Edexcel

AS Level

Biology

CODE: (WBI11)

Topic 4

Plant structure and function, biodiversity and conservation

4A Plant structure and function

THE PLANT CELL WALL

Animal cells can be almost any shape. Plant cells are usually more regular in their appearance. This is largely because each cell is bounded by a **cell wall**.

However, **suberin** is added to the cell wall in cork tissues, and **lignin** is part of the cell wall structure in wood. These compounds reduce the permeability of the cell wall so that water and dissolved substances cannot pass through it.

The plant cell wall consists of several layers. The **middle lamella** is the first layer and is made when a plant cell divides into two new cells. It is mostly made of **pectin**, a polysaccharide that acts like glue and holds the cell walls of adjacent plant cells together.

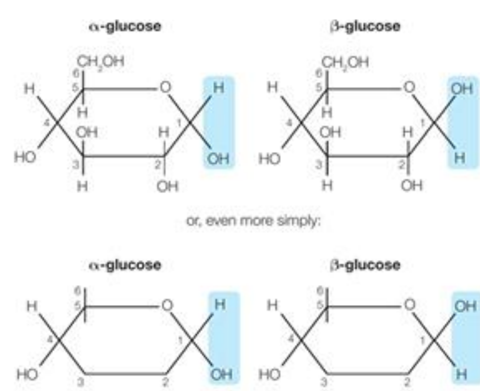
The calcium pectate binds to the cellulose on either side. The cellulose microfibrils and the matrix build up on both sides of the middle lamella. To begin with, these walls are very flexible, with the cellulose microfibrils all being arranged in a similar direction. They are called **primary cell walls.**

Secondary thickening may occur as the plant ages. A **secondary cell wall** builds up, with the cellulose microfibrils laid densely at different angles to each other. This makes the composite material much more rigid. **Hemicelluloses** help to harden it further In some plants, particularly woody perennials, lignin is then added to the cell walls to produce wood, which makes the structure even more rigid.

Within the structure of a plant, there are many long cells with cellulose cell walls that have been heavily lignified. These are called **plant fibres** and people use them in many ways including for clothing, building material, ropes and paper (see Section 4A.5).

THE CHEMISTRY OF CELLULOSE

Cellulose is the main compound in plant cell walls. Cellulose is a complex carbohydrate and is similar to starch and glycogen which you studied in Section 1A.3. It consists of long chains of glucose joined by glycosidic bonds. However, glucose comes in two different forms (isomers), called o-glucose and B-glucose. The two isomers come from different arrangements of the atoms on the side chains of the molecule (see fig B).



In these diagrams, the positions of carbon atoms are represented by their numbers only.
Note carefully the different arrangement of atoms around the carbon 1 atom in α-glucose and β-glucose.

▲ **fig B** The difference in structure between α-glucose and β-glucose may seem small, but it has a big impact on the function of the molecule.

Cellulose, a material with strong hydrogen bonds, forms long, straight chains, unlike starch, which forms compact globular molecules for storage. Starch is important for animals as an energy source, but most lack enzymes to break the 1,4-glycosidic bonds, making it difficult for them to digest. Ruminant animals and termites use cellulose-digesting enzymes.

They act in the same way as glue, binding to each other and to the cellulose molecules. Mannose, xylose and arabinose are examples of the sugars involved. The combination of the cellulose microfibrils in the flexible matrix makes a **composite material**, combining the properties of both these materials in the plant cell wall. The cells are **turgid** (firm) most of the time, giving the strength to support the plant in a vertical position, yet the plant can wilt when water is in short supply and the cells become **flaccid** (floppy).

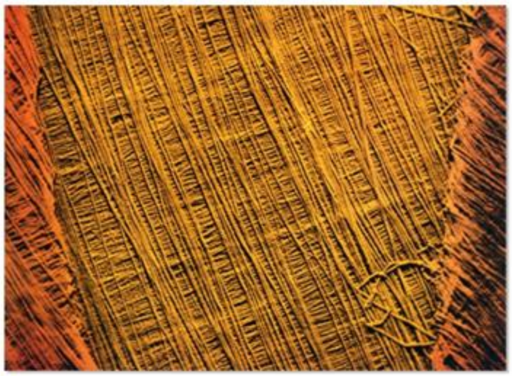


fig D These cellulose microfibrils consist of thousands of cellulose chains held together by hydrogen bonds. The way they are arranged is different in primary and secondary cell walls, affecting both flexibility and strength.

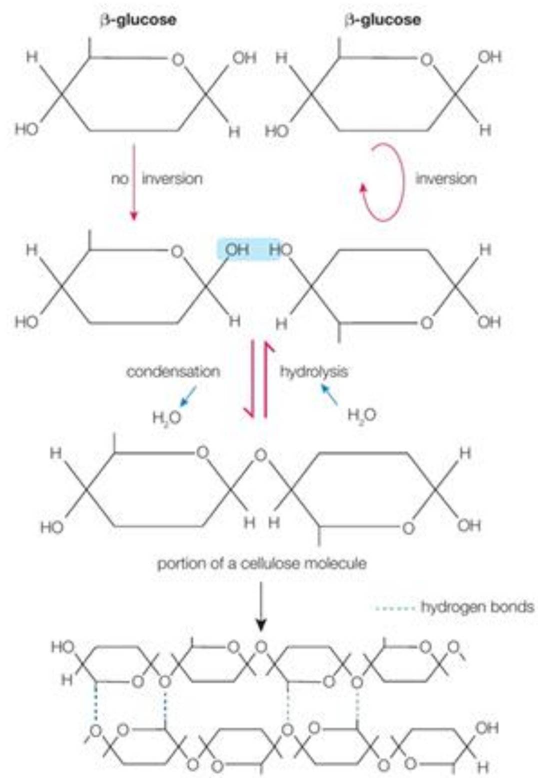


fig C Cellulose molecules consist of β-glucose monomers joined by 1,4-glycosidic bonds.

PLASMODESMATA

Plant cells seem to communicate closely with each other even though they are encased in cellulose cell walls. In primary cell walls and in cell walls which do not have lignin in them, materials are exchanged through special cytoplasmic bridges called **plasmodesmata** (singular: plasmodesma) (see fig E).

The interconnected cytoplasm of the cells is called the **symplast**. The cell walls are thinner in the region of the plasmodesmata.

When secondary thickening takes place, hemicelluloses and lignin are deposited in the cell wall making it thicker. In the areas around the plasmodesmata, this process doesn't happen, leaving thin areas of the cell wall called **pits**.

Scientists are working hard to discover exactly how plant cells communicate through plasmodesmata. One clear piece of evidence comes from work with plant grafts: it shows that these intercellular junctions are vital in the life of plants. If a rose is grafted onto a root stock, the graft tissue will only start healthy cell division and grow after plasmodesmata bridges have established between the host tissue and the graft tissue.

SUBJECT VOCABULARY

cell wall a freely permeable wall around plant cells, made mainly of cellulose
suberin a waterproof chemical that impregnates cellulose cell walls in cork tissues and makes them impermeable
lignin a chemical that impregnates cellulose cell walls in wood and makes them impermeable
middle lamella the first layer of the plant cell wall to be formed when a plant cell divides, made mainly of calcium pectate (pectin) that binds the layers of cellulose together
pectin a polysaccharide that holds cell walls of neighbouring plant cells together and is part of the structure of the primary cell wall
primary cell walls the first very flexible plant cell walls to form, with all the cellulose microfibrils orientated in a similar direction
secondary cell wall the older plant cell wall in which the cellulose microfibrils have built up at different angles to each other making the cell wall more rigid
hemicelluloses polysaccharides containing many different sugar monomers
plant fibres long cells with cellulose cell walls that have been heavily lignified so they are rigid and very strong
composite material a material made of two or more materials which combined together make a composite with different properties from either of the constituent materials
turgid swollen
flaccid floppy, soft
plasmodesmata cytoplasmic bridges between plant cells that allow communication between the cells
symplast all of the material (cytoplasm, vacuole, etc.) contained within the surface membrane of a plant cell
pits thin areas of cell wall in plant cells with secondary thickening, where plasmodesmata maintain contact with adjacent cells; in xylem vessels, where the cells are dead, they become simple holes through which water moves out into the surrounding cells

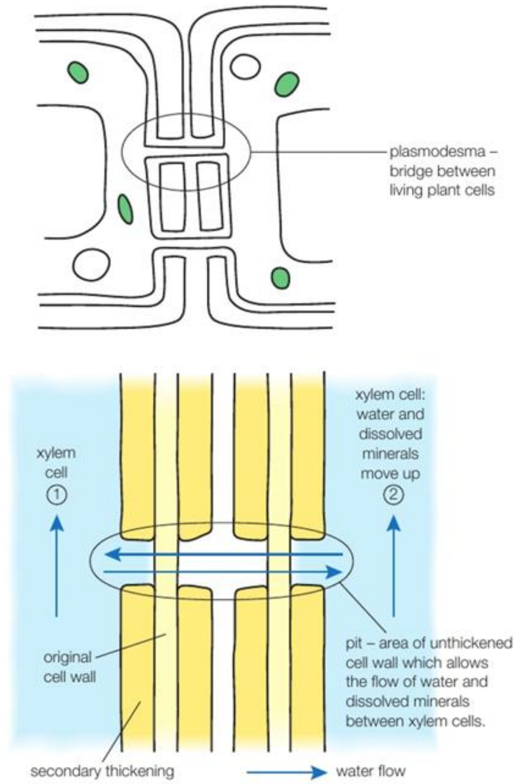


fig E Plasmodesmata provide a route for plant cells to communicate but scientists are still trying to find out exactly how this works.

4A 2 Plant organelles

PERMANENT VACUOLE

The vacuole can occupy up to 80% of the volume of a plant cell. It is surrounded by a specialised membrane called the **tonoplast** (see fig A). The tonoplast contains many different protein channels and carrier systems. It controls the movements of substances into and out of the vacuole and so it controls the water potential of the cell. The vacuole is filled with **cell sap**, a solution of various substances in water. This solution causes water to move into the cell by **osmosis** (see Section 2A.3), and this means the cytoplasm is kept pressed against the cell wall.

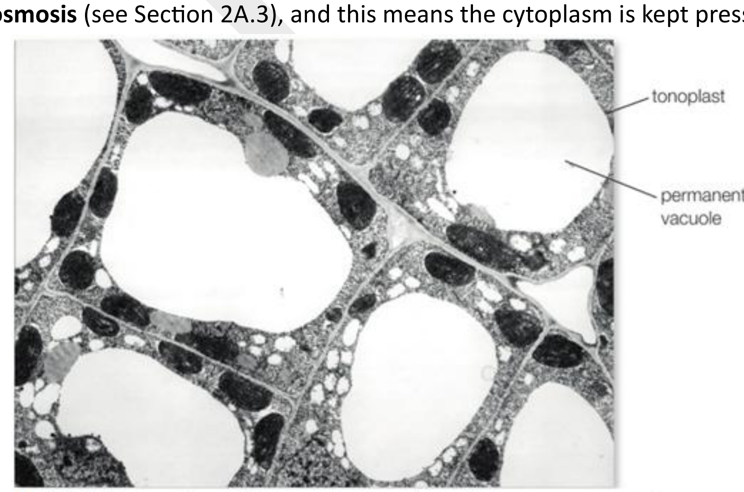


fig A The tonoplast and the permanent vacuoles are important structures in the support systems of plants, but they also have many other functions.

CHLOROPLASTS

Of all the differences between plant and animal cells, the presence of **chloroplasts** in plant cells is probably the most important because they enable plants to make their own food. Not all plant cells contain chloroplasts - only cells from the green parts of the plant.

Chloroplasts and mitochondria are similar in many ways. Like mitochondria, chloroplasts:

- are large organelles – they have a biconvex shape with a diameter of 4–10 μm and are 2–3 μm thick
- contain their own DNA
- are surrounded by an outer membrane
- have an enormously folded inner membrane that gives a greatly increased surface area where enzyme-controlled reactions take place
- are thought to have been free-living prokaryotic organisms that were engulfed by and became part of other cells more than 2000 million years ago.

However, there are also some clear differences. Chloroplasts:

- are the site of photosynthesis
- contain **chlorophyll**, the green pigment that is largely responsible for trapping the energy from light, making it available for the plant to use.

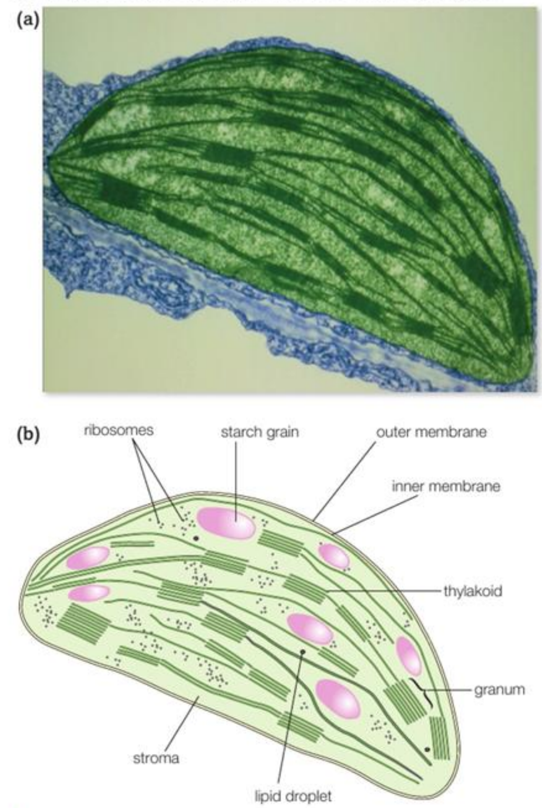


fig B **(a)** Micrograph of a chloroplast; and **(b)** a labelled diagram to show structures in a chloroplast

AMYLOPLASTS

Amyloplasts are another specialised plant organelle. They are colourless and store starch (see Section 1A.3). Remember starch is made of amylose and amylopectin joined together- this is where the amyloplasts get their name. The starch can be converted to glucose and used to provide energy when the cell needs it. Large numbers of amyloplasts are found in areas of a plant that store starch, for example potato tubers (see fig C).

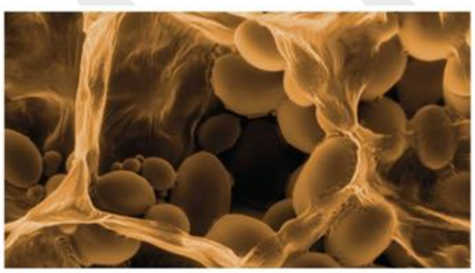


fig C Amyloplasts in plant cells from a potato – they are full of stored starch.

SUBJECT VOCABULARY

tonoplast the specialised membrane that surrounds the permanent vacuole in plant cells and controls movements of substances into and out of the cell sap
cell sap the aqueous solution that fills the permanent vacuole
osmosis a specialised form of diffusion that involves the movement of solvent molecules down their water potential gradient
chloroplasts organelles adapted to carry out photosynthesis, containing the green pigment chlorophyll
chlorophyll the green pigment that is largely responsible for trapping the energy from light, making it available for the plant to use in photosynthesis
amyloplasts plant organelles that store starch

4A 3 Plant stems

PROVIDING SUPPORT AND TRANSPORT

Stems serve two main functions in plants: supporting leaves for photosynthesis and pollination, and facilitating material movement. They provide flexible support, allowing plants to withstand weather and weather conditions. They also facilitate the movement of materials, carrying photosynthesis products from leaves to other parts of the plant. Most stems are green due to chlorophyll, but not all plants have stems. Not all complex plants have stems, such as liverworts and mosses.

THE TISSUES THAT MAKE UP THE STEM

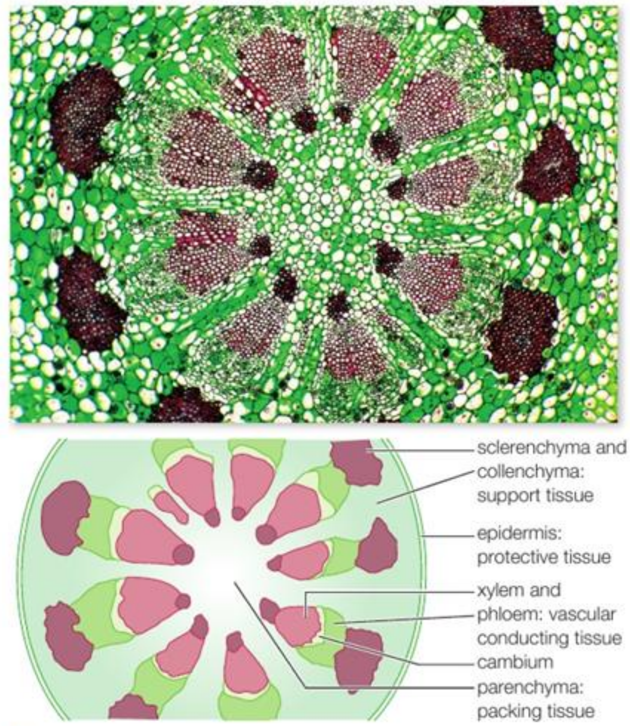
The outer layer of the stem is the epidermis, which does not provide support but protects the cells beneath it. Much of the stem is packing tissue which consists of the most common type of plant cell, **parenchyma**. These are unspecialised cells, but they can be modified in several ways, so they become suitable for storage and photosynthesis.

Collenchyma cells have thick cellulose primary cell walls, which are even thicker at their corners (see fig B). This gives the tissue its strength.

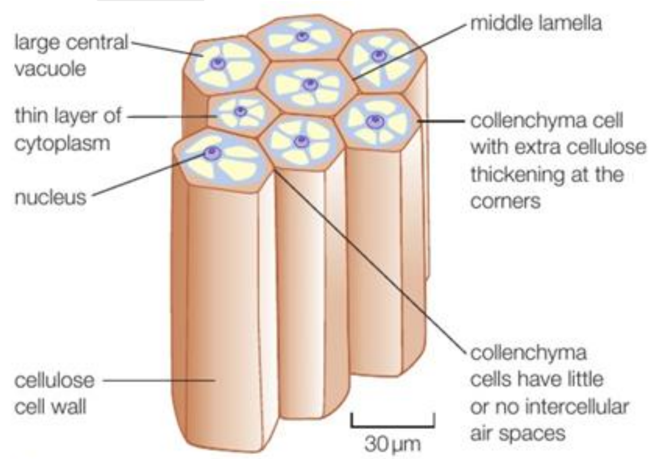
SCLERENCHYMA

Sclerenchyma is a modified parenchyma tissue found in plant stems and leaves, developed to support the plant's growing weight. It has strong secondary walls made of cellulose microfibrils. Some sclerenchyma creates fibres, which are long cells with lignin deposits. The strength of these fibres depends on their length and lignification. Once lignified, the fibres become hollow tubes, preventing plant growth.

Sclerenchyma cells can also become completely impregnated with lignin and form **sclereids**. These very tough cells may be found in groups throughout the cortex of the stem or individually in plant tissue.



▲ **fig A** The distribution of the different tissues in the stem of a plant



▲ **fig B** Collenchyma cells

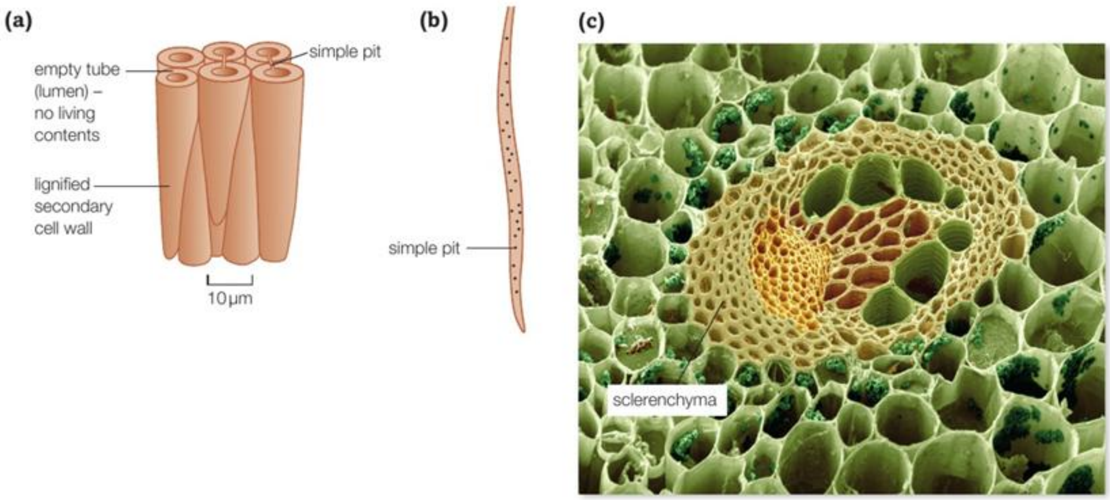
TRANSPORT TISSUES IN PLANTS

Plants, like other large, multicellular organisms, need a system to transport substances to all the cells. The main transport tissues in plants are the **xylem and phloem** and they are found associated together in **vascular bundles** throughout the plant, including the stem, roots and leaves (see fig D).

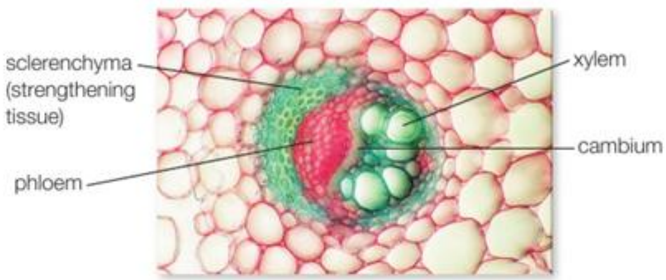
• Xylem tissue carries water and dissolved mineral ions from the roots to the photosynthetic parts of the plant. The movement in the xylem is always upwards. **Xylem** consists of several different types of cell; most of the xylem cells are dead. Long tubular structures called xylem vessels are the main functional units of the xylem.

• Phloem is living tissue made of phloem cells which transport the dissolved product of photosynthesis (sucrose) from the leaves to where it is needed for growth or storage as starch. The flow through phloem can go both up and down the plant.

• **Cambium** is a layer of unspecialised cells which divide, giving rise to more specialised cells that form both the xylem and the phloem.



▲ **fig C** The structure of **(a)** sclerenchyma cell and **(b)** sclerenchyma fibres. The cross-section of a plant stem **(c)** shows the very thickened sclerenchyma cell walls.



▲ **fig D** The arrangement of tissues in a vascular bundle combine strength and transport functions.

XYLEM

The xylem starts off as living tissue. The first xylem the plant makes is called the **protoxylem**. It can stretch and grow because the walls are not fully lignified. The cellulose microfibrils in the walls of the xylem vessels are arranged vertically in the stem. This increases the strength of the tube and allows it to resist the compression forces from the weight of the plant pressing down on it.

Increasing amounts of lignin are incorporated into the cell walls as the stem ages and the cells stop growing. This means that the cells become impermeable to water and other substances. The tissue becomes stronger and more supportive, but the contents of the cells die. This lignified tissue is called the **metaxylem**.

Water and mineral ions are transported from the roots to the leaves and shoots in the **transpiration stream**. Water moves out of the xylem into the surrounding cells through the specialised pits in the walls of the xylem vessels. The lignified xylem vessels are very strong and help to support the stems of plants, particularly in larger plants.

PHLOEM

Mature phloem is a living tissue that transports food in the form of organic solutes around the plant. These molecules move from the leaves where they are made by photosynthesis to the tissues where they are needed. Materials in the phloem can be transported both up and down the stems in an active process called **translocation**.

The phloem consists of many cells joined to make very long tubes that run from the highest shoots to the end of the roots. However, the phloem cells do not become lignified and so the contents remain living. The walls between the cells become perforated creating specialised **sieve plates** and the phloem sap flows through the holes in these plates. The nucleus, the tonoplast and some of the other organelles break down as the gaps in the sieve plates are made. The phloem sieve tube becomes a tube filled with phloem sap and the mature phloem cells have no nucleus. They survive because they are closely associated with cells called **companion cells**.

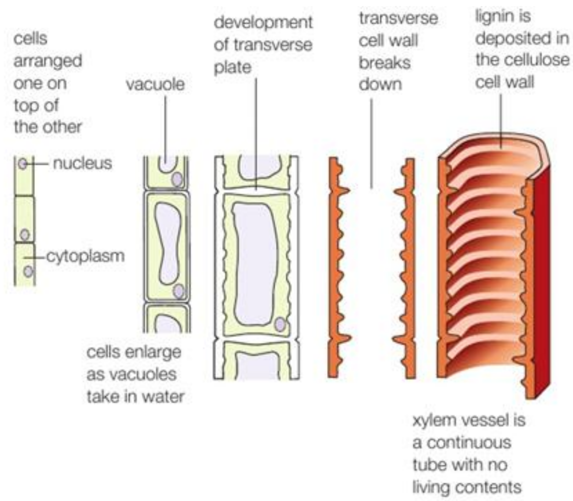


fig E The xylem vessels change from living cells to dead tubes of lignin as they develop.

SUPPORT AND TRANSPORT THROUGHOUT THE PLANT

The plant's roots, leaves, and stems require support and strength from sclerenchyma and xylem for water, mineral ions, and sugar transport. These tissues are found throughout the plant, often in vascular bundles. The xylem is inside the stem and root, while the phloem is outside and surrounded by a layer of strengthening sclerenchyma. The arrangement varies across different plant areas.

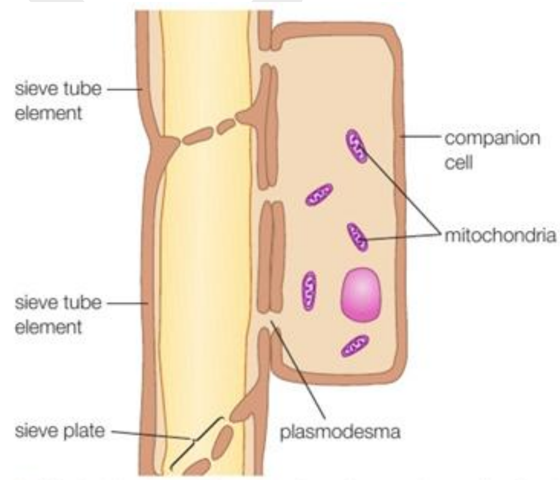


fig F These are phloem vessels and companion cells – the tissue that moves sugars around plants.

SUBJECT VOCABULARY

parenchyma relatively unspecialised plant cells that act as packing in stems and roots to give support
collenchyma plant cells with areas of cellulose thickening that give mechanical strength and support to the tissues
sclerenchyma plant cells that have very thick lignified cell walls and an empty lumen with no living contents
sclereids sclerenchyma cells that are completely impregnated with lignin
xylem the main tissue transporting water and minerals around a plant
phloem the main tissue transporting dissolved food around the plant
vascular bundle part of the transport system of a plant, with phloem on the outside and xylem on the inside – often with strengthening sclerenchyma
cambium the layer of unspecialised plant cells that divide to form both the xylem and the phloem
protoxylem the first xylem the plant makes; it can stretch and grow because the walls are not fully lignified
metaxylem consists of mature xylem vessels made of lignified tissue
transpiration stream the movement of water up from the soil through the root hair cells, across the root to the xylem, then up the xylem, across the leaf until it is lost by evaporation from the leaf cells and diffuses out of the stomata down a concentration gradient
translocation the active movement of substances around a plant in the phloem
sieve plates the perforated walls between phloem cells that allow the phloem sap to flow
companion cells very active cells closely associated with the sieve tube elements that supply the phloem vessels with everything they need and actively load sucrose into the phloem

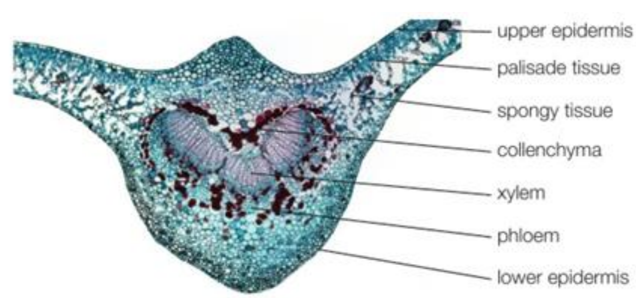


fig G The arrangement of the xylem, phloem and sclerenchyma tissue varies in the different areas of the plant to give the support needed in different situations.

4A 4 Importance of water and minerals of the plant

WHY DO PLANTS NEED WATER?

Water is a vital element in all living organisms - most of the reactions of animal life take place in water, and plants are no different. In fact, plants are about 90% water (compared with humans who are about 65% water) so water is fundamental for their survival. As well as the need for water shared by all organisms, plants also have some further specific requirements.

• Plants need water for photosynthesis. They combine carbon dioxide and water to make glucose and oxygen, using energy from light. You will learn more about this in Book 2 Chapter 5A

• Plants need water for support. Non-woody plants rely on the pressure that builds up as water moves into the vacuoles of the cells by osmosis. This forces the cytoplasm against the cell walls, making the cells rigid. If non-woody plants lack water, they wilt and cannot keep upright.

• Plants need water for transport. Mineral ions are carried around the plant in the xylem in a mass transport system which is powered by transpiration as water evaporates from the surfaces of cells in the leaves and diffuses out into the air. Sugars are carried around the plant in the phloem where they are dissolved in the water and moved by active transport.

• Plants need water to keep them cool - the evaporation of water from the leaves helps cool the plant.

WHY DO PLANTS NEED MINERALS?

Although plants can synthesise their own carbohydrates by photosynthesis, they also need other molecules such as proteins and fats. Certain minerals are needed to synthesise these and other substances essential for healthy growth. Plants must extract these minerals from the soil.

NITRATES

Nitrate ions are used to make amino acids and therefore proteins. These proteins include plant enzymes without which the cells could not function. Nitrates are also needed for the plant to make DNA and many hormones, as well as a range of other compounds in plant cells. When plants lack nitrates, the older leaves turn yellow and die, and growth is stunted. Eventually the plant dies.

CALCIUM

Calcium ions in the middle lamella of plant cell walls combine with pectin to make the calcium pectate which holds plant cells together. Calcium ions are also important in the permeability of membranes. When plants lack calcium, the growing points die back and the young leaves are yellow and crinkly.

MAGNESIUM

Magnesium ions are needed to produce the green pigment chlorophyll. Chlorophyll is vital to trap the light needed for photosynthesis, so if a plant cannot make enough chlorophyll it will eventually die. Magnesium is also needed for the activation of some plant enzymes and the synthesis of nucleic acids. Without magnesium, yellow areas develop on the older leaves and growth slows down.

4A 5 Using plant starch and fibers

We use other plant products, including olives, sunflowers, linseed and many nuts, for the oils they contain. Pulses such as beans, peas, lentils, soya beans and chickpeas provide much of the protein requirement for people who eat little or no meat. Fleshy and succulent fruits including dates and bananas are also important foods, and are sources of sugars as well as vitamins. In addition to eating many parts of plants ourselves, the animals that we raise as a source of food are fed on fodder plants such as grass.

▲ **fig A** Plant foods are a staple part of the human diet around the world.

FROM CONSTRUCTION TO CLOTHING

Food is only one way in which people use plants. You have already learned that the structure of cellulose fibres gives them great strength. These fibres may be further toughened and strengthened by lignin, turning them into what we recognise as wood. The properties of plant fibres and wood make them very useful to us.

PLANT FIBRES

Plant fibres have great **tensile strength** - they cannot easily be broken by pulling (under tension). This, along with their flexibility, makes them very useful. They usually exist in bundles of fibres which are much stronger than the individual cells.

HOW FIBRES ARE PROCESSED TO MAKE PRODUCTS

Many traditional methods of producing fibres such as flax (often used for ropes) simply relied on the actions of natural decomposers to break down the material around the fibres. This is called retting. In many countries, natural retting has been replaced by manufacturing processes using chemicals and enzymes, which do the job much more quickly.

Probably the best known and most widely used of the natural fibres is cotton (see fig B).

▲ **fig B** Cotton bushes produce 'ready-to-use' cotton fibres around their seeds.

WOOD

Wood is a composite material, made of lignified cellulose fibres embedded in hemicelluloses and lignin. The great benefit of a composite is that it has the properties of both materials. The cellulose fibres make the wood very resistant to compression (squeezing by weight) so it is excellent for weight-bearing in buildings and can be used in supporting columns as well as in horizontal beams. Wood also keeps some of the matrix flexibility and, because of the intermeshing cellulose fibres, it doesn't crack in the way that a stiff material does. So you can hammer a nail into it or cut out small pieces to make joints without damaging the strength of the wood.

Wood also locks up carbon dioxide and is a sustainable resource if it is managed carefully with replanting programmes. Even if it is burned, wood can be **carbon neutral -** taking in carbon as it grows and releasing it as it is burnt - but it has the great advantage of also being a renewable energy source.

BIOPLASTICS: A SUSTAINABLE FUTURE?

The use of natural materials in developed countries has declined due to the development of synthetic materials, particularly plastics, made from oil-based chemicals. However, in the 21st century, modern materials are being developed from natural products due to the increasing environmental problems caused by plastics.

fig C Local wood and earth bricks are used as renewable resources to rebuild homes in Sri Lanka after the 2004 tsunami.

BIOLOGICAL POLYMERS

Scientists are increasingly looking at the possibilities of producing and using bioplastics - plastics based on biological polymers such as starch and cellulose. These have two large potential benefits.

• They are a sustainable resource. The starch or cellulose comes from plants such as maize, wheat, potatoes and sugar beet. These plants can be grown easily to supply the needs of the bioplastics industry. When oil runs out, we will need another source of plastics.

• Bioplastics are biodegradable. Bacteria and fungi can usually break down bioplastics because they are based on biological molecules, though the process can be very slow.

fig D Plastics are found almost everywhere on the planet, from the Arctic circle to the Antarctic. They are causing enormous environmental damage – and most will not degrade and disappear.

DIFFERENT TYPES OF BIOPLASTICS

Cellulose-based plastics, such as cellophane and thermoplastic starch, are used in various industries, including the pharmaceutical industry. Thermoplastic starch, extracted from potatoes and maize, is the most widely used bioplastic, making it easy to digest and absorb water. Other bioplastics include polylactic acid (PLA), produced from maize or sugar cane, and poly-3-hydroxybutyrate (PHB), used in ropes, bank notes, and car parts. Bioplastics can be burned, producing methane, a harmful greenhouse gas, and generating electricity. While bioplastics have potential benefits, they are still more expensive than oil-based alternatives due to their new technology and economies of scale. The use of crops like maize, wheat, sugar cane, and sugar beet for food, biofuel, and bioplastics raises questions about the future of food production and sustainable consumption.

SUBJECT VOCABULARY

tensile strength the resistance of a material to breaking under tension
carbon neutral a process where no net carbon is released into the atmosphere
bioplastics plastics based on biological polymers

4A 6 Plant – based medicines

PLANTS VERSUS MICROBES

There are more bacteria than any other type of organism. As you have learned, some types of bacteria cause human diseases such as tuberculosis and diphtheria. You may not know that bacteria can also cause plant diseases - in fact, millions of tonnes of crops are lost each year due to bacterial infections in plants.

BACTERIAL GROWTH

Bacteria reproduce by simply splitting in half in a process called **binary fission**. In ideal conditions, some bacteria can split into two cells every 20 minutes. For many types of bacteria, ideal conditions mean plenty of food, oxygen and water - and a warm temperature. Bacteria are so small they cannot be seen with the naked eye (see Section 3A.4 to remind yourself of the size and structure of bacteria). To investigate bacteria, for example for scientific experiments or to investigate potential medicines, we need to **culture them**.

It is important to take great care when culturing microorganisms because:

- even if the microorganism you are planning to culture is completely harmless, there is always the risk of a mutant strain arising that may be pathogenic
- there is a risk of contamination of the culture by pathogenic microorganisms from the environment
- when you grow a pure strain of a microorganism, the entry of any other microorganisms from the air or your skin into the culture will contaminate it.

Health and safety precautions must always be followed very carefully when handling, culturing or disposing of microorganisms. It is important to use **aseptic techniques** to keep everything **sterile** and uncontaminated by other microorganisms. All the equipment must be sterile before the culture is started.

PLANT DEFENCES AGAINST MICROORGANISMS

Plants can provide an ideal place for microorganisms, such as bacteria and fungi, to grow. The only problem is that the microorganisms can damage and may even destroy the plants. Consequently, many plants have evolved chemical defences to kill any microbes which will invade and cause disease. These chemical defences can include both antiseptic compounds and antibiotics.

ANTIMICROBIAL PLANT EXTRACTS

Some plants and fungi have been shown to have antimicrobial properties - they contain chemicals that kill bacteria and fungi. The antimicrobial properties of different plant extracts can be investigated in laboratories. Classically, agar culture plates are used to grow bacterial cultures with discs of filter paper soaked in plant extract placed on the agar. If the plant extract kills the bacteria, or stops them growing, you can see a clear area of agar around the disc.

EXTRACTING DRUGS FROM PLANTS

Plants produce other compounds besides antimicrobial chemicals. Some other compounds have effects from pain relief to destroying cancer cells. For example, salicylic acid is an everyday example of a drug which is derived from a species of willow. For centuries, willow bark was chewed or brewed up into a drink to relieve pain and fever. People even chewed on the anal glands of dead beavers to get pain relief. Now we take a carefully measured dose of a closely related but safer compound, acetylsalicylic acid, in the form of a small white tablet called **aspirin** (see fig B).

One of the major advantages of extracting and purifying the beneficial drugs found in plants is that it is possible to give known, repeatable doses of the active ingredient. The levels of a chemical in any part of a plant will vary with the age of the plant, the season of the year or even the time of day.

SUBJECT VOCABULARY

binary fission asexual reproduction in bacteria in which the bacteria split in half
culture growing microorganisms in the laboratory, providing them with the nutrients, oxygen, pH and temperature they need to produce large numbers so they can be observed and measured
aseptic technique method of carrying out a procedure to prevent contamination by unwanted microorganisms
sterile something free from living microorganisms and their spores
aspirin a widely used drug which relieves pain and reduces blood clotting and inflammation

▲ **fig B** Taking aspirin in tablet form is more convenient for pain relief than chewing willow bark or beaver anal glands.

4A 7 Developing new drugs

WILLIAM WITHERING AND DIGITALIS SOUP

Digitalis is a chemical found in foxgloves that has been used as a poison for centuries. However, at the same time, there were many reports about the role of foxgloves in curing 'the dropsy'. This is an old name for the swelling (**oedema**) that results when the circulation is failing. Dropsy, a serious heart condition, was discovered by British doctor William Withering in the 18th century. After a patient's recovery from a local 'wise woman's soup, Withering discovered that foxgloves contained the active ingredient. He tested various potions made from foxgloves on 163 patients at Birmingham General Hospital, finding that the best treatment was a soup made from the dried and powdered leaves of the foxglove. Boiling the leaves reduced the drug's effect, and Withering extracted the digitalis chemical from the leaves, which successfully treated his patients with dropsy and heart failure.

Drugs based on the chemicals in foxgloves, now called **digoxin**, are still in regular use by doctors today, about 230 years after William Withering carried out his ground-breaking work.

▲ **fig A** Foxgloves are the source of digoxin, a drug which can be a poison but also a cure.

TESTING PROMISING NEW MEDICINES

In the past, herbal remedies were often used as a source of new drugs. However, this is not the way new drugs are usually found in the 21st century. Every medicine that comes onto the market today is the result of years of research and development (R & D). A new medicine has to be:

- effective - it cures, prevents or relieves the symptoms of the disease for which it is designed
- safe - non-toxic and without unacceptable side-effects
- stable can be stored for some time and used under normal conditions
- easily taken into and removed from your body - able to get to its target in your body, and to be excreted (removed from the body) once it has done its job
- can be made on a large scale - can be manufactured in a very pure form, in large quantities and quite cheaply.

DRUG DEVELOPMENT AND ANIMAL TESTING

Drug delivery systems, such as tablets, liquid medicine, injections, or nasal sprays, are crucial for ensuring drug stability and safety. Animal testing is used to test the drug's effects on cells, body chemical changes, and safe excretion. Common animals used for initial tests are mice and rats, but animal testing is expensive, time-consuming, and ethically debated. To reduce animal use, tissue cultures and computer models are used, but not enough information is available to move to drug testing without animal testing.

fig B Laboratory mice are widely used in drug testing and there are strict regulations to ensure they are kept in humane conditions.

CLINICAL TRIALS

If the animal testing has been successful, the very first human trials follow. A regulatory authority will usually take decisions about the testing and licensing of new medicines. They will only allow a drug to be trialled on people if they are happy with all the tests carried out so far. In drug trials, some of the people will be given a **placebo**. Phase 1 trials involve giving a new drug or placebo to healthy volunteers to ensure it works as expected and doesn't cause unexpected side-effects. Animal trials continue to evaluate the drug's long-term effects. If successful, the drug moves to phase 2 trials, where it's used on patients with the target disease. This stage closely monitors the drug's effectiveness and side-effects, indicating its potential as a useful medicine. Phase 3 trials involve thousands of patients, with over 5000 volunteers used.

DOUBLE-BLIND TRIALS

Phase 2 and 3 trials are normally carried out as **double-blind trials**. This means neither the doctor/scientist nor the patient knows whether the patient is receiving the new medicine, a control medicine or a placebo. Patients often appear to respond to a treatment because they believe that it will do them good - there is much that is not understood about how the mind affects the body. This response is called the **placebo effect**. A double-blind trial measures the effectiveness and safety of a new drug, with Phase 3 trials confirming its effectiveness and safety. Large patient numbers increase the chance of unexpected adverse side-effects. Data on effectiveness, side-effects, and other information is collected to assess statistical differences between the new medicine and the control/placebo.

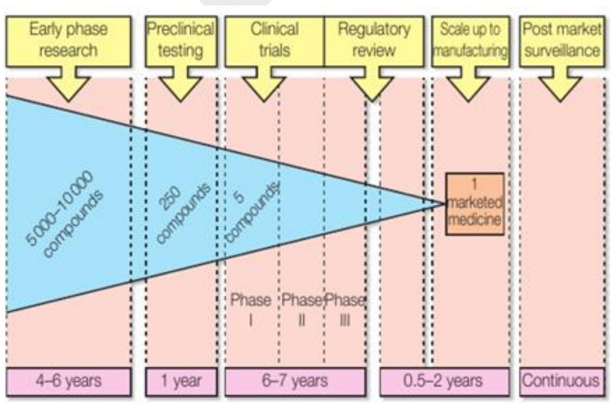


fig C This diagram summarises the main stages in a standard drug development protocol.

SUBJECT VOCABULARY

digitalis a chemical found in foxgloves that affects the beating of the heart
oedema swelling of the tissues due to fluid retention
digoxin a drug based on the chemical found in foxgloves that improves heart function
placebo an inactive substance resembling a drug being trialled which is used as an experimental control
double-blind trial a clinical drug trial where neither the doctor nor the patient knows whether the patient is receiving the new medicine, a control medicine or a placebo
placebo effect when patients appear to respond to a drug simply because they think it is doing them good

4B Classification

THE BACKGROUND TO BIODIVERSITY

Biodiversity is a measure of the variety of living organisms and their genetic differences. It is an important concept at the moment because the Earth's biodiversity is reducing rapidly. Many scientists think this may affect the future health of the planet.

WHY CLASSIFY?

Biodiversity, a result of millions of years of **evolution**, leads to a vast variety of living organisms with varying names across countries and areas. To quantify biodiversity, biologists need an internationally recognized way to identify different groups of organisms based on similarities and differences. A good classification system helps scientists monitor population changes and understand ancestral relationships between different types of organisms.

fig A This plant is a rose in English, English, ورد in Arabic, ρόδο in Greek, *rosa* in Spanish and *die Rosen* in German. The official classification Rosa is used and understood by biologists everywhere. The many different species of rose can be identified even more precisely, for example, *Rosa canina* (the Wild dog rose) and *Rosa acicularis* (the Arctic rose).

THE HISTORY OF TAXONOMY

Taxonomy is the science of describing, classifying and naming living organisms. This includes all of the plants, animals and microorganisms in the world, and it is an enormous task.

From the time of the Greek philosopher Aristotle onwards, people put organisms into groups based mainly on their physical appearance or **morphology**. People often used **analogous features** to classify organisms. But such features may not have the same biological origin so this system can easily create misconceptions. A valid classification system must be based on careful observation and the use of **homologous structures** - that is, structures that genuinely show common ancestry.

THE MAIN TAXONOMIC GROUPS

The biggest taxonomic groupings are huge - the largest are the three **domains**, a grouping developed more recently which you will look at in more detail in Section 4B.4. The main taxonomic groups are, from the largest to the smallest: domain, **kingdom**, **phylum (division, for plants), class, order, family, genus and species**.

The **Archaea** domain contains one kingdom:

• Archaebacteria: ancient bacteria thought to be early relatives of the eukaryotes. They were thought to be found only in extreme environments, but scientists are increasingly finding them everywhere - particularly in soil.

The Bacteria domain also contains one kingdom:

• Eubacteria: the true bacteria are what we normally think of when we are describing the bacteria that cause, for example, disease, and which are so useful in the digestive systems of many organisms and in recycling nutrients in the environment.

There are four kingdoms in the Eukaryota domain:

• Protista: a very diverse group of microscopic organisms. Some are heterotrophs - they need to eat other organisms - and some are autotrophs - they make their own food by photosynthesis. Some are animal-like, some are plant-like and some are more like fungi. Examples include Amoeba, Chlamydomonas, green and brown algae and slime moulds.

• Fungi: all heterotrophs - most are saprophytic and some are parasitic. They have chitin, not cellulose, in their cell walls.

• Plantae: almost all autotrophs, making their own food by photosynthesis using light captured by the green pigment chlorophyll. These include the mosses, liverworts, ferns, gymnosperms and angiosperms (flowering plants).

• Animalia: all heterotrophs that move their whole bodies around during at least one stage of their life cycle. These include the invertebrates (e.g. insects, molluscs, worms, echinoderms) and the vertebrates (e.g. fish, amphibians, reptiles, birds, mammals).

THE BINOMIAL SYSTEM

The binomial system of naming organisms was originally devised by Linnaeus. Biologists now use it universally. The way different organisms are classified is constantly under review as new data are discovered.
In the binomial system, every organism is given two Latin names - the word 'binomial' means 'two names'. The first name is the genus name and the second is the species or specific name which identifies the organism precisely. There are certain rules to writing binomial names:

- use italics
- the genus name has an upper-case letter and the species name a lower-case letter, e.g. Homo sapiens (human beings), Bellis perennis (common daisy)
- after the first use, binomial names are abbreviated to the initial of the genus and then the species name, e.g. H. sapiens, B. perennis.

fig B These two butterflies both belong to the genus *Vanessa*, but they are different species (*Vanessa atalanta* and *Vanessa cardui*).

Table A shows a number of different species with all of their levels of classification.

LEARNING TIP

Remember the sequence of classification groups or taxa. It may help to make up a mnemonic such as: Desperate King Philip Came Over For Great Spaghetti.

DOMAIN	Bacteria	Eukaryota	Eukaryota	Eukaryota
KINGDOM	Eubacteria	Animalia	Fungi	Plantae
PHYLUM/DIVISION	Proteobacteria	Chordata	Basidomycota	Magnoliophyta
CLASS	Gammaproteobacteria	Mammalia	Agaricomycetes	Liliopsida
ORDER	Enterobacteriales	Perissodactyla	Agaricales	Poales
FAMILY	Enterobacteriaceae	Equidae	Amanitaceae	Poaceae
GENUS	*Escherichia*	*Equus*	*Amanita*	*Oryza*
SPECIES	*Escherichia coli* *E. coli* common bacterium in the intestines	*Equus caballus* *E. caballus* domestic horse	*Amanita muscaria* *A. muscaria* fly agaric	*Oryza sativa* *O. sativa* rice

table A Full classification of four different organisms

SUBJECT VOCABULARY

biodiversity a measure of the variety of living organisms and their genetic differences
evolution the process by which natural selection acts on variation to bring about adaptations and eventually speciation
taxonomy the science of describing, classifying and naming living organisms
morphology the study of the form and structure of organisms
analogous features features that look similar or have a similar function, but are not from the same biological origin
homologous structures structures that genuinely show common ancestry
domains the three largest classification categories: the Eukaryota, the Bacteria and the Archaea
kingdom the classification category smaller than domains; there are six kingdoms: Archaebacteria, Eubacteria, Protista, Fungi, Plantae and Animalia
phylum (division, for plants) a group of classes that all share common characteristics
class a group of orders that all share common characteristics
order a group of families that all share common characteristics
family a group of genera that all share common characteristics
genus a group of species that all share common characteristics
species a group of closely related organisms that are all potentially capable of interbreeding to produce fertile offspring
Archaea domain made up of bacteria-like prokaryotic organisms found in many places including extreme conditions and the soil; they are thought to be early relatives of the eukaryotes
Archaebacteria ancient type of bacteria found in many different environments
Eubacteria true bacteria (prokaryotic organisms)
Protista a kingdom in the five-kingdom classification system that contains all single-celled organisms, green and brown algae and slime moulds
Fungi a eukaryotic kingdom of heterotrophs with chitin in their cell walls
Plantae a mainly autotrophic eukaryotic kingdom containing mosses, liverworts, ferns, gymnosperms and angiosperms (the flowering plants)
Animalia a mainly heterotrophic eukaryotic kingdom including all the invertebrates and vertebrates

4B 2 What is a species?

THE CONCEPT OF SPECIES

The concept of species is a very important one for biologists. We use species numbers to measure biodiversity (see Chapter 4C). We also look for changes in species to help us monitor the effect of both natural environmental changes and changes that result from human activity. Biologists look for both adaptations within a species and for changes in the numbers or types of species in an environment.

THE MORPHOLOGICAL SPECIES CONCEPT

The definition of species that Linnaeus originally developed was a **morphological species model**, which was based solely on the appearance of the organisms he observed. However, the appearance of an organism can be affected by many different things and there can be a huge amount of variation within a group of closely related organisms. In fact, in organisms that show **sexual dimorphism** - in which there is a great deal of difference between the male and female - the different sexes could be confused as different species in a morphological species model (see fig A).

fig A Most people would not classify these two birds in the same species, unless they were seen mating, but the peacock and peahen are male and female peafowl.

fig B Agaves and aloes are both adapted to survive in similar desert conditions, but they come from different parts of the world and are not closely related.

THE REPRODUCTIVE OR BIOLOGICAL SPECIES CONCEPT

For many years, a morphological definition of a species was used almost without question. However, over time biologists moved to a basic model of a species based on the reproductive behaviour of the organisms. One widely used definition of a species is:

- a group of organisms with similar characteristics that interbreed to produce fertile offspring. This definition of species overcomes issues such as sexual dimorphism and is regarded as a good working definition for many animal species, but it has limitations..

For example, lions and tigers are different species, but if a lion and tiger mate most of the offspring produced are fertile. To help overcome these limitations, two slightly more sophisticated definitions of species based on reproductive capability are:

- a group of organisms with similar characteristics that are all potentially capable of breeding to produce fertile offspring
- a group of organisms in which genes can flow between individuals.

A reproductive concept of species is a good working model for most animals, but it is much less helpful in classifying plants, which frequently interbreed with similar species to produce fertile offspring.

(a) (b) (c)

fig C When donkeys breed they produce young donkeys **(a)**, which grow up to produce more donkeys. When horses breed they produce foals **(b)**, which will produce more horses in the future. But if a horse and a donkey breed they produce an infertile mule **(c)** – so they are definitely separate species.

OTHER DEFINITIONS OF SPECIES

The definition of a species is constantly evolving, with scientists using various methods to determine organisms' belonging and relationships. The fundamental chemicals of life, like DNA, RNA, and proteins, are universal but differences are revealed through molecular phylogeny, leading to new species models. They include:

• **Ecological species model** - based on the ecological niche occupied by an organism. This is not a very robust way of identifying species, as niche definitions vary and many species occupy more than one niche.

• **Mate-recognition species model** - a concept based on unique fertilisation systems, including mating behaviour. The difficulty is that many species will mate with or cross-pollinate other species and may even produce fertile offspring, but are nevertheless different species.

• **Genetic species model** - based on DNA evidence. This might seem the ultimate, reliable method of determining species, but people still have to decide how much genetic difference is needed for two organisms to be members of different species.

LIMITATIONS OF SPECIES MODELS

All the ways to define species have limitations, which include:

1. Finding the evidence - many living species have never been observed mating. This is particularly true if a new species is found that is similar to an existing species. Setting up a breeding programme is time-consuming, expensive and may not prove anything.

2. Plants of different but closely related species frequently interbreed and produce fertile hybrids. When should the hybrids themselves be regarded as a separate species?

3. Many organisms do not reproduce sexually. Any definition involving reproduction or reproductive behaviour is irrelevant for bacteria and the many protists, fungi and others that mainly reproduce asexually.

4. Fossil organisms cannot reproduce and do not usually have any accessible DNA, but they still need to be classified.

IDENTIFYING A SPECIES

Classifying organisms and identifying their species remains a useful biological tool, with information technology (IT) providing essential tools for scientists to answer questions about absolute or comparative species. The Natural History Museum in London, UK, houses millions of specimens of organisms collected over centuries, with most species identified by external features. New specimens are regularly sent for identification, demonstrating the importance of IT in classification processes.

fig D Breeding experiments or DNA analysis are not helpful in identifying shells and fossils.

THE IMPORTANCE OF DNA IN CLASSIFICATION

In recent years, scientists have developed techniques that allow them to analyse the DNA and proteins of different organisms. In **DNA sequencing** the base sequences of all or part of the genome of an organism is revealed. DNA sequencing leads to **DNA profiling**, which looks at the non-coding areas of DNA to identify patterns.

THE SAME...

Identifying species from their phenotype can be difficult. External conditions can result in major differences in the appearance of individuals of the same species.

...BUT DIFFERENT

In contrast, for many years the plant disease scab, which can destroy crops such as wheat and barley, was thought to be caused by a single fungus, Fusarium graminearum. Molecular geneticists in the United States have investigated the disease to try and help plant breeders and disease control specialists worldwide. DNA evidence shows that there are at least eight different species of Fusarium pathogens, which have a similar effect on crop plants. This evidence is based on the divergence of six different genes and the proteomic evidence of the proteins they produce (see fig E).

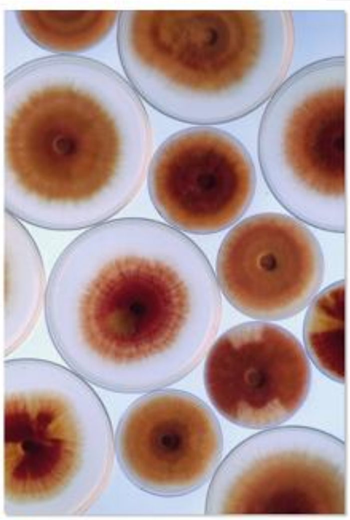


fig E These cultures may all look the same, but DNA evidence shows that they are distinct species of fungi, all of which cause similar diseases in plants.

SUBJECT VOCABULARY

morphological species model a species definition based solely on the appearance of the organisms observed

sexual dimorphism describes species where there is a great deal of difference between the appearance of the male and female

molecular phylogeny the analysis of the genetic material of organisms to establish their evolutionary relationships

ecological species model a species definition based on the ecological niche occupied by an organism

mate-recognition species model a species definition based on unique fertilisation systems, including mating behaviour

genetic species model a species model based on DNA evidence

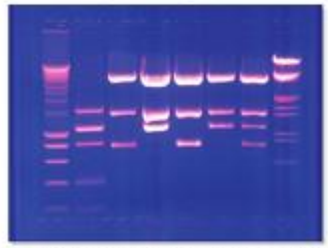
DNA sequencing the process by which the base sequences of all or part of the genome of an organism is worked out

DNA profiling the process by which the non-coding areas of DNA are analysed to identify patterns

4B 3 Domains, kingdoms or both

GEL ELECTROPHORESIS: A VITAL TECHNIQUE

Patterns in DNA or RNA fragments are being used more and more in species identification. Comparisons between the amino acid sequences of similar proteins in different species or groups of organisms are also used to help us classify them or trace their developmental pathways. A useful technique in these processes is **gel electrophoresis**. This is a variation of chromatography which can be used to separate DNA and RNA fragments, proteins or amino acids according to their size and charge (see fig A).



▲ **fig A** Gel electrophoresis can be used to identify patterns in the DNA, RNA and proteins of different organisms. This can help to determine both the species they belong to and their evolutionary links.

More biochemical relationships

Understanding biochemical relationships between organisms is crucial for expanding classification and relationships over time.

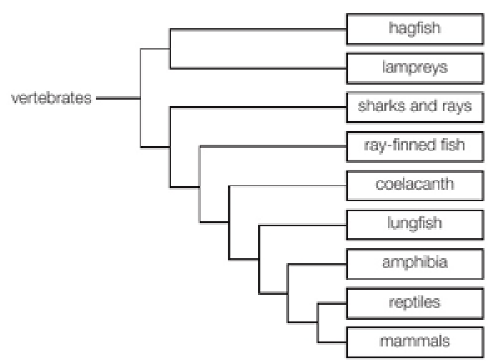
▲ **fig B** Starfish and sheep do not seem to have much in common, but biochemical and gel electrophoresis analysis shows that they are more closely related than you might think.

• Blood pigments are important in many animal groups. Analysis has shown that any group contains only one type of blood pigment - all vertebrates and many of the invertebrates have haemoglobin, all polychaete worms have chlorocruorin and all molluscs and crustaceans have haemocyanin. This allows scientists to build up a more detailed picture of the relationships between the different groups.

• Analysis of the sequence of amino acids in some specific proteins can help show the relationships within higher groups, such as a phylum. For example in mammals, analysis of fibrinogen (the protein involved in blood clotting) reveals how closely the different mammalian groups are related. Single amino acid changes are used to plot relationships.

PHYLOGENETIC TREES

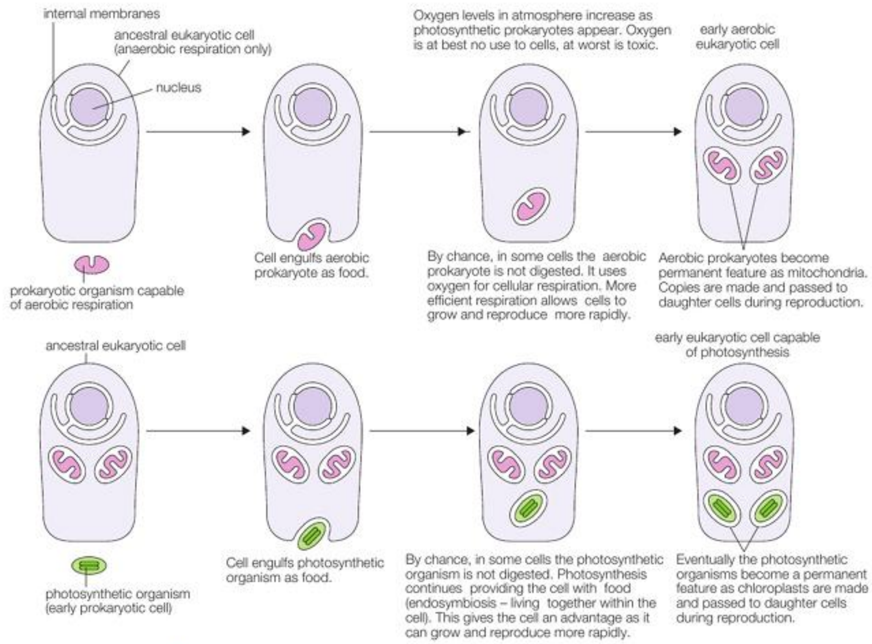
One way of showing the relationships between different groups of organisms is to use a **phylogenetic tree.** Phylogenetic trees are models of how different organisms are related. They may show the relationships between all living organisms, or just the relationships between a particular group of animals or plants.



▲ **fig C** This phylogenetic tree shows the relationships between a range of different animals.

TWO DOMAINS OR THREE?

For many years biologists divided living organisms into two large groups or domains. They named them the eukaryotes, cells with a complex cell structure (see **Sections 3A.2** and **3A.3**), and the prokaryotes, which included bacteria (see **Section 3A.4**). The theory was that eukaryotes developed from prokaryotes billions of years ago (see **fig D**). Some scientists think that chloroplasts became part of 'eukaryotic ancestor' cells first; others think that mitochondria were the first **endosymbionts**. It is possible that both processes happened at the same time because evidence to support one idea or another is almost impossible to obtain.



▲ **fig D** One model of how eukaryotic cells may have developed by engulfing prokaryotes.

CHARACTERISTIC	BACTERIA	ARCHAEA	EUKARYOTA
membrane-enclosed nucleus	absent	absent	present
membrane-enclosed organelles	absent	absent	present
peptidoglycan in cell wall	present	absent	absent
membrane lipids	ester-linked, unbranched	ester-linked, branched	ester-linked, unbranched
ribosomes	70S	70S	80S
initiator tRNA	formylmethionine	methionine	methionine
operons	yes	yes	no
plasmids	yes	yes	rare
RNA polymerases	1	1	3
ribosomes sensitive to chloramphenicol and streptomycin	yes	no	no
ribosomes sensitive to diphtheria toxin	no	yes	yes
some are methanogens	no	yes	no
some fix nitrogen	yes	yes	no
some conduct chlorophyll-based photosynthesis	yes	no	yes

table A Some of the cellular and molecular characteristics of the three domains of life on Earth

Apart from the ribosomes, scientists see two essential differences in the mass of data that has been generated about the three domains. Archaea replicate by binary fission which is controlled within a cell cycle. It is very similar to the cell cycle in eukaryotic cells but is different from replication in bacteria. Conversely, the membrane structure and the membrane proteins of the Archaea are unique – they are different from the bacteria and the eukaryotes, which have homologous structures. The Archaea have an ester link in their lipids, giving branched molecules that may provide extra strength in extreme environments. This supports a model which suggests a different origin for some of the cellular systems of the Archaea and Bacteria, but shows eukaryotes combining features of them both. Research which aims to establish these links has been published in peer-reviewed journals so that other scientists can repeat the procedures to verify the results. Most biologists now accept the three-domain theory but there is still debate about the domains and their origins (see **fig E**). However, evidence showing horizontal gene transfer between groups of organisms is increasing, so the idea of a complex interwoven network of ancestry also remains.

HOW MANY KINGDOMS?

Linnaeus initially classified living things into the plant and animal kingdoms, including fungi. As technology and scientific knowledge advanced, the world of microscopic organisms emerged, leading to a five-kingdom classification system. This grouped prokaryotes into one kingdom, Monera, and single-celled organisms and algae into Protista. Today, biologists use a six-kingdom system, recognizing the differences in biochemistry and biochemistry between Archaea and Eubacteria.

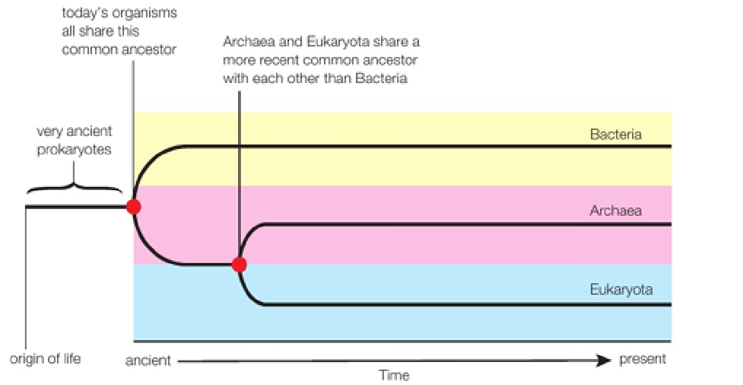


fig E This phylogenetic tree shows possible relationships between the three domains of the living world – most but not all biologists think that the three domains share a common prokaryotic ancestor.

ARCHAEBACTERIA (ARCHAEA): PROKARYOTIC CELLS

These are ancient bacteria that have a wide variety of lifestyles and include the **extremophiles** - bacteria that can survive extreme conditions of heat, cold, pH, salinity and pressure. They normally reproduce asexually.

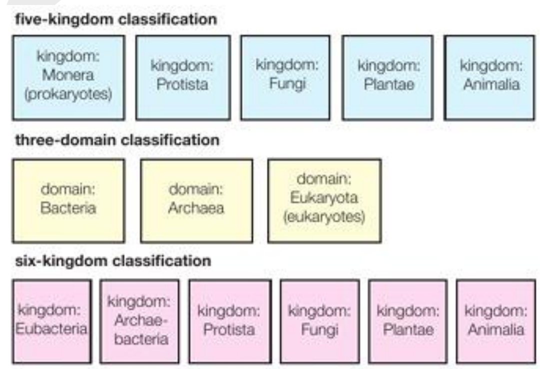


fig F A six-kingdom classification makes more sense when the three domain system is also accepted.

EUBACTERIA (BACTERIA): PROKARYOTIC CELLS

This kingdom includes the true bacteria and the cyanobacteria, which used to be called the blue- green algae. They normally reproduce asexually.

PROTISTA: EUKARYOTIC CELLS

This kingdom includes all the single-celled eukaryotic organisms, the green algae, the brown algae and the slime moulds. It is something of a catch-all for the organisms that do not fit in the other kingdoms. They mainly reproduce asexually.

FUNGI: EUKARYOTIC CELLS

This kingdom includes both unicellular organisms, for example yeasts, and multicellular organisms, for example toadstools and moulds. They are all heterotrophs. They reproduce both asexually and sexually.

PLANTAE: EUKARYOTIC CELLS

Almost all these organisms are multicellular autotrophs, making their own food by photosynthesis for which they need chlorophyll. They include the mosses, liverworts, ferns, gymnosperms and angiosperms (flowering plants).

ANIMALIA: EUKARYOTIC CELLS

The organisms in this kingdom are all multicellular and they are all heterotrophs. They include invertebrates and vertebrates. Sexual reproduction is common but some animals also reproduce asexually. The models for the five-kingdom, six-kingdom and three-domain classification systems are summarised in fig F.

SUBJECT VOCABULARY

gel electrophoresis a method of separating fragments of proteins or nucleic acids based on their electrical charge and size
phylogenetic tree model used to show the relationships between different groups of organisms
endosymbionts organisms that live inside the cells or the body of another organism
Monera a kingdom in the five-kingdom classification system that contains the Archaea and Eubacteria
extremophiles bacteria that can survive extreme conditions of heat, cold, pH, salinity and pressure

4C Biodiversity ad conservation

4C 1 Biodiversity and endemism

Biodiversity is an important word right now because the Earth's biological diversity, which has become extensive over millions of years of evolution, is reducing rapidly.

DEFINING BIODIVERSITY

The Convention on Biological Diversity, the largest international organisation working on the subject, uses biodiversity as a term to describe the variety of life on Earth, from the smallest microbes to the largest animals and plants. They suggest the concept of biodiversity includes genetic diversity between individuals within a species and between different species, as well as the variety of different **ecosystems.**

WHY IS BIODIVERSITY IMPORTANT?

The evidence suggests that biodiversity is crucial for the functioning of large-scale ecosystems, as it affects physical conditions and natural balance. Organisms in ecosystems interdependently affect the air, water, and waste, making them non-toxic.

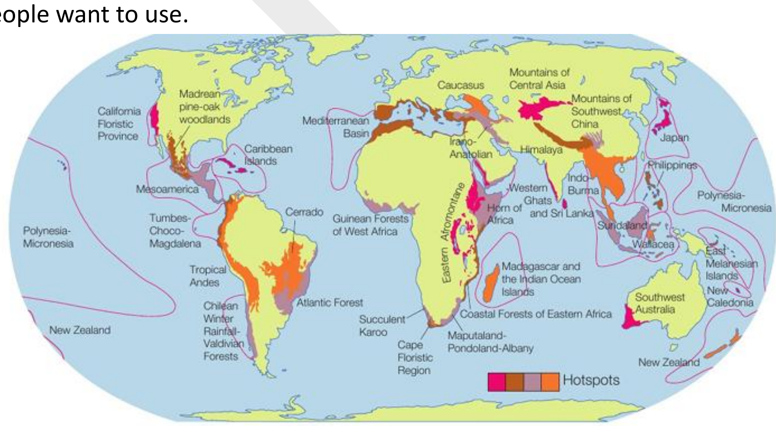
▲ **fig A** Ecosystems such as this rainforest contain a huge range of biodiversity, with the potential to help humanity in many different ways.

ASSESSING BIODIVERSITY AT THE SPECIES LEVEL

Biodiversity can be measured in several ways. There are two main factors which need to be considered when measuring biodiversity at the species level. One is the number of different species in an area - the **species richness**. The other is the evenness of distributions of the different species - the **relative species abundance of** the different types of organism that make up the species richness. You will learn how to measure biodiversity yourself in Book 2.

SPECIES RICHNESS

As you move away from the wet tropics, the species diversity generally decreases. In temperate rainforests, tree species richness drops to 20-25 species in 0.1 hectares. Further north again, in the boreal forest in Scandinavia and Northern Canada, it falls to 1-3 species in 0.1 hectares. To highlight this, scientists have identified some **biodiversity hotspots** (see fig B) of unusual biodiversity. They occupy only 15.7% of the Earth's land surface, but are home to 77% of the Earth's terrestrial vertebrate species. Unfortunately, these areas are often areas with other resources that people want to use.



▲ **fig B** Known biodiversity hotspots around the world

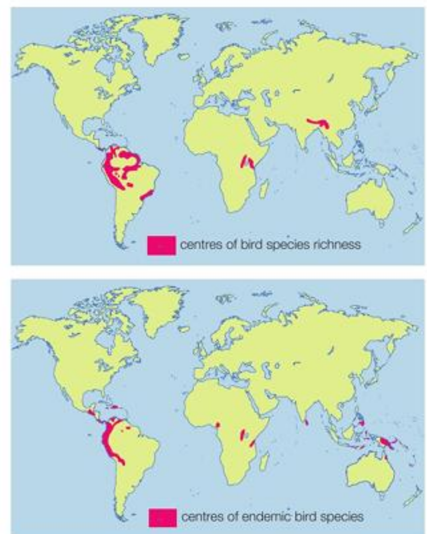
ENDEMISM

Another important way of measuring biodiversity is by looking at the number of endemic species in an area (see fig D). When a species evolves in geographical isolation - for example, on an island - and is found in only one place, it is said to be endemic to that place.

There have been many ideas about why some areas have very rich biodiversity - in fact, around 125 different theories have been published. Most have been eliminated because they do not apply to all organisms or they are not supported by the evidence. The best current model suggests that:

- a very stable ecosystem allows many complex relationships to develop between species
- high levels of productivity (when photosynthesis rates are very high) can support more niches
- when organisms can grow and reproduce rapidly, it is more likely that mutations occur, leading to adaptations which allow organisms to exploit more niches.

▲ **fig C** The unique fauna of Australia, including the iconic koala bear, is the result of its geographical isolation from the rest of the world.



▲ **fig D** Hotspots of biodiversity can be measured by species richness and by endemic species.

ENDEMIC SPECIES OF MADAGASCAR

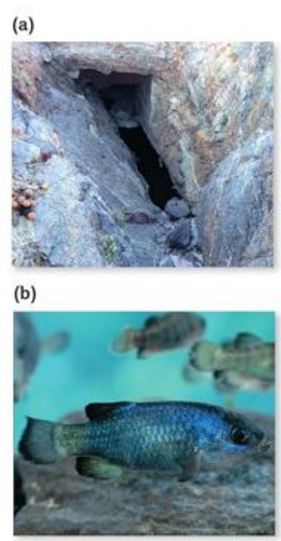
Madagascar is a large island off the coast of East Africa. Almost all the species found there are endemic to the island (see fig E). Organisms range from the amazing giant baobab trees to ring- tailed lemurs, from the bizarre elephant's foot plant to the tailless tenrec (a small mammal which can have over 30 babies at a time).

▲ **fig E** The ring-tailed lemur is just one of the unique species endemic to Madagascar.

DESERT PUPFISH

The fish trapped in each area could no longer interbreed with those from other areas and evolved independently. Now there are four completely separate species of desert pupfish in this refuge oasis. Each species has different colouring and different courtship displays, and each is endemic to one place:

- the Ash Meadows Amargosa pupfish
- the Devils Hole pupfish
- the Warm Springs pupfish
- the Ash Meadows speckled dace.



▲ **fig F** **(a)** Devils Hole in the Nevada desert and **(b)** the endemic Devils Hole pupfish

The Devils Hole is perhaps the most extreme of the tiny ecosystems - the fish there have adapted to survive in a warm water environment, with water levels that rise and fall when there are earthquakes in Mexico and other countries (see fig F).

SPECIES ABUNDANCE

The absolute number of species is not the only important factor in biodiversity. Relative species abundance is also significant. This is a measure of the relative numbers of the different types of organism.
Picture two areas of land in Europe, plot A and plot B (see fig G). There are five species of plant growing on each plot - grass, daisies, buttercups, dandelions and lady's bedstraw - in the proportions shown in table A.

fig G Sections of plots A and B examined for **table A**

	GRASS	DAISIES	DANDELION	BUTTERCUPS	LADY'S BEDSTRAW
Plot A	95%	2%	1%	1%	1%
Plot B	30%	20%	15%	15%	20%

table A Showing species data for plot A and plot B

The risks to biodiversity are not evenly spread around the world. Certain areas are much more vulnerable to damage and loss, particularly small isolated ecosystems such as islands, rainforests, coral reefs, bogs and wetlands. Many of these areas are also biodiversity hotspots so if they are damaged, many species will be lost. Every time a species becomes extinct, the biodiversity of the world decreases. On the other hand, every time a new species evolves, biodiversity increases.

SUBJECT VOCABULARY

ecosystems biological communities where organisms interact with one another and with their physical environment
species richness the number of different species in an area
relative species abundance the relative numbers of species in an area
biodiversity hotspot an area with a particularly high level of biodiversity
endemic a species that evolves in geographical isolation and is found in only one place

4C 2 Measuring biodiversity

THE DIVERSITY INDEX

Scientists have developed many different ways of measuring the biodiversity of an ecosystem such as a pond (see fig A). Some are more useful than others, and all have limitations. In this example, both the species richness and the species abundance of an area are taken into account in a formula that gives a diversity index at the species level within a habitat:

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

where

D = diversity index

N = the total number of organisms of all species

n = the total number of organisms of each individual species – the abundance of the different species

$\sum$ = the sum of all the values that follow. (You need to calculate $n(n-1)$ for each species and then add them together.)

fig A Natural and artificial ponds both quickly build up a range of biodiversity as algae, bacteria, protists, plants and animals colonise the water.

HOW BIODIVERSITY VARIES

As you saw in Section 4C.1, there have been many ideas about why some areas have particularly rich biodiversity. The best current model suggests that high biodiversity is seen in:

- very stable ecosystems
- areas where there are high levels of productivity (when photosynthesis rates are very high)
- areas where organisms can grow and reproduce rapidly.

In general, when an environment has extreme environmental conditions (e.g. a desert) the biodiversity is low (see fig B). Any change in this extreme environment has a big impact on population numbers. This type of ecosystem tends to be unstable and very susceptible to change.

fig B Relatively few species can survive in extreme environments like the desert, and small changes can threaten those organisms.

WHEN TO MEASURE BIODIVERSITY

Biodiversity is not constant. For example, the animal species in an area can vary with the time of day. Many bat species flying on a warm evening will not be visible the next morning. What is more, in the temperate and alpine areas of the world there are distinct seasons.

BIODIVERSITY WITHIN A SPECIES

Biodiversity within an individual species is also a very important concept. The gene pool of a species is all of the genes in the genome, including all the different variants of each gene. Modern DNA analysis allows us to measure biodiversity on a different scale, at a genetic level - and we are discovering that genetic diversity within a species is very important.

GENE AND ALLELE FREQUENCY

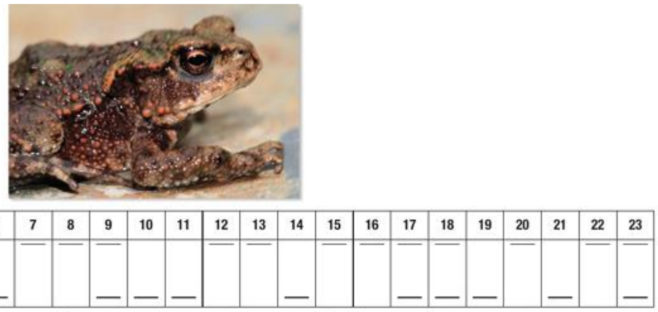
You learned in Chapter 2C that mutations are changes in the DNA structure. Many mutations have no effect at all on the phenotype, while others may have useful, or damaging or lethal effects. Mutations can increase the gene pool of a population by increasing the number of different alleles available. The relative frequency of a particular allele in a population is called the **allele frequency**.

MEASURING GENETIC BIODIVERSITY

The genetic variation within a population is an important measure of biological health and well-being - without variation, a population is vulnerable. Modern technology has made it possible to build up a clear model of **genetic diversity** within a population by analysing the DNA and comparing particular regions for similarities and differences.

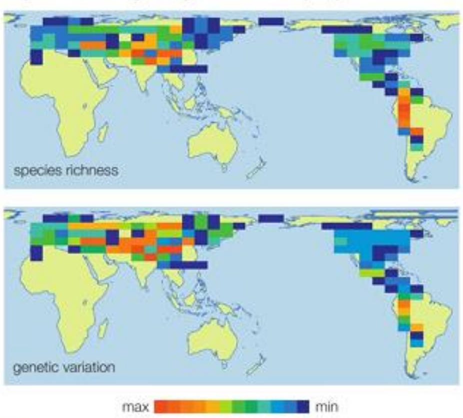
When the DNA is analysed, only one band will show up if an organism is a homozygote. For heterozygotes, two bands appear, one for each allele. This can be used to calculate a **heterozygosity index** for the population for the particular DNA sequence. It is calculated using the equation:

$$\text{heterozygosity index} = \frac{\text{number of heterozygotes}}{\text{number of individuals in the population}}$$



▲ **fig C** The DNA analysis of 23 European toads for a single gene shows some heterozygous individuals but most are homozygous.

Models of the molecular phylogenetic relationships between related organisms based on DNA and other evidence are a useful tool for measuring biodiversity. For example, scientists at the Natural History Museum in London, UK, have built up contrasting maps of biodiversity based on both numbers of species and DNA similarities. The ones shown in **fig E** show bee populations – the most biodiverse areas for bees are Ecuador (highest species richness) and Kashmir (highest genetic diversity). This type of study can be hugely important for conservation work. If you are trying to conserve biodiversity with limited funding – and funding is always limited – you need to be confident that you have chosen the area with the highest biodiversity. Maps like these can be generated for overall biodiversity or for the diversity of particular groups of animals and plants. They can be produced for the whole world, for individual countries or for small local areas. The value of this type of data is that it can be used to highlight areas that need protection. If it is regularly updated, it also provides a way of monitoring changes in biodiversity anywhere.



▲ **fig E** These maps show the biodiversity of bees around the world measured by species richness and by genetic diversity.

THE ISOLATED ISLANDS OF HAWAII

The Hawaiian island populations show clearly how living organisms adapt to a particular niche or role in the community. They also demonstrate why it is important for scientists to look at biodiversity at the level of species numbers and abundance, and at the level of genetic diversity.

The Hawaiian Islands are very isolated – 4000 km from the nearest continental land mass and 1600 km from other islands. They have a great deal of biodiversity in terms of species numbers – 1000 species of native flowers, 10 000 species of insects, 1000 species of land snails and around 100 species of birds. But before people introduced them, there were no reptiles and only one species of mammal – a bat. Analysis of the DNA of the endemic populations shows that they are very closely related, even though some of them look very different. All those insect species seem to have evolved from only about 400 original species, while there appear to have been only seven founder species of land birds. So, in these isolated conditions, a small group of founder organisms have adapted and evolved to take advantage of the different ecological niches that were available to them. Places where endemism is common often have a rich biodiversity in terms of species numbers, but quite low genetic diversity. This is one reason why areas with many endemic populations are very vulnerable to the introduction of disease.

SUBJECT VOCABULARY

diversity index a way of measuring the biodiversity of a habitat using the formula:

$$D = \frac{N(N-1)}{\Sigma n(n-1)}$$

allele frequency the frequency with which a particular allele appears within a population

genetic diversity a measure of the level of difference in the genetic make-up of a population

heterozygosity index a useful measure of genetic diversity within a population expressed as:

$$\frac{\text{number of heterozygotes}}{\text{number of individuals in the population}}$$

4C 3 Adaptation to a niche

Every species is part of the complex system of interactions between the physical world and other living organisms. We call this system **ecology**. Each species exists in a specific **niche**. The niche occupied by an organism is an important concept that is difficult to define. It describes the role of the organism in the community - rather like a job description or a way of life.

SUCCESSFUL ADAPTATION

A successful species is well adapted to its niche, meaning that individuals in that species have characteristics that increase their chances of survival and reproduction, and therefore of passing those characteristics on to the next generation. Adaptations may be of many different kinds, including anatomical, physiological and behavioural.

- Anatomical adaptations involve the form and structure of an organism. Examples include the thick layer of blubber in seals and whales, and the sticky hairs on the sundew plant that enable it to capture insects (see fig A).

- Physiological adaptations involve the way the body of the organism works and include differences in biochemical pathways or enzymes. For example, diving mammals can stay

- Behavioural adaptations involve changes to programmed or instinctive behaviour making organisms better adapted for survival. For example, many insects and reptiles orientate themselves to get the maximum sunlight on their bodies when the air temperature is relatively low. This allows them to warm up and move fast enough to feed and to escape predators.

fig A The sticky hairs of a sundew leaf are anatomical adaptations that enable the plant to capture insects. The plant can then digest the insects to supplement the nutrients in the poor soil of the bogs where it grows.

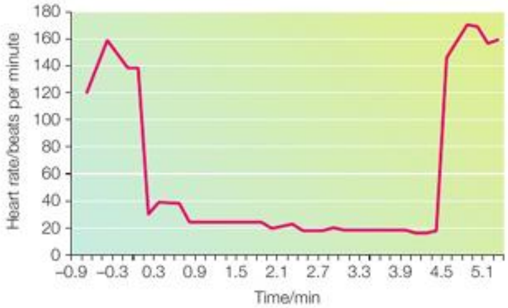


fig B The heart rate of a seal slows as it dives. This slowing is called bradycardia.

fig C Early in the day, lizards flatten themselves against the warm ground to heat up. When they start to get too hot, they will push themselves away from the ground so they can cool down more easily.

ADAPTATIONS FOR SURVIVAL

Successful adaptations enable species to exploit every possible habitat and the different niches within each habitat. Most organisms have a mixture of different types of adaptation that enable them to survive and succeed in their particular environment. Carnivorous fungi and camels are two examples.

FUNGAL CARNIVORES

Fungi, often considered saprophytes, can also be active carnivores, such as Arthrobotrys anchonia, which actively lassoes nematodes through constriction rings. This involves forming a ring with three fungal cells, which inflates and holds the nematode in its grip. The fungus grows more hyphae, which digest the nematode, absorbing nutrients and transporting them within the fungus. These predatory fungi evolved from saprophytic fungi in a high-carbon, low-nitrogen environment.

fig D Some carnivorous fungi have adaptations that enable them to lasso their moving prey.

CAMELS: THE ULTIMATE SURVIVORS

Camels are large mammals. They live and breed in some of the hottest, driest and most inhospitable niches available. The incredible adaptations of the camel allow it to survive and thrive as a plant-eater in desert environments. The animal is vital in the survival of civilisations who make desert environments their home.

Camels have a huge range of anatomical, physiological and behavioural adaptations, and the combination of them all means they are the ultimate survivors: large mammals in niches where few other organisms can live, whatever their size (see **fig E**).

SOME ANATOMICAL ADAPTATIONS OF CAMELS

- Large eyes give good vision in many directions and are protected by long lashes which protect the eyes against the sandy environment.
- The nostrils are long and slit-like and the camel can close them to protect against sand and wind.
- The upper lip is split, hairy, extensible, slightly prehensile and sensitive. This allows it to identify and gather food, and avoid the thorns which are a protective adaptation of many desert plants.
- A hump on the back helps insulate the animal from the heat of sun. The fat concentrated in the hump allows easy evaporation of sweat over the rest of the skin surface as there is little fatty insulation under the skin. This is important in cooling down.
- The feet are large and flat with tough pads. These spread out the weight of the camel as it walks over sand and also prevent heat damage.
- Tough pads on the knees prevent damage from hot sand when the camel rests.

▲ **fig E** Camels are perfectly adapted to their desert niche. See how many of the anatomical adaptations of camels you can identify in this photo.

Thermoregulation

Camels face extremes of temperature in the desert: extreme heat in the day and cold at night. They have evolved some sophisticated physiological mechanisms to help them cope with these extremes without using all their resources.

- The supple skin is covered in fine hairs which can be erected to trap an insulating layer of air during cold nights.
- The camel can withstand a wide variation of internal (core) body temperature. Most mammals – and camels under ideal conditions – maintain their body temperature within a 2 °C range. Under heat stress, or when a camel is dehydrated and cannot afford to lose water in thermoregulation, a camel can allow its body temperature to vary over 6 °C. This saves energy and water as it does not need to produce so much sweat.
- Camels can lose 30% of their body weight through water loss and then make it up in 10 minutes drinking water, without changing the osmotic potential of the blood. Consequently, the blood does not become thick and unable to flow when the camel is extremely dehydrated.

• Camels have a hump on the back where most of their fatty tissue is found. This acts as a food store. As the fat is broken down to release energy during cellular respiration, water is produced as a by-product (see Book 2 Topic 7). This metabolic water means camels can survive longer than most mammals without actually drinking water.

Water balance

The desert niche of the camel means it often has to survive without water for considerable periods of time. It has some adaptations which mean it uses very little water and can restrict normal water losses when the supply is limited.

• Camel body tissues can withstand a loss of up to 30% of the body water without being damaged - it can go without water in the desert heat for up to 10 days.

• Camels can drink up to 180 litres of water in 24 hours without affecting the osmotic balance of their cells.

• The fat in the hump acts as an energy store. When this fat is broken down in aerobic respiration (see Book 2 Topic 7) water is produced as a waste product.

• Water is lost by sweating, and in urine and faeces. Camels can withstand big temperature variations which means that they minimise water loss by sweating. They have kidneys adapted to produce very concentrated urine - this reduces water loss and enables camels to drink quite salty water.

• Camels can continue to produce dilute milk even when they are dehydrated. This enables them to breed successfully in the desert and also means they can provide a good source of food and drink for people in these dry environments.

SOME BEHAVIOURAL ADAPTATIONS OF CAMELS

The behavioural adaptations of camels are particularly clear in wild camels - the behaviour of domesticated camels is often directed by their human masters.

• When it is hot and camels are dehydrated, they sit down early in the morning before the ground warms up, with their legs tucked underneath so they absorb as little heat from the ground by conduction as possible.

• Groups of camels may lie down together, again minimising the amount of surface area of each camel exposed to the sun.

• Camels are browsers - they eat a wide range of vegetation and their height makes many shrubs and trees available to them which other animals cannot reach.

Perhaps the camel is the ultimate example of how organisms can be adapted to a very special and challenging niche.

SUBJECT VOCABULARY

ecology the study of the relationships of organisms to one another and to their physical environment
niche the role of an organism within the habitat in which it lives
anatomical adaptations adaptations involving the form and structure of an organism
physiological adaptations adaptations involving the way the body of the organism works, including differences in biochemical pathways or enzymes
behavioural adaptations adaptations involving programmed or instinctive behaviour making organisms better adapted for survival

4C 4 Gene pool and genetic diversity

POPULATION GENETICS

In population genetics, we take the gene as the unit of evolution and look at how the genetic composition of a population evolves over time. The sum total of all the alleles in a population at a given time is called the gene pool, and it will be millions or even billions of genes. Fortunately, it is usually **the gene pool** for a single trait that we look at. At any point in time, a population of organisms will have a particular gene pool, with different alleles occurring with varying frequencies, as you saw in Section 4C.2.

ALLELE FREQUENCIES

The frequency of alleles in a population is not fixed. As the environment changes, so the frequency of different alleles changes through the process of natural selection and adaptation. For example, warfarin is a chemical that prevents the blood from clotting and it has been used as rat poison for about 70 years - the rats die of internal bleeding (see fig A). When warfarin was introduced, some rats already carried a mutation that, by chance, gave them resistance to the poison. The poison acted as a powerful **selection pressure** and resulted in a rapid increase in the frequency of the resistance allele.

Selection pressure occurs when an environment changes, leading to individuals with advantageous alleles. For example, rats with resistance to warfarin poison are more likely to survive and reproduce, while those with susceptible alleles are less likely to survive and reproduce. This leads to a decrease in the frequency of susceptible alleles, eventually leading to the development of more powerful poisons. Speciation is driven by these selection pressures over time.

fig A The presence or absence of the allele that gives rats resistance to warfarin is obvious only once they have been exposed to the poison.

THE HARDY-WEINBERG EQUILIBRIUM

The amount of change that takes place in the frequency of alleles in a population indicates whether the population is stable (unchanging) or is evolving. The **Hardy-Weinberg equilibrium** theory states that in a population that is not evolving, the allele frequencies in the population will remain stable from one generation to the next if there are no other evolutionary influences. If the population is evolving, the allele frequencies will change from generation to generation and so the population is not in equilibrium. When a new species is formed, gene flow will be reduced because there will be no more breeding between the two original populations.

The algebraic equation developed by Hardy and Weinberg is expressed as:

p^2	+	$2pq$	+	q^2	=	1
frequency of homozygous dominant genotype in population		frequency of heterozygous genotype in population		frequency of homozygous recessive genotype in population		

USING THE HARDY-WEINBERG EQUATION

The frequency of homozygous recessive individuals is represented as q2. From this, q is easily obtained by finding the square root of q2. The result gives the frequency of the recessive allele and by substituting this figure into our initial formula of p + q = 1, the frequency of the dominant allele p can be found.

fig B A striking phenotype such as this albino alligator makes it very easy to see that here is an animal with only recessive alleles.

there are no factors that change the equilibrium, allele frequencies will remain constant within a population from generation to generation. In this theoretical population:

- there are no mutations
- there is random mating
- the population is large
- the population is isolated (no immigration or emigration - no organisms move in or move out)
- there is no selection pressure (all genotypes are equally fertile/successful).

MUTATIONS

For the allele frequency to remain stable in a population, no mutations must occur. Mutations involve changes in the genetic material, so the alleles are changed. As you know already. spontaneous mutations occur within a population all the time. Mutations in the somatic cells of animals will not be passed on to their offspring and may or may not affect the individual themselves. In animals, only mutations in the germ line cells - the cells that create the eggs and sperm - will affect the alleles of the next generation. In plants, the germ line cells are not fixed in the embryo. A mutation that takes place in a single plant stem as it grows can therefore become part of the gametes of a flower that forms on that stem (see fig C).

fig C Ruby red grapefruit result from two separate mutations in the growing cells of grapefruit trees. One produced pink fleshed fruit. Several years later, another mutation produced a redder and much sweeter flesh. In both cases, the mutation produced a new dominant phenotype.

NON-RANDOM MATING

One of the most important requirements for a gene pool to remain in equilibrium is for random mating to occur. Random mating means that the likelihood of any two individuals in a population mating is independent of their genetic make-up. If mating occurs randomly, the frequency of the alleles in the population will stay the same.

Non-random mating occurs when some feature of the phenotype affects the probability of two organisms mating – and as a result natural selection takes place. For example, if a male animal displays in some way to attract the female, it is not random mating (see **fig D**). The male peacock with the most impressive tail, the buck with the largest antlers and most aggressive nature, the butterfly with the brightest wings and most spectacular display flight – these will appear to be more attractive than average to the females of the species and this applies a selection pressure. Consequently, they will be more likely to have the opportunity to mate and pass on their genes, ensuring that their offspring are likely to carry the alleles for these attractive characteristics. This is natural selection in action.

fig D Male magnificent frigatebirds display their red throats to attract a mate. The female selects the most impressive one, so mating is not random.

SUBJECT VOCABULARY

population a breeding group of individuals of the same species occupying a particular habitat and a particular niche
gene pool the sum total of all the genes in a population at a given time
selection pressure the effect of one or more environmental factors that determine whether an organism will be more or less successful at surviving and reproducing; selection pressure drives speciation
Hardy-Weinberg equilibrium the mathematical relationship between the frequencies of alleles and genotypes in a population; the equation used to describe this relationship can be used to work out the stable allele frequencies within a population
gene flow the migration of either whole organisms or genetic material into or out of a population and into another population, tending to make different populations more alike, but changing the allele frequencies within each individual population all the time

POPULATIONS OF VARYING SIZES

The Hardy-Weinberg equation is only valid if it is applied to a large population - at least several thousand individuals. This is because maintaining genetic equilibrium depends on a random assortment of the alleles. Large populations containing many individuals usually have large gene pools - the chance of losing an allele by random events is reduced in a large population.

ISOLATION

If the Hardy-Weinberg genetic equilibrium is to be maintained, the population must exist in isolation. There should be no migration of organisms either into or out of the population. Of course, this is very rarely the case in the living world. Insects carry pollen from one population of flowers to another and the wind can carry it for miles. Male animals frequently leave their family groups and go in search of other populations to find a mate.

SELECTION PRESSURE

For Hardy-Weinberg equilibrium to apply, all alleles would have the same level of reproductive advantage or disadvantage, but we know this is not the case. Many alleles are neutral in their effect, but some alleles code for a phenotype which gives an advantage or disadvantage to the individual.

4C 5 Reproductive isolation and speciation

ISOLATION AND SPECIATION

A species is a group of organisms sharing several features, which are capable of interbreeding to produce fertile offspring. **Speciation** is the formation of a new species. It happens as a result of the isolation of parts of a population. The important factor in the process is reproductive isolation, and the reduced gene flow between the different populations which is a consequence of that isolation.

Speciation can also occur as a result of **hybridisation** and this is particularly common in plants. Sometimes, two closely related species can breed and form fertile hybrids that are successful in their own right and may be better adapted to the niche.

ISOLATING MECHANISMS

For different species to evolve from an original species, different populations of the species usually have to become reproductively isolated from each other. This means that mating and, therefore, gene flow between them is restricted. There are several ways in which this can happen.

• Geographical isolation: a physical barrier such as a river or a mountain range separates individuals from an original population.

• Ecological isolation: two populations inhabit the same region, but develop preferences for different parts of the habitat.

• Seasonal isolation (also known as temporal isolation): the timing of flowering or sexual receptiveness in some parts of a population becomes different from the usual timing for the group. This can eventually lead to the two groups reproducing several months apart.

• Behavioural isolation: changes occur in the courtship ritual, display or mating pattern so that some animals do not recognise others as being potential mates. This might be due to a mutation that changes the colour or pattern of markings.

• Mechanical isolation: a mutation occurs that changes the genitalia of animals, so they can only mate successfully with some members of the group.

ALLOPATRIC SPECIATION

Allopatric speciation occurs when populations become physically or geographically separated. Scientists recognise allopatric speciation as the main evolutionary process. Allopatric speciation is of enormous importance in the history of evolution, as great land masses moved and separated. The physical isolation of populations continues to occur as a result of natural changes,

ADAPTIVE RADIATION

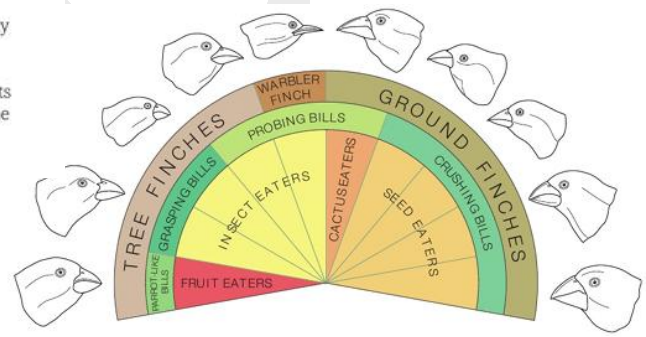
Allopatric speciation is often followed by adaptive radiation. Adaptive radiation occurs when one species develops rapidly to form several different species, which all fill different ecological niches. There are some well-known examples of adaptive radiation.

AUSTRALIAN MARSUPIALS AND MONOTREMES

Australia is well known for its unusual fauna and flora. Perhaps most unusual are two groups of mammals, the **marsupials**, which protect their young in pouches, and the much rarer egg- laying **monotremes**. In the rest of the world, the **placental mammals dominate**.

DARWIN'S FINCHES

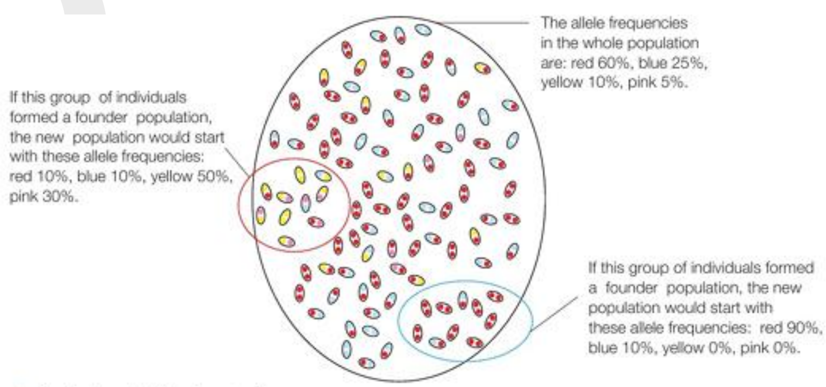
These birds provide a classic example of how different selection pressures result from the availability of a range of different niches and then lead to adaptive radiation. The finches were discovered by the great 19th century naturalist, Charles Darwin, on his voyage on HMS *Beagle*. On the Galapagos Islands near the equator, there are several feeding niches for birds (e.g. small seeds, large nuts, insects living in rotten bark). The original finches that arrived on the islands were of a single species. No one is quite sure how they got there because the islands are over 500 miles from land, but a small flock was probably carried there by a storm or a hurricane.



▲ **fig A** Over several million years, at least 14 species of finch developed from the original ancestor species. The anatomy of the beaks and adaptations for feeding of 10 of these finches is shown in this diagram.

SYMPATRIC SPECIATION

Sympatric speciation occurs between populations of a species living in the same place that become reproductively isolated by mechanical, behavioural or seasonal changes. Some gene flow continues as speciation happens - a very different model to allopatric speciation. Sympatric species are closely related and occupy overlapping ranges.



▲ **fig C** A model of the founder effect

POPULATION BOTTLENECKS

A large population is necessary to maintain a diverse gene pool, but allele frequencies can change significantly due to factors like mutations and non-random mating. A population bottleneck, caused by environmental disasters, diseases, human hunting, or habitat destruction, can significantly reduce the gene pool and genetic diversity. Cheetahs, the fastest land animals, have very little genetic diversity due to their ancestral **population bottleneck**.

THE FOUNDER EFFECT

The founder effect is the loss of genetic variation that occurs when a small number of individuals leave the main population and set up a separate new population, producing a voluntary population bottleneck. The alleles carried by the individuals who leave the main population are unlikely to include all the alleles, or at the same frequencies, as the original population. Any unusual genes in the founder members of the new population may become more frequent as the population grows.

4C: 6 Conservation: why and how?

The growing human population contributes to greenhouse gases through activities like breathing, electricity, and driving. Food production, livestock, and waste production also contribute to pollution. Over 200 million tonnes of untreated human waste end up in oceans, rivers, and lakes, affecting ecosystems. Human activities also deplete resources from the biosphere, leading to species extinction and loss of biodiversity.

THE HUMAN POPULATION EXPLOSION

As people learned to farm plants and animals to provide a reliable supply of food, so more children survived and populations grew, but on a fairly small and local scale. Later, tools and then machines enabled us to farm on a much bigger scale. Now we can change the environment with reservoirs, roads, canals, towns and cities (see fig B). We have developed medicines that keep us and our children alive and allow many of us to survive to great age. We have also developed engines that burn fossil fuels and release large quantities of exhaust gases into the atmosphere.

THE HUMAN THREAT TO BIODIVERSITY

Human effects on ecosystems are many and widespread. Biodiversity is essential at both the species and the genetic level. The extensive variety of life, which has evolved over millions of years, is now being threatened in many different ways because of human activities.

SUBJECT VOCABULARY

speciation the formation of a new species
hybridisation the production of offspring as a result of sexual reproduction between individuals from two different species
allopatric speciation speciation that occurs when populations are physically or geographically separated and there can be no interbreeding or gene flow between the populations
adaptive radiation a process by which one species develops rapidly resulting in several different species which fill different ecological niches
marsupials mammals that give birth to very immature young and then protect them in pouches
monotremes primitive mammals that lay eggs and feed their offspring with milk from mammary glands
placental mammals mammals that provide for the developing fetus during gestation through a placenta
sympatric speciation speciation that occurs between populations of a species in the same place; they become reproductively separate by mechanical, behavioural or seasonal mechanisms; gene flow continues between the populations to some extent as speciation occurs
population bottleneck the effect of an event or series of events that dramatically reduces the size of a population and causes a severe decrease in the gene pool of the population, resulting in large changes in allele frequencies and a reduction in genetic diversity
founder effect the loss of genetic variation that occurs when a small number of individuals become isolated, forming a new population with allele frequencies not representative of the original population

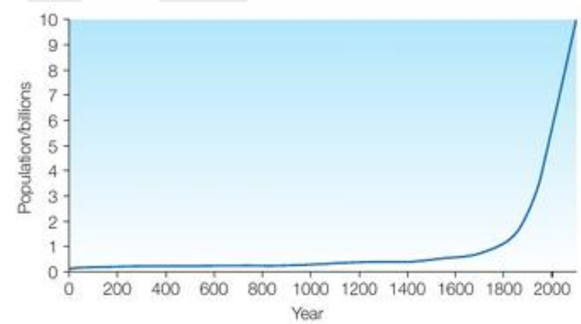


fig A This graph shows the enormous increase in world population in recent centuries. This increase has been built in part on fossil fuels (see below) and so it is not sustainable.

CLIMATE CHANGE

From individual observations to major scientific studies there is growing agreement that the Earth's climate is changing. Global temperatures are rising. This is seen in overall climate patterns and in the increasing number and frequency of 'extreme weather events' all over the world.
The world's climate has changed regularly over time. The fossil record shows us how often the world has gone through ice ages and periods of tropical heat or desertification.

DEPLETION OF BIOLOGICAL RESOURCES

A growing world population means an increase in the demand for resources such as food, firewood and land. In the more economically developed parts of the world, people have gone way beyond simply fulfilling the basic needs of life. They eat far more food than they need and want a great variety of different foods, which may need to be imported from far away.

fig B A city ecosystem is very different from a natural ecosystem. This shows Nairobi, the largest city in Kenya.

CONSERVATION

Biodiversity is being reduced through activities such as overfishing habitat reduction and as a result of climate change. However, many people around the world are working hard to reduce these trends and to conserve the biodiversity we still have. This can be tackled in many different ways.

Conservation means keeping and protecting a living and changing environment. It is an active process involving an enormous range of projects. Examples of conservation include:

- reclaiming land after industrial use
- helping to set up sustainable agriculture systems in the developed world
- protection of a single threatened species
- global legislation on pollution levels and greenhouse gas emissions.

Around the world, there are many animals and plants that are threatened with extinction. This often, but not always, results from human activities which cause habitat loss or climate change. There are two main ways of conserving animals and plants. We can conserve them outside their natural habitat, in zoos or seed banks. This is called ***ex-situ* conservation**. The alternative is ***in-situ* conservation**, which takes place in the natural habitat of the organism.

fig C Seeds like these, stored at low temperatures, will still be able to germinate and grow in hundreds of years – by which time it is hoped their habitats will have been restored and conserved.

EX-SITU CONSERVATION

The United Nations Convention on Biological Diversity in 1992 defined ex-situ conservation as 'the conservation of components of biological diversity [living organisms] outside their natural habitats. Sometimes, when an organism is threatened with extinction, there is not time to conserve their habitat or protect them in situ (on site). It is sometimes possible to conserve the species by removing some of the animals or plants from their natural habitat.

EX-SITU CONSERVATION OF PLANTS

25% of the world's flowering plant species could disappear within the next 50 years, causing 60,500 species to disappear in less than one human lifetime. This would be a disaster for plants and human survival. To maintain the long-term health of crop plants, cross-breeding crop plants back to wild plants or using wild plants for genetic engineering can be used.

EX-SITU CONSERVATION OF ANIMALS

It is not always possible to conserve animal species in the wild because the conditions that have put them under threat of extinction continue. Zoos and wildlife parks used to exist just for people to look at the animals, but today they are very important in animal conservation. In **captive breeding programmes** individuals of an endangered species are bred in zoos and parks in an attempt to save the species from extinction. Usually, the ultimate aim is to reintroduce the captive-bred animals into the wild to restore the original populations.

Reintroduction does not always work, but it can be successful in national parks or other protected areas. Species that have been saved by captive breeding and successfully reintroduced into protected areas in their own countries include Californian condors and Przewalski's horses. Captive breeding programmes for the white and black rhino, along with much conservation work in east Africa, gives hope that these amazing creatures will also be saved from extinction (see **fig D**).

fig D The Mkomazi Game Reserve Rhino Sanctuary in Tanzania has been established to help build up the population of black rhinos and protect them from the poachers who have hunted them almost to extinction.

There are several problems with captive breeding and reintroduction programmes.

• There is not enough space or sufficient resources in zoos and parks for all the endangered species.

• It is often difficult to provide the right conditions for breeding. even if scientists know what those conditions are. For example, it is well known that the giant panda is difficult to breed even when conditions are ideal.

• Reintroduction to the wild will be unsuccessful unless the original reason for the species being pushed to the edge of extinction is removed.

• Animals that have been bred in captivity may have great problems in adjusting to unsupported life in the wild.

• When the population is small, the gene pool is reduced, and this can cause serious problems. Zoos try to overcome this by keeping detailed records of the genetic data of their breeding individuals.

• Reintroduction programmes can be very expensive and time- consuming, and they may fail.

SUSTAINABILITY

In an ideal world, we would not need seed banks, zoos and other methods of conserving biodiversity. People are increasingly trying to find ways to prevent the loss of biodiversity in the first place. Habitats and ecosystems can be conserved with less conflict by encouraging sustainable methods of land use. For example, illegal logging operations in rainforests use 'slash and burn' techniques (cutting down all the trees and burning the ground afterwards) to harvest wood to sell and clear the soil for farming. The soil is soon exhausted and biodiversity lost. However, if we harvest the trees selectively and replant for the future, biodiversity can be maintained while people continue to use the forest for income. This is sustainable forestry.

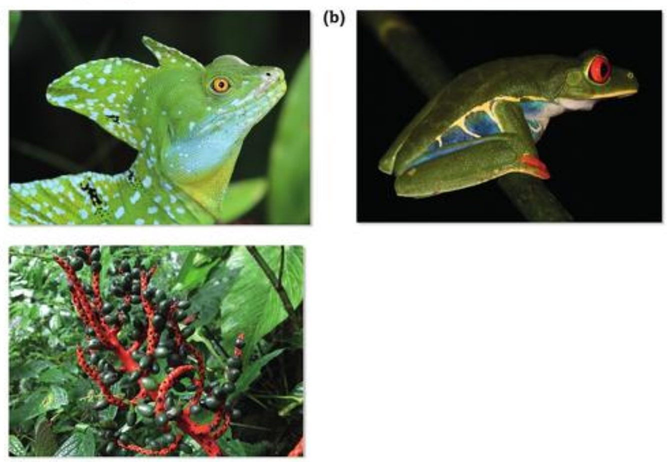
THE IMPORTANCE OF EDUCATION

People have to work hard to reduce pollution and to support conservation programmes. To help them understand why it is important to conserve biodiversity they need to learn about:

- the impact of human activities on the natural world
- ways in which people can act to protect animals, plants and habitats.

Costa Rica is a good example of a country which has reversed its habitat loss and is working hard to conserve its rich biodiversity. More than 25% of the country is now protected in some way, and most of the electricity is generated using renewable resources. Costa Rica now earns a considerable proportion of its national income from sustainable ecotourism. From the President to the children in the schools, people in Costa Rica have become passionate about conserving the rich biodiversity of their country. As a result, ecotourism is growing, but in a managed way which does not destroy the biodiversity people want to see. The ecotourism industry now provides many people with jobs and contributes around 6% of the national GDP. This small country shows that it is possible to use natural resources to make money and conserve biodiversity. You can see some examples of Costa Rican biodiversity in **fig E**.

(a) (b) (c)



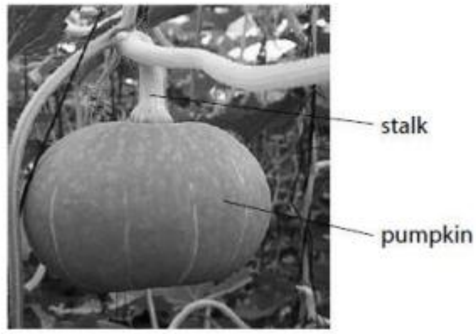
▲ **fig E** Costa Rica covers only about 0.03% of the surface of the Earth, but it has more than 4% of the world's biodiversity. The country is determined to maintain this biodiversity. **(a)** Green basilisk lizard; **(b)** red-eyed tree frog; **(c)** coral palm.

SUBJECT VOCABULARY

conservation maintaining and protecting a living and changing environment
***ex-situ* conservation** the conservation of components of biological diversity (living organisms) outside their natural habitats
***in-situ* conservation** the conservation of ecosystems and natural habitats, and the maintenance and recovery of viable populations of species in their natural surroundings
captive breeding programmes programmes where individuals of an endangered species are bred in zoos and parks in an attempt to save the species from extinction, and if possible to reintroduce them to their natural wild environment

Revision questions

1. The photograph shows a pumpkin.



Source from: https://www.aliexpress.com/price/winter-outdoor-plants_price.html

The scientists Crafts and Lorenz investigated the rate of translocation through the phloem in pumpkins.

The flow chart shows the method used in this investigation.

Step 1
The mean increase in dry mass of a pumpkin after 792 hours of growth was estimated

↓

Step 2
The cross-sectional area of the phloem tissue in the stalk was determined

↓

Step 3
The cross-sectional area of the sieve tubes in the stalk was estimated

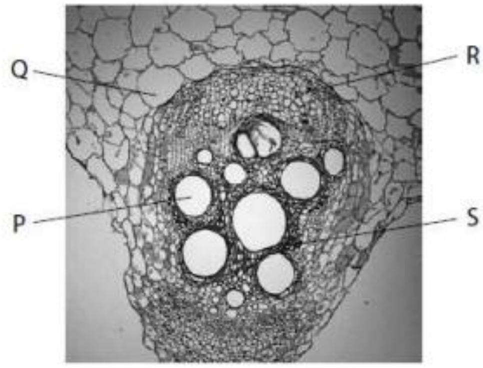
↓

Step 4
The rate of translocation was calculated

(a) (i) Suggest how the mean increase in dry mass of a pumpkin could be estimated in **Step 1**.

(ii) Explain why Crafts and Lorenz used dry mass in this investigation.

(b) (i) The photograph shows a cross-section through part of a stalk, as seen using a light microscope.



Which letter is pointing to the phloem?

(1)

- ☒ **A** P
- ☒ **B** Q
- ☒ **C** R
- ☒ **D** S

(ii) Describe a method that could be used to determine the cross-sectional area of the phloem in **Step 2**.

(2)

(c) Give a reason why only the cross-sectional area of the sieve tubes, rather than the phloem tissue, was estimated in **Step 3**.

(d) What are the units for the rate of translocation calculated in **Step 4**?

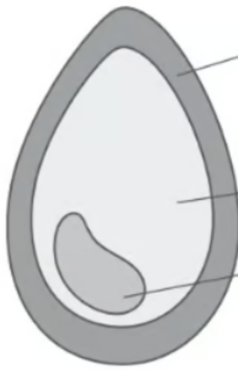
(1)

- ☒ **A** g cm^{-2} hr^{-1}
- ☒ **B** g cm^{2} hr^{-1}
- ☒ **C** g cm^{-3} hr^{-1}
- ☒ **D** g cm^{3} hr^{-1}

2. Plant-based products can replace plastics produced from oil.

Wheat bran comes from the outer layers of grains of wheat.

The diagram shows the structure and composition of a grain of wheat.



Wheat bran contains 43 % fibre.

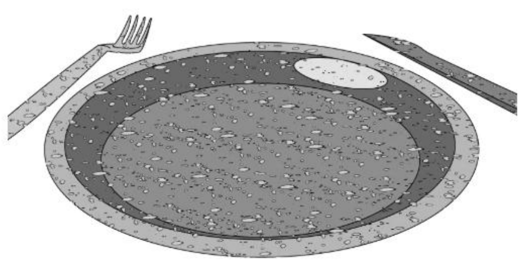
A grain of wheat has a mass of 48 mg.

Calculate the mass of fibre in the wheat bran of this grain of wheat.

Give your answer to **two** significant figures.

b. Disposable plates and cutlery can be made from either plant-based products or from oil-based plastics.

The photograph shows cutlery and a plate made from wheat bran.



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Explain the advantages of using cutlery and plates made from wheat bran instead of oil-based plastics.

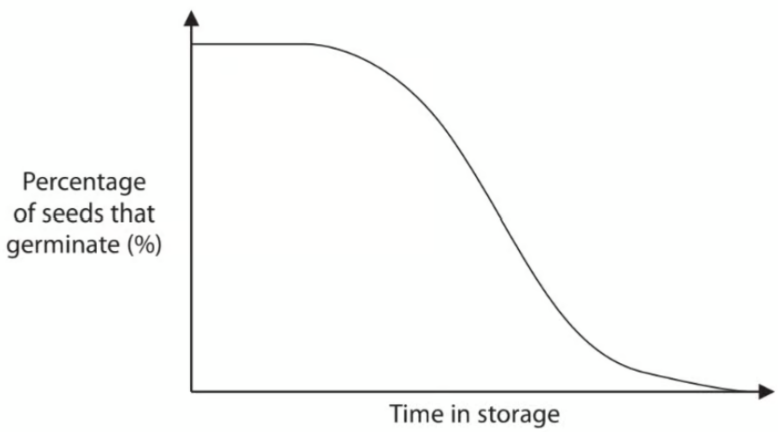
3. Seed banks are used to store seeds from a wide variety of plants. Some plants are a sustainable source of bioplastics.

The Germplasm Bank of Wild Species is the largest seed bank for wild species of plants in Asia.

Seeds from 8 500 species have been collected and stored.

Seeds were dried before being stored at temperatures below 0 °C.

The effect of length of time in storage on seed germination is shown in the graph.



(i) Describe the effect of length of time in storage on the germination of these seeds.

(2)

(ii) Two of the methods used in seed banks are:

- store seeds from many different plants of the same species, instead of many seeds from just one plant
- regularly germinate samples of the stored seeds, allowing them to grow into adult plants.

Explain the advantages of these methods.

(4)

The photograph shows bioplastic straws and cutlery. Bioplastic can be produced from the seeds of avocados.

F. Kesselring, FKuR Willich, CC BY-SA 3.0 DE <https://creativecommons.org/licenses/by-sa/3.0/de/deed.en>, via Wikimedia

(i) In 2018, a company in Mexico produced 130 000 kg of bioplastic cutlery and straws per month.

40 % of the products were straws.

Calculate the mass of cutlery produced per year by this company.
Give your answer to **two** significant figures.

(2)

(ii) The use of these plant-based products is more sustainable than the use of cutlery and straws made from oil-based plastic.

Explain what is meant by the term sustainable, with reference to the cutlery produced from the seeds of avocados.

(2)

4. a)

Sehuencas water frogs are endemic to Bolivia.

It was once believed that this frog was extinct in the wild.

This was due to human activity and a disease caused by a fungus.

Suggest how human activity could cause the extinction of the Sehuencas water frog in the wild.

b) In 2008, there was only one Sehuencas water frog in captivity.

In 2018, five Sehuencas water frogs were discovered in a Bolivian mountain forest.

Three of these frogs were male.

Scientists suggested that these five frogs were resistant to the fungal disease.

Explain how resistance to this fungus could develop in a population of Sehuencas water frogs.

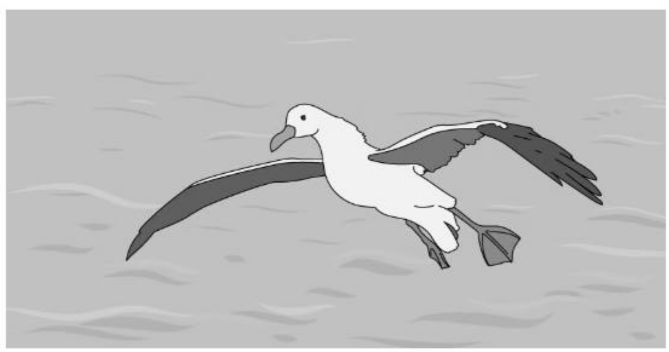
c)

One way of studying the genetic diversity within a species is to calculate the heterozygosity index.

Describe how the scientists could calculate the heterozygosity index for a population of Sehuencas water frogs.

5. a) The Tristan albatross (*Diomedea dabbenena*) was once classified as the same species as the wandering albatross (*Diomedea exulans*).

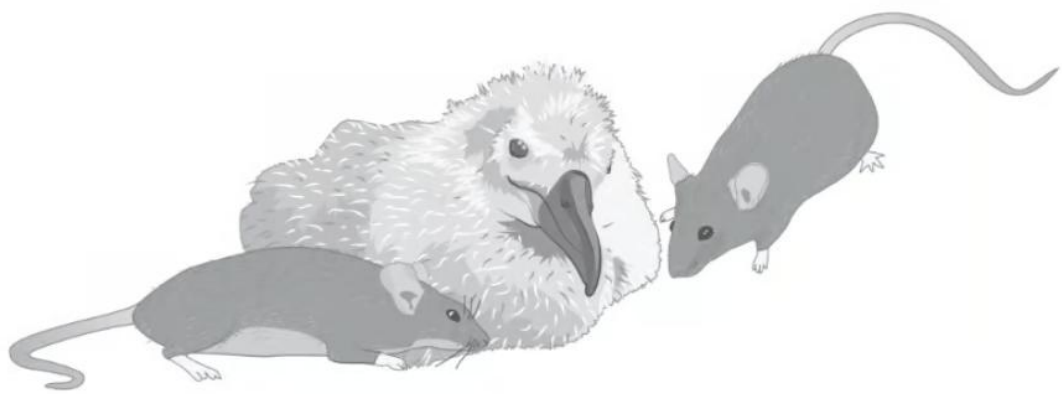
The illustration shows a wandering albatross.



Suggest why the Tristan albatross and wandering albatross were once classified as the same species.

b) Tristan albatross chicks in nests on one island have been found to be at risk of predation from mice.

The diagram shows an albatross chick and two mice on this island.



Over a long period of time, mice on this island have become 50 % larger than normal mice.

It has been suggested that the mice from this island are a new species.

Suggest how the mice on this island have evolved to become a new species.

C)

Scientists have suggested that the Tristan albatross could be conserved.

Some suggestions are conservation strategies on the island where the mice are found.

Some suggestions involve zoos in other countries.

Explain how the Tristan albatross could be conserved.

Use the information in Question 8 to support your answer.

6. a) The Galapagos Islands are located off the west coast of South America.

The biodiversity on these islands has changed over the past 40 years due to human activity.

One of these islands is called Santa Cruz.

The population of Santa Cruz increases by approximately 6.4 % per year.

The majority of the population, 85 %, live in urban areas.

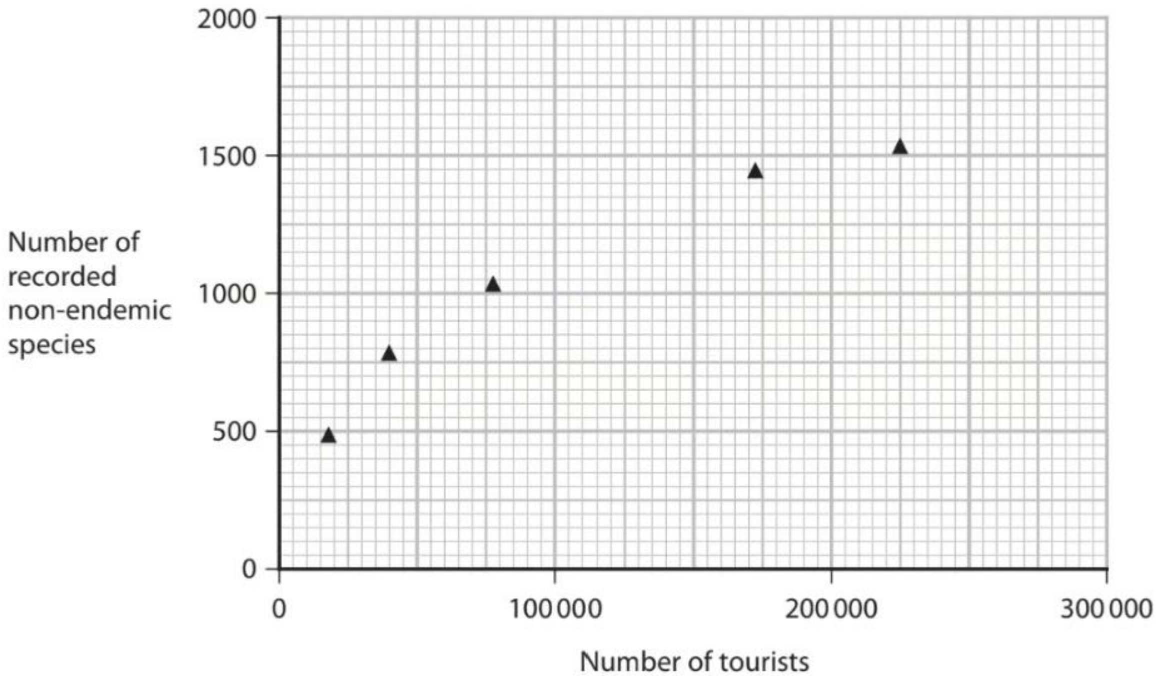
The population of Santa Cruz living in urban areas in 2020 was 17 000.

Predict the total population of Santa Cruz in 2025.

Assume that the rate of increase stays constant.

b)

The graph shows the number of tourists to all the islands and the number of recorded non-endemic species.



https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0184379

State the relationship shown in the graph.

7. a) Organisms can be classified using the three-domain system.

Molecular evidence is used to place an organism into one of the three domains.

(i) Give **one** example of the molecular evidence used to support the three-domain system.

(1)

(ii) Describe the role of the scientific community in evaluating the evidence for this system of classification.

(2)

b)

The table shows some features of living organisms.

Place an X in each row to show whether the feature is found in these domains.

Feature	Archaea only	Archaea and Bacteria only	Archaea and Eukarya only	Archaea and Bacteria and Eukarya
absence of a nuclear envelope	☐	☐	☐	☐
presence of circular DNA	☐	☐	☐	☐
presence of a cell membrane	☐	☐	☐	☐
presence of ribosomes	☐	☐	☐	☐