

Chapter 3.4 Gas exchange in plants

Science Understanding

In plants, gas exchange is facilitated by the structure of the leaf.

Gases are exchanged mainly via stomata. Their movement within the plant is by diffusion and does not involve the plant transport system.

- Describe and explain how gases move into, through, and out of plants.
- Describe the loss of water through open stomata.

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Plants and exchange of materials

Like animals, shrubs, trees and all other types of plants exchange materials with their environment. In daylight when **photosynthesis** is taking place, plants take up carbon dioxide and give out oxygen. Other materials taken in by plants during the day include liquid water and a variety of mineral nutrients from the soil; for example, minerals like **nitrates** and **phosphates**. Materials released by plants during the day also include water in the form of **water vapour**, and in the case of plants that live in soil or mud with a very high salt content, salts; for example, mangroves. The exchange of some materials between a Eucalyptus tree and its environment in bright sunlight is shown in *Figure 341*.

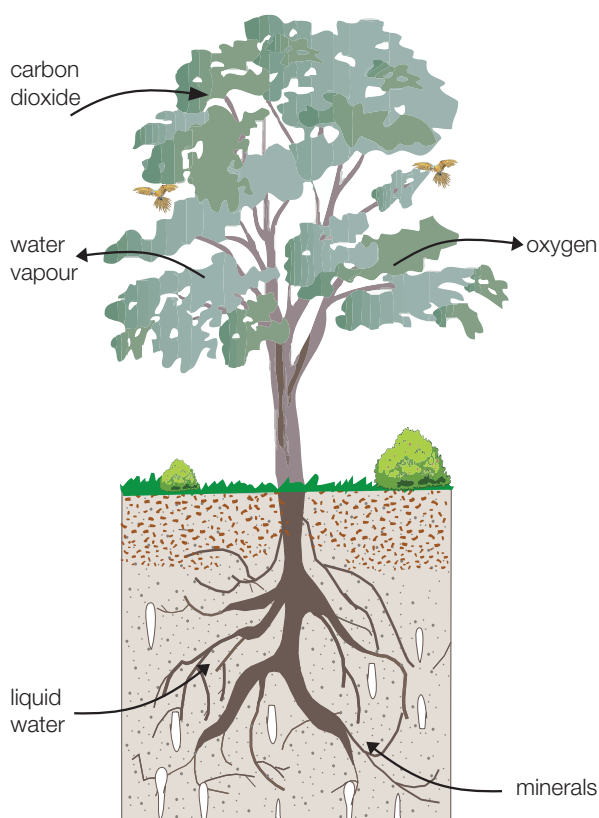


Figure 341 Exchange of materials between a tree and its environment

Photosynthesis and aerobic respiration

One exchange surface of plants is the leaf. To understand gas exchange by leaves it is important to know more about photosynthesis and a process that occurs in all cells called **aerobic respiration**.

Photosynthesis is a series of biochemical reactions that takes place in cells that contain green organelles called **chloroplasts**; for example, palisade cells that form part of the mesophyll tissue in leaves. Plants use photosynthesis during the day to synthesise the organic compounds required for survival. For this reason, a plant is called an **autotroph**. In photosynthesis plants chemically change carbon dioxide and water into a sugar called glucose and oxygen gas. Light energy is also converted into stored chemical energy.

Photosynthesis can be summarised using the following word equation:



Aerobic respiration is a series of biochemical reactions that mostly take place in an organelle found in all cells called a **mitochondrion** (pl. mitochondria). Plants (and animals) use aerobic respiration all the time to chemically change glucose and oxygen into carbon dioxide and water to release the chemical energy stored in glucose for use; for example, to produce new cells, or to grow. Aerobic respiration can be summarised using the following word equation:



Gas exchange at leaves

During daylight hours, plants perform photosynthesis and aerobic respiration. For most of the day the abundance of bright light causes photosynthesis to occur much faster than aerobic respiration. This means all the carbon dioxide produced by aerobic respiration is used for photosynthesis, and there is more oxygen produced by photosynthesis than is needed for aerobic respiration. The result is an input to the leaves of carbon dioxide (CO_2) and release of oxygen (O_2) during the day. This is shown in **Figure 342 (a)**.

Photosynthesis occurs more slowly in low light; for example, during the early morning or evening. At some point photosynthesis will occur at the same speed as aerobic respiration. The lack of nett exchange of gases that results is shown in **Figure 342 (b)**. In darkness photosynthesis does not take place but respiration continues. The input of oxygen and release of carbon dioxide that results during darkness is shown in **Figure 342 (c)**.

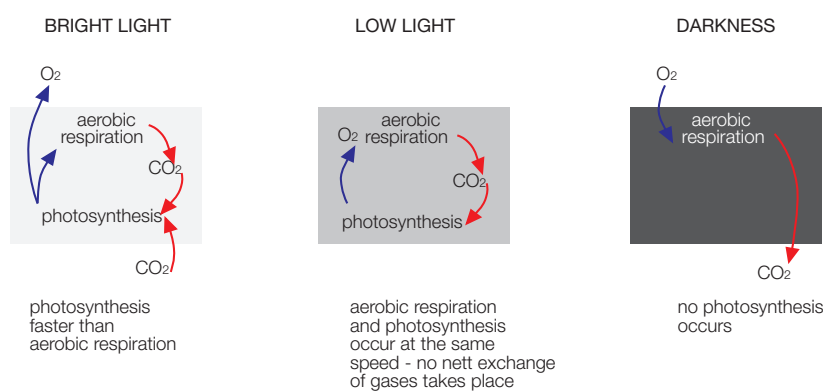


Figure 342 (a) Gas exchange at leaves in bright light, (b) low light and (c) darkness

Leaf structure and gas exchange

In plants, the main site of exchange of gases between the external and internal environments is the leaf. The typical structure of a leaf is shown in **Figure 343 (a)**. It is attached to the stem by a structure called a petiole that continues into most leaves to form the mid-rib. The surface of the leaf is called the **lamina**. In dicotyledons, a network of **veins** extends from the mid-rib across the lamina. A vertical slice or section through the lamina is shown in **Figure 343 (b)**. Note the presence of xylem and phloem tissue within the vein.

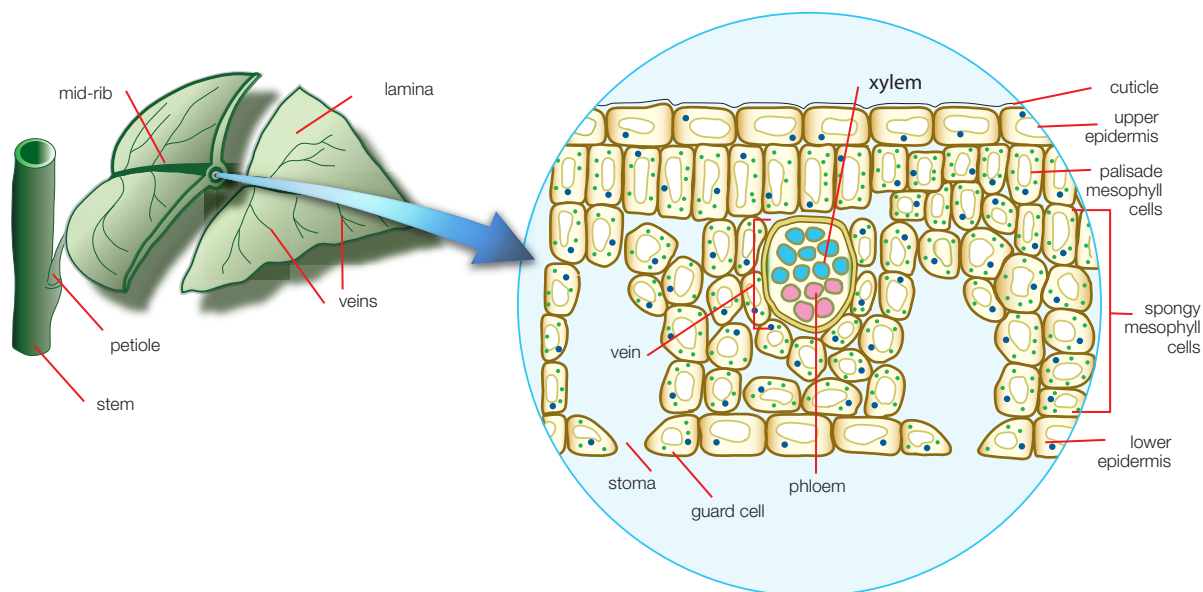


Figure 343 (a) The structure of a leaf and (b) The organisation of cells and tissues inside

The structure of the leaf facilitates gas exchange. Gases are exchanged via leaf structures called **stomata**. Their movement into and out of the plant is by **diffusion**. Parts of a dicotyledons leaf that facilitate the movement of gases into and out of the leaf are shown in the following table.

Part of the leaf	How the part facilitates gas exchange
Lamina	Is thin to reduce the distance gases have to move by diffusion and is broad and flat to increase the surface area for gas exchange
Lower epidermis	Contains stomata to permit gases to diffuse into and out of the mesophyll
Spongy mesophyll	Loosely packed to provide the mesophyll with air spaces that assist the diffusion of gases through the leaf

Stomata

? The lower epidermis of the dicotyledon leaf contains a large number of stomata (singular; stoma(te)). Each stoma consists of a pair of cells called **guard cells** that surround an opening called a pore. Changes in the shape of the guard cells cause stomata to open or close. As a rule, stomata are open during daylight hours while photosynthesis occurs, and closed during the early evening and at night. An open and a closed stoma is shown in **Figure 344 (a) and (b)**. Refer also to **Figure 345(c)** which is a scanning electron micrograph (SEM) of a stoma surrounded by guard cells, it is from a tobacco leaf and has been magnified ~X2500.

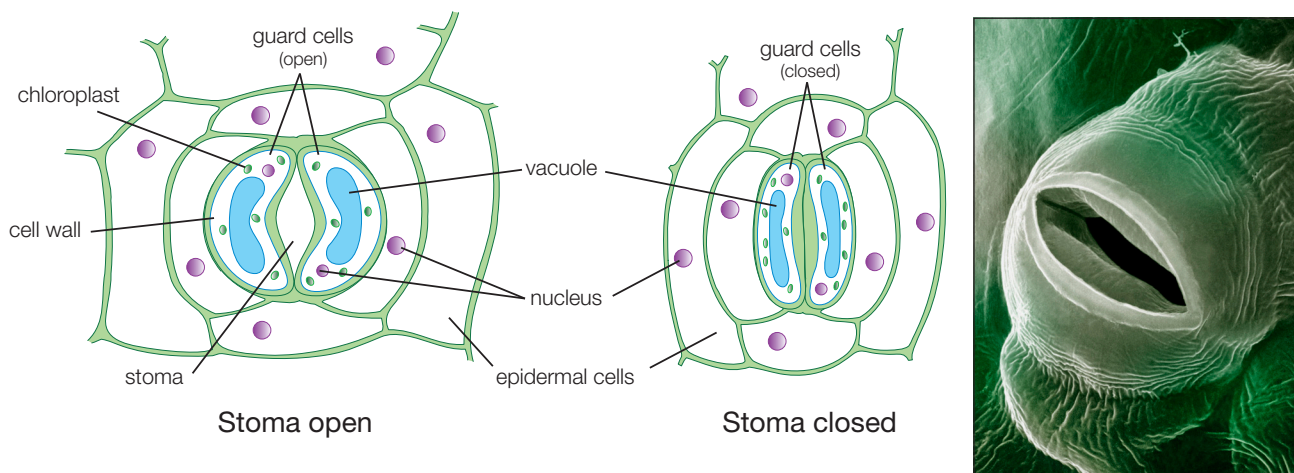


Figure 344 A stoma(te) that is (a) open (b) closed and (c) viewed with a SEM

Diffusion of gases into and out of leaves

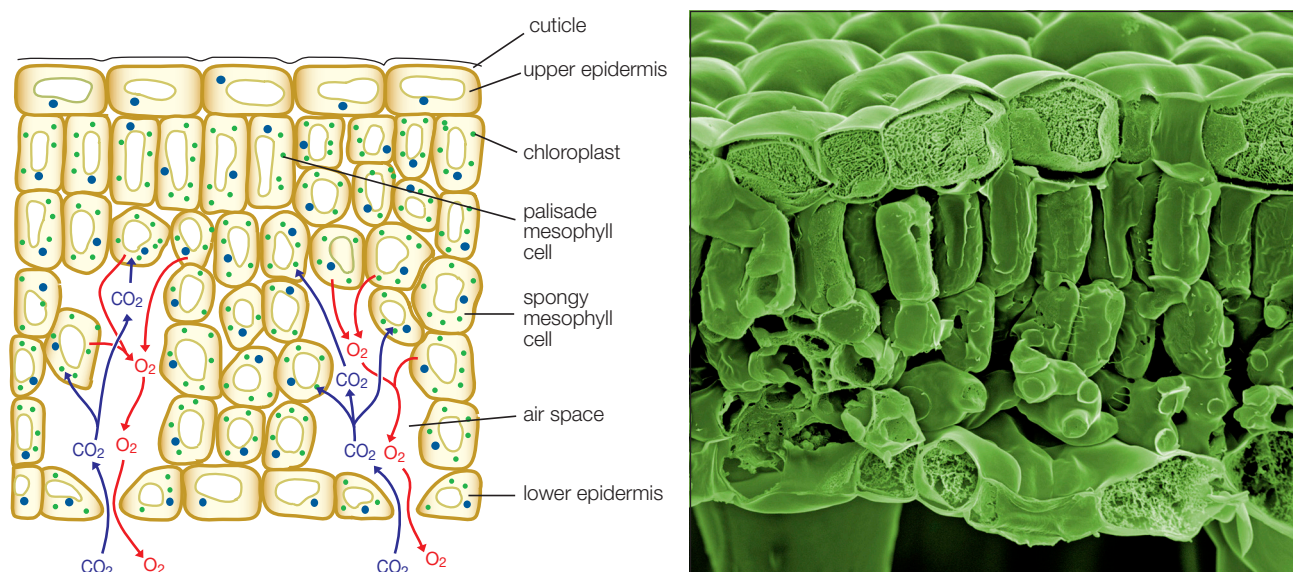


Figure 345 Cross section of a leaf shown (a) as a drawing and (b) an electron micrograph

In daylight, carbon dioxide enters the air spaces in the mesophyll via the open stomata by diffusion. It then diffuses into chloroplasts in the mesophyll cells. Oxygen that is produced by mesophyll cells during photosynthesis diffuses out of the mesophyll into the air spaces and then diffuses out of the leaf via the stomata.

Carbon dioxide diffuses into a leaf when mesophyll cells are photosynthesising, or when they are 'using up' carbon dioxide. This causes carbon dioxide in the air spaces to remain at a concentration lower than in the outside air. The result is that carbon dioxide diffuses from the outside air via stomata into the air spaces. The presence of air spaces permits the carbon dioxide concentration to increase enough for it to continue to diffuse into mesophyll cells.

Oxygen production by mesophyll cells during the day means the concentration of oxygen in the cells remains higher than in the air spaces, so oxygen diffuses into these air spaces. As the oxygen concentration in the air spaces rises, it then diffuses out through the stomata. The movement of carbon dioxide (CO₂) and oxygen (O₂) into and out of a leaf is shown in *Figure 345(a)*. Refer to *Figure 345(b)* which is a scanning electron micrograph of a cross-section through a stinging nettle. Note the structures are very similar to the diagram of the leaf shown adjacent in *Figure 345(a)*.



Helpful Online RESOURCES to view an EVA on leaf structure and function

To view an Essentials Video Animation (EVA) on this topic, use this QR code to visit:

<<http://essentialseducation.com.au/resources/sace-1/biology/leaf-structure-function/>>



Leaf structure and photosynthesis

The structure of the leaf facilitates photosynthesis as well. Some are shown in the following table.

Part of the leaf	How the part facilitates photosynthesis
Cuticle	Is transparent to maximise the absorption of light by mesophyll cells
Upper epidermis	Is thin to maximise the absorption of light by mesophyll cells
Lamina	Is broad and flat with a large surface area – this allows mesophyll cells to be spread out over a wide area to maximise the absorption of light
Palisade mesophyll	Cells are just under the epidermis, are upright and packed with green chloroplasts to maximise the absorption of light
Spongy mesophyll	Cells have chloroplasts to perform photosynthesis Air spaces between them helps carbon dioxide diffuse to mesophyll cells
Veins	Contains xylem vessels to deliver water and mineral nutrients to leaf cells Contains phloem tubes to move sugars out of leaves
Lower epidermis	Contains stomata to permit gases needed/produced by photosynthesis to diffuse into/out of the mesophyll



Key Concepts

1. Plants exchange materials with their environment.
2. Gas exchange by plants is influenced by the rates of photosynthesis and aerobic respiration.
3. In plants, the structure of the leaf facilitates the exchange of gases.
4. Leaves have stomata that permit gases to enter and leave the mesophyll tissue.
5. Stomata generally open during daylight hours and close during the early evening and at night.
6. Gases move into, through and out of leaves by diffusion.
7. Water can be lost from a plant through open stomates.

What have you learned?

Key Terms

water vapour

nitrates

phosphate.....

photosynthesis

aerobic respiration

chloroplast

autotroph.....

mitochondrion

stomata

guard cell

diffusion

lamina

lower epidermis

spongy mesophyll

palisade mesophyll.....

upper epidermis

cuticle.....

veins

xylem vessel.....

phloem tube

Knowledge and Understanding

1. Draw a simple, labelled diagram of a magnified side view of a leaf. On this diagram, use different coloured arrows and more labels to indicate the flow of energy and matter into and out of the leaf. In a sentence or two, explain why leaves are sometimes referred to as the 'the world's largest factory'.

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2. List examples of materials that are exchanged between plants and their environment.
3. Describe the effect of opening and closing of the stomata on the rate of gas exchange between the leaf and the external environment.
4. Describe the gas exchange that takes place at a leaf during bright sunlight.
5. In contrast to the answer above, explain why plants only take up oxygen at night and give out carbon dioxide.
6. Explain why the presence of air spaces in the spongy mesophyll assists the diffusion of carbon dioxide through the leaf.

Application, Analysis and Evaluation

3.4

7. During the summer, many species of Eucalyptus drop some of their leaves. Correlate this observation with the possible survival advantage for these plants.

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8. Leaves of plants in tropical forests usually have a very large surface area and are very dark green in colour. Explain how these features assist these plants to survive.

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9. Refer to *Figures 344 (a) and (b)* to help answer these questions:

- a) Describe the difference in the vacuoles in the guard cells when the stoma is open and closed.

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- b) Propose a possible mechanism that would explain the opening and closing of stomata.

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10. The results of a study of gas exchange by a Eucalypt woodland is included the following table:

Gas	Concentration at leaf level at 7am	Concentration at leaf level at 1pm
Oxygen	18%	21%
Carbon dioxide	0.05%	0.02%

- a) Describe the pattern of results observed for O₂ and CO₂ levels in the air at different times of the day.

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- b) Use an understanding of gas exchange to formulate a possible conclusion based on the data.

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Science as a Human Endeavour 3.4 - Green walls

Application and limitation

Scientific knowledge may have beneficial ...consequences...

A 'green wall' is a wall that is partly or completely covered with living plants. Green walls may be located outdoors or indoors (*refer to photo*).

The construction of green walls dates back to the 1970s. In recent years there has been a great deal of interest in constructing green walls inside buildings, including in offices, and not just because they provide employees with something attractive to look at. Evidence is emerging that suggests that greenery in the office may provide real health benefits to those who work there.

Recent research by the University of Technology Sydney (UTS) provides a good example. This UTS study found that exchange of materials between green wall-plants and their building/office environment can lead to an overall improvement in air quality. Given the increasing amounts of time people spend working indoors in office-like environments, such results may prove to be significant.



You may need to refer to the online resource below to answer the questions that follow:

- a) Suggest how a green-wall plant gas exchange might improve office air quality? Consider the role of photosynthesis, and a process indoor plants are known to carry out called bio-filtration.

- b) The use of extensive indoor green walls by Companies might result in unexpected economic and environmental benefits. Describe one such possible economic benefit and one possible environmental benefit.



Helpful Online RESOURCE to learn about 'Green wall' research

This website will provide some useful information for this assignment:

<<http://www.efig.co.uk/index.php/item/uts-study-shows-green-office-walls-purify-air-and-body>>



Helpful Online RESOURCE to learn more about 'Green walls

This website will provide some more useful information about 'green walls':

<https://en.wikipedia.org/wiki/Green_wall>



? Science Inquiry Skills 3.4 – Examining stomata

Introduction

In most plants that are dicotyledons stomates are only distributed throughout the lower epidermis. In monocotyledons stomata are located in both the upper and lower epidermis. Stomata can be examined using a microscope to see the guard cells and stoma. It may also be possible to observe the fact that guard cells have chloroplasts. The shape and size of guard cells and stoma vary across different plant species. The number of stomata per unit area, or the stomatal density, varies as well.

Materials

samples of dicot and monocot leaves

white tile

colourless nail varnish

light microscope

slide

clear cellotape

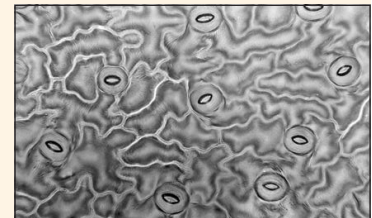
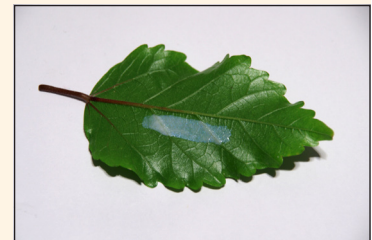
small dropper bottle of water

coverslip

dissection needle or toothpick

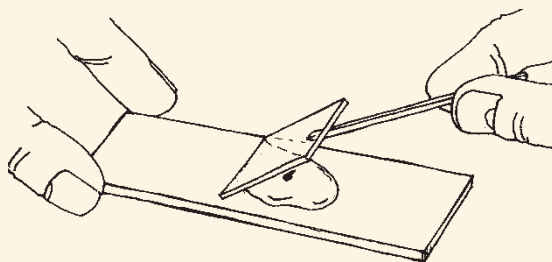
Part A: Measuring stomatal density in a dicot

1. Lay the leaf on a white tile, lower epidermis side up.
2. Paint a layer of nail varnish onto the leaf, as shown in the accompanying photographs.
3. Wait for the nail varnish to dry.
4. Press a piece of cellotape down over the varnish.
5. Peel the tape off.
6. Put the tape sticky side up on a microscope slide.
7. Observe at 100X and count the number of stomata, sample shown in adjacent Figure.
8. If the field of view is 2mm (or 2000 μm), calculate the stomatal density.



? Science Inquiry Skills PRACTICAL 3.4 – Examining stomata (continued)**Part B: Observing guard cells and stoma in monocots**

1. Fold a piece of leaf over near one end.
2. Carefully tear away some lower epidermis.
3. Place the piece of lower epidermis on a slide.
4. Add a drop of water, then lower a coverslip onto the tissue, as shown in drawing opposite.
5. Observe at 100X and look for pairs of guard cells.
6. Draw a labelled diagram of a stoma.



7. Describe the shape of the guard cells, and estimate the size of them and the stoma.