland.

## ORGANISMS CONSIST OF CELLS

The **cell theory** is one of the fundamental principles of biology. It is based on microscopic and experimental studies of tissues, from all types of organisms, carried out over the last 300 years.

The cell theory states:

- all organisms are made up of cells (and the products of cells)
- all cells come from pre-existing cells
- the cell is the smallest living organisational unit.

There is really no such thing as a typical cell, but some features are common to all or most cells. All cells have an outer p**lasma membrane** (cell membrane) that encloses the fluid contents of the cell, the **cytoplasm**, and all cells have DNA as their genetic material. There are many different types of cells in animals and plants, and they have very different appearances and functions.

Modern techniques allow us to examine the smallest structures within cells, to visualise the surfaces of cell organelles (Figure 1.1.3), to grow and study single cells in culture, and to grow cells and use them as tiny factories to produce medically and commercially important molecules in huge quantities. In the following chapters of this unit we will consider the similarities and differences in the structure, activities and needs of various types of cells.

● *You will now be able to answer Key Questions 1 and 2.*

In phylogeny, a branching diagram (tree) shows how organisms are related to one another through evolution.

## EVOLUTION EXPLAINS DIVERSITY

**Evolution** is another fundamental principle of biology. Scientists have concluded that organisms have changed through time and that evolution is a fact. Observations which led them to this conclusion include:

- the diversity of living organisms
- their similarities and differences (Figure 1.1.4)
- the richness of the fossil record
- the geographic distribution of organisms
- the discovery of DNA and the genetic code.

Also techniques such as the ability to sequence and compare the DNA of different species support this conclusion. But how evolution occurs is still debated by biologists.

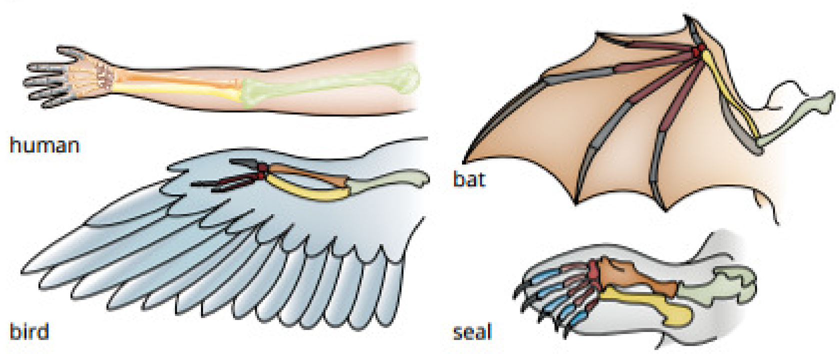



**FIGURE 1.1.4** Humans stand upright, bats and birds fly, and seals swim, but the skeletons of their forearms have the same pattern of bones. Only the shapes of the bones are different.

Taxonomists are biologists who draw together information from a wide variety of sources to discover how closely organisms are related to each other. Organisms can be grouped or classified in many ways (see Chapter 6). Scientific classification, which involves a hierarchy of names for all organisms, ensures that communication between scientists is accurate and efficient.

## CHARACTERISTICS OF ORGANISMS

In later chapters you will examine particular aspects of different organisms in much more detail. But there are certain features and requirements that characterise all living organisms (Figure 1.1.5). You are probably familiar with many of these from your earlier studies in science, and from your own reading and observations.


**FIGURE 1.1.5** (a) Rounded noonflower (*Disphyma crassifolium*). (b) An intermediate egret (*Ardea intermedia*) and its offspring. The rounded noonflower and the intermediate egret both show complexity, energy exchange, sensing and responding to the environment, growth and reproduction, and adaptive change over generations—all features that characterise living things.

All living organisms have the following features:

- movement—to find food, shelter and avoid predators; plants move more slowly as they grow, with leaves and stems moving as they grow towards sunlight to capture solar energy and roots moving down into the soil
- reproduction—the ability to produce offspring to keep the species in existence
- sensitivity—awareness of changes in the environment, and the ability to respond to those changes if necessary
- growth—animals grow to adulthood; plants grow throughout their life; even when growth stops, there is still growth and replication of cells to replace old or damaged cells and for repair
- respiration—extracting energy from food to support all other processes
- excretion—getting rid of wastes and toxic substances
- nutrition—animals eat plants and other animals for their nutrition; plants are able to make their own food by photosynthesis.

Additionally, all living organisms:

- are made of cells
- are chemically complex and highly organised
- show changes that are often adaptive over succeeding generations.

These features are common to all organisms: plants, animals, fungi, protists and bacteria. No non-living thing possesses all of these attributes.

● *You will now be able to answer Key Question 3.*

## COMMON REQUIREMENTS FOR LIFE

To carry out their various activities, organisms have certain requirements. All life requires a source of energy. The amount of energy required depends on the type of organism, its stage of growth, its level of activity and its reproductive state. Organisms also require nutrients and water for growth, maintenance and repair. The nutrients are organic compounds (including proteins, carbohydrates, lipids and vitamins) and minerals. These materials, or simpler substances from which they can be made, must be obtained from the surrounding environment. Organisms also require environmental conditions in which they can survive and reproduce.

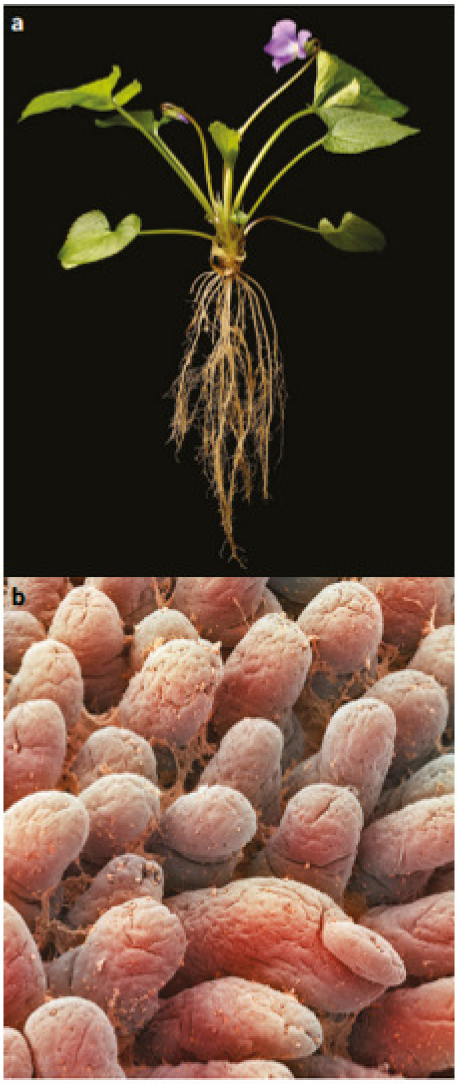



**FIGURE 1.1.6** Two examples of highly increased surface areas that are especially adapted for the uptake of nutrients: (a) the root system of a plant and (b) the internal surface of a human gut.

**FIGURE 1.1.7** To the males of a certain wasp species, the flying duck orchid (*Caleana major*) looks and smells like a female wasp.

In using energy and carrying out the processes of growth, maintenance and repair, an organism produces substances that are of no use to them, and some of these substances may be harmful to the organism. These waste substances are often removed by releasing them into the environment.

The ways that organisms carry out exchanges with their environment depend partly on the size of the organism and partly on the amount of material that needs to be exchanged. For small organisms with moderate needs, the processes are relatively simple; exchange and distribution within the organism occurs by diffusion. Larger organisms, and smaller organisms with very high nutritional requirements, have evolved large or complex systems for transport and exchange, such as the leaves and root systems of plants and the circulatory, digestive and excretory systems of animals (Figure 1.1.6). Organisms must also be able to sense and respond to changes in their internal and external environments.

● *You will now be able to answer Key Questions 4 and 5.*

## ORGANISMS ARE ADAPTED TO THEIR ENVIRONMENTS

When studying the ways that different organisms function, the advantages of some features are often very clear. For example, the blood of Antarctic icefishes contains a substance that lowers the freezing point of their blood, allowing them to live at temperatures that would freeze the blood of other fishes. Banksia cones are woody and hard, and seeds are protected in the cone until they are released into the nutrient rich ash following a fire. (Banksia seedlings have a greater chance of surviving if there has been a fire.) The native orchid *Caleana major* is commonly called the flying duck orchid because to us it looks like a tiny flying duck (Figure 1.1.7). To the male of a certain wasp species, however, it looks and smells like a female wasp. The wasp attempts to mate with the orchid, and in doing so transfers pollen from one orchid flower to another. In each of these examples the feature makes the organism better able to succeed in its environment.

Any study of the ways that organisms function is enhanced by an understanding of the principle of **adaptation**. Over time, species accumulate genetic changes that make them structurally, physiologically and behaviourally adapted to the particular environment in which they live. This adaptation is the result of **natural selection**. Individuals with features most suited to their environment are likely to survive and produce more offspring than those with less favourable features. So the next generation will have more individuals who have inherited the favourable feature and fewer individuals who lack it. Over many generations, favoured features become more frequent in the **population** and undesirable features become less frequent.

Adaptation means that the inherited structures, functions and behaviours of organisms make the individuals well suited to their environments and life styles.

● *You will now be able to answer Key Questions 6 and 7.*

## 1.1 Review

### SUMMARY

- The cell theory is a fundamental principle of biology, and is based on evidence collected over the last 300 years.
- Evolution and adaptation are fundamental principles of biology that are underpinned by a vast amount of experimental and observational evidence.
- Living organisms have common characteristics and requirements. They are made of cells, are chemically complex and highly organised, exchange energy and materials with their environment, grow and reproduce, sense and respond to their environment, and show changes that are often adaptive.

### KEY QUESTIONS

**1** Which of the following statements about cells is true?
- **A** Cells are made of organelles, which are the smallest organisational units of life.
- **B** All cells have a plasma membrane, cytoplasm and nucleus.
- **C** All cells are composed mainly of inorganic material such as carbohydrates, proteins, nucleic acids and lipids.
- **D** Cells and their products are the components of all living things.

**2** Name three components that all cells possess.

**3** List the features shared by plants and animals that enable scientists to classify them all as 'living things'.

**4** Decide whether each of the items listed is living, dead, or inorganic. Give reasons for your decision in each case.

| | |
|---|---|
| grass | timber chair |
| bee | dry fallen twig |
| honey | ripening peach on a tree |
| gravel | sleeping possum |
| hair | hibernating bat |
| spider web | growing crystals |

**5** Define the term 'adaptation'.

**6** Give two examples of adaptations mentioned in the text.

**7** The idea of adaptation is a key component of which biological principles?

# 1.2 The molecular composition of organisms

There are 92 different types of naturally occurring atoms on Earth, and each type is known as an element. Some of these elements, such as carbon, aluminium, silicon, iron, oxygen and hydrogen, are very common, while others such as osmium, thallium and tellurium are very rare. The same elements can be found in rocks, soil, air, plants and animals. But there is a difference in the way that these atoms are organised into larger compounds (compounds are molecules containing different elements) in living organisms. Organisms produce characteristic complex compounds that contain carbon and hydrogen (Figure 1.2.1). These are called **organic compounds** because the first ones discovered were produced by organisms or found in them. Most large organic molecules are composed of many smaller organic molecules linked together.

All other compounds, whether in living or non-living things, are called **inorganic compounds**. Inorganic compounds that are important for living organisms include water, oxygen, carbon dioxide, nitrogen and minerals.

● *You will now be able to answer Key Questions 1 and 2.*

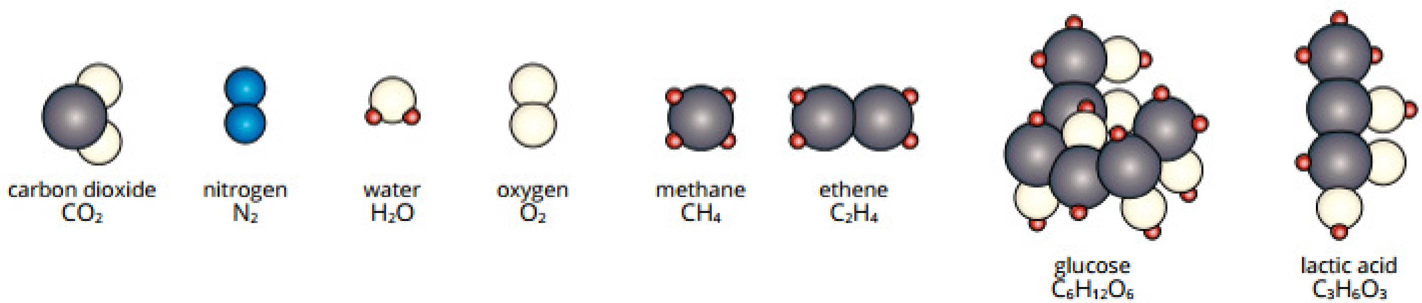



**FIGURE 1.2.1** Some common molecules in organisms. Carbon atoms are coloured black, oxygen white, hydrogen red and nitrogen blue.

## INORGANIC COMPONENTS

### Water

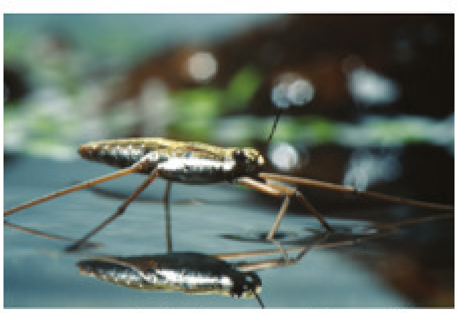


**FIGURE 1.2.2** A wingless water strider walking over the surface of a lake.

Life evolved in water. Most organisms are 70–90% water, and the chemical reactions that take place in cells take place in a watery medium. This is why the properties of water, such as pH, cohesiveness and heat capacity, are important in many biological processes. Water molecules are very **cohesive**, which means they have a strong tendency to stick together. This property allows thin columns of water to be pulled up tree trunks without breaking. Bonds between surface molecules also cause **surface tension**, which allows small insects to walk across the surface of water without breaking into the water molecules and sinking (Figure 1.2.2).

Water has a high **heat capacity**; that is, it can absorb a great deal of heat with very little increase in temperature. This is important for temperature regulation. When you exercise, the chemical reactions taking place in your cells produce heat. Much of this heat can be absorbed by water in your body, without the cells heating up significantly. Because water has a high heat of vapourisation, the evaporation of even small amounts of water will be effective in cooling that part of the body surface.

● *You will now be able to answer Key Question 3.*

## Oxygen and carbon dioxide

In most cells, oxygen is needed to release energy from food molecules in processes known collectively as **cellular respiration**. A constant supply of oxygen is therefore necessary to maintain the activity of these cells. This is usually easy for organisms that get their oxygen from air, because the atmosphere is 21% oxygen. However, oxygen is not very soluble in water (Figure 1.2.3), so organisms that get their oxygen from water are either small, flat and relatively inactive, or have very efficient ventilation systems, such as fish gills.

Carbon is the key atom in organic molecules. Carbon dioxide ($CO_2$) is taken from the atmosphere (which contains approximately 0.033% by volume of carbon dioxide) by plants, some bacteria and some protists. It is used in the process of photosynthesis to make sugars, some of which are eaten by animals. Carbon dioxide is returned to the atmosphere mainly by the decay of organic material and as an end-product of cellular respiration. This cycling of carbon through organisms and the atmosphere is critical to the survival of all organisms.

FIGURE 1.2.3 Carbon dioxide is a byproduct of cellular respiration, and is expelled from your lungs when you breathe out.

## Nitrogen

Nitrogen is required by organisms in relatively large amounts because it is a key component of all proteins. There is plenty of nitrogen around because the atmosphere is about 78% nitrogen gas ($N_2$). Atmospheric nitrogen is trapped by certain bacteria and converted into compounds that can be used by plants in a process known as **nitrogen fixation**. Symbiotic bacteria in the roots of some plants, such as legumes, she-oaks and acacias, are by far the most important for this (Figure 1.2.4).

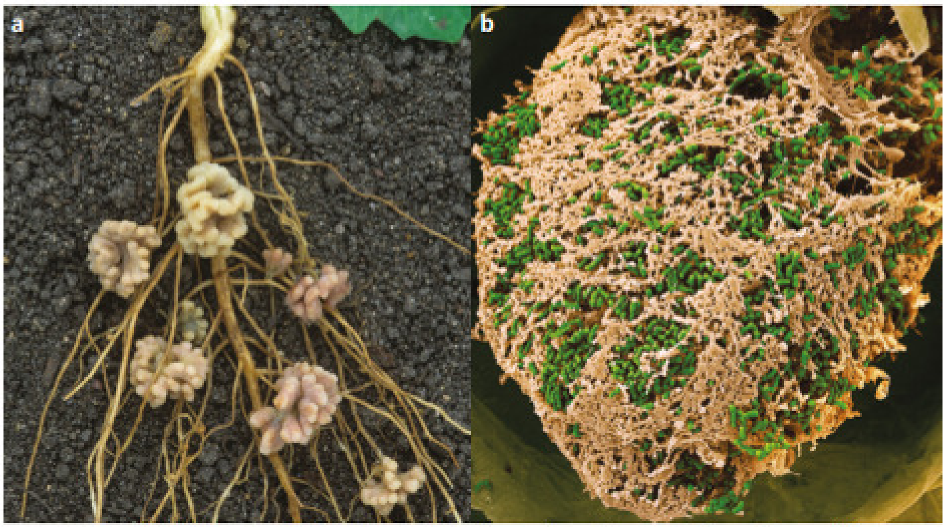



FIGURE 1.2.4 (a) Nodules containing nitrogen-fixing bacteria on the roots of a garden pea (*Pisum sativum*). b) Nitrogen-fixing bacteria. Coloured scanning electron micrograph (SEM) of nitrogen-fixing soil bacteria (*Rhizobium* species) in a root nodule of a bean plant. These bacteria (green) have a symbiotic relationship with the plant.

FIGURE 1.2.5 A soil profile showing the horizons (layers) which vary in colour depending on the mineral content in the soil. Plants absorb these minerals when they draw water out of the soil.

## Minerals

Biologically important minerals include phosphorus, potassium, calcium, magnesium, iron, sodium, iodine and sulfur. Many others are needed in small (trace) amounts. Mineral salts are produced by the weathering of rocks and are absorbed in solution by the roots of plants (Figure 1.2.5). Mineral ions are found in the cytosol of cells, in structural components (such as bone) and in the molecules of many enzymes and vitamins. They may also be incorporated into other important organic compounds in cells. Humans require more than 20 minerals, some in only minute quantities.

# ORGANIC MOLECULES

The photosynthetic parts of plants and algae—usually coloured green—are able to trap carbon dioxide from the air and convert it into the simple carbohydrate glucose by a process known as photosynthesis (see Chapter 3). In this way, plants and algae are the ultimate sources of organic molecules. The more complex organic molecules needed for growth are made by linking simple molecules together or by attaching other chemical groups such as amines (containing $NH^{2-}$) or phosphates (containing $PO_4^{2-}$).

The four main types of organic molecules are carbohydrates, lipids, proteins and nucleic acids (Figures 1.2.6 to 1.2.9). In mammals these can be converted from one form into another within cells. Units may be linked together to form larger molecules, and other chemical groups may be attached to form molecules such as glycoproteins (proteins with sugars attached) and phospholipids (lipids with phosphate attached). When food is plentiful, carbohydrates are converted into fats for storage; when it is scarce the reverse will occur and even proteins can be converted into small molecules to use for energy.

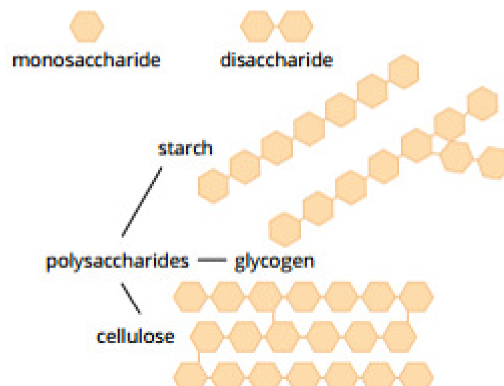



**FIGURE 1.2.6** The structures of some carbohydrates.

## Carbohydrates

**Carbohydrates** are the most abundant organic compounds in nature. They are an important source of energy for living organisms. In plants, starch is a carbohydrate used for energy storage and cellulose is a carbohydrate used for structural support. In animals, glycogen is a carbohydrate used for energy storage.

Carbohydrates are compounds made of carbon, hydrogen and oxygen. The basic subunits of carbohydrates are simple sugars called **monosaccharides** (meaning 'single sugars'). For example, glucose is a monosaccharide formed during photosynthesis. In simple carbohydrates the hydrogen and oxygen are present in the same proportions as in water: there are two hydrogens for each oxygen atom. The general formula is $C_nH_{2n}O_n$.

When two sugars are joined together they form a **disaccharide** (meaning 'two sugars'), and a molecule of water is removed. When many are joined together they form long chains called **polysaccharides** ('many sugars') (Figure 1.2.6).

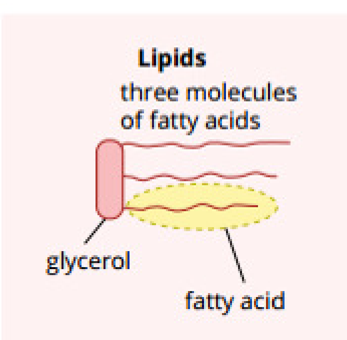



**FIGURE 1.2.7** The structure of lipids.

## Lipids

**Lipids** are fatty substances. They include fats and oils, which are important as energy-storing molecules (Figure 1.2.7). Phospholipids are an important component of cell membranes, which contain the cell's contents and subdivide it into many sub-cellular compartments. Steroids are lipids that act as membrane components, hormones and vitamins.

Lipids are composed of carbon, hydrogen and oxygen, but in different proportions to carbohydrates. Lipids contain a much smaller proportion of oxygen, and they can contain other elements such as phosphorus and nitrogen.

## Proteins

**Proteins** are more complex than carbohydrates or lipids. There are thousands of different kinds of proteins, and their functions vary widely. While carbohydrates and lipids are similar in all plants and animals, each kind of organism has its own unique proteins. Some proteins form structural components of cells; others are enzymes, hormones or carrier molecules. For example, haemoglobin is a protein that carries oxygen in the blood.

All proteins contain carbon, hydrogen, oxygen and nitrogen; many also contain sulfur, and often phosphorus and other elements. Proteins are composed of chains of smaller subunits called **amino acids** (Figure 1.2.8). Amino acids in proteins are linked by a particular kind of chemical bond called a peptide bond, and proteins are called polypeptides or polypeptide chains. There are 20 different amino acids commonly found in proteins.

The study of all the proteins of an organism is known as proteomics. In medicine, 99% of all drugs are proteins, or act by binding to proteins. A better understanding of proteins and proteomes (all the proteins produced by organisms) will aid the development of new pharmaceuticals, clarify the relationships between genes and diseases (e.g. by identifying marker proteins for diseases), and lead to better treatments.

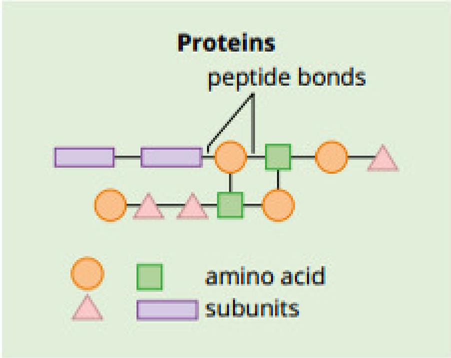



**FIGURE 1.2.8** The structures of proteins.

## Nucleic acids

**Nucleic acids** are the genetic material of all organisms, and they determine many of the features of an organism. There are two types of nucleic acid: **DNA** (deoxyribonucleic acid) and **RNA** (ribonucleic acid). Both are made of long chains of subunits called nucleotides (Figure 1.2.9).

DNA carries the information needed to assemble proteins from amino acid subunits. It is accurately passed from cell to cell during cell division. RNA plays a major role in the manufacture of proteins within cells.

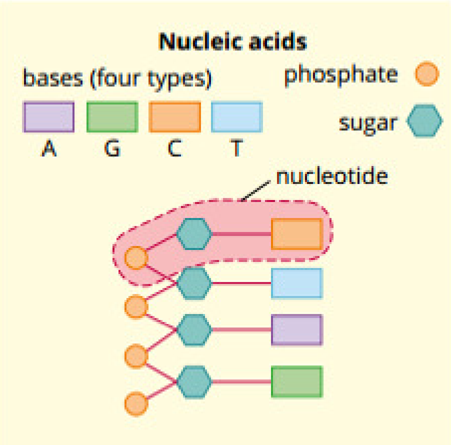



**FIGURE 1.2.9** The structures of nucleic acids.

## Vitamins

Vitamins are organic molecules required by animals in small amounts for normal functioning. Animals may be able to synthesise some vitamins, but others must be obtained in their diet. For example, most mammals can synthesise vitamin C, but humans must obtain it in their diet. Vitamins may be water-soluble (such as vitamins B and C) or lipid-soluble (such as vitamins A, D, E and K). Water-soluble vitamins must be consumed regularly in the diet because they cannot be stored in body tissues. Lipid-soluble vitamins can be stored. Many vitamins are important because they are needed to make particular enzymes.

● *You will now be able to answer Key Questions 4–6.*

# 1.2 Review

## SUMMARY

- Inorganic components of living organisms include water, oxygen, carbon dioxide, nitrogen and minerals.
- Organic components include carbohydrates, lipids, proteins and nucleic acids.
- Important properties of water include cohesiveness, surface tension, heat capacity and pH.
- Oxygen is needed for efficient energy supply in organisms.
- Carbon dioxide is the ultimate source of carbon for organic molecules, and nitrogen is a key molecule of proteins.
- Carbohydrates are important as energy sources and for structural components of organisms.
- Lipids play an important role in cell membranes.
- Proteins are composed of amino acids and their functions vary. Organisms have their own unique proteins.
- Minerals are important for building many enzymes.
- Structural organic molecules and vitamins are small organic molecules that are vital for normal cell function.
- Nucleic acids carry the genetic information of cells.

## KEY QUESTIONS

**1** **a** Define the terms 'organic compound' and 'inorganic compound'.

**b** Is carbon dioxide organic or inorganic? Explain.

**2** Which of the following statements is true?

**A** All organic compounds contain carbon and nitrogen.

**B** All organic compounds contain carbon and hydrogen.

**C** All organic compounds contain carbon, hydrogen and oxygen.

**D** All organic compounds contain carbon and oxygen.

**3** Copy and complete the following table, which should list the four main types of organic compounds that make up organisms, the elements of which each is composed, and the main function of each compound.

| Organic compound | Elements | Main function |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | carbon, hydrogen, oxygen, phosphorus, nitrogen | |

**4** Match each of the following terms to the correct statement about it.

| | |
|---|---|
| carbohydrate | byproduct of cellular respiration |
| carbon dioxide | composed of amino acids |
| lipid | compound of carbon, hydrogen and oxygen |
| mineral | examples are phosphorus, calcium and potassium |
| nucleic acid | fatty substance stored in tissues |
| oxygen | made of subunits called nucleotides |
| protein | may be water-soluble or lipid-soluble |
| vitamin | needed for cellular respiration |

**5** Name the units that make up the following compounds.

**a** nucleic acids

**b** proteins

**c** carbohydrates

**6** Are minerals and vitamins inorganic or organic? Explain your answer.

# 1.3 The scientific method

Biology is the study of living organisms. As scientists, biologists extend their understanding using the scientific method, which involves investigations that are carefully designed, carried out and reported. Well-designed research is based on a sound knowledge of what is already understood about a subject, as well as careful preparation and observation (Figure 1.3.1).

FIGURE 1.3.1 An entomologist (a scientist who studies insects) collecting insects from the top of a tropical rainforest tree.

## OBSERVATION

**Observation** includes using all your senses and the wide variety of instruments available to allow closer observation. Through careful inquiry and observation you can learn a lot about organisms, the ways they function, and their interactions with each other and the environment. For example, animals clearly function very differently from plants. Animals usually move around, take in nutrients and water, and often interact with each other in groups. We find them in water, on land, and flying in the air. Some are fast, efficient predators (Figure 1.3.2). Some maintain high body temperatures. They may mate to reproduce, and some care for their offspring as they grow. On the other hand, plants are green, stationary, turn their leaves towards the light and grow. Sometimes they lose all their leaves then grow new ones. Many develop flowers and fruit for reproduction. All of these things can be learned from simple observation. Observational studies are a common research method you'll learn more about in the next section.

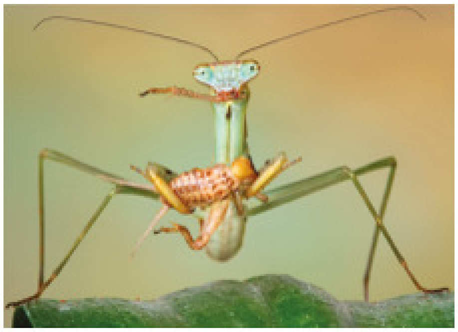


FIGURE 1.3.2 The praying mantis is a fast, efficient predator. Its green colouration and leaf-like shape give it the deadly advantage of camouflage.

The idea for a first-hand investigation of a complex problem arises from prior learning and observations. This tells us there are questions to be answered. For example, indoor plants do not grow well in the long term without artificial lighting, which suggests light is required for photosynthesis in plants. This aspect of photosynthesis can be researched.

How observations are interpreted depends on past experiences and knowledge, but to enquiring minds they will usually provoke further questions such as:

- How is a grassland ecosystem different from a forest?
- What are the basic differences between plants, animals, bacteria, fungi and protists?
- How do organisms grow?
- What materials and conditions do they need to grow?
- What do particular structures do?
- How do these structures work?

Many of these questions cannot be answered by observation alone, but they can be answered through scientific investigations. For example from his careful observations, Lazzaro Spallanzani was able to suggest an explanation for the night vision of bats (see the Biology in Action below). However, he did not know whether he was likely to be correct until he performed certain experiments.

● *You will now be able to answer Key Question 1.*

**BIOFILE**

### Large bats do not use echolocation

Small bats use echolocation to catch insects or other small animals. However, larger bats such as flying-foxes (fruit bats) do not use echolocation, because their main diet is fruits and other plant matter. Instead they have large eyes for better night vision.

**FIGURE 1.3.4** Fruit bats do not use echolocation, but they have large eyes for better night vision.

**BIOLOGY IN ACTION**

## Flying blind

**FIGURE 1.3.3** The large nose of this microbat is adapted to send ultrasonic signals, and its ears are adapted to pick up the faint returning echoes.

In 1793, Italian scientist Lazzaro Spallanzani observed that owls could not fly in complete darkness, or with their eyes covered, but that bats could. Bats could not only 'fly blind', but they were apparently just as efficient at catching insects for food when their eyes were covered as they were when they could see. He wondered how they did this. He found that if he plugged their ears, the bats had no sense of direction and collided randomly into obstacles, but if the plugs had a central hole then they flew normally. He concluded that bats used their ears to detect obstacles and prey at night (Figure 1.3.3). This suggestion was ridiculed and then virtually forgotten. Everyone thought bats must use a sense of touch to avoid obstacles.

Over 100 years later, during the First World War, sonar (also known as echolocation) was developed for detecting submarines under water. By sending out a sound signal and analysing the returning echoes, the position and size of any object that reflects the sound could be determined.

Soon after the war, when a bat inadvertently flew into his room at Cambridge, English physiologist Hamilton Hartridge realised bats might rely on ultrasonic echolocation to orientate themselves at night (ultrasonic sounds are too high in frequency to be heard by humans). Finally, in 1938, the ultrasonic signals made by bats were detected with a receiver designed to hear the high-pitched signals emitted by insects. Spallanzani's original prediction that bats used hearing to navigate at night had been validated by an independent researcher's supporting evidence.

## LEARNING BY EXPERIMENTATION

Scientists observe, study what is already known, and then ask questions. Using their knowledge and experience, scientists suggest possible explanations for the things they observe. A possible explanation is called a **hypothesis**. A hypothesis can be used to make certain predictions. Often these predictions can be tested experimentally. This is the basis of the scientific method (Figure 1.3.5).

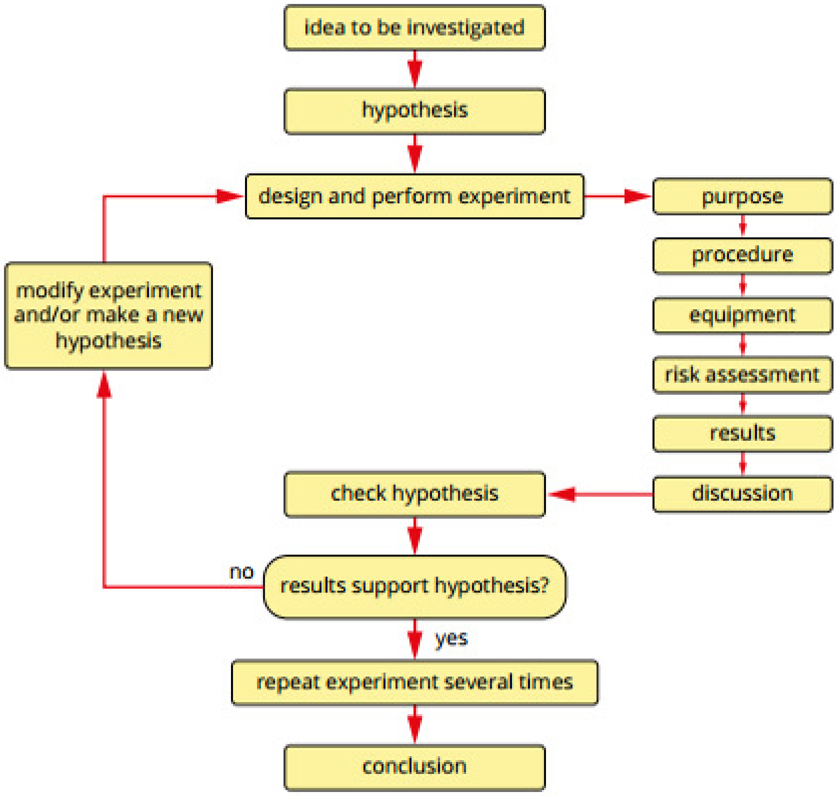



**FIGURE 1.3.5** The scientific method.

Carefully designed experiments are carried out to determine whether the predictions are accurate or not. If the results of an experiment do not fall within an acceptable range, the hypothesis is rejected. If the predictions are found to be accurate, the hypothesis is supported. If, after many different experiments, one hypothesis is supported by all the results obtained so far, then this explanation can be given the status of a **theory** or **principle**.

There is nothing mysterious about the experimental approach to the study of science that is called the **scientific method**. You might use the same process to find out how an unfamiliar machine works if you had no instructions. Careful observation is usually the first step.

● *You will now be able to answer Key Question 2.*

## ASKING THE RIGHT QUESTIONS

In science, there is little value in asking questions that cannot be answered. An experimental hypothesis must be testable, but your inability to test a particular hypothesis does not mean that the hypothesis cannot be correct. If you asked the question, 'How do bats navigate at night?', there would be no point in your hypothesis being 'Bats use thought waves to navigate', because it is not possible to test this.

You must also ask the right questions to get answers that are relevant to the problem you are examining. There is no point in asking how long bats live when you are studying their navigation, as the information you obtain will not help to test the hypothesis. Spallanzani had two hypotheses that were both testable and relevant:

- Hypothesis 1: Bats do not depend on their eyes to navigate at night.
- Hypothesis 2: Bats use their ears to navigate at night.

● *You will now be able to answer Key Question 3.*

## CHOOSING THE RIGHT METHOD

To conduct a scientific experiment correctly, the methods used must be reliable. Methods must be described clearly and in sufficient detail to allow other scientists to repeat the experiment. If other scientists cannot obtain similar results when an experiment is repeated, then the experiment is considered unreliable. It is also important to avoid personal bias that might affect the collection of data or the analysis of results. A good scientist works hard to be objective (free of personal bias) rather than subjective (influenced by personal views). The results of an experiment must be clearly stated and must be separate from any discussion of the conclusions that are drawn from the results.

> Experiments and their results must be able to be repeated by other scientists to be validated.

In science, doing an experiment once is not usually sufficient. You can have little confidence in a single result because you cannot be sure that the result was not due to some unusual circumstance that occurred at the time. The same experiment is usually repeated a number of times over a period of time and the combined results are then analysed statistically. If the statistics show that there is a low probability (usually less than 5%, referred to as $P < 0.05$) that the results could have occurred as a result of chance, then the result is accepted as being significant.

Spallanzani tested his first hypothesis by using a number of blindfolded bats. They were still able to fly and catch insects for food. He tested his second hypothesis by blocking their ears. Bats with tightly blocked ears were unable to navigate at night or catch insects.

- *You will now be able to answer Key Question 4.*

## THE NEED FOR EXPERIMENTAL CONTROLS

> The experimental conditions of the control group are identical to the experimental group, except that the variable of interest (the independent variable) is also kept constant.

It is difficult—sometimes impossible—to eliminate all **variables** that might affect the outcome of an experiment. In biology, time of day, temperature, amount of light, season, and level of noise are examples of such variables. A way to eliminate the possibility that random factors affect results is to set up a second group within the experiment (called a **control group**) that is identical in every way to the first group (the **experimental group**) except for the single experimental variable that is being tested. This is a controlled experiment. Because it allows us to examine one variable at a time, it is an important way of testing a hypothesis.

> In an experiment, controlled (fixed) variables are kept constant; only one variable (the independent variable) is changed, and the dependent variable is measured to determine any effect of the change.

The variable that the experimenter is testing is the **independent variable**. In our example, Spallanzani separately tested two independent variables—the abilities to see and to hear. The **dependent variable** is what is measured when the independent variable changes. In this example the dependent variable that Spallanzani measured in each case was the number of insects caught.

- *You will now be able to answer Key Question 5.*

What experimental controls were needed in Spallanzani's experiments? Did blindfolded bats catch the same number of insects as normal bats? Measuring the number of insects caught by normal bats was a necessary control. Did the earplugs interfere in some other way with the bat's behaviour? Spallanzani made a device to place in the bats' ears that was similar to the one used to block their hearing, but allowed sound through. With this device in their ears bats flew perfectly well, indicating that it was the loss of hearing not the presence of the plugs in their ears that prevented navigation. More detail on setting up an investigation with controls and variables is included in section 1.4.

**BIOFILE**

### The simplest hypothesis

The idea that the simplest hypothesis should be accepted was first put forward by the Greek philosopher Aristotle. It is sometimes called Ockham's Razor, because a 14th century English philosopher named William of Ockham accepted it as a fundamental principle of philosophy.

## MAKING VALID CONCLUSIONS

Conclusions are based on results and other knowledge. Making valid conclusions depends on the reliability of results and whether they are correctly interpreted. Speculation involves going beyond the results to make suggestions about what might be occurring. Conclusions are necessary, but speculation is interesting and thought-provoking. Both concluding and speculating are worthwhile, but you must be careful to keep them separate. It is also the usual practice of scientists to accept the simplest hypothesis that accounts for all the evidence available.

**BIOFILE**

### Moths can hear bats

Some moths (Figure 1.3.6) can tune their hearing organs (which are on the sides of their thorax) to the frequency of the echolocation signals of bats, and then respond appropriately. This has been demonstrated experimentally (Figure 1.3.7).

**FIGURE 1.3.6** This eyed hawk-moth, (*Smerinthus ocellatus*) is capable of tuning its hearing organs so that it can hear bats.

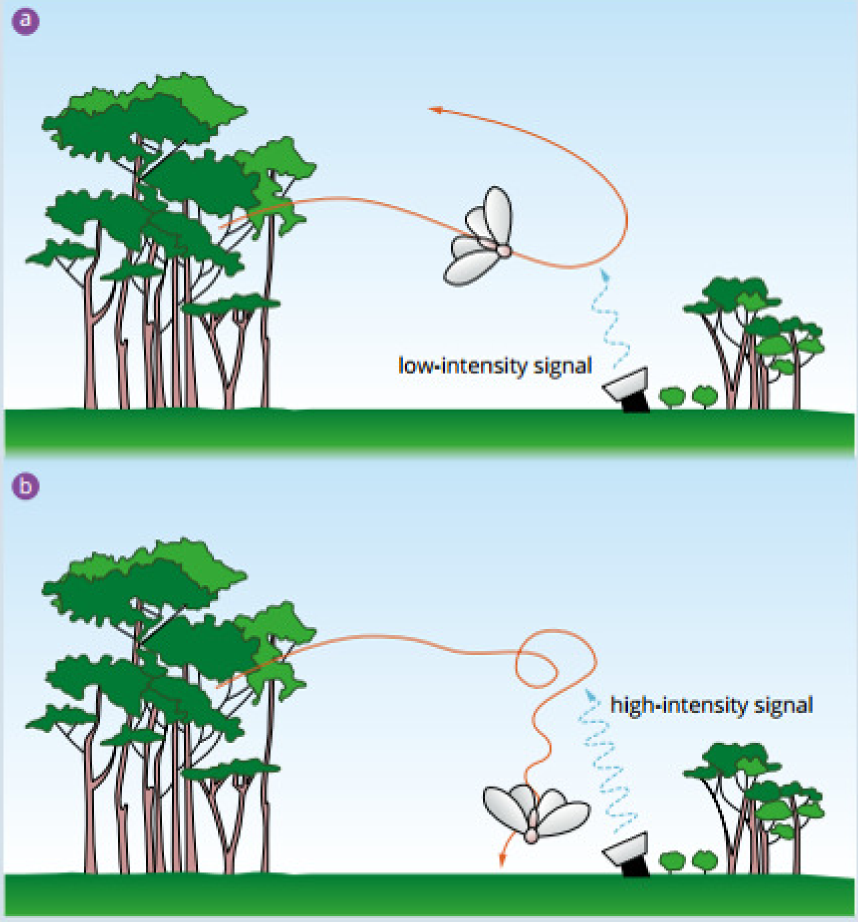



**FIGURE 1.3.7** A loudspeaker was set up in a field and the experimenter was able to see moths as they came into the clearing. (a) When a low-intensity bat echolocation call was played (simulating a bat that was some distance away) the moths simply flew away again. (b) When a high-intensity call was played (simulating a bat that was very close) the moths quickly went into a downward spiral, dropping out of the echolocation range.

The conclusions made by Spallanzani were valid. He concluded that the bats he studied did not need to see to navigate at night, but that they did need to hear. Even so, he was not believed for a long time.

Imagine you are Spallanzani and that you are going to write a report about your bat experiments. What type of information should be included in your report? What headings could you use? What would you include under each heading? What other information might be useful to other scientists?

## LIMITATIONS OF THE SCIENTIFIC METHOD

The scientific method is not perfect; however, it remains the best way to understand our surroundings, and to constantly improve on that understanding. Even when the scientific method is strictly adhered to, there is still an element of chance in scientific discovery. Many great discoveries have been made when a scientist has been busy investigating another problem. Good scientists have acute powers of observation and enquiring minds, and they make the most of these chance opportunities (Figure 1.3.8, page 18).

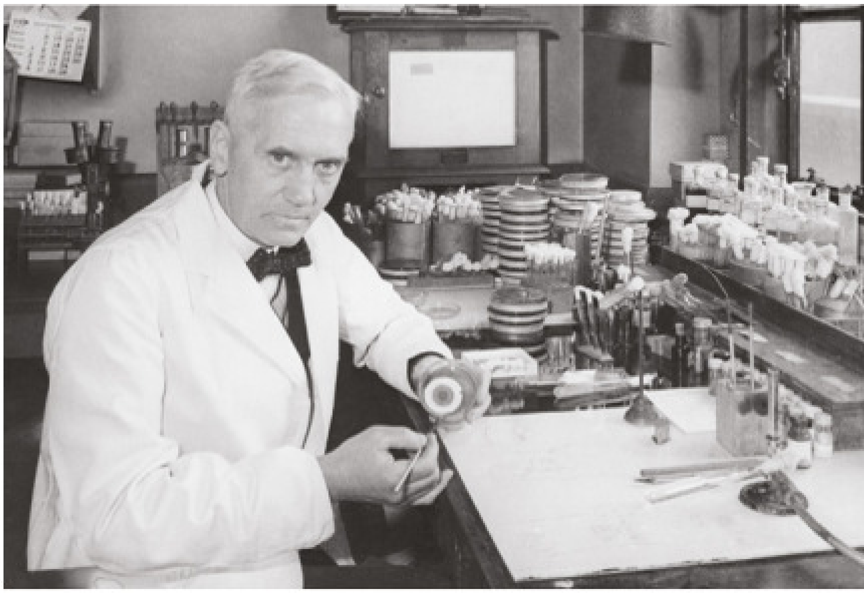


**FIGURE 1.3.8A** Scottish biologist Alexander Fleming discovered penicillin when one of his agar plates containing *Staphylococcus* bacteria was contaminated with a fungus (*Penicillium notatum*). He noticed that bacterial colonies were unable to grow in the zone around the fungus, as if it were secreting something that inhibited their growth. That something would later be called penicillin, the first antibiotic.

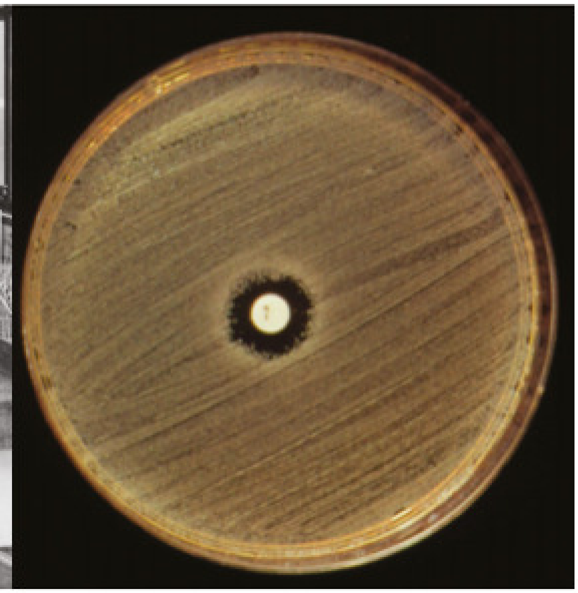


**FIGURE 1.3.8B** A culture of *Staphylococcus aureus* bacteria with a white disc containing penicillin placed at the centre. *Staphylococcus aureus* has not been able to grow near the penicillin disc.

The scientific method can be applied only to hypotheses that can be tested, and to questions that can be answered. A hypothesis that is not testable can be neither supported nor disproved by the scientific method. Such hypotheses therefore remain as possible explanations. For example, we cannot use scientific experiments to determine whether there is 'life after death', because we cannot do suitable experiments. It is also important to understand, that while science can prove a particular hypothesis wrong, it cannot prove that hypothesis to be true in all circumstances—only under the conditions that have been tested.

Science and the scientific method also cannot be used to test morality or ethics. These judgements belong to the fields of philosophy, history, politics and law. Science can, however, provide valuable information that people can take into account when making these judgements. For example, science can be used to predict the environmental consequences of pollution and the medical consequences of chemical weapons, but it cannot itself make value or moral judgements about either.

## EXPERIMENTATION

Once you have a testable hypothesis, you are ready to conduct an experiment to test it. Every experiment has to be designed and planned carefully. You need to be sure that somebody else can repeat your experiment exactly the way you did it and get similar results. In the next section, you will learn how to formulate your hypothesis and design an experiment to test it.

- *You will now be able to answer Key Questions 6 and 7.*

BIOLOGY IN ACTION

## Intertidal molluscs

If you wander along rocky seashores when the tide is out, you will see many different species of molluscs on the rocks (soft-bodied animals which often have shells). Limpets, mussels, periwinkles, and tiny blue littorinids are some of the molluscs commonly found along the Victorian coastline.

We can learn something about the dependence of the different mollusc species on water, and their ability to withstand drying out when the water recedes to the low tide mark, by observing the pattern of distribution of the molluscs along the shoreline (Figure 1.3.9).

Rocky shorelines can be divided into a subtidal zone (always covered with water), an intertidal zone (between low and high tide marks), a spray zone (splashed by water at high tide) and a supratidal zone (out of range of sea water).

Few molluscs are found in the subtidal and supratidal zones. In the intertidal region, limpets are scattered randomly, mussels are clumped together, and periwinkles are often found under rocks and in crevices. Littorinids are found mainly in the spray zone.

Some possible explanations for these observations are as follows:

- Each of these molluscs needs some contact with sea water.
- Limpets can tolerate a wide range of environmental conditions.
- Periwinkles cannot withstand long periods out of water.
- Mussels maintain higher moisture levels by clumping together.
- Littorinids need very little water.
- Periwinkles are eaten by predatory birds and only survive where they are hidden from view.

These explanations lead to further questions. How do molluscs protect themselves from drying out when they are out of water? Do different molluscs have different levels of resistance to drying out? Water is not likely to be the only factor affecting distribution. What other factors might be involved? You should think about whether your observations tell you anything about the importance of food sources, predation, temperature variation, the ability of the mollusc to withstand wave action, and how tightly each species of mollusc can hold onto rocks.

**FIGURE 1.3.9A** Black mussels clump together along rock crevices in the intertidal region of the shoreline.

**FIGURE 1.3.9B** Limpets distributed randomly over an exposed rock surface in the intertidal zone.

**FIGURE 1.3.9C** In the spray zone, tiny blue littorinids can be seen among the larger cream-coloured barnacles (which are small crustaceans in shells) and striped siphon-limpets.

*You will now be able to answer Key Question 8.*

**FIGURE 1.3.10** The glass in this greenhouse behaves like greenhouse gases such as carbon dioxide and methane in the Earth's atmosphere. Like greenhouse gases, the glass lets the sunlight in but prevents the reflected heat from escaping back out into space.

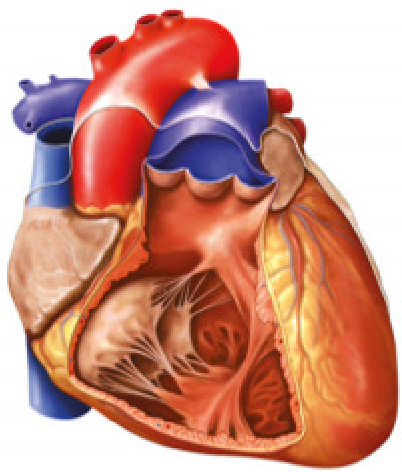


**FIGURE 1.3.11** A visual model of the human heart showing the external structure and internal structure of the right ventricle.

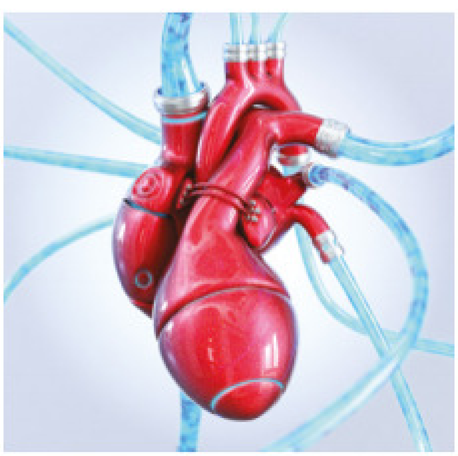


**FIGURE 1.3.12** An artificial heart model made from metal (red) and plastic tubes (blue) is useful for showing the movement of blood into and out of the heart. However, it is not useful for showing the rhythmic contractions of the heart muscles, or for showing the internal structure of the heart.

## MODELS

Scientific models are used to create and test theories and explain concepts. Different types of models can be used to study systems such as parts of the body or particular environments. However, each model has limitations on the type of information it can provide.

### Modelling concepts

Models are created to answer specific questions. How a model is designed will depend on the questions you want to answer. The two most familiar types of models are visual models and physical models, but mathematical models and computational models are also common. Models help to make sense of ideas by visualising:

- objects that are difficult to see because of their size (too big or too small) or position, such as an ecosystem, a cell, and a heart
- processes that cannot easily be seen directly, such as digestion and feedback loops
- abstract ideas such as energy transfer and the particulate nature of matter
- complex ideas such as climate change.

For example, the greenhouse effect on Earth can be modelled using a real greenhouse (Figure 1.3.10).

Using digital modelling software to develop physical or mathematical models has enhanced our understanding in many areas. For example, flight simulators have enabled pilots to learn how to fly new aircraft, and dissection and surgery simulations can replace the practice of dissecting living organisms.

A deeper understanding of concepts can be developed through models. However, you need to identify the benefits and limitations of using a particular model to represent a concept.

#### *Visual models*

Visual models are used to represent concepts. They are two-dimensional representations of concepts. Diagrams and flow charts are examples of visual models. A picture of the human heart with red and blue colouring to represent oxygenated and deoxygenated blood is an example of a visual model (Figure 1.3.11). It is difficult for us to see this phenomenon, so models can be used to represent it. The introduction of computer technology, including two-dimensional and three-dimensional animations, has helped to create more detailed and realistic representations of biological processes.

#### *Physical models*

Physical models can be scaled-up or scaled-down three-dimensional versions of reality. You have probably already used physical models many times in the classroom without being aware of it. The human skeleton is a physical model often seen in classrooms.

Although models help us to understand concepts, they are limited in how well they can represent what they are modelling. For example, although a plastic model of a lung does inflate and deflate, it does not take in oxygen and release carbon dioxide, and it is hard and solid instead of soft and flexible.

When making physical models (Figure 1.3.12), it is important to consider what materials are used to represent reality, so that the model has fewer limitations. The materials you use to construct your model should relate to what you are modelling.

● *You will now be able to answer Key Questions 9–13.*

# 1.3 Review

## SUMMARY

- Well-designed experiments are based on a sound knowledge of what is already understood or 'known' and careful observation.
- The scientific method is an accepted procedure for conducting experiments.
- A hypothesis is a possible explanation for a set of observations that can be used to make predictions, which can then be tested experimentally.
- Controlled experiments allow us to examine one factor at a time; they are the major means of testing hypotheses.
- Science can prove that a particular hypothesis is wrong, but it cannot prove it to be true in all circumstances.
- Science cannot be used to evaluate hypotheses that are not testable, nor can it make value or moral judgments.
- Models are useful tools that can be created and used to assist in a deeper understanding of concepts.

## KEY QUESTIONS

**1** What is the scientific method based on?
**A** observation
**B** subjective decisions
**C** manipulation of results
**D** generalisations

**2** Name the key components of the scientific method.

**3** Scientists make observations from which a hypothesis is stated and this is then experimentally tested.
**a** Define 'hypothesis'.
**b** How are theories and principles different from a hypothesis?

**4** **a** What do 'objective' and 'subjective' mean?
**b** Why must experiments be carried out objectively?

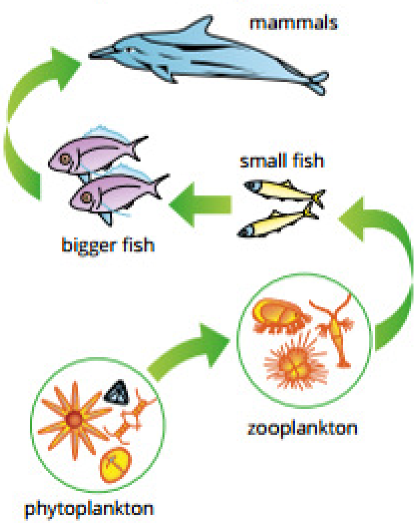
**5** Which of the following is an important part of conducting an experiment?
**A** disregarding results which do not fit the hypothesis
**B** making sure the experiment can be repeated by others
**C** producing results that are identical to each other
**D** changing the results to match the hypothesis

**6** **a** Explain what is meant by the term 'controlled experiment'.
**b** Using an example, distinguish between independent and dependent variables.

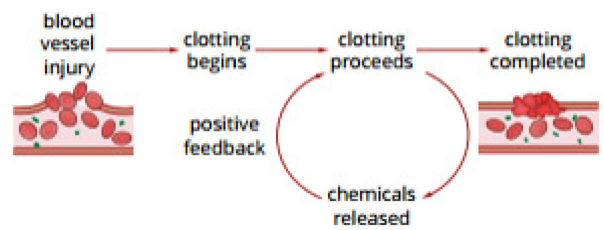
**7** A scientist carries out a set of experiments, analyses the results and publishes them in a scientific journal. Other scientists in different laboratories repeat the experiment, but do not get the same results as the original scientist. Suggest several reasons that could explain this.

**8** Design an experiment to test whether temperature is an important factor in the distribution of a mollusc species on a rocky coast. Clearly state the hypothesis that your experiment will test. Explain the methods that you would use. Do not forget to include experimental controls.

**9** Explain what is represented by the visual model below.




**10** Discuss the benefits and limitations of using the feedback loop model shown below.




**11** Explain the benefits of using a torso model to learn about the parts and relative positions of the organs in the human body.

**12** Explain two limitations of using models. Include an example.

**13** Discuss how computer modelling could assist in representing and learning scientific concepts.

# 1.4 Planning investigations

First-hand investigations are those where you gather the raw data for yourself. These often take the form of experiments, activities, field trips or surveys (Figure 1.4.1). There are many elements to this type of practical investigation. A step-by-step approach will help you through the process and assist you in completing a solid and worthwhile investigation.

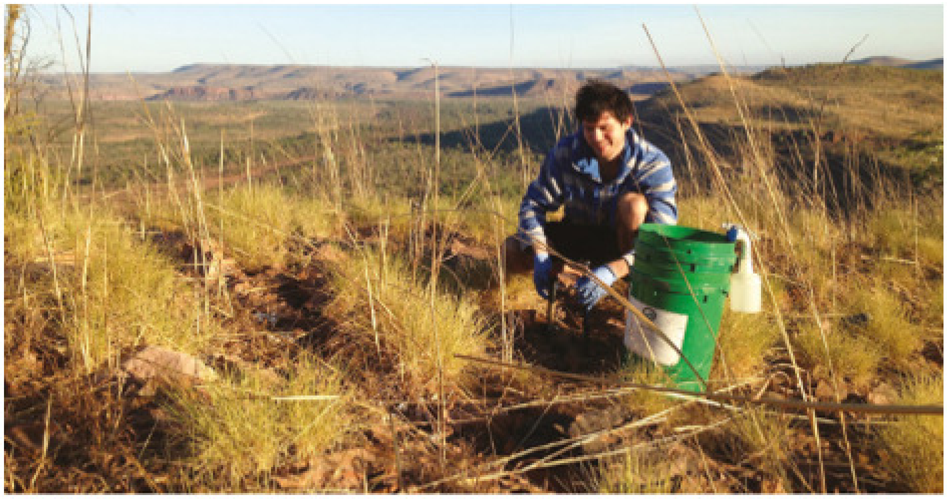


FIGURE 1.4.1 A microbiologist in the field collecting soil samples to test for bacteria in the East Kimberley, Western Australia.

Taking the time to carefully plan and design an investigation before you begin will help you maintain a clear and concise focus throughout. Preparation is essential. Ensure you have both a solid understanding of the theory behind your investigation and a detailed plan for the practical components of your investigation.

In this section you will learn about some of the key steps to take when planning and designing investigations:

- choosing a topic
- defining the key terms
- sourcing information
- research techniques
- ethics approval
- occupational health and safety.

## CHOOSING A TOPIC

Throughout the course of your studies, you will be required to conduct two major investigations. One will relate to the survival of an individual or species (your practical investigation), and the other will focus on applications of genetics knowledge and reproductive science in society (your investigation of an issue). The following sections in this chapter will provide you with the information you need to complete both.

### Practical investigation

In your practical investigation you will need to:

- develop a question and plan a course of action to answer the question
- undertake an experimental investigation to collect the appropriate primary qualitative and/or quantitative data; in the next section you will learn about how this data can be collected from laboratory work, fieldwork and/or observational studies
- organise and interpret the data and reach a conclusion in response to the question.

The question for your investigation must be related to the survival of an organism or a species. Some examples of things you might study include:

- how cellular structure or cellular organisation in an organism functions to sustain life
- how a structural, physiological or behavioural adaptation enhances the survival of an organism or enables it to exist in a wide range of environments.

### Investigation of an issue

In your investigation of an issue relating to genetic and reproductive science you will need to:

- explain the scientific concepts behind the genetic or reproductive technology or application chosen
- describe the technology or application
- discuss the impacts of this technology or application on individuals and society including the related social, economic, legal and ethical issues, which can be complex and controversial
- gather information from laboratory work, literature searches, global databases and/or interviews with experts.

When choosing a topic, choose one that you are interested in, including both the scientific theory and the implications for society. You must be willing to research different points of view in relation to your topic and discuss them.

Another thing to consider is the scope of your investigation. Remember you will need to keep to your word count, so you need to be concise, while still being accurate and complete. Choosing a specific focus rather than a general one will help ensure you are able to cover it thoroughly. For example, the specific topic 'Gene modification in plants or crops' can be covered more thoroughly in a limited format than the broader topic `Gene modification', which would include gene modification in all organisms.

## DEFINING KEY TERMS

When beginning a research investigation, you first have to develop and evaluate a research question, and determine the associated variables, hypothesis, and aims. It is important to understand that each of these can be refined as the planning of your investigation continues.

The research question is a statement defining what is being investigated. For example: Is the rate of transpiration in plants dependent on temperature?

The variables are the factors that change during your experiment. For example: temperature is a variable.

The hypothesis is a suggested outcome of the experiment based on previous knowledge and evidence or observations that attempts to answer the research question. For example: If the temperature increases from 20°C to 40°C then the rate of transpiration in plants will increase.

The aim is a statement describing in detail what will be investigated. For example: To investigate the effect of temperature on the rate of transpiration in plants at 20°C, 30°C and 40°C.

### Determining your research question

Before conducting an experimental investigation you need a research question to address. You may come up with a topic or idea of interest, so the first thing you need to do is conduct a literature review; that is, reading scientific reports and other articles on the topic, to find out what is already known, and what is not known or not yet agreed upon. The literature also gives you important information for the introduction to your report and ideas for experimental methods.

A literature review is an analysis of second-hand information. When conducting a literature review you should write down questions or correlations you find. Compile a list of possible ideas. Do not reject ideas that initially may seem impossible. Use these ideas to generate questions.

When you have defined the question, you are able to formulate a hypothesis, identify the measurable variables, proceed with designing your investigation and suggest a possible outcome of the experiment.

Stop to evaluate the question before you progress; it may need further refinement or even further investigation before it is suitable as a basis for an achievable and worthwhile investigation. Consider the following checklist:

- ☐ relevance—Your question must be related to your chosen topic. For your practical investigation decide whether your question will relate to cellular structure or organisation, or to structural, physiological or behavioural adaptations of an organism to an environment.
- ☐ clarity and measurability—Your question must be able to be framed as a clear hypothesis. If the question cannot be stated as a specific hypothesis, then it is going to be very difficult to complete your research.
- ☐ time frame—Make sure your question can be answered within a reasonable period of time. Ensure your question isn't too broad.
- ☐ knowledge and skills—Make sure you have a level of knowledge and a level of laboratory skills that will allow you to explore the question. Keep the question simple and achievable.
- ☐ practicality—Check the resources you require, like reagents and laboratory equipment, are going to be available. You may need to consult your teacher. Keep things simple. Avoid investigations that require sophisticated or rare equipment. More readily available equipment may include thermometers, photometers, light microscopes and other common laboratory equipment.
- ☐ safety and ethics—Consider the safety and ethical issues associated with the question you will be investigating. If there are issues determine if these need to be addressed.
- ☐ advice—Seek advice from your teacher on your question. Their input may prove very useful. Their experience may lead them to consider aspects of the question that you have not thought about.

## Defining your variables

The factors that can change during your experiment or investigation are called the variables. An experiment or investigation determines the relationship between variables, measuring the results. There are three categories of variables:

- independent—a variable that is controlled by the researcher (the one that is selected and changed)
- dependent—a variable that may change in response to a change in the independent variable, and is measured or observed
- controlled variables—the variables that are kept constant during the investigation.

You should have only one independent variable. Otherwise you could not be sure which independent variable was responsible for changes in the dependent variable.

## Constructing your hypothesis

The hypothesis is an educated guess (based on evidence and prior knowledge) to answer your research question. It defines a proposed relationship between two variables. To do this, you will need to identify the dependent and independent variables.

A good hypothesis is written in terms of the dependent and independent variables:

If *x* happens, then *y* will happen.

For example:

**If** *I bake potatoes, pumpkin and sweet potatoes at the same temperature,* **then** *the pumpkin will cook the fastest.*

The 'if' part of the hypothesis refers to the independent variable—the variable you alter in the experiment. The 'then' part relates to the dependent variable, which is the variable you measure or observe.

A hypothesis does not need to include 'if' and 'then' in its wording. For example, the previous hypothesis could also be worded in the following way:

*Pumpkin will cook faster than potatoes and sweet potatoes*
**when** *they are cooked at the same temperature.*

A good hypothesis can be tested to determine whether it is true (verified), or false (falsified) by investigation. To be testable, your hypothesis should include variables that are measurable.

### Writing a hypothesis from an inference

Scientists often develop a hypothesis by **inference** (reasoning) based on preliminary observations. For example, in summer the colour of grasses usually changes from green to brown or yellow. One observation is that grass growing near the edges of a concrete path stays green for longer than grass farther from the edges (Figure 1.4.2).

**FIGURE 1.4.2** The grass closer to the concrete and in between the cracks in the concrete is green.

A valid inference is one that explains all the observations. Some inferences that may explain why grass growing near the edge of the concrete path remains green in summer are as follows:

- Inference 1: This grass receives the rain runoff from the path when it rains.
- Inference 2: The concrete path insulates the grass roots from the heat and cold.
- Inference 3: People do not walk on this part of the grass.

For Inference 2 the hypothesis might be: 'The temperature of the soil around the grass roots under the path is less than the temperature of the soil around the grass roots beside the path.'

Creating a table like Table 1.4.1 will assist in evaluating your research question, the variables to be considered, and different hypotheses to be considered.

| Research question | Independent variable | Dependent variable | Controlled variables | Potential hypothesis |
|---|---|---|---|---|
| Does fertiliser make plants grow bigger? | fertiliser | plant height | type of plant, soil, temperature, water, and sunlight | If fertiliser is added to the soil, plant X will grow taller. |

**TABLE 1.4.1** Summary table of research question, variables and potential hypothesis

● *You will now be able to answer Key Questions 1 and 2.*

### Determining your aims

The aims are the key steps required to test your hypothesis. Each aim should directly relate to the variables in the hypothesis, describing how each will be studied or measured. The aims do not need to include the details of the method.

**Example 1**

- Hypothesis: If the temperature is increased, then the rate of transpiration in plants will also increase.
- Aim: To compare the rate of transpiration of corn seedlings in air temperatures of 15 °C, 25 °C, 35 °C and 45 °C over 24 hours.
- Variables: temperature (independent) and transpiration rate (dependent).

**Example 2**

- Hypothesis: Red flowers attract more bees than blue flowers.
- Aim: To compare the number of visits by bees to red flowers with the number of visits by bees to blue flowers over a set period.
- Variables: number of visits by bees (dependent) and level of contrast of the colour of flowers with their background (independent).

● *You will now be able to answer Key Questions 3–6.*

## SOURCING INFORMATION

When sourcing information for the literature review, researching experimental methods and investigating a broader issue, consider whether that information is from primary or secondary sources. You should also consider the advantages and disadvantages of using resources like books or the internet.

### Primary and secondary sources

Primary and secondary sources provide valuable information for research. Sometimes the same type of resource may be classified as both a primary and a secondary source, depending on when and by whom it was written. For example, a scientist's journal article on a clinical trial of treatments for teenage obesity is a **primary source**, while a general magazine article about teenage obesity written by a journalist and referring to the scientific study is a **secondary source**. Table 1.4.2 compares primary and secondary sources.

| | Primary sources | Secondary sources |
|---|---|---|
| **Characteristics** | • first-hand records of events or experiences<br>• written at the time the event happened<br>• original documents | • interpretations of primary sources<br>• written by people who did not see or experience the event<br>• use information from original documents but rework it |
| **Examples** | • results of experiments<br>• scientific journal/magazine articles<br>• reports of scientific discoveries<br>• photographs, specimens, maps and artefacts<br>• interviews with experts<br>• websites (if they meet the criteria above) | • textbooks<br>• biographies<br>• newspaper articles<br>• magazine articles<br>• documentaries<br>• websites that interpret the scientific work of others |

**TABLE 1.4.2** Summary of primary and secondary sources.

Secondary sources of information include books, journals, magazines, newspapers, interviews, television programs and the internet. You should aim to use a wide range of data sources when performing your second-hand data investigations. Secondary sources of information may have a bias, so you need to determine if they are accurate, reliable and valid sources of information. You will learn about assessing the accuracy, reliability and validity of second-hand data in section 1.5.

## Using books and the internet

The resources you use affect the quality of your research. Peer-reviewed scientific journals are the best sources of information, but you are unlikely to have access to them. Books, magazines and internet searches will be your most commonly used resources for information. However, you should be aware of the limitations of these resources (Table 1.4.3). Reputable science magazines you might find in your school library include *New Scientist*, *Cosmos*, *Scientific American* and *Helix* (Figure 1.4.3).

FIGURE 1.4.3 You will find reputable science magazines in your school library.

| | Book resources | Internet resources |
|---|---|---|
| **Advantages** | • written by experts<br>• authoritative information<br>• proofread, so information is accurate<br>• logical, organised layout<br>• content is relevant to the topic<br>• contain a table of contents and index to help find relevant information | • quick and easy to access<br>• allow access to hard-to-find information<br>• access to the whole world; millions of websites<br>• up-to-date information |
| **Disadvantages** | • may not have been published recently<br>• usable by only one person at a time | • time-consuming looking for relevant information<br>• a lot of 'junk' sites and biased material<br>• search engines may not display the most useful sites<br>• cannot always tell how up-to-date information is<br>• difficult to tell if information is accurate<br>• hard to tell who has responsibility for authorship<br>• information is not ordered<br>• less than 10% of sites are educational |

TABLE 1.4.3 Advantages and disadvantages of book and Internet resources.

### *Evaluating websites*

Remember that anyone can publish anything on the Internet, so it is important to evaluate the credibility, currency and content of online information:

- ☐ credibility—Consider who the author is, their qualifications and expertise; check for their contact information and for a trusted abbreviation in the web address, such as .gov or .edu; websites using .com may have a bias towards selling a product, and .org sites might have a bias towards one point of view.
- ☐ currency—Check the date the information you are using was last revised.
- ☐ content—Consider whether the information presented is fact or opinion; check for properly referenced sources; compare to other reputable sources, including books and science journals.

### *Evaluating books and journals*

Your textbook should be your first source of reliable information. Other information should agree with this. Articles published in journals can often present findings of new research, which may or may not be confirmed later, so be careful not to treat such sources of information as established fact. Scientific journals are peer-reviewed (critically reviewed by other specialist scientists), which gives them more credibility than other sources.

● *You will now be able to answer Key Questions 7 and 8.*

## RESEARCH METHODS

Many research methods are used in scientific investigations. In your studies you are required to undertake investigations through a combination of laboratory work and fieldwork.

### Laboratory work

In an investigation into the survival of an organism or species, laboratory work will likely involve light microscopy. For example, you might choose to investigate and observe a microscopic organism, or investigate the role of microscopic features in the survival of a larger organism. While researching the topic, look for methods that can be used in your school laboratory.

Types of things you might investigate in a lab include factors affecting the survival and growth of organisms. Check that you can:

- obtain and grow (or culture) the organism (might be plants, bacteria, protists or invertebrates)
- obtain the equipment and any reagents needed to perform the experiments; get trained in their use
- order any materials needed
- access the school laboratory when you need to.

#### *Protocol and schedule*

Write a protocol (detailed description) of how to conduct the experiment so that your teacher can check that it is appropriate, and so that others can repeat it exactly.

Test the protocol and evaluate and modify it if necessary. You need to be able to do it independently and in the time available in the school lab and with minimum support from your teachers and school laboratory staff.

Make a work schedule (including sufficient time to repeat experiments if necessary) and give this to your teacher and laboratory technician.

#### *Microscope lenses and magnification*

The eyepiece (or ocular lens) of a microscope is the lens closest to the eye, and usually magnifies objects by 10 times their actual size (×10). The other lens is the objective lens and is located on the rotating part of the microscope barrel. There are usually three or four objective lenses, each allowing for a different degree of magnification.

Start off with the lowest magnification lens (usually ×4) and rotate through each lens until you have the view of the specimen that you want. Other lenses are usually a ×10 medium power lens, a ×40 high power lens, and sometimes a ×100 oil immersion lens designed for use with a special oil.

The magnification of the microscope is determined by multiplying the magnification on the ocular lens by the magnification on the objective lens being used. For example, using a ×10 ocular lens and a ×40 objective gives a total magnification of ×400.

#### *Field of view and size of specimens*

Being able to calculate the field of view is essential in order to estimate the size of specimens you are looking at under the microscope. Also, all biological drawings require a scale. To calculate the field of view you use a minigrid. This is a 1 mm × 1 mm grid with a smaller microgrid of 100 μm × 100 μm in the centre (used with the ×40 objective). If you do not have a minigrid, you can use a clear ruler marked in mm or a 1 mm × 1 mm grid on clear plastic film.

To calculate the field of view:

- ☐ place the minigrid on the microscope stage.
- ☐ focus using the ×4 objective lens so that you can see the grid clearly.
- ☐ adjust the slide position so that one line is on the edge of the field of view (Figure 1.4.4).

**Typical magnifications and fields of view with a ×10 eyepiece:**

| Objective lens | Field of view |
|---|---|
| ×4 | 4.5 mm |
| ×10 | 1.5 mm |
| ×40 | 450 μm |
| ×100 | 150 μm |

- ☐ count the grid lines across and estimate the diameter of the circle you see (on extra low power, it should be about 4.5 mm or 4500 μm).
- ☐ now change to the ×10 objective lens and estimate the size again (it should be about 1.5 mm or 1500 μm). You should be able to use the microgrid to measure the exact distance across the field of view.
- ☐ move the microgrid to the centre of the field of view.
- ☐ focus on the microgrid using the ×40 objective lens (remembering that the microgrid lines are 100 μm apart). The field of view on high power should be about 450 μm.

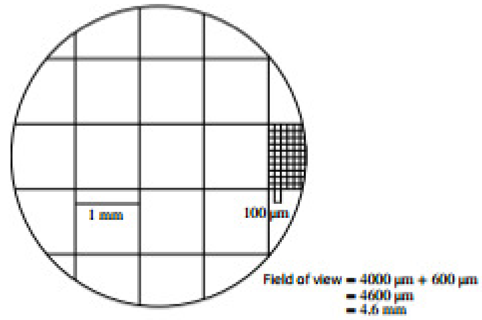



**FIGURE 1.4.4** The field of view of this microscope using the ×4 lens is 4.6 mm (or 4600 μm). You can work this out using the minigrid.

It is important that you measure the field of view every time you use a different microscope, because there are differences between microscopes and this will affect your estimates of the size of specimens.

Now that you have calculated your field of view for each lens, it is possible to estimate the size of a whole specimen or the size of individual features such as cells.

Place the slide with your specimen on the microscope stage and focus your microscope. Knowing the field of view, you can estimate the size of the specimen. For example, if you are looking at a transverse section of a leaf and you can see exactly half of the leaf under extra low power, then you can estimate that the leaf is 2 × 4.5 mm = 9 mm long.

If you wish to calculate the size of the individual cells in the leaf, then you can count the number of cells across the high power field of view, as shown in Figure 1.4.5.

Microscopy is covered in more detail in Chapter 2.

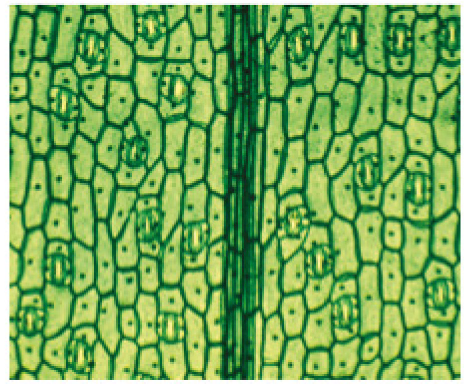


**FIGURE 1.4.5** Leaf epidermis cells under a high power lens (×40). The field of view is 450 μm. There are about 30 cells across the field of view, so the average width of a leaf epidermis cell is 450/30 = 15 μm.

## Field work

Your investigation may look at the population of a particular species in two different areas. When studying ecology, it may be necessary to determine the type and number of living organisms in an area. There are many different ways to do this, including quadrats and transects. Whatever way you use, it is important to always leave the environment the way you found it (Figure 1.4.6).

● *You will now be able to answer Key Questions 9 and 10.*

**FIGURE 1.4.6** When working in the field, a good principle to work by is to take only photographs, leave only footprints.

In natural environments it is usually impossible to count all the individuals of a species. Even just counting the living things in your school would take a very long time. Sampling gives us a good idea of the organisms in an ecosystem without needing to count each one. Table 1.4.4 on page 32 outlines some sampling techniques and when they are best used.

When sampling in the field you should always consider the time and equipment available, the organisms involved and the impact the sampling may have on the environment.