

CHAPTER 1

LIFE PROCESSES

Objectives

At the end of this chapter you should be able to:

- Identify different types of cells
- Understand the functions of carbohydrates, proteins and lipids
- Explain the cell processes that control chemical reactions
- Identify the components of the human digestive system
- Identify the components of the circulatory system
- Understand the five senses and how they work

There are seven things that all living organisms do. These are called life processes. To be 'alive' an organism must perform all seven of these processes – breathe, grow, move, eat, reproduce, excrete and have senses.

cell (biology)

The smallest unit of life (that is alive)

organism

A single living thing

CELLS

The **cell** is the basic unit of life. Some of these cells live alone, while others form groups to make large, multicellular **organisms**. In large organisms, there are many special types of cells, such as skin cells, muscle cells and nerve cells. Each type of cell carries out a different task for the organism.



There are two broad types of organisms. Organisms made of cells that do not have a **nucleus** are called **prokaryotes**. Organisms made of cells that have a nucleus are called **eukaryotes**.

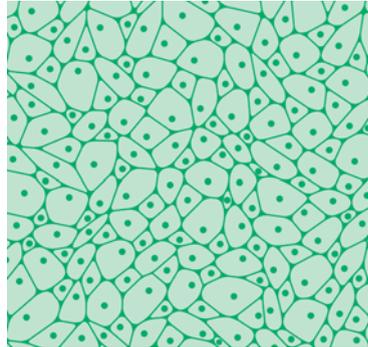


Figure 1.1: Cells

nucleus (biology)

The central part of a cell where the chromosomes are stored and from where the cell is controlled

prokaryote

An organism whose cells do not have a nucleus (mostly bacteria)

eukaryote

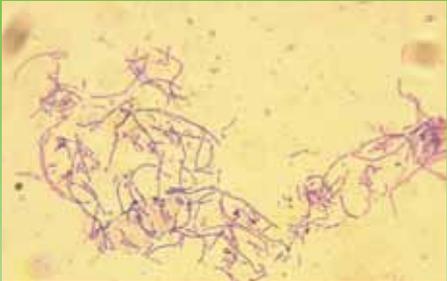
An organism whose cells have a nucleus (plants and animals but not bacteria)



SciFACTS

An adult human is made up of around one hundred billion (that is 100 000 000 000 000) cells!

Table 1.1: Differences between prokaryotic and eukaryotic cells

Prokaryotic cells	Eukaryotic cells
No nucleus Example: bacteria 	Nucleus Example: plants, animals, algae, fungi 
Figure 1.2: Cells without a nucleus	Figure 1.3: Cell with a nucleus
Single loop of free-floating deoxyribonucleic acid (DNA)	Chromosomes made of DNA
Single membrane that surrounds the cell wall	Membrane around the cell wall and membrane around each of the organelles inside the cell
Never form multicellular organisms	Often form multicellular organisms
Form organisms that seldom undergo sexual reproduction	Form organisms that regularly reproduce sexually
Tend to be smaller than eukaryotic cells	Tend to be larger than prokaryotic cells

DNA

Deoxyribonucleic acid, the chemical instructions for living things, made up of the four bases adenine, thymine, cytosine and guanine

chromosome

A structure found in cells that is made of DNA and carries the cell's genetic information

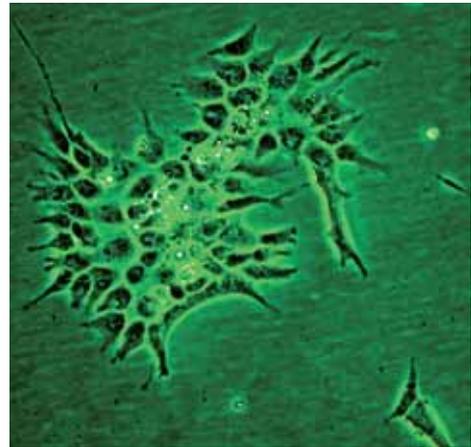
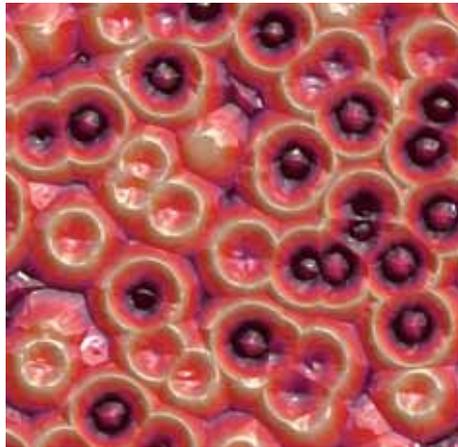
membrane

A thin, clear, flexible layer that protects a cell and regulates what goes in and out of it; also surrounds organelles inside eukaryotic cells

organelle

A specialised membrane-bound part inside cells

Plants and animals are both types of eukaryotic organisms, but they have some significant differences in the structure of their cells (see Figures 1.4 and 1.5).



Figures 1.4 and 1.5: Plant cells and animal cells

SciFACTS

In 1665 Robert Hooke produced a book showing what he had found using the microscope he had invented. One specimen he looked at was a thin layer of a cork. To his surprise he saw tiny squares that reminded him of jail cells. He could not have known that within a few centuries his name 'cells' would become so important and widespread.

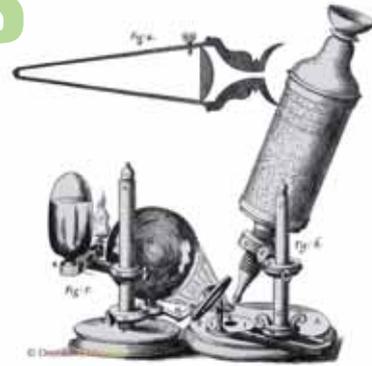


Figure 1.6: Hooke's microscope

The largest cells are only just visible to the naked eye. Cells must stay small to be efficient and survive. This is because as a cell grows, the surface area to volume decreases, making it harder for the cell to get enough oxygen. In a large cell it is also harder to get rid of wastes and to detect what is happening outside the cell. Similarly, as a whole organism becomes bigger it becomes more difficult to get rid of heat and wastes, because its 'insides' increase in volume much more than its skin does.

In large, multicellular organisms the materials needed by each cell, such as oxygen and water, are transported to and from each cell. For example, humans transport oxygen throughout their bodies using the lungs, red blood cells and the heart. Cell wastes are also passed out of cells before being disposed of through the kidneys or lungs.

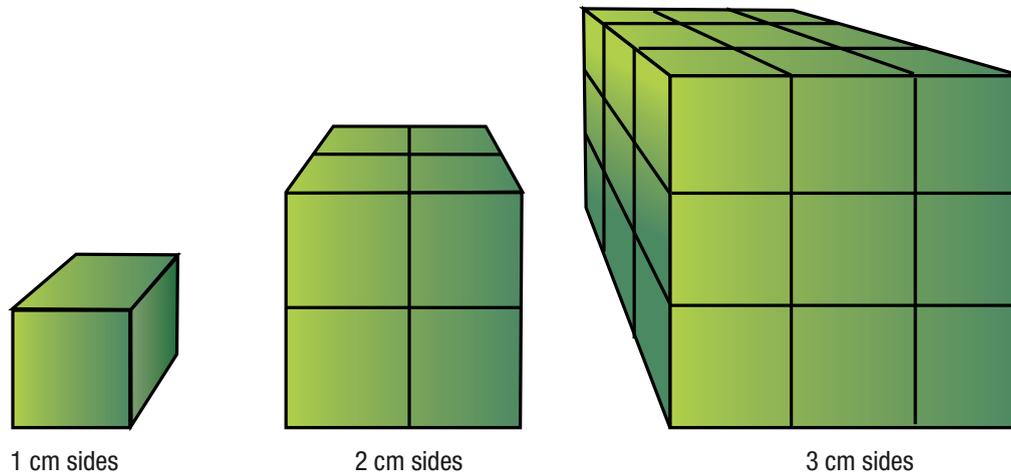
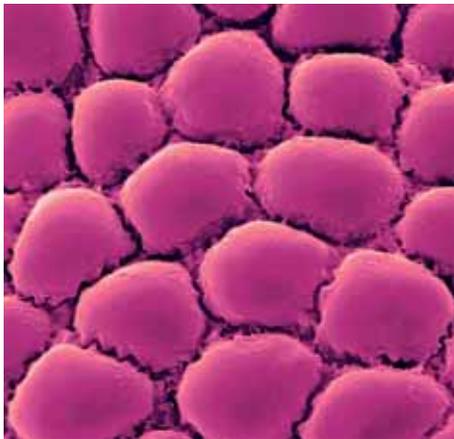
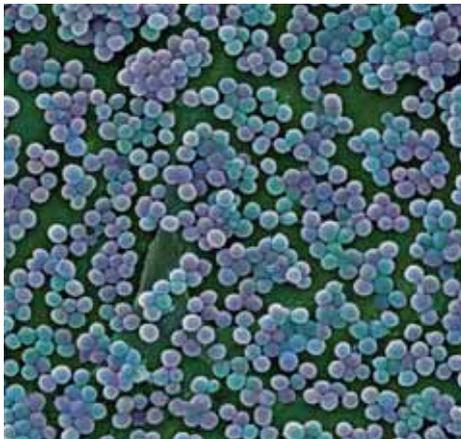


Figure 1.7: This diagram demonstrates how the surface area to volume ratio drops as an organism becomes larger – from 6:1 in the first diagram to 2:1 in the final one.



Figures 1.8 and 1.9: Cells vary in size



SciFACTS

When looking at cells under high power on a school microscope, the magnification is about the same as making you the size of a sports oval.

Cells evolve

The first simple cells evolved about 4 billion years ago and their descendants (bacteria) are still alive today. These simple cells had Earth to themselves for 2 billion years until some evolved into having a nucleus with chromosomes containing the cell's DNA. These more advanced cells then evolved into the millions of different species that are alive today, or existed in the past and became extinct.



ACTIVITY 1.1: CELLS

- 1 What kinds of cells do not have a nucleus?
- 2 Large, multicellular organisms are made up of what type of cells?
- 3 Why are large cells less efficient than small cells?
- 4 What are three differences between plant and animal cells?

CHEMICALS OF LIFE

Despite many variations in cells, they all have similar chemicals and reactions occurring inside them. This is because cell chemistry evolved millions of years ago, and the information has been passed on through millions of generations of cells to the present. Even today as new organisms evolve the basic chemistry of cells stays the same. This allows some organisms to eat and digest others, then reassemble the chemicals into their own body tissues. This is the basis of all food chains.

carbohydrate

A molecule that contains carbon, hydrogen and oxygen atoms; crucial to life functions

monosaccharide

The simplest of sugars, $C_6H_{12}O_6$

photosynthesis

The process where plants use carbon dioxide, water and energy from light to 'feed' themselves; this process also releases oxygen

disaccharide

A sugar molecule with two monosaccharides joined together

polysaccharide

A sugar molecule with more than three monosaccharides joined together

cellulose

A strong complex carbohydrate that forms plant cell walls

starch

A polysaccharide made up of hundreds of sugars

Carbohydrates

Carbohydrates are molecules that contain carbon, hydrogen and oxygen atoms. Longer carbohydrates are made by joining chains of sugars together.

SUGARS

There are many types of sugars:

Monosaccharides are single sugars. Glucose is the most common monosaccharide and is produced by **photosynthesis**. It consists of six carbon atoms, 12 hydrogen atoms and six oxygen atoms with the formula $C_6H_{12}O_6$. This molecule has two main uses: as a source of energy and as a building block to construct longer carbohydrates. A common example of a monosaccharide is fructose, a sugar found in fruit.

Disaccharides are 'double sugars' because they consist of two monosaccharides joined together. Common examples are sucrose (table sugar) from sugar cane and lactose in milk.

Polysaccharides consist of anything from three to thousands of sugars joined together. Starch (also discussed below) is a polysaccharide made up of hundreds of sugars. Cellulose is made up of thousands of sugars and is the most abundant organic molecule on Earth because it forms plant cell walls. **Cellulose** is constructed in a much stronger way than starch and this makes it tougher, insoluble in water and very difficult for animals to digest.

STARCH

There are many different types of **starch**. Starch is used for storing energy as it can be quickly broken down into glucose molecules. It is common in the parts of plants



used to survive the winter (root vegetables) or attract animals (fruits). In animals the carbohydrate used for storage is **glycogen**. Glycogen is stored in the muscles and liver of animals, for whenever energy is quickly needed.

OTHER CARBOHYDRATES

Carbohydrates may have other chemical elements added to build special tissues such as **chitin** and **cartilage**. Chitin is used to build the **exoskeletons** of insects and crabs and the walls of fungi. Cartilage gives a soft, smooth covering on the ends of bones, allowing joints to move easily.

Proteins

Proteins are very important and are used to build cell membranes, muscles, bones and skin. They also form **enzymes** that control reactions inside cells. Proteins in the blood provide protection against invading bacteria and viruses. The nervous system and the brain are also made of proteins.

BUILDING PROTEINS

Proteins are chains of **amino acids**. There are 20 different amino acids used to make proteins. Assembling these 20 amino acids in different ways produces the whole range of life on Earth. For example, imagine that a friend built a model using 20 different pieces of Lego®. You could build an entirely different one using the same pieces.

To build a protein the assembly instructions are read from the DNA in the chromosomes. Changing the DNA creates new building instructions. Ninety percent of changes to the DNA are fatal because the new construction does not work, so the cell dies. Nine percent of changes have no effect. One percent of changes may lead to a better construction and the cell might improve; this leads to **evolution**.

Lipids

Lipids are a group of energy-rich compounds that do not dissolve in water. If they are liquid at room temperature they are called **oils**. If they are solid they are called **fats**. Lipids provide a great way for cells to store energy for future use. Some plants such as olives, avocados, beans and nuts have large quantities of lipids stored for the next generation of the plant. This makes them a rich energy source for animals.

Lipids are very useful for coating cells to control what enters and leaves them. If a chemical cannot get through the lipid layer, but the cell needs it, then the cell will have a special 'gate' system to drag it through.



glycogen

The carbohydrate used for energy storage in animals

chitin

A special carbohydrate that forms the exoskeletons of insects and crustaceans

cartilage

A smooth, white, shiny layer in joints that covers the ends of the bones

exoskeleton

An outer casing that supports the structure of an organism instead of internal bones

protein

A long chain of amino acids

enzyme

A naturally occurring protein that speeds up a reaction

amino acid

A molecule that forms proteins

evolution

A process driven by natural selection that leads to the creation of new species

lipid

A compound that is not water-soluble; fats and oils

oil

A lipid that is liquid at room temperature

fat

A lipid that is solid at room temperature



ACTIVITY 1.2: RESEARCH CARBOHYDRATES, PROTEINS AND LIPIDS

Carbohydrates, proteins and lipids are important for our health, but why is it important to eat a mixture of them?

CELL PROCESSES

An organism needs to be able to control the millions of chemical reactions inside its cells. If these reactions are not controlled in a cell, the cell dies. Understanding the chemical reactions in cells allows us to understand what keeps organisms alive.

Diffusion

Diffusion is where molecules move passively from an area of high concentration to an area of low concentration until they are spread out evenly in the available space. This is an important phenomenon as it allows substances to be transported without using any energy.

Diffusion is fastest when it is warm (as molecules move faster then because they have more energy), when the molecules are small and when there is lots of space between the molecules.

Osmosis

Osmosis is a special type of diffusion. Osmosis is the diffusion of water through the membrane that surrounds a cell. Most cell membranes are **semipermeable membranes** because they only allow some molecules to pass through. During osmosis the water moves from areas of high water concentration to areas of low water concentration.

Osmosis will continue moving water molecules until the concentration is the same on both sides of the cell membrane. When there is a difference in the water concentration across a membrane, it is called an **osmotic gradient**. When there is no difference in the water concentration, it is called an **osmotic equilibrium**. During osmotic equilibrium water does not stop moving, it just moves in both directions at the same rate.



diffusion

The random movement of molecules that results in them continually spreading out

osmosis

Diffusion of water through a semipermeable membrane

semipermeable membrane

A membrane that allows only certain molecules through depending on their size

osmotic gradient

Where there is a difference in water concentration on either side of a semipermeable membrane (osmosis occurs)

osmotic equilibrium

When the water concentration is equal on either side of a semipermeable membrane

Photosynthesis

Photosynthesis is where light (photo) is captured and used to make (synthesise) food. Only plants, algae and some bacteria can photosynthesise. During photosynthesis



red and blue light is captured by special structures in cells called **chloroplasts**. Green light cannot be captured by chloroplasts and is reflected; this is why most plants appear green. The light energy of the red or blue light is used to split water molecules into hydrogen and oxygen. The oxygen is a waste gas and diffuses out of the cell. The hydrogen is added to carbon dioxide to make the simple sugar glucose.

The glucose molecules produced are used as fuel during respiration, or are assembled like building blocks to create tough materials (e.g. cellulose in plants) or food storage molecules (e.g. starch).

Chloroplast

The specialised part of a cell in plants that captures the energy in light

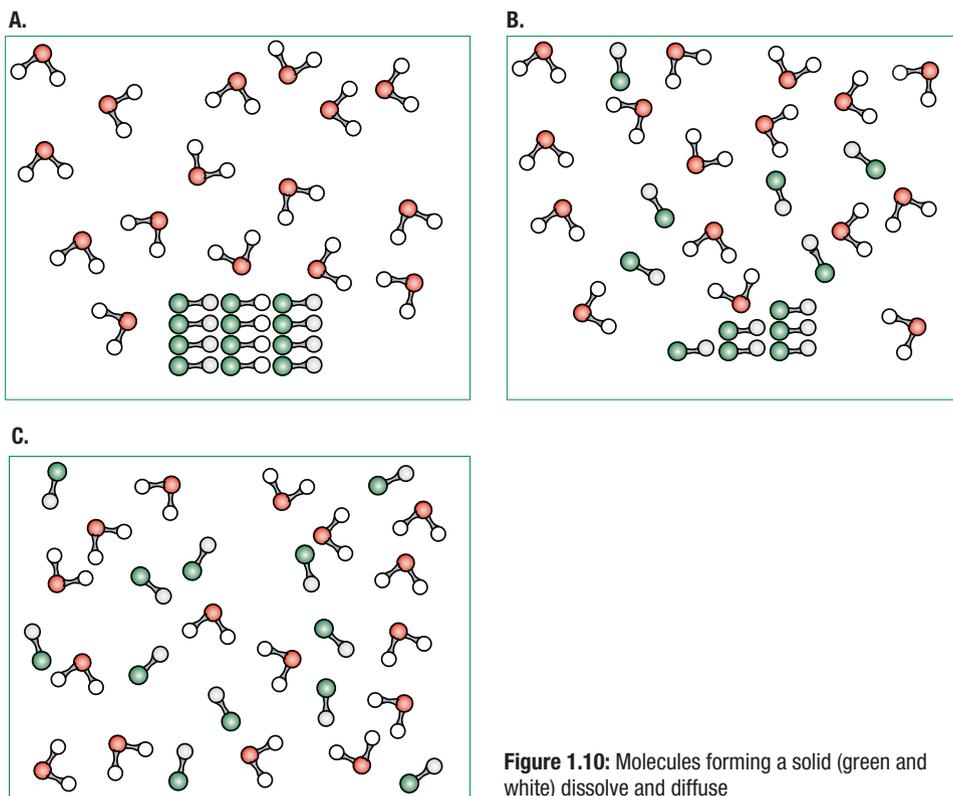


Figure 1.10: Molecules forming a solid (green and white) dissolve and diffuse

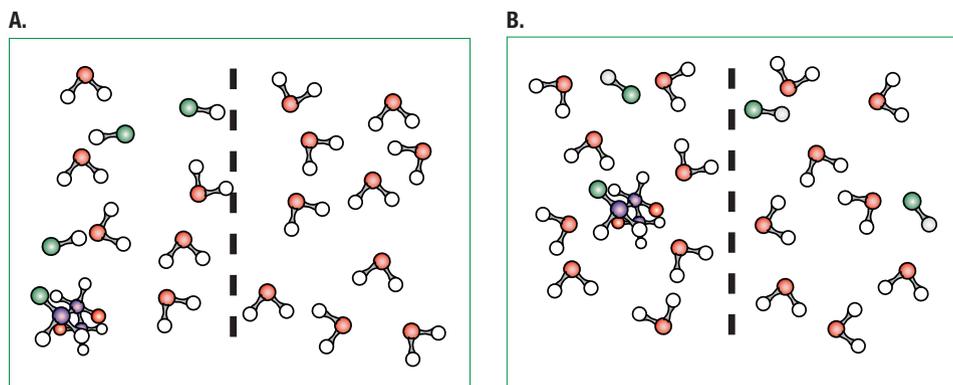


Figure 1.11: Osmosis through a semipermeable membrane: the green and white molecules can diffuse through the membrane

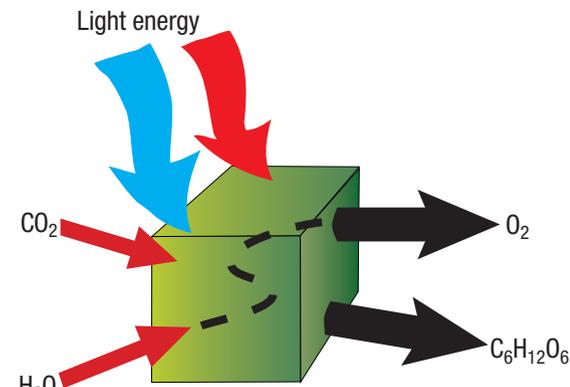


Figure 1.12: Photosynthesis

The equation for photosynthesis in plants is:



This equation means that six molecules of water plus six molecules of carbon dioxide plus the energy from sunlight react to form six oxygen molecules and one molecule of glucose.

Ninety percent of all photosynthesis occurs in the top metre of oceans and lakes, which means tropical rainforests and grasslands play only a tiny part in keeping the oxygen levels in the atmosphere at 20%.

Respiration

respiration

The process plants use oxygen to break down sugars to release energy; this process also releases carbon dioxide

Respiration is the addition of oxygen to glucose molecules to release energy. All cells need energy to carry out chemical reactions that otherwise would not happen. Respiration happens in special structures within a cell that act like tiny power stations and then deliver the energy around the cell. When oxygen is plentiful carbon dioxide is produced. This is called aerobic respiration. It is interesting to note that the equation for aerobic respiration looks like the reverse of the equation for photosynthesis.

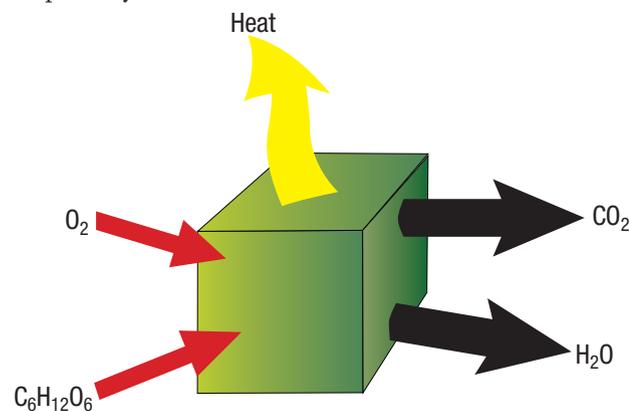


Figure 1.13: Respiration



The equation for aerobic respiration is:



This means that six molecules of oxygen plus six molecules of glucose react and release energy, forming six molecules of water and six molecules of carbon dioxide as they do so.

Sometimes oxygen is in short supply. This can happen at the bottom of the ocean, in mud or warm water, when a cell is working very hard or when an organism cannot deliver oxygen to its cells quickly enough. In these situations cells will keep operating by another form of respiration called anaerobic respiration. Anaerobic respiration does not release as much energy as aerobic respiration. What is finally produced depends on the organism – in plants it is alcohol and in animals it is lactic acid. Anaerobic respiration is used to make wine and beer (when some types of yeast are placed in a sealed bottle, with sugars, they produce alcohol) and in baking (some species of yeast produce bubbles of carbon dioxide in dough, causing it to rise).

Introduced plants such as didymo, water net and oxygen weed are a problem in New Zealand because they grow so quickly they block drains, streams and the intakes of hydropower stations. However, these plants provide oxygen, food and a place to live for insects and fish. On the other hand, at night their respiration rate can be so great that oxygen levels in the water drop, sometimes to a level so low that other species die. These plants grow into large mat-like shapes, but eventually they break down and release nutrients into the water. The surge in nutrients encourages decomposers to respire and this drops the oxygen levels again, killing more species.



Figure 1.14: Didymo is a problem in New Zealand



ACTIVITY 1.3: CELL PROCESSES

- 1 What are three factors that affect the speed of diffusion?
- 2 Why is it untrue to say 'water molecules stop moving when there is osmotic equilibrium'?
- 3 Why will plants not grow under green light?
- 4 Animals and plants need both carbon dioxide and oxygen to live. Why is this?



DIGESTION

Animals digest food for two reasons: to break down large molecules into small molecules so they can travel into cells, and to turn molecules that are insoluble in water into soluble molecules.

To help digestion many animals have a gut or digestive stem. The gut is an extension of the skin and animals really inhabit the area between the gut and their outer skin. The gut does not digest an animal because the gut is really outside the animal. Humans are animals, too, so our digestion technically occurs outside our bodies. The lining of the gut is not digested because it is protected by a layer of slimy mucus. Parasites that live in the gut are also protected by a layer of mucus.

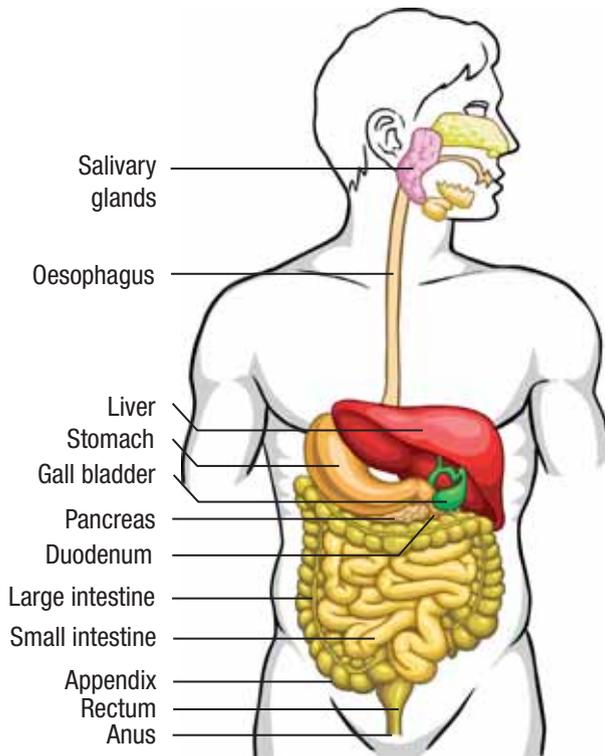


Figure 1.15: The human digestive system

Mouth

Human adults have 32 teeth. Each side of the jaw has two incisors, one canine, two premolars and three molars. The upper surfaces of the premolars and molars have special interlocking ridges called cusps, which ensure food is ground up well. Human teeth are not specialised for defence or attack. They are suited to chewing a wide range of food. When chewing, the tongue rolls around the mouth and spreads food between the molars. Hunger and chewing produce saliva from the salivary glands, which surround the mouth. Every day we produce about 1 L of saliva that helps chewing and swallowing, and prevents mouth infections.



Figure 1.16: Human teeth

Oesophagus

The oesophagus connects the mouth and the stomach. Within the oesophagus is the larynx (vocal cords), and a valve called the epiglottis that allows breathing but prevents food entering the lungs when we swallow. Chewed food moves down the oesophagus and through the whole gut by **peristalsis**, muscular contractions that push the food along. In the oesophagus swallowing can start peristalsis, but in the rest of the gut it is automatically controlled. During vomiting the direction of peristalsis is reversed, often powerfully.

Cardiac sphincter

The cardiac sphincter is the first of three rings of circular muscle in the gut. It prevents acid and partly digested food in the stomach from moving back up into the oesophagus. Heartburn occurs when the cardiac sphincter relaxes and stomach acid burns the oesophagus.

peristalsis

Muscular contractions that push the food through the gut



Stomach

The stomach is a stretchy bag that allows food to be stored and partly digested. Without a stomach it would be necessary to eat small amounts of food continuously. Muscles in the stomach wall ensure that the stomach is constantly moving and mixing the food. The stomach walls produce hydrochloric acid and the enzyme pepsin, both of which break down proteins. The acid also kills many of the bacteria eaten with the food. The stomach is lined with a protective layer of mucus to prevent it from being digested. Only a few substances can be absorbed directly by the stomach, including aspirin, caffeine and alcohol; this is why these things have such an immediate effect when consumed.

Pyloric sphincter

The pyloric sphincter forms the exit from the stomach and is the second of three rings of circular muscle in the gut. By opening briefly and regularly it produces a small but steady supply of partially digested food to the rest of the gut. It takes about four hours for the contents of a full stomach to pass through the pyloric sphincter.

Duodenum

The duodenum is a short section of the gut, where the pancreas and gall bladder add their digestive salts and enzymes to the gut. Despite its short length it is where most digestion occurs.

Liver

The liver is a large organ that controls what travels in the blood. It receives all the blood that has flowed past the gut, thereby picking up a huge range of different digested molecules. If the molecules are needed immediately, the liver allows them to be delivered around the body. If they are not needed straightaway, they are stored in a more stable form within the liver. The large vein that carries the blood from the intestines to the liver is called the hepatic portal vein. The liver also produces bile salts that break down fats.

Gall bladder

The gall bladder stores bile, which is produced by the liver. Bile moves into the duodenum, through the bile duct, where it works on fats in the diet. Fats and water do not mix, but bile stops the fats collecting in groups. By keeping the fats separate, lipase (the enzyme that works on fats) can break each one down much more easily.

Pancreas

The pancreas produces enzymes that make big food molecules smaller and more soluble. It makes a range of enzymes for a range of foods. These include amylase (which converts starch into maltose sugar), trypsin and peptidase (which convert proteins into amino acids), lipase (which converts fats to glycogen), and nuclease (which breaks down DNA). Natural antacids (which neutralise the hydrochloric acid from the stomach) are also produced.

**genetics**

The branch of biology that studies heredity and variation in organisms

The pancreas also secretes chemicals directly into the bloodstream. Chemicals released in this way are called hormones. An important hormone produced by the pancreas is insulin; this controls the level of glucose in the blood. Usually the amount of glucose in a person's blood is equivalent to that of about five jellybeans. Having too much or too little glucose in the blood can be fatal. Diabetics are unable to produce the correct levels of insulin at the right times. This means they have trouble maintaining the correct glucose level. People get diabetes in two main ways: either they are born with it (type 1 diabetes) or they develop it (type 2 diabetes). People often develop type 2 diabetes because they are overweight or have an unhealthy lifestyle, but there is also a **genetic** influence involved.

Small intestine

The small intestine (ileum) is where most of the digested food is absorbed into the blood. It is a coiled tube that is 6 m long. It is called 'small' because it is narrow, not because it is short in length. The lining of the small intestine is covered with millions of small folds called villi, which greatly increase the surface area for absorbing nutrients. The villi increase the area for absorption to 250 square metres, or about the size of a tennis court.

Appendix

The appendix is a small dead end, about the size of a finger. As humans evolved from herbivores to omnivores it has become smaller and smaller, until it is now too small to be of use. However, in many herbivores it is much larger and an important area for the breakdown of cellulose by bacteria that live there.

Large intestine

The large intestine (colon) is where most water and salts are absorbed. The large intestine is home to immense populations of bacteria, many of which produce vitamins for us. A common species of bacteria found here is *E. coli*. Changes to the bacterial population may cause problems. For instance, the carbohydrates in beans cannot be digested by humans, but the bacteria living in the colon can digest them. They rapidly break down the carbohydrates, but because there is no oxygen in the colon they produce large quantities of methane and hydrogen sulfide gas.

Rectum

The rectum (bowel) is a space for the storage of semi-solid waste before it is excreted through the anus. The brown colour of mammal faeces is due to the iron from their old red blood cells.

Anus

The anus is the third sphincter muscle in the gut and controls when wastes are disposed.



ACTIVITY 1.4: RESEARCH THE DIGESTIVE SYSTEM

It is not unusual for people to have parts of their digestive system removed. Which parts are commonly removed? Why are they removed? What effects, if any, do losing these parts have on the person?

CIRCULATION

The circulatory system carries blood around the body. Like the digestive system, it is a complex system made up of many parts.

The heart

Humans, like all mammals, have four-chambered hearts. These four chambers are arranged so they work as two pumps side by side. The parts of the heart are named 'left' and 'right' as though a person is talking about their own heart inside themselves (e.g. left meaning the person's left). This is why drawings of the heart like the one below seem to be reversed.

Blood flows back to the heart through **veins** that join together at the vena cava. This blood contains little oxygen but lots of carbon dioxide, so it is a dark red-blue colour. It needs to be pumped through the lungs to pick up new oxygen and release the carbon dioxide. To do this the blood is pumped by the right side of the heart through to the lungs. This happens in two steps. First it travels into the right atrium where it is pumped down into the right ventricle. It is then pumped from the right ventricle to the lungs via the pulmonary artery.

vein
Carries de-oxygenated blood back to the heart

To keep the blood flowing in one direction, the heart has one valve that acts like a one-way swinging door that allows blood to pass from the right atrium into the right ventricle, but does not allow it to flow back. Another valve ensures that blood that has been pumped from the right ventricle through to the pulmonary artery cannot flow backwards either. Our heart is close to our lungs to make our circulation system efficient.

From the lungs, the oxygen-rich blood flows through the pulmonary veins into the left atrium, then down to the left ventricle. This ventricle is surrounded by thick heart muscle that contracts and forces the blood up and out of the heart, through the aorta.

The beating of the heart is a remarkable series of coordinated steps that ensure both pumps work together, so that each side of the

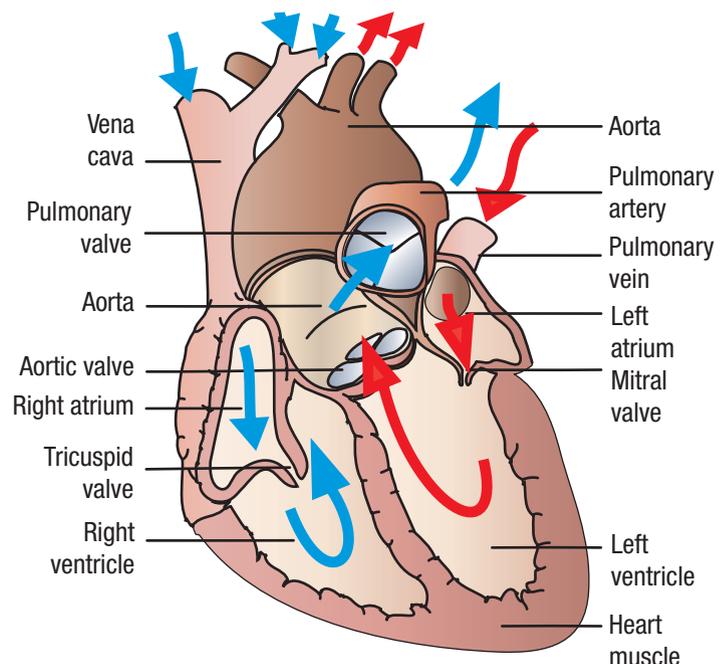


Figure 1.17: The human heart



heart pumps simultaneously to move the same volume of blood. Each heartbeat is started by pacemaker cells near the right atrium, followed by a powerful electrical signal that spreads down and across the heart. The result of this signal is that the two atria contract in unison and push blood into the ventricles. The ventricles then contract in unison, pushing blood up through the top of the heart. The path that the electrical signals take produces a wringing motion in the heart. After a pause lasting a mere fifth of a second, the pacemaker cells fire again. The electrical signals that run the heart are so powerful they can easily be detected by sensors placed on the chest.

The thump of a heartbeat is the sound of the valves slamming shut, firstly those from the atria to the ventricles and next those leading away from the heart. These two events give the familiar 'lub-dub' sound and feel of a heartbeat. A heartbeat of about 80 beats per minute is fairly common; however, this can be quickly changed either automatically by the brain or by chemicals in the blood. One such chemical is the hormone adrenalin, which is released when we are stressed and rapidly increases the heart rate.



SciFACTS

The number of chambers in the heart varies. Fish have two, reptiles have three and birds (like mammals) have four.



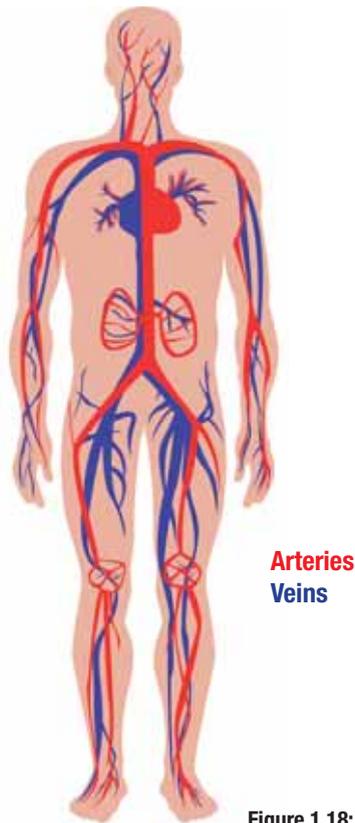
WHY WE NEED A HEART

A single cell swimming about in water does not need a heart or blood, because it is so small that oxygen can easily get to its centre by diffusion. However, as bigger organisms (made of millions of tiny cells) evolved on this planet, it became harder for the cells in the middle of the organism to get

what they need, and to get rid of their wastes. A circulation system made up of a heart, lungs and blood travelling in tubes around the body solved this problem, ensuring every cell has a fast, reliable 'courier service' to meet its needs.

Capillaries, arteries, veins and the lymphatic system

Blood does not just slosh around inside us; it is contained within a network of tubes. This plumbing system can make changes to where the blood flows; for example, in cold weather blood may be directed away from fingers, toes and ears, which is why they get particularly cold. This is done to keep the important organs in your body's core warm enough. Likewise, if we are too hot, blood will be directed towards the skin surface to cool us down, making our skin look redder.



Arteries
Veins



SciFACTS

An adult has 4 to 6 L of blood, which is approximately 8% of their body weight.

Figure 1.18: The blood circulatory system

CAPILLARIES

Capillaries are very fine tubes through which blood cells must pass in single file. By being so narrow, they ensure that every red blood cell has as much contact with the capillary wall as possible, which means that the surrounding cells pick up as much oxygen as possible. The walls of capillaries are also very thin so that glucose and salts can get through easily. Likewise, wastes such as carbon dioxide can diffuse out of cells into capillaries to be carried away by the blood. Large molecules such as proteins cannot get through capillary walls and must stay in the blood.

ARTERIES

Arteries carry oxygen-rich blood away from the heart to deliver it to the rest of the body. Artery walls are flexible to cope with the pulsing of the blood through them. Their flexibility also means that they smooth out the flow of blood from the heart, stretching outwards with a beat and returning inwards between beats. They continually branch throughout the body until they become tiny capillaries. Most arteries are deep within the body, but sometimes a pulse can be felt where they cross a joint.

Arterial disease is the result of a build-up of fatty deposits called plaque on the inside lining of arteries. The plaque often starts being deposited from the age of seven, and plaque build-up is well underway in many teenagers. The build-up of plaque is increased by eating fatty food, obesity, smoking, high blood pressure, diabetes and a lack of exercise. Fortunately, changes to diet and behaviour can help to reverse plaque build-up.

artery

Carries oxygenated blood from the heart to the rest of the body

**platelet**

A cell fragment in the blood that sticks to other platelets to form a blood clot

thrombosis

A blood clot blocking a blood vessel

Continuous plaque build-up has two effects. The first is that it slowly reduces the diameter of the artery, limiting the flow of blood to an area. Eventually, because **platelets** stick to the plaque, it may block the artery completely, resulting in a **thrombosis**. The three coronary arteries that supply the heart with oxygenated blood are especially at risk from this. A heart attack occurs when a coronary artery gets blocked and the heart muscle is starved of oxygen, which can damage or kill the heart muscle tissue.

The second effect of plaque deposits is that the blood does not flow smoothly; instead, the flow becomes more turbulent like rapids in a river. This turbulent flow may pluck pieces of the plaque, with blood platelets, off the artery wall, carrying them away. These pieces float along in the blood until they reach a narrower section, and then block the flow. If this happens in the brain it can cause a stroke. Arterial disease is the largest killer of people in the western world, and half of New Zealanders are likely to die of it.

VEINS

Veins carry deoxygenated blood towards the heart. To stop the blood flowing backwards, the veins have regularly spaced valves that ensure that blood can only flow one way.

LYMPHATIC SYSTEM

Lymph is a clear fluid in the lymphatic system that returns water and materials that have not been picked up by capillaries to the blood. This is done by a network of fine pipes that empty the lymph fluid into the vena cava (top right of the heart). Like blood in the veins, the lymph fluid is moved by body movement and one-way valves. Along the lymph system are 'nodes', which are sites specialising in producing white blood cells and digesting foreign bacteria and viruses. Important lymph nodes are in the neck and these may become swollen during infections.

Blood

Blood does many jobs within the body, including:

- controlling temperature, water levels, salt concentrations and acidity
- fighting infection
- delivering oxygen, nutrients and hormones
- removing wastes.

Not everybody's blood is the same as there are different blood types. Your blood type depends on what message or code is carried on the surface of your red blood cells. This means that only some types of blood can be swapped from one person to another.

PLASMA

Plasma is a straw-coloured fluid that makes up 55% of the blood's volume. Plasma is made up of 90% water and important proteins that control the water levels around cells, fight infections and help with clotting. All of these proteins are made in the liver.



RED BLOOD CELLS

Red blood cells are the oxygen carriers for the body. A single drop of blood contains 6 million red blood cells, each disc-shaped with their flat surfaces bowed inwards like a saucer so they can squeeze through the narrowest capillaries. Each red blood cell can carry 1000 million oxygen molecules. These oxygen molecules are strongly attached to **haemoglobin** molecules in the red blood cell. When a haemoglobin molecule gets to a part of the body low in oxygen it relaxes its hold on the oxygen molecule, allowing oxygen to pass through the capillary wall into the area that needs it.

Haemoglobin molecules have an iron atom at their centre; hence with so much haemoglobin in the blood it is important to eat iron-rich foods. A shortage of iron may cause **anaemia**, which reduces the blood's ability to carry oxygen.

Red blood cells have a short life of about 100 days. They have no nucleus, and therefore have no information on how to repair themselves. The body's red blood cells are replaced by **stem cells** in the **bone marrow** at the rate of 2 million per second.

WHITE BLOOD CELLS

White blood cells are the cells of the immune system and protect the body from invaders. Some types of white blood cells engulf and destroy invaders, while others digest dead cells, old tissues and old red blood cells. To do this they patrol the blood and the spaces between the cells of the body. If the skin is punctured and invading organisms get in, extra white blood cells and resources will be directed to the site. This is done by increasing the blood flow to the area, which is why the area becomes warm, red and swollen.

Sometimes the white blood cells are killed in large numbers by the invaders and their remains appear as pus, which you might find in an infected wound. Some white blood cells make **antibodies**, which are like marker flags stuck on invading cells. These antibody flags identify the invader so that different white blood cells can attack them. White blood cells are made in the same way as red blood cells; they even start from the same stem cells.



Figure 1.19: A red blood cell

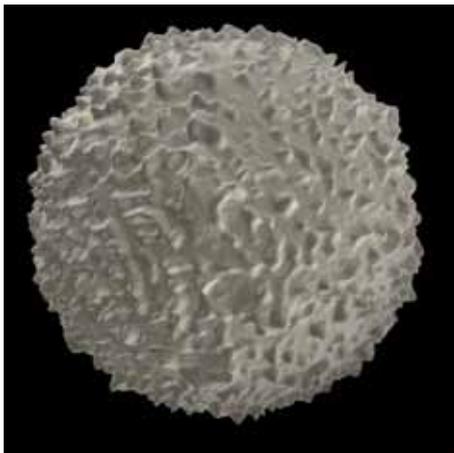


Figure 1.20: A white blood cell

haemoglobin

Molecule in red blood cells that carries oxygen

anaemia

A condition in which the blood cannot carry enough oxygen

stem cell

A cell that can produce different types of cells

bone marrow

Soft centre of long bones containing stem cells

antibody

A marker flag that allows the body to identify invaders



PLATELETS

Platelets are tiny fragments of cells and are covered in chemicals and enzymes. If they meet oxygen in air, they swell, distort and become sticky. When one platelet does this others follow. When blood flows out of a cut in the skin the platelets and red blood cells jam and stop the flow of blood. The leak is also sealed by platelets producing chemicals that make the capillaries shrink in size, which further reduces the flow.



Figure 1.21: Platelets

Blood clotting is a very fine balancing act. If we cut or puncture our skin, blood will quickly turn to a solid when it comes in contact with the oxygen in the air. However, in the body it must not do this even though it is in contact with millions of oxygen atoms carried on the red blood cells. If blood clots formed inside the body, it could be fatal.



SciFACTS

The blood of haemophiliacs does not clot properly because they miss one small step in the clotting process.



ACTIVITY 1.5: GIVING BLOOD

The New Zealand Blood Service collects donations of blood from volunteer donors and uses them to treat injured or sick patients. Visit www.nzblood.co.nz and make a list of what blood components are used, and who is likely to receive each component.

THE SENSES

Senses have evolved to let an organism know about changes in the world around them. These changes might be that the organism is getting closer to food, water or a mate; or the change could be that a predator is close by.

A neuron is a specialised cell that can transmit electrical impulses. Some neurons run the length of the organism's body. Neurons are often bundled together to form nerves.

In animals with backbones (vertebrates) the nerves are organised, with a brain in the head region, a spinal cord inside the spine and branching nerves that run out from this.

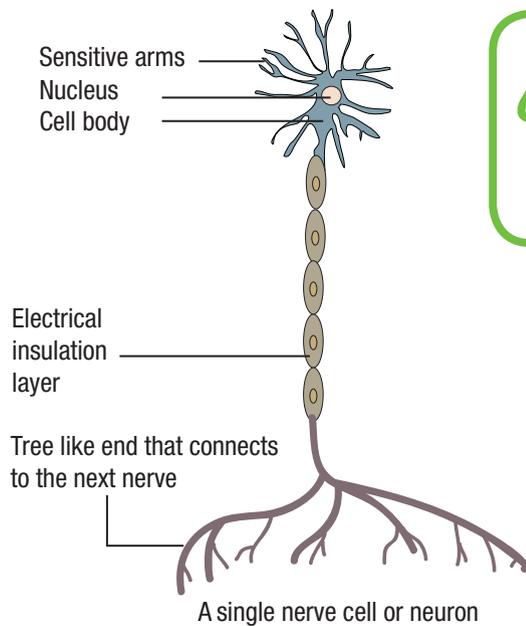


Figure 1.22: Structure of a typical neuron

SciFACTS

The longest cell in a human is a neuron, at almost 2 m.

Hearing

Sound is an excellent way to communicate and get clues about what is happening around you. Sound travels quickly and far, works in the dark, turns corners and can get the attention of someone who is not watching or cannot see. Sound can also be varied so animals can quickly send complicated messages. The ears of most vertebrates not only detect sound, but allow the animal to balance when moving.

HEARING IN HUMANS

Ears gather and direct sound to receptors. To do this the ear has three main regions called the outer, middle and inner ear.

The outer ear is what we usually just call 'the ear'; however, it is more accurately known as the pinna. The pinna directs the sound to the eardrum, which vibrates back and forth. Higher notes cause the eardrum to vibrate more quickly and lower notes more slowly.

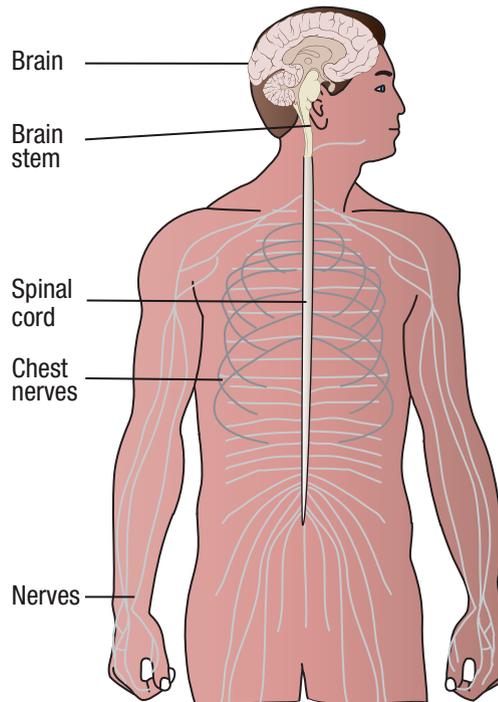


Figure 1.23: The central nervous system and the peripheral nervous system

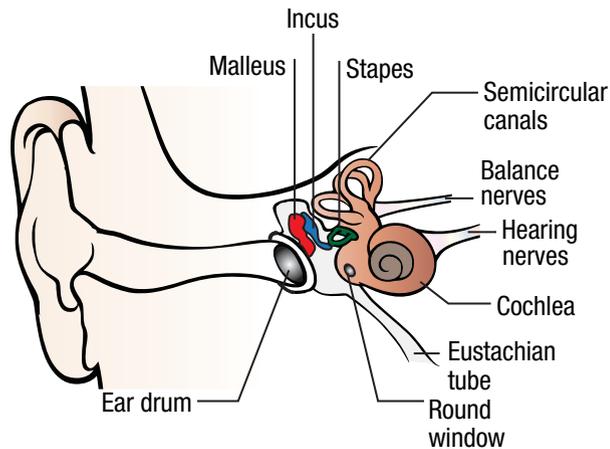


Figure 1.24: The human ear



Beyond the eardrum is the air-filled middle ear that has three tiny bones that move as the eardrum vibrates. The first bone is the malleus (hammer), the second is the incus (anvil) and the third is the stapes (stirrup). The hammer hits the anvil, which in turn causes the stirrup to move. However, because each part moves like a lever the stirrup moves 20 times further than the eardrum, hence the sound is amplified 20 times. The stirrup is attached to a thin layer called the oval window that moves as the stirrup moves.

As the middle ear is filled with air, it will only work if the air pressure is the same on both sides of the eardrum. To ensure the pressures are equal a pipe called the eustachian tube runs from the middle ear to the back of the mouth. Changes in pressure, such as a change in altitude, reduce hearing as the eardrum cannot vibrate freely. To fix this you simply need to swallow, which briefly opens the eustachian tube and allows air to enter or leave. This equalises the pressures and causes the ears to 'pop' as normal hearing returns.

Beyond the oval window lies the inner ear that is fluid-filled and leads to a snail-shaped tunnel called the cochlea. Tiny hairs in the cochlea sweep back and forth as the oval window vibrates the fluid. Hairs close to the oval window detect rapid movements of the fluid, caused by high frequency sounds. Low frequency sounds are detected by hairs that are further away from the oval window. So the fluid can move easily, the cochlea has a tiny round window at the end. This creates a continuous loop in which the fluid can move freely.

The main causes of hearing loss are stiffness of the eardrums (or ear bones) caused by aging and repeated infections, and damaged hair cells in the cochlea from loud noise. Both stop the ear bones moving quickly and therefore prevent high notes from being heard.

HEARING IN OTHER ANIMALS

The ears of mammals and birds are very similar, but only mammals have pinnae, though most marine mammals do not.

Reptiles have inner ears, but do not generally rely on hearing as much as birds and mammals. Most fish have organs to detect sound inside their heads.



Figure 1.25: Monkeys use hearing for communication and protection



SciFACTS

By diving into deep, cold water, humpback whales can get sound waves to travel hundreds of kilometres, which is very useful for finding each other across large distances.



Frogs have tympanums, a membrane on either side of the head, which vibrate to detect sound. Cicadas and many other insects also have tympanums of a different design.

Many mammals, such as rabbits and horses, can swivel their pinnae (both 'ears'), so they can better hear in a particular direction.

BALANCE

Mammals work out which way is up using a part of the middle ear called the vestibular apparatus, and most other vertebrates have a similar feature. It is made of three fluid tubes, all at right angles to each other. Each tube forms a semicircular canal and there is one for each direction we move: left and right, up and down, and forwards and backwards. As our head moves, the fluid moves around. This movement is detected by tiny hairs that line part of the semicircular canals. Extra information comes from tiny ear stones that are made of calcium carbonate. These stones lie across the bottom of the vestibular apparatus and move as we do. Their movement is detected by a thin layer of tiny hairs that transmit the message to the brain.

Motion or travel sickness is caused by the vestibular apparatus telling the brain the body is moving in a certain way and the eyes telling the brain it is moving in another way. This confusion results in nausea, anxiety and sweating.

Touch

Many organisms find out about the world around them by touch. Some plants use touch to wrap themselves around objects for support.



Figure 1.26: Plants use touch to wrap themselves around objects for support

TOUCH IN HUMANS

Our skin has millions of sensitive nerve endings that can detect pressure, vibration, temperature, pain, itchiness and stretching. These sensors are also present inside our bodies, but there are far fewer of them there. This means we are not very aware of where sensations inside us are coming from. This is why pain anywhere inside the abdomen can only be described vaguely as a 'stomach ache', but sensations on the skin can be very specific. For example, we can describe not only on which finger a sensation is occurring, but where on the finger the feeling is.

Hairless areas of the body, such as fingertips and lips, have large numbers of pressure-sensitive neurons that detect fine detail. For example, by rolling something between our fingertips we are able to 'feel' what it is like, but if we stop rolling, the information stops. Other nerves provide longer-term information about what is touching us. Deeper in the skin, neurons detect the movement of hairs.



Figure 1.27: Fingertips have large numbers of pressure-sensitive neurons that detect fine detail



TOUCH IN OTHER ANIMALS

Communicating by touch is common, especially in social insects like ants, termites and wasps. The most remarkable communication is between bees, when a returning female bee uses a 'waggle dance' to describe where pollen can be found. During her dance other bees follow and touch her. The path, speed and direction of her complicated dance indicates the direction and distance they need to fly, using the sun as a guide.

Figure 1.28: Bees communicate by touch



Taste

Taste helps animals find the best food, and can often let them know when something is poisonous or spoiled.

TASTE IN HUMANS

Humans have about 10 000 tastebuds arranged on tiny folds (papillae) on the tongue. The numerous papillae give the tongue a furry appearance. There is so much wear and tear on a tongue that each tastebud

only lasts a few days before it is replaced. However, the nerve beneath each tastebud is not replaced. We can only detect a limited number of tastes: sweet, bitter, sour, salt and umami (savoury, meatiness). However, these are arranged in overlapping areas and when combined with the sense of smell give us the illusion of many flavours. The importance of smell to taste can be seen when we have a cold and we lose our sense of taste.



TASTE IN OTHER ANIMALS

Flies and crabs can taste salt, proteins and sugars with their feet, so they can find food by walking around. Flatworms taste with their 'ears'. Vertebrate animals living on the land have tastebuds in their mouths, but fish taste with their lips and skin.



Figure 1.29: Humans have about 10 000 tastebuds on their tongues



Figure 1.30: Crabs taste with their feet



Smell

As life evolved on Earth, one of the first ways organisms communicated with each other was probably by smell. The first 'smell', like today, is simply chemicals released by an organism into air or water.

SMELL IN HUMANS

Humans detect smell through a collection of nerves at the top of the nose that can detect chemicals in the air. Humans have a good sense of smell, but we usually do not make much use of it; we prefer to use our vision. Every smell we detect is the result of us detecting a different chemical or combination of chemicals. How strong the smell is depends on how many molecules of the chemical we detect. Different smells have powerful effects. For instance, the odour of freshly baked bread makes us produce saliva and feel hungry, yet the smell of decay may make us feel sick.



Figure 1.31: Humans detect smell through a collection of nerves at the top of the nose

SMELL IN OTHER ANIMALS

Some chemicals produced by animals last for a long time and are used to mark the animal's territory. For example, chemicals sprayed by members of the cat family, and the urine of dogs, give information about how big and mature the animal is, its sex and how long ago it was there. Chemicals released to attract mates are short-lived and are made of small molecules so that they will spread further. Insects make excellent use of this. In fact, the males of some species can detect a single female many kilometres away! This is because they have thousands of chemical detectors on their antennae, as well as on hairs covering their bodies.



Figure 1.32: Chemicals in dogs' urine provide information about the dog





Sight

Animals with backbones, along with squid and octopi, have eyes that not only detect light but also form three-dimensional images of the world around them.

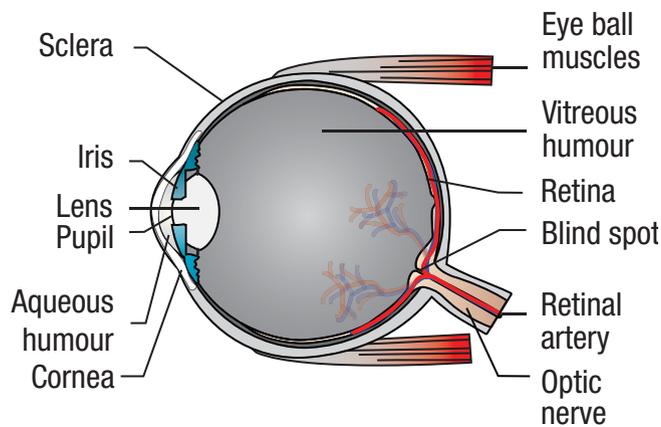


Figure 1.33: The human eye



Figure 1.34: Birds' excellent colour vision is useful in attracting mates

SIGHT IN HUMANS

Eyes are tough, fluid-filled bags that have a clear area called the cornea in the front where light enters. Just inside the cornea is a network of coloured muscles called the iris, which controls the size of the hole through which light enters. This hole is called the pupil. The iris is important for controlling how much light enters the eye. In bright light it makes the pupil small; in dim light the pupil gets larger. Behind the iris is a lens that changes shape to focus the light. When the lens is thin, distant objects are in focus. When the lens is thick, close objects are in focus.

The retina is the 'screen' at the back of the eye that detects light. It is made up of rod-shaped cells and cone-shaped cells. There are about 100 million rods and 3 million cones in each eye. The rods are very sensitive to light but can only detect black and white. Cones are not as sensitive as rods, and they detect red, blue and green light. When it is dark, the cones do not work well but the rods do. This is why we see in colour when it is bright but only greys when it is dark. Light absorbed by the rods and cones creates electrical impulses that travel down the optic nerve to the brain.



SIGHT IN OTHER ANIMALS

Birds have excellent colour vision and can see ultraviolet light, both of which are important for flying fast, catching small prey, navigating and avoiding predators. Birds' colour

vision enables them to attract mates of the same species by having brightly coloured feathers. Bees, turtles, lizards and fish can also see ultraviolet light.



ACTIVITY 1.6: THE FIVE SENSES

- 1 What are the names, in order, of the three bones that move when the eardrum vibrates?
- 2 Name two places where you have many nerve endings. How does this help you survive?
- 3 What are the five tastes your tongue can detect?
- 4 How do you detect such a wide range of flavours with only five tastes?
- 5 What are the parts of the eye, in order, that light passes through to get to the retina?

CHAPTER REVIEW

Short-answer questions

- 1 Proteins are long chains of what?
- 2 What colours of light are captured by chloroplasts?
- 3 What substance is stored in the gall bladder?
- 4 What substance do red blood cells carry around the body?
- 5 Which of the five senses is also connected to your sense of balance?

Extended-response questions

- 1 What are two advantages and two disadvantages of your stomach producing hydrochloric acid?
- 2 If you were a red blood cell, how would your world change as you moved from an artery to a vein?