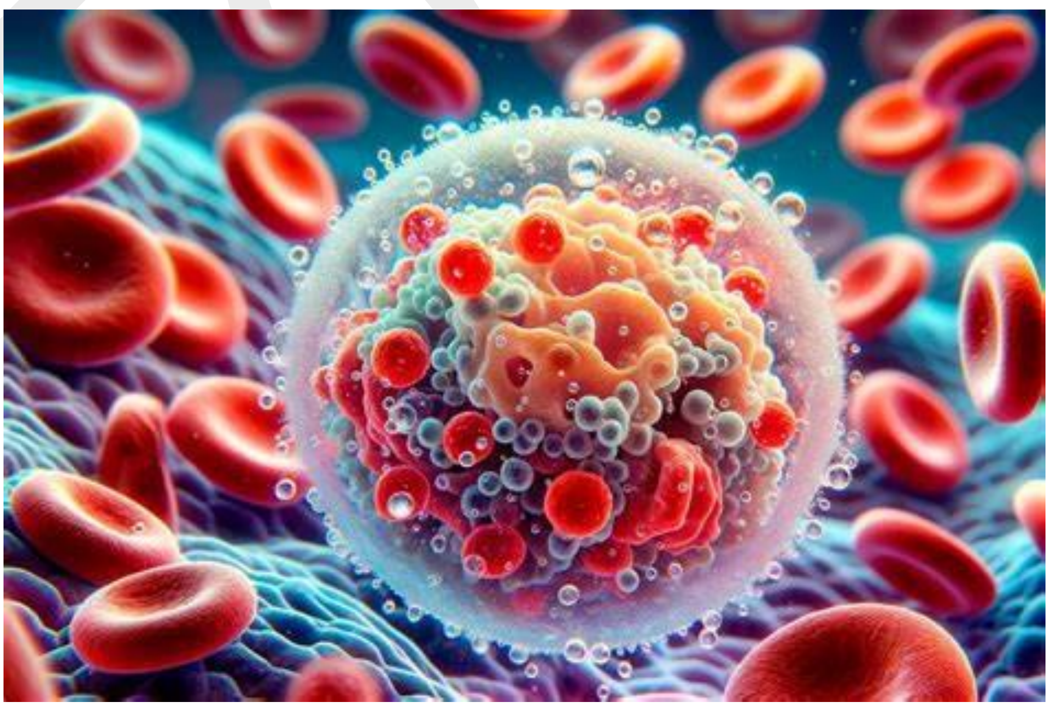
Cambridge OL

Biology

CODE: (5090)

Chapter 05 and chapter 06

Enzymes and Plant nutrition



Enzymes, proteins in living cells, act as catalysts, allowing for repeated use and speeding up reactions. They control cell functions by ensuring quick and efficient cell reactions.

Key definitions

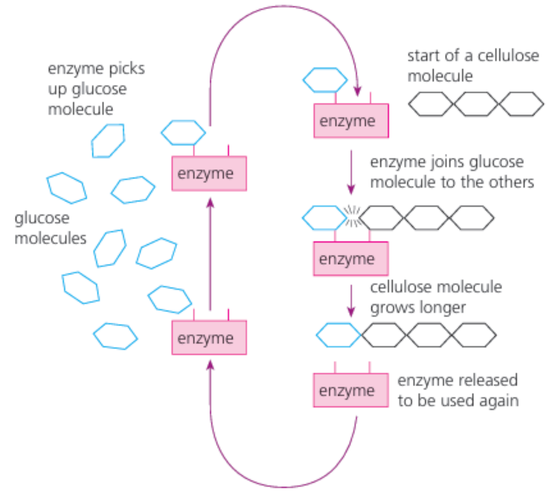
A **catalyst** is a substance that increases the rate of a chemical reaction and is not changed by the reaction.

Enzymes are proteins that function as **biological catalysts** and are involved in all metabolic reactions.

Enzyme action

An enzyme-controlled reaction involves a **substrate**, an enzyme and a product. The substrate and product may be two or more different molecules:

substrate —enzyme→ product



▲ **Figure 5.1** Building up a cellulose molecule

Enzymes are specific

Specificity simply means that an enzyme which normally works on one substrate will not act on a different one.

The enzyme in Figure 5.2(a) has a shape called the **active site**, which exactly fits the substrates on which it works but which will not fit the substrate in Figure 5.2(b).

The shape of the active site of the enzyme molecule and the substrate molecule are said to be **complementary**.

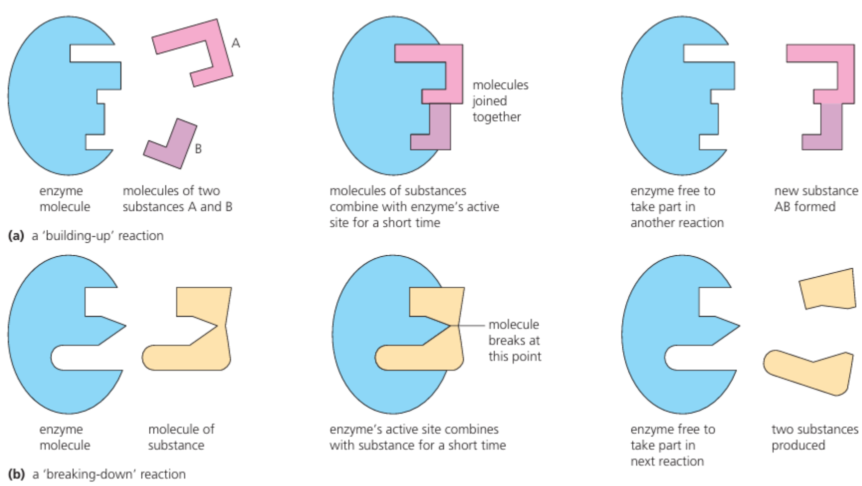
In addition, if a reaction takes place in stages, such as:

starch ⟶ maltose (stage 1)
maltose ⟶ glucose (stage 2)

For example, an enzyme that works on proteins may be called a **protease**; one that removes hydrogen from a substance is a dehydrogenase. When the enzyme joins with the substrate, an **enzyme–substrate complex** is formed temporarily.

The product (substance AB in Figure 5.2(a)) is released from the enzyme's active site and the enzyme is then free to repeat the reaction with more substrate molecules.

Eventually you should detect the food tasting sweeter, as maltose sugar is formed. If starch is mixed with water, it will break down very slowly to sugar. The process takes years. In your saliva there is an enzyme called **amylase**.



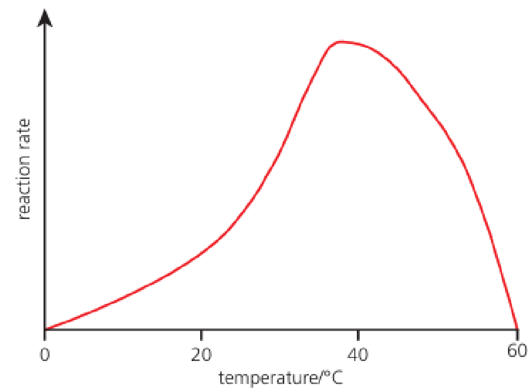
▲ **Figure 5.2** The lock and key hypothesis for enzyme action

Effects of temperature and pH

Enzymes and temperature

Usually, a rise of 10 °C will double the rate of an enzyme-controlled reaction in a cell, up to an **optimum** temperature of about 37 °C (body temperature). This is because the enzyme and substrate molecules are constantly moving, using **kinetic energy.**

As the temperature is increased, the molecules gain more kinetic energy, so they move faster and there is a greater chance of **collisions** happening.



▲ **Figure 5.3** Graph showing the effect of temperature on the rate of an enzyme-controlled reaction

Denaturation is a permanent change in the shape of the enzyme molecule. Once it has happened, the enzyme will not work anymore, even if the temperature is reduced below 37 °C.

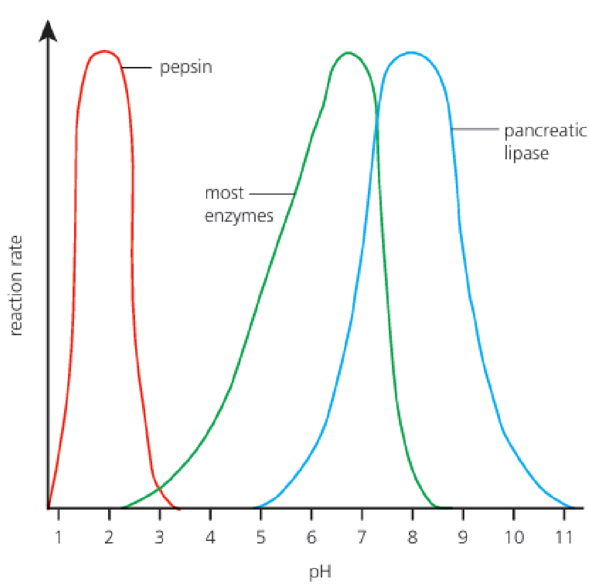
High temperatures can kill organisms due to denatured enzymes in their cells, leading to slow chemical reactions. Egg white, a protein, undergoes denatured transformation when heated, causing it to change shape and become a white solid. Enzymes and cell structures stop working, leading to cell death. Enzymes can be tested by boiling them, but if they cannot continue, they are not enzymes.

This technique is used as a control (see 'Aerobic respiration' in Chapter 10) in enzyme experiments.

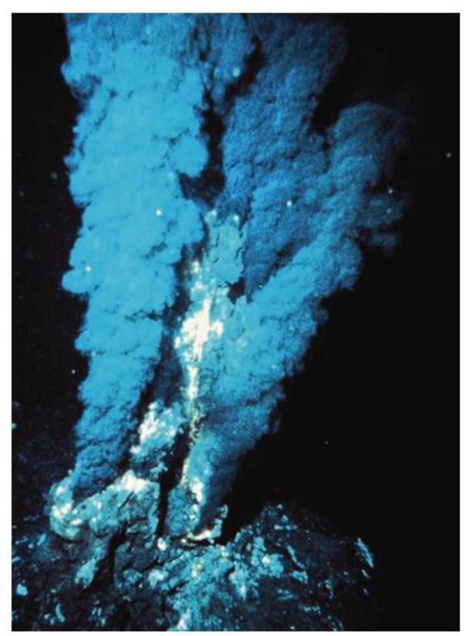
Enzymes and pH

Acid or alkaline conditions can denature some enzymes. Most enzymes work best at a particular level of acidity or alkalinity (pH), as shown in Figure 5.5.

Conditions in the **duodenum** are slightly alkaline: the optimum pH for pancreatic **lipase** is pH 8.



▲ **Figure 5.5** The effect of pH on digestive enzymes



▲ **Figure 5.4** A hydrothermal vent, made as a result of volcanic activity on the sea floor. It is a good habitat for marine organisms, including bacteria and invertebrates, because the water is so rich in nutrients. However, these organisms need to survive at very high temperatures

Chapter 06 – Plant nutrition

Key definitions

Photosynthesis is the process by which plants make carbohydrates from raw materials using energy from light.

Photosynthesis

When complicated food molecules are built up from simpler substances the process is called **synthesis**. It needs enzymes and energy to make it happen. The enzymes are present in the plant's cells. The energy for the first stages in the synthesis comes from sunlight. So, the process is called **photosynthesis** ('photo' means 'light').

The chemical equation for photosynthesis is

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light energy}} \text{glucose} + \text{oxygen}$$

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

In order to keep the equation simple, glucose is shown as the food compound produced. However, the glucose is quickly converted to sucrose for transportation around the plant.

▲ **Figure 6.1** All the reactions involved in producing food take place in the leaves. You can see that the leaves do not overlap a lot to make sure they absorb as much light as possible

The process of photosynthesis

Photosynthesis is a process in plants that involves the absorption of water from the soil by roots, carbon dioxide from the air through stomata, and the reaction of carbon dioxide and water to form glucose. Energy for this reaction comes from sunlight, which is absorbed by chlorophyll in leaf cells. Chloroplasts, small green structures, absorb energy from light and use it to split water molecules into hydrogen and oxygen, converting the energy into carbohydrates.

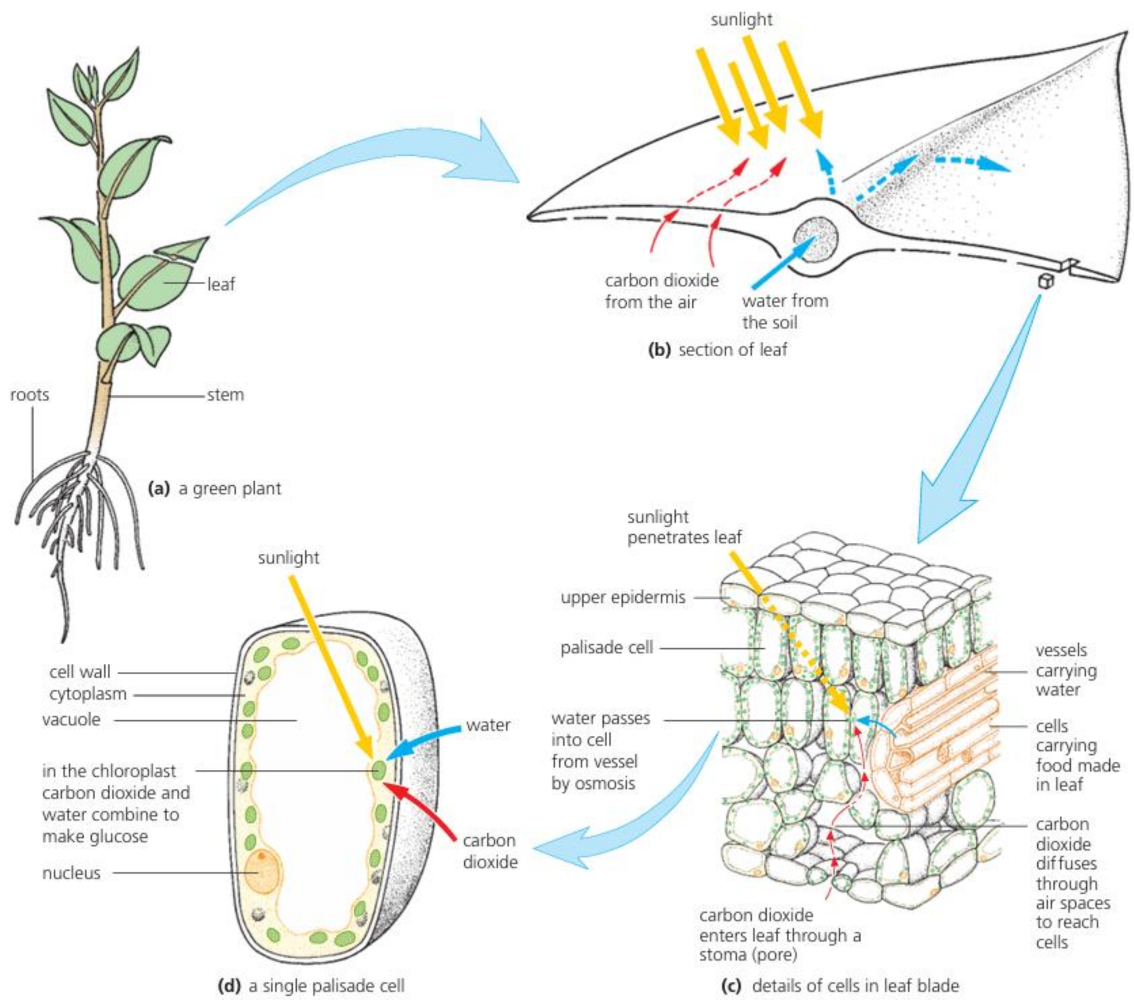
The plant's use of photosynthetic products

Glucose

The glucose produced during the process of photosynthesis is used in respiration to provide energy. It is quickly changed to sucrose for transport around the plant.

Starch

Starch is a compound that converts glucose not needed for respiration into starch, which is stored or changed into other molecules. It is insoluble and does not alter cell contents. Some plants store starch grains in stem or root cells, while others have special storage organs. Sugar is stored in fruits like grapes.



▲ **Figure 6.2** Photosynthesis in a leaf

Sucrose

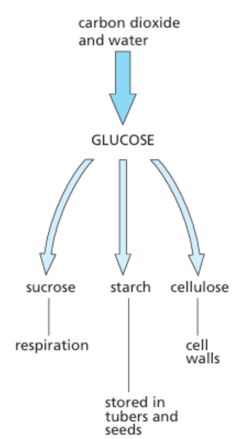
The starch is steadily broken down to sucrose (Chapter 4), which is soluble. The sucrose is transported out of the cell into the phloem. These are the food-carrying cells (see Chapter 7) of the leaf veins.

Cellulose

The cellulose cell wall holds in the contents of the cell but is freely **permeable** (it will allow most molecules to pass through).

Respiration

The glucose can be used to provide energy. The process of respiration oxidises the glucose. The products are carbon dioxide and water, and the energy released is used for other chemical reactions like the building-up of proteins.



▲ **Figure 6.3** Green plants can make all the materials they need from carbon dioxide, water and salts

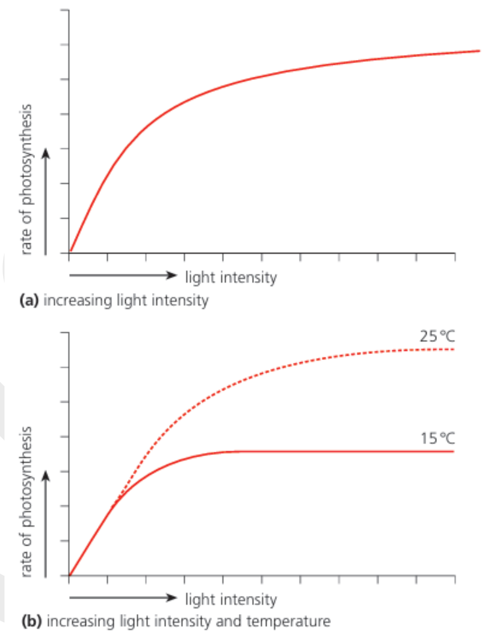
Effects of external factors on the rate of photosynthesis

The rate of the light reaction depends on the light intensity. Water molecules in the chloroplasts will split faster as the light becomes brighter. The dark reaction is affected by temperature. The rate that carbon dioxide combines with hydrogen to make carbohydrate increases as the temperature increases

Limiting factors

A **limiting factor** is something present in the environment in such short supply that it limits life processes.

The increase in light intensity speeds up photosynthesis up to a point, but beyond that point, further increase has only a small effect. This limit may be due to chloroplasts fully engaging in light absorption, insufficient carbon dioxide in the air, or low temperature limiting enzyme reactions. If the temperature of a plant is raised, the effect of increased light intensity is not limited. The limiting factor is the external factor that limits the effect of the other two.



▲ **Figure 6.10** Limiting factors in photosynthesis

Glasshouses and polytunnels increase crop yields by artificially high levels of carbon dioxide, maintaining higher temperatures, and optimizing light. While tropical countries benefit from optimal temperatures and rainfall, growers still use these structures to control water and nutrient intake, reduce crop damage, and optimize light.

Photosynthesis is a crucial process in the natural environment, influenced by temperature and light intensity. Temperature affects enzyme-controlled reactions, while light provides energy for plant synthesis. Seasonal climates, such as winter months, cause slow photosynthesis. Plants produce vegetative structures like bulbs, corms, rootstocks, or tubers, which grow only in spring when light intensity and temperature rise. Some plants, like bluebells, complete their growing season early to benefit from light. Extreme conditions, like arctic tundra and tropical forests, can also limit photosynthesis. Other processes, such as fertilizer, also have limiting factors, such as root absorbing area, respiration rates, soil aeration, and availability of carbohydrates from photosynthesis.


▲ **Figure 6.11** Carrot plants grown in increasing concentrations of carbon dioxide from left to right

Leaf structure

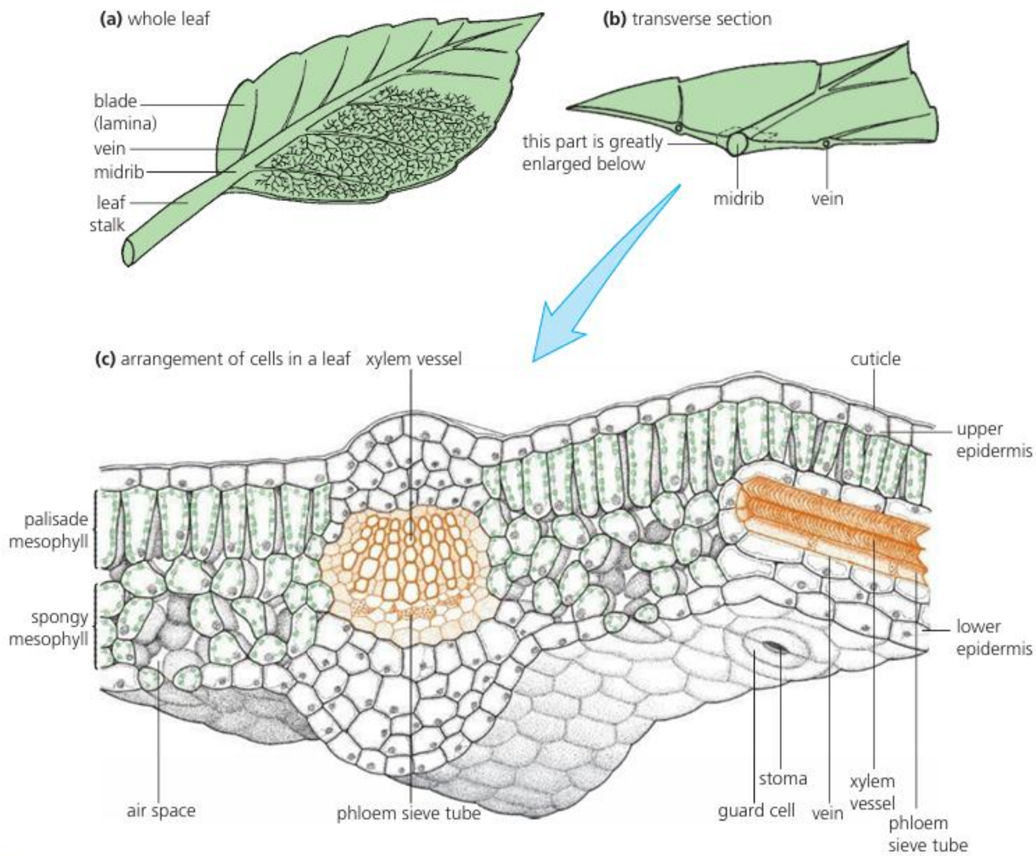
Chapter 7 details the relationship between a leaf and the plant. A broad-leaved plant has a leaf structure with a transverse section, attached to the stem by a leaf stalk called a midrib. A network of veins branches from the midrib, carrying water, mineral ions, and food, and supporting the leaf blade.

Adaptation of leaves for photosynthesis

When biologists say that something is adapted, they mean that its structure is well suited to its job. Although there are many types of leaf shape, the following statements apply to most leaves and are shown in Figure 6.17(b) and (c).

» Their broad, flat shape gives a large surface area for the absorption of sunlight and carbon dioxide.

» Most leaves are thin, so the carbon dioxide only needs to diffuse across short distances to reach the inner cells.



▲ **Figure 6.17** Leaf structure

Parts of the leaf and their functions

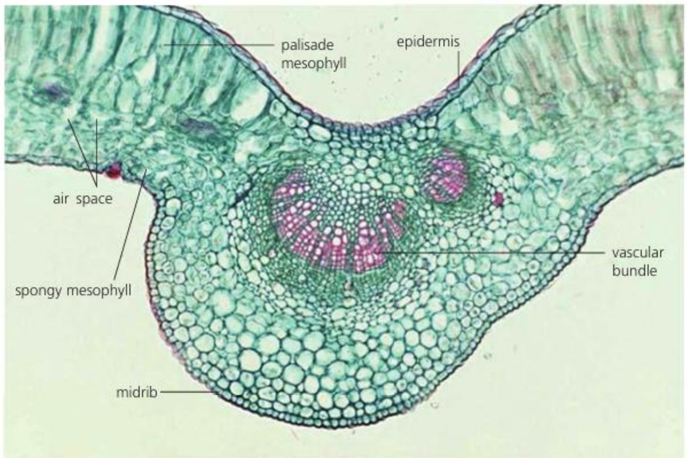
Figure 6.18 is a photograph of a leaf section under the microscope.

Epidermis

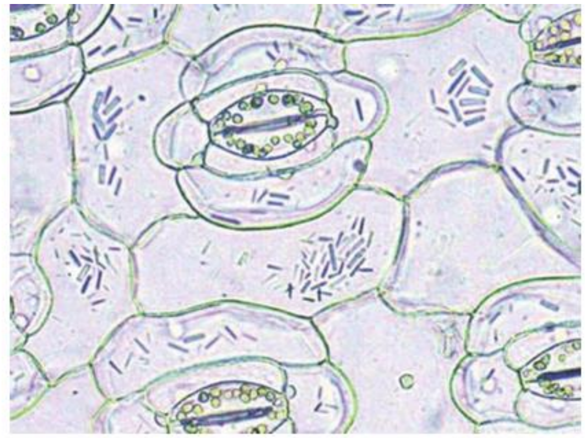
The epidermis is a single layer of cells on the upper and lower surfaces of the leaf. There is a thin waxy layer called the **cuticle** over the epidermis.

Stomata and guard cells

There are structures in the leaf epidermis called stomata (singular = **stoma**). A stoma consists of a pore enclosed by two **guard cells** (Figure 6.19).

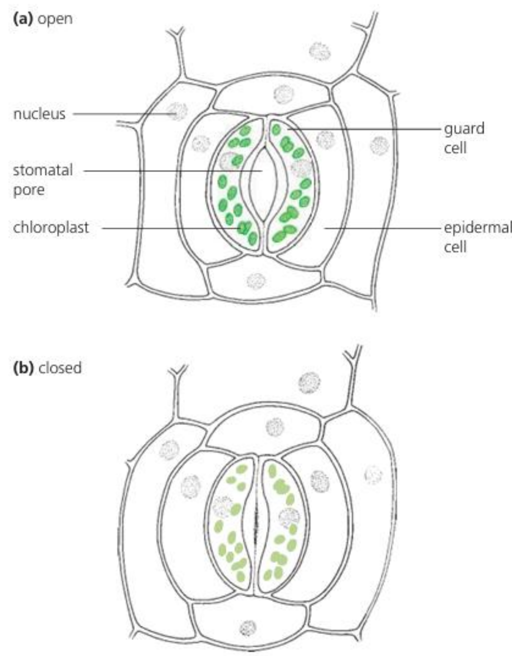


▲ **Figure 6.18** Transverse section through a leaf (×30)



▲ **Figure 6.19** Stomata in the lower epidermis of a leaf (×350)

Guard cells in plants change their shape when the pressure of water in them changes. The stomatal pore can open or close, depending on the plant species. Stomata allow carbon dioxide to enter the leaf during photosynthesis and prevent excessive water vapour loss. The opening and closing patterns depend on the plant species. In light, potassium concentration in guard cell vacuoles increases, making cell sap more concentrated. Water enters the cell through osmosis, increasing the pressure inside the cell. The thicker inner wall prevents expansion, causing the cell to curve and open.



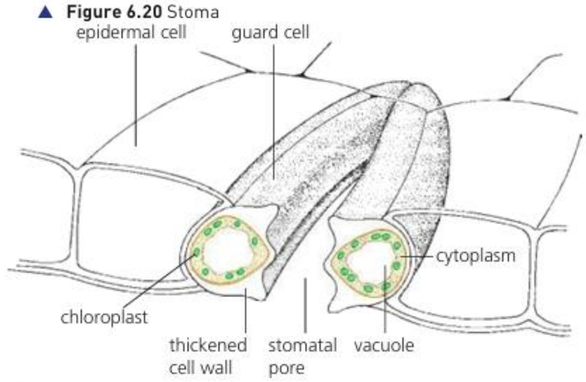
▲ **Figure 6.20** Stoma

Mesophyll

Mesophyll, the tissue between the upper and lower epidermis, consists of two areas: upper palisade mesophyll and lower sponge mesophyll. Palisade cells are long and contain chloroplasts, while sponge mesophyll cells have different shapes and contain chloroplasts. Palisade cells make food through photosynthesis, while sponge mesophyll cells absorb sunlight and use it to form glucose. In daylight, mesophyll cells use up carbon dioxide, reducing air space concentration.

Air spaces

The large spaces between the spongy mesophyll cells inside the leaf make it easy for the carbon dioxide to diffuse. Water vapour goes into the air spaces, evaporated from the surface of the cells around them. This is part of the process of transpiration



▲ **Figure 6.21** Structure of guard cells

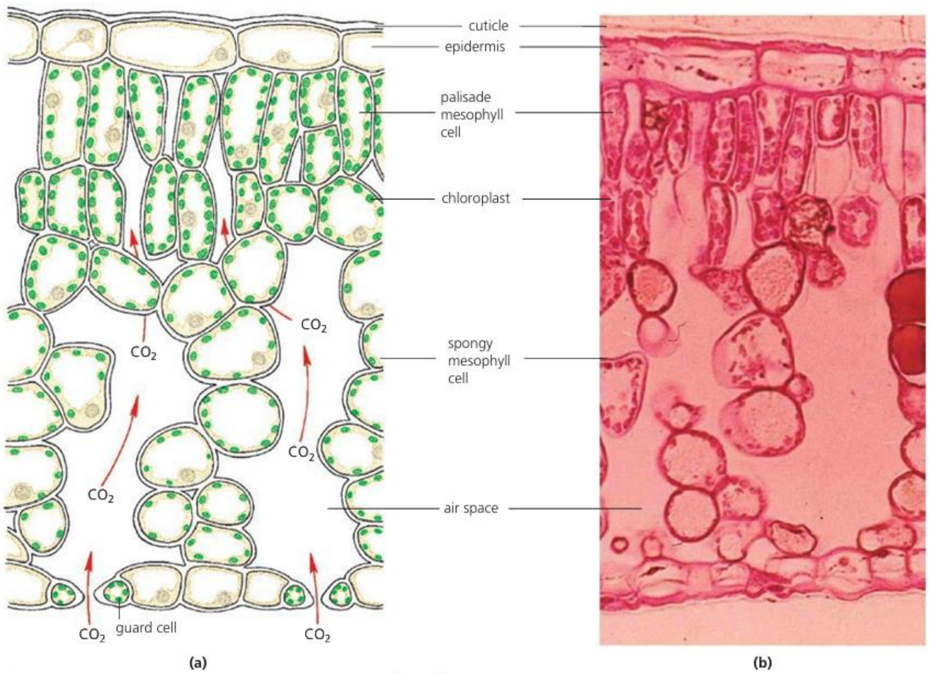
Vascular bundles (veins)

The main vein of the leaf is called the midrib. Other veins branch off from this and make a network through the leaf. Vascular bundles are made of two different types of tissues, called xylem and phloem. The xylem vessels are long, thin tubes with no cell contents when mature (cytoplasm, nucleus or sap vacuole). They have thickened cell walls, containing a material called **lignin**.

The sugars made in the mesophyll cells are passed to the phloem cells (Chapter 7) of the veins. Phloem cells carry the sugars and other food substances like amino acids away from the leaf and into the stem to other parts of the plant (a process called **translocation**).

Distribution of chloroplasts

There are more chloroplasts in the upper (palisade mesophyll) cells than in the lower (spongy mesophyll) cells. The palisade cells are near the upper surface, so they get most sunlight. This will reach the chloroplasts without being absorbed by many cell walls. There are also some chloroplasts in the guard cells (Figure 6.21). Other epidermal cells do not have chloroplasts.



▲ **Figure 6.22** Vertical section through a leaf blade (×300)

▼ **Table 6.1** Summary of parts of a leaf

Part of leaf	Details
cuticle	Made of wax, waterproofing the leaf. It is secreted by cells of the upper epidermis.
upper epidermis	These cells are thin and transparent to allow light to pass through. No chloroplasts are present. They act as a barrier to disease organisms.
palisade mesophyll	The main region for photosynthesis. Cells are columnar (quite long) and packed with chloroplasts to trap light energy. They receive carbon dioxide by diffusion from air spaces in the spongy mesophyll.
spongy mesophyll	These cells are more spherical and loosely packed. They contain chloroplasts, but not as many as in palisade cells. Air spaces between cells allow gaseous exchange – carbon dioxide to the cells, oxygen from the cells during photosynthesis.
vascular bundle	This is a leaf vein made up of xylem and phloem. Xylem vessels bring water and minerals to the leaf. Phloem vessels transport sugars and amino acids away (this is called translocation).
lower epidermis	This acts as a protective layer. Stomata are present to regulate the loss of water vapour (this is called transpiration). It is the site of gaseous exchange into and out of the leaf.
stomata	Each stoma is surrounded by a pair of guard cells. These can control whether the stoma is open or closed. Water vapour passes out during transpiration. Carbon dioxide diffuses in and oxygen diffuses out during photosynthesis.

Mineral nutrition

Plants require nitrate ions for amino acid production, essential for cell enzymes and cytoplasm. They absorb nitrates from soil through roots. Magnesium is needed for chlorophyll production, sourced from soil.

Revision questions

1. Dairy cattle are kept for milk production. Approximately half of all the calves born are male.

(a) Sex is determined in cattle in exactly the same way as it is in humans.
Explain why 50% of all cattle are born male. You may draw a genetic diagram to help your explanation

(b) Dairy farmers only need a very small number of male calves. They limit the number by using sex selection. Sperm cells are identified and sorted before they are used in artificial insemination (AI).

Explain how artificial insemination is carried out.

(c) Table 2.1 shows the composition of 100 g of cow's milk compared with the same quantities of commercial formula milk and human milk.

Table 2.1

nutrient	cow's milk	formula milk	human milk
carbohydrate / g	6.5	7.3	7.5
protein / g	3.3	1.3	1.3 – 1.6
fat / g	3.9	3.6	4.1
calcium / mg	120	42	34
iron / mg	0.02	0.64	0.07
vitamin D / μg	0.05	1.20	0.06
vitamin A / μg	19	66	58

Some women do not breast-feed their babies but bottle-feed them using formula milk. Health authorities advise against the use of cow's milk until babies are about 9 months old.

Use the information in Table 2.1 to explain the advantages of using formula milk rather than cow's milk.

One of the components of human milk is the enzyme lysozyme that is present in many body fluids and is responsible for breaking down the cell walls of bacteria.
(d) Define the term enzyme.

2. Microorganisms in the soil release enzymes to digest dead leaves.
(a) Explain how enzymes catalyse chemical reactions.

(b) Protease and cellulase are two enzymes secreted by soil microorganisms. Protease digests protein.
Suggest what part of the dead leaf cells are digested by the enzyme cellulase

(c) Table 6.1 shows the results of a study comparing the decomposition of dead leaves at two locations A and B.

Table 6.1

	location **A**	location **B**
protease activity / $\mu mol\,min^{-1}$	2750	2670
cellulase activity / $\mu mol\,min^{-1}$	4790	2500
soil pH	6.0	3.5
soil water content / %	10	77

(i) Compare the enzyme activity at location A with the enzyme activity at location B. You will gain credit for using the data from Table 6.1 to support your answer.

(ii) Suggest possible reasons for any differences in the enzyme activity at location A and location B

(d) Describe how nitrogen in proteins in dead leaves is recycled to be absorbed by plants.

(e) Microorganisms also process and convert atmospheric nitrogen to form a nitrogen compound that can be absorbed by plants.
(i) Name this process of converting atmospheric nitrogen.
(ii) Explain how this process happens

3. (a) Starch, glucose and fructose are carbohydrates. Fructose syrup is used as a sweetening agent as an alternative to sucrose. The flow chart in Fig. 3.1 shows how fructose is prepared from maize starch

(i) Name enzyme 1.
(ii) State why it is necessary to adjust the pH before an enzyme is added to the process.

(b) Maize grains contain protease enzymes. With reference to the processes shown in Fig. 3.1, suggest why it is important that these enzymes do not contaminate the glucose syrup.

(c) The formation of fructose syrup from glucose syrup is carried out at a temperature of 60 °C. Suggest an important property of enzyme 2 that allows it to be used at temperatures as high as 60 °C.

(d) Enzyme 2 is found naturally in many bacteria. Enzymes for use in washing powders are obtained from bacteria. Describe how bacteria are used to produce enzymes for washing powders.

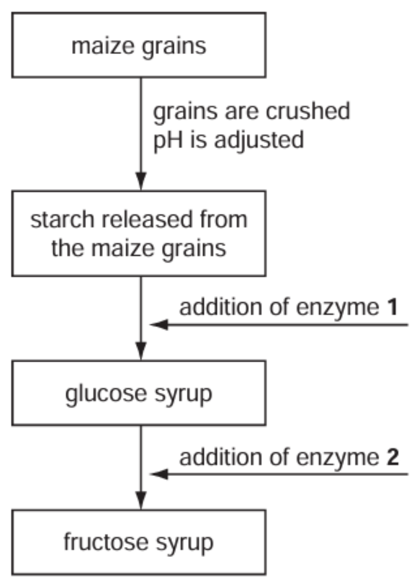


Fig. 3.1

4. Sewage disposal involves the removal of human waste in pipes from houses to sewage treatment works. Fig. 6.1 is a diagram that shows how sewage is treated.

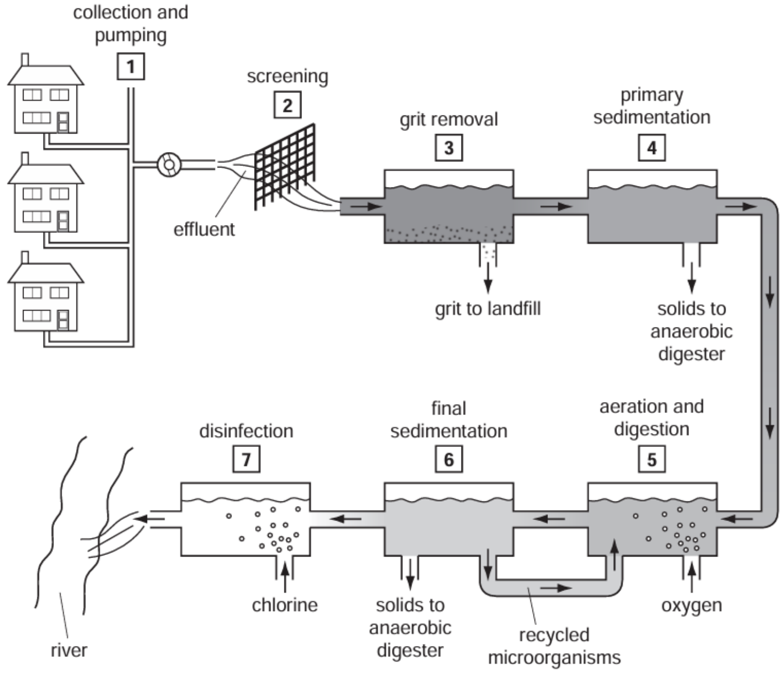


Fig. 6.1

(a) During stage 5 microorganisms break down organic matter consisting of cellulose, starch, protein and lipid (fat). The microorganisms multiply during this stage and are recycled.

Complete Fig. 6.2 by writing in the boxes the names of the enzymes used to catalyse the reactions shown. The first box has been completed for you.

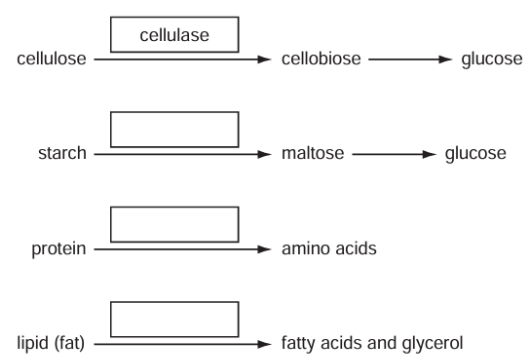


Fig. 6.2

(b) State why it is important that sewage is treated.

(c) At stage 5 in Fig. 6.1, oxygen and microorganisms are added. Explain why oxygen is bubbled through the tank at this stage.

(d) Suggest and explain the advantage of recycling microorganisms from stage 6 to stage 5 as shown in Fig. 6.1.

(e) Explain why chlorine is added at stage 7.

5. Fig. 1.1A shows a buttercup, Ranunculus cymbalaria. Fig. 1.1B shows details of a flower of the same plant.

Fig. 1.1

(a) Explain, using only features visible in Fig. 1.1, why Ranunculus cymbalaria is classified as a dicotyledonous plant rather than as a monocotyledonous plant.

Fig. 1.2 shows a transverse section through a buttercup root at the end of the cold winter (W) and at the end of the warm, moist summer S). At the end of the winter, the cells contain very few starch grains. At the end of the summer, most of the root cells contain many starch grains

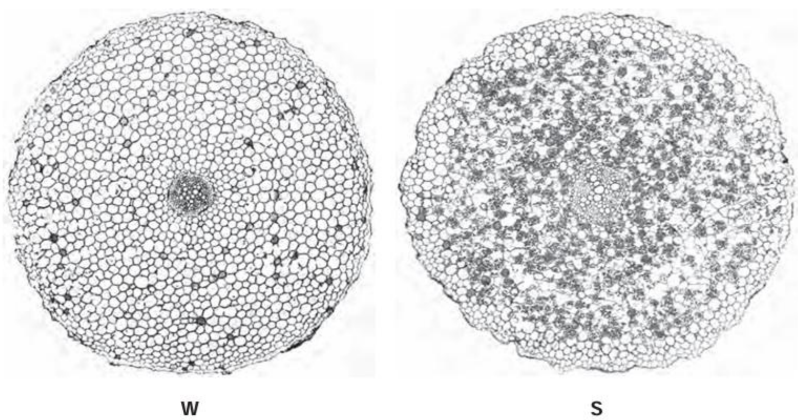


Fig. 1.2

(b) Suggest why there are few starch grains in the cells of W compared with a large number of starch grains in the cells of S.

(c) Describe how enzymes in root cells synthesise starch.

(d) As temperature is increased, for example from 10˚C to 30˚C, enzyme activity increases. Explain how increasing temperature affects enzyme activity.

6. (a) State the balanced chemical equation for photosynthesis.

$$\ldots\ldots\ldots\ldots \xrightarrow[\text{chlorophyll}]{\text{light}} \ldots\ldots\ldots\ldots$$

A student investigated the effect of different wavelengths of light on the rate of photosynthesis of the water plant, Cabomba.
The student used the apparatus shown in Fig. 6.1.

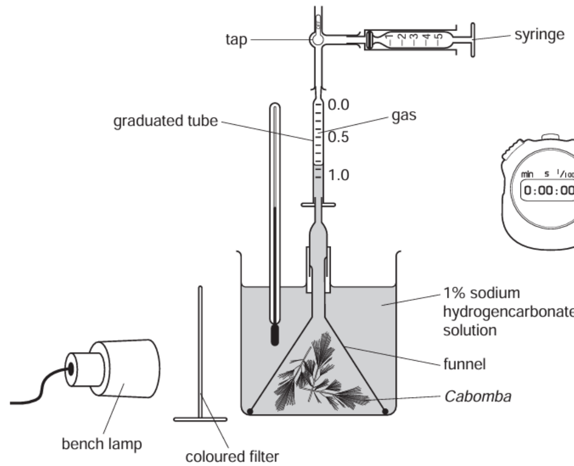


Fig. 6.1

(b) The student collected the gas produced by the plant for five minutes. The results are shown in Table 6.1.

Describe the effect of wavelength of light on the rate of photosynthesis as shown in the student's results in Table 6.1.
You will gain credit if you use data from the table.

(c) State how the student would calculate the rates of photosynthesis from the results in Table 6.1.

(d) State why the student:
(i) kept the lamp at the same distance during the investigation,
(ii) used sodium hydrogencarbonate solution.

7.

(a) Write a balanced chemical equation for photosynthesis.

.... → .... [3]

A student investigated the effect of light intensity on the rate of photosynthesis of algae.

Fig. 2.1 shows the apparatus set up for the investigation.

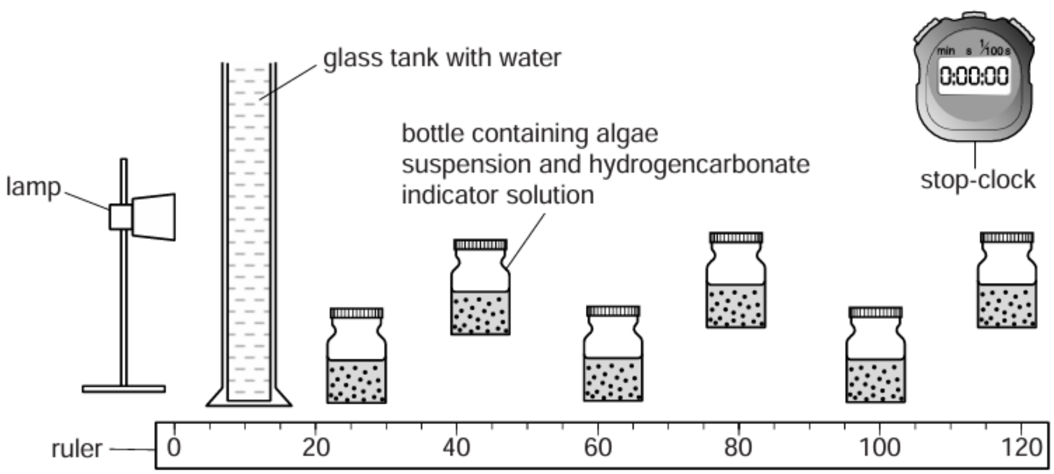


Fig. 2.1

(b) Suggest why a glass tank with water was placed between the lamp and the bottle in the investigation.

(c) The hydrogencarbonate indicator solution changes colour when the pH changes. At pH 8.4 it is red, at pH 7.6 it is yellow and at pH 9 it is purple.

Predict the colour of the hydrogencarbonate indicator solution in the bottle nearest the lamp at the end of the investigation. Explain your answer.

(d) The student's results are shown in Fig. 2.2.
Describe and explain how the rate of photosynthesis is affected by light intensity

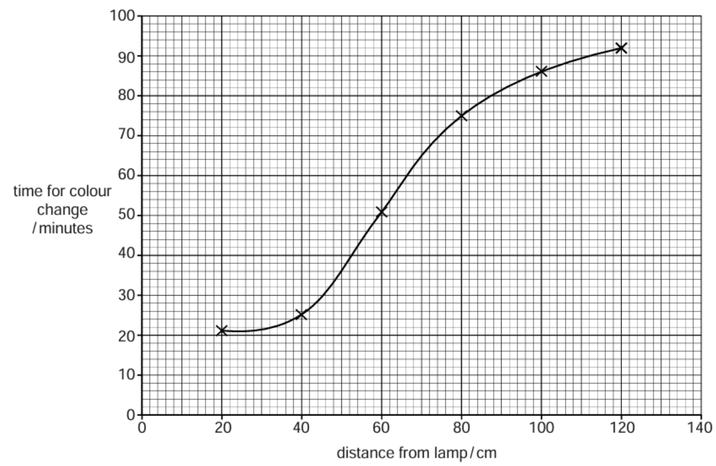


Fig. 2.2

8. Fig. 6.1 shows the carbon cycle. P, Q, R, S and T each represent a part of the carbon cycle

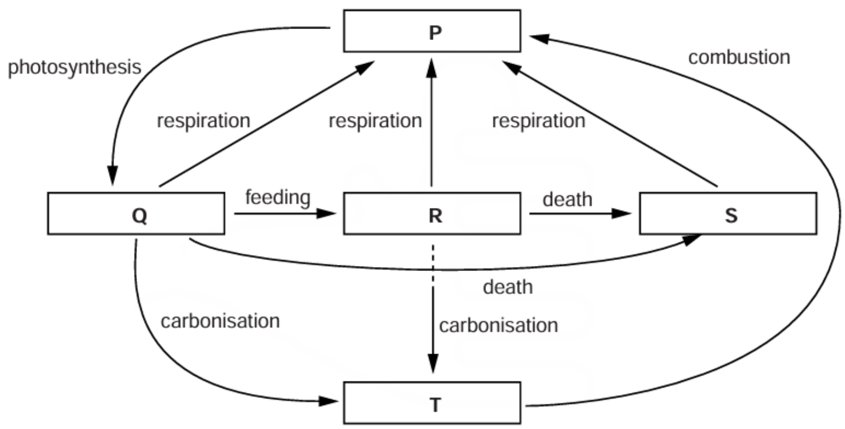


Fig. 6.1

(a) Complete Table 6.1 by identifying P, Q, R and S and the name of one example of a carbon compound found in each. T has been completed for you

Table 6.1

letter	part of cycle	carbon compound found in each part
P		
Q		
R		
S		
T	fossil fuels, e.g. natural gas	methane

(b) Photosynthesis is a very important process in the carbon cycle. Explain how the process of photosynthesis converts carbon compounds from P to carbon compounds in Q.

(c) The rate of photosynthesis varies as a result of changes in environmental factors. State one environmental factor and explain how it can affect the rate of photosynthesis.

(d) Environmental factors can be controlled in glasshouses. Describe how three environmental factors are controlled in a glasshouse to improve crop yield.

9. In some country's forests are cleared by burning. This produces carbon dioxide and ash.
(a) Outline the environmental effects of an increase in carbon dioxide in the atmosphere as a result of burning forests.

(b) The ash helps crops to grow because it is rich in minerals, such as magnesium ions, but it is deficient in nitrate ions. Explain why nitrate ions and magnesium ions are important for plants.

(c) When mineral ions from soils are washed into streams and rivers there is often a rapid growth of algae.

(i)State the name of the effect that is caused by adding mineral ions to streams and rivers.
(ii) These streams and rivers often have low concentrations of dissolved oxygen. Explain why.
(d) Untreated domestic sewage contains organic waste as well as dissolved minerals. Outline how sewage is treated so that the water may be recycled as drinking water

10.

Fanwort, *Cabomba caroliniana*, is an aquatic plant often used to provide oxygen in fish tanks.

Some students investigated the effect of temperature on the rate of photosynthesis of *C. caroliniana*. The apparatus that they used is shown in Fig. 2.1.

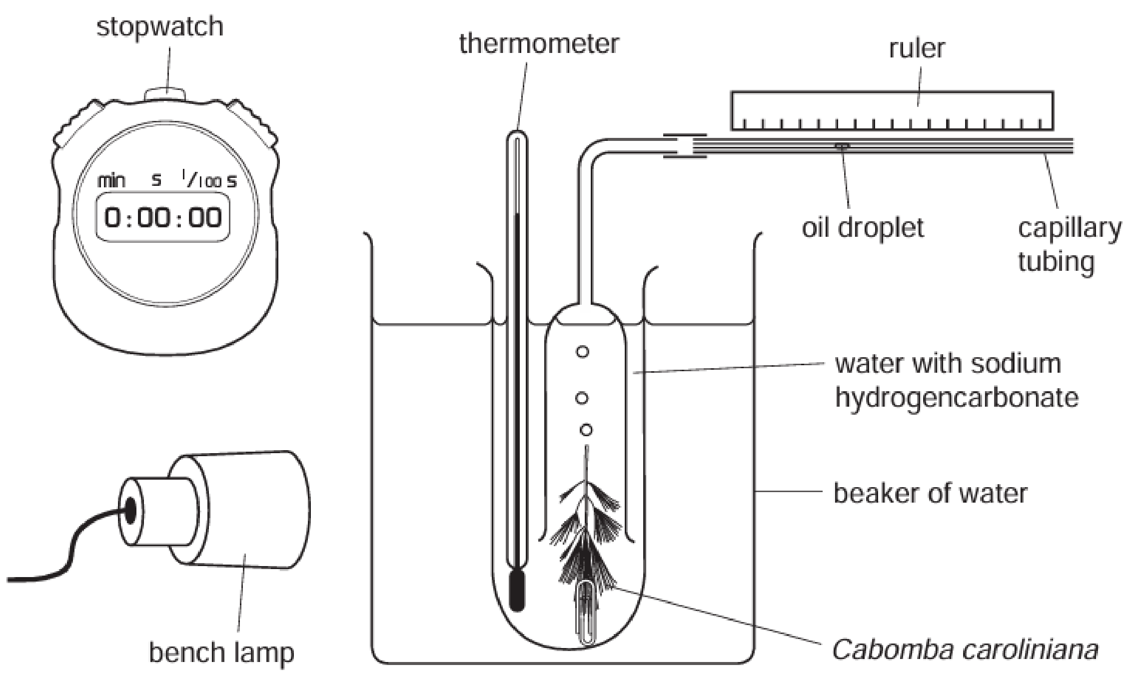


Fig. 2.1

(a) Explain why:
(i) the lamp was kept at the same distance from the C. caroliniana throughout the investigation;
ii) the water was enriched with carbon dioxide by adding sodium hydrogencarbonate.

The students determined the rate of photosynthesis by measuring the movement of the oil droplet along the glass tubing. Their results are shown in Table 2.1.

Table 2.1

temperature / °C	distance travelled by the droplet / mm per minute			
	1		3	mean
17		3	3	3.7
21		15	11	12.0
23		10	15	15.0
25		15	15	20.0
30		40	30	40.0
45		3	5	4.3
50		0	1	0.7

(b) Describe the effect of temperature on the rate of photosynthesis of C. caroliniana

(c) Photosynthesis is a chemical process catalysed by enzymes.

Explain how the results shown in Table 2.1 support the idea that enzymes are involved in photosynthesis.

d. C. caroliniana originally grew only in Latin America.

This plant has escaped into the wild in Australia where its rapid growth has reduced the biodiversity of many streams and rivers.

Suggest why the growth of C. caroliniana in Australia is far greater than in Latin America.